



## Analysis of Tartu e-bus pilot



**Baltic Innovation Agency OÜ & Mangrove OÜ**

Contact: Rene Tõnnisson

E-mail: [rene@bia.ee](mailto:rene@bia.ee)

Telefon: +372 502 9873



31.03.2020

## Table of Contents

Acronyms .....	3
Executive summary .....	4
Purpose of this report.....	7
Logic of the report .....	11
1.    Global E-bus trends.....	12
1.1 European trends .....	12
1.2 Estonian perspective.....	14
2.    Tartu context.....	16
2.1 Bus network in Tartu.....	16
2.2 E-bus pilot in Tartu.....	16
3.    E-bus overview – technological specifications.....	20
3.1 E-bus propulsion system .....	20
3.2 Battery technology .....	21
4.    Charging technology .....	22
4.1 Charging strategies and technology .....	22
4.1 Case study – Turku (Finland) .....	23
4.2 Charging considerations for Tartu .....	24
5.    Climate & performance.....	26
5.1 Ambient temperature – Battery performance.....	26
5.2 Seasonal differences – Impact on energy expenditure.....	27
5.3 Case study – Turku (Finland) and Edmonton (Canada).....	29
5.4 Climate considerations for Tartu .....	31
6.    Environmental impact of an e-bus fleet .....	35
6.1 Primary pollutants and their impact.....	35
6.2 Case study – Edmonton (Canada) & Gothenburg (Sweden) .....	36
6.2.1 Emission reduction.....	36
6.2.1 Noise pollution reduction .....	40
6.3 Environmental considerations for Tartu .....	43
7.    Total cost of ownership .....	45

7.1 TCO – Cost components .....	45
7.2 TCO of Tartu bus-fleet.....	48
7.3 Cost considerations for Tartu .....	51
8 Strengths and weaknesses of e-buses .....	53
8.1 User experience .....	53
8.1.1 Results of street interviews .....	53
8.1.2 Results of online survey.....	56
8.2 Operator experience .....	59
8.3 Case study - Edmonton (Canada) .....	60
9 The future of electric buses - key trends .....	62
9.1 Market trends for electric buses.....	63
9.2 Battery innovation trends .....	64
10. Results and recommendations.....	67
Annex 1 – Tartu city bus lines and their distances.....	72
Annex 2 – Rationale for cost components used in the TCO model.....	73

## Acronyms

**BMS** – Battery management system

**CAPEX** – capital expenses

**E-bus** – electricity powered bus

**EV** – electric vehicle

**HC/VO** – High hydrocarbon/Volatile organic compounds

**HVAC** - Heating, ventilation, and air conditioning

**HVO** – Hydrogenated vegetable oil

**ICE** – internal combustion engine

**Li-ion** – Lithium ion

**LFN** – Low frequency noise

**NO<sub>x</sub>** - Nitrogen oxide

**PM** – Particulate emissions

**OPEX** – operational expenses

**SUMP** – Sustainable Urban Mobility Plan

**TCO** – Total Cost of Ownership

## Executive summary

The evaluation team has been tasked with evaluating the results from the city of Tartu e-bus pilot to assess whether it would be feasible to procure a fleet of e-buses in 2029. In addition to the Tartu pilot, other case studies were used with similar climatic and operational conditions (i.e. similar bus size and pilot conditions) to provide further insight. The research included interviews with people closest to the pilot as well as user interviews and an analysis of an online user survey conducted by the city. A TCO model was created in Excel for the city to be used as a tool to estimate the costs for procuring e-buses in Tartu and comparing those to current public transportation options. Guiding the evaluation were six research questions. An executive summary of the results and answers to each question are shown as follows:

### 1. What technical e-bus solutions would be the best and most effective for Tartu?

The main technological factor to consider is the charging strategy i.e. whether to choose opportunity charging, with pantograph charging stations along the bus route or depot charging, which is a plug-in charger at the depot.

The pantograph system has a higher infrastructure cost as the charging stations need to be built along the bus route however it extends the e-bus range, making them more reliable. Depot charging is less expensive but less reliable for longer routes. The Edmonton, Turku, and Gothenburg case studies used a combination of opportunity and depot charging as their strategy of choice. This seems to be the common strategy as it ensures e-bus range reliability and has multiple charging options in case a charger is not available due to maintenance or malfunction.

Regarding effectiveness, a combination of depot and opportunity charging has proven to be effective in increasing the reliability of e-buses and is economically feasible in Turku and Edmonton. While opportunity charging was not tested in Tartu, it seems reasonable for the Tartu bus network if one looks at the average length of a bus route which is approximately 13km. This length is suitable for buses that carry small batteries and get quick charges at the end of the route. **Therefore, opportunity charging combined with overnight depot charging are the most effective charging methods identified in this study.**

With regards to what is best for Tartu, this cannot be answered without a thorough study on the current bus routes. Strategic charging points will need to be identified for pantograph stations and the network of bus routes, including length and duration, 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 right strategy for the city's needs.**

### 2. How does the cost of the electric bus used in the pilot compare to today's cost for diesel buses and gas buses?

The data from the e-bus pilot in Tartu indicate that e-buses are significantly more expensive than biogas and diesel buses. However, it is the opinion of the evaluation team that the results do not accurately reflect the real costs for operating an e-bus. The conditions for the bus pilot were atypical of a public transportation procurement as the acquisition cost and operational cost only reflect the year in which the pilot was in operation, not the entire lifetime of operation.

To adjust for the pilot data, an Excel model was created for the city of Tartu that allows the user to input cost data for different bus profiles and compare them over a longer period. Using this model, **the evaluation team found that when comparing a single bus on a single route, both e-buses with depot charging only and opportunity charging were less expensive than diesel and biogas buses over an operational period of 15 years.** Further, depot charging buses reach price parity with ICE buses between 9-10 years and 11-13 years for opportunity charged buses.

It is important to note that the model was not used to calculate the cost for a fleet of e-buses because an assessment of Tartu's current bus network and electrical grid capabilities would need to be conducted to estimate the infrastructure costs. However, new information can be inserted into the model to provide an updated estimate for bus fleets.

Using the model, the current data assumptions, and adjusting the operational time frame to 15 years, it **can be said that e-buses compared to diesel and biogas buses are more economically feasible.**

### **3. What are the strengths and weaknesses of the electric bus in terms of user and operator perspective compared to diesel and gas buses?**

User and operator experiences for the Tartu bus pilot were assessed through interviews with bus users and operators. Further, the results of the online survey used by the city of Tartu were also analysed.

Although both the user interviews and online surveys had limited and non-representative samples, they both provided a favourable indication towards e-buses. The respondents saw e-buses as environmentally friendly and quiet alternative to diesel buses. Most respondents were in favour 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 people (N=3) who were closest to the e-bus pilot. 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.

### **4. How will the electric buses operate in Tartu's climatic conditions?**

A linear regression model was used to compare the ambient temperature data to the energy consumption data provided by the city. It was found that there was a weak correlation between ambient temperature changes and energy consumption in e-buses. **This indicates that ambient temperature has little impact on the energy performance of the e-bus used in the pilot.** This is also supported by the results from the Edmonton and Turku case study where it was found that battery performance was not impacted by temperature changes.

This can be attributed to two factors: First, the Li-ion battery is equipped with a battery management system (BMS) which insulates the battery from outside temperatures. Second, a diesel heater was used for the pilot so battery would not be responsible for powering the HVAC system.

It is important to note that the **energy demand for heating increases significantly in the winter months**. Therefore, it will be important for Tartu to make sure that a reliable heating system is in place at the time of procurement.

#### **5. What important technological innovations are expected for electric buses in the next decade?**

Improvements to Li-ion batteries are predicted to dramatically decrease the cost of Li-ion batteries over the next ten years, making the CAPEX for e-buses cheaper. **The technological innovation can be attributed to two main components: innovation to the battery chemistry and innovation in the processes of the manufacturing plants for Li-ion batteries.**

Market trends show that demand for e-buses have been steadily increasing. From the perspective of bus suppliers (manufacturers), this indicates that the market will continue to grow and based on economic theories like competition-driven pricing, e-bus manufacturers will try to grab the largest share of the growing e-bus market, **driving the cost down.**

Taken together, it is estimated that the **costs for Li-ion batteries will continue to drop, enabling e-buses to reach price parity with ICE buses between 2024 and 2030.**

#### **6. Is the use of electric buses today and in 2029 economically and environmentally feasible?**

Considering the results from question 2, the evaluation team believes that the use of e-buses in Tartu today can be economically feasible. The findings from the model support the findings from Edmonton and Turku which also concluded that e-buses in their city are economically feasible. However, special attention must be given to the planning and integration of an overall charging strategy for e-buses in Tartu. **Taken together, if the right components are in place (charging infrastructure, bus routes, depot charging etc.), e-buses can be economically feasible in Tartu.**

Environmentally, the report shows that ICE buses, including biogas, produce harmful greenhouse gas emissions. Comparing only the operation of the bus (i.e. emissions from an ICE bus during operation to an e-bus), **our results indicate that e-buses are less harmful for the environment.** However, to truly be environmentally friendly the city would need to purposefully use electricity produced from green sources rather than the highly polluting oil shale.

Based on cost projections mentioned in this study, it is likely that by 2029 e-buses will be economically feasible compared to ICE buses. Environmental feasibility in 2029 will depend on whether Estonia can reduce its dependence on oil shale for electricity production. **Assuming that these targets are accurate and Tartu transitions to 100% renewable electricity use, it can be said that integrating e-buses in 2029 will be environmentally feasible.**

## Purpose of this report

The city of Tartu carried out an electric bus (e-bus) pilot to ascertain the feasibility of using e-buses in urban areas. The project was carried out between 01.09.2018-31.08.2019 under the BSR Electric project financed by the Interreg Baltic Sea Programme and the regular service was partly financed by the European Development Fund.

Tartu identifies a sustainable and environmentally friendly transportation system as a key element to creating a clean and human-friendly urban environment. In line with this policy, the city has recently contracted a fleet of environmentally friendly gas buses which went into operation on July 1<sup>st</sup>, 2019. The service contract for these buses lasts for ten years and following the end of this contract in 2029, a following long-term contract must be procured.

Technological developments in environmentally friendly transportation has been rapid in recent years. Given these trends, e-buses may become economically feasible in the next ten years, making them an attractive option to meet environmental targets and improve the current public transportation system in Tartu. Therefore, this evaluation report seeks to determine whether it could be feasible for the city to procure a service contract that uses a fleet of electric buses once the current contract expires in 2029.

Baltic Innovation Agency OÜ and Mangrove OÜ have conducted this evaluation of Tartu's e-bus pilot for the Tartu City Government.

### **Research questions**

Per the procurement document the city of Tartu has tasked the authors of this report to provide input to the following research questions:

- What technical e-bus solutions would be the best and most effective for Tartu?
- How does the cost of the electric bus used in the pilot compare to today's cost for diesel buses and gas buses?
- What are the strengths and weaknesses of the electric bus in terms of user and operator perspective compared to diesel and gas buses?
- How will the electric buses operate in Tartu's climatic conditions?
- What important technological innovations are expected for electric buses in the next decade?
- Is the use of electric buses today and in 2029 economically and environmentally feasible?

These research questions have been answered through desk research, analysis of case studies and primary data provided by the city government. Additional data has been collected through interviews for the purpose of this evaluation. Lastly, an excel model was created to assess the compare the costs of e-buses to diesel and biogas buses.

### **Desk research**

Traditional desk research methods of applied research were used to identify relevant sources of information, to generate a background understanding of the topic on the level of policy and technology. The work has relied on other pilot studies, modelling exercises and academic research to provide the most adequate information regarding feasibility and technological innovations of the next decade.



## Case studies

In the recent years many cities across Europe have piloted or even procured e-bus fleets. Luckily, sometimes these pilots are accompanied by written assessments and reports. The reports provide valuable information based on the experience of other regions. Through desk research Turku, Edmonton, and Gothenburg have been identified as ideal case studies to compare to Tartu. They will be referenced throughout the document in sections regarding charging technology, climate and environmental considerations and user experience. A quick overview of each of the pilot is presented below.

Since 2017 the **City of Turku** (Finland) has a fully operational fleet of six fully electric Linkker city buses. The buses are used on a single bus line in the city that runs between the Turku harbour and airport.

**Table 1. Vehicle and line specifications of the Turku e-bus fleet**

Pilot city	Turku (Finland)
Time period (in use)	October 2016 – October 2018 <sup>1</sup>
Bus type	Linkker 13LE
Nr. of buses	6
Battery capacity	55 kWh. Theoretical charging time of about 11 minutes from empty to full which gives around 30-50km operative range.
Opportunity charging	A pantograph down system. Recommended charging power 300kW. Three minutes median + 1 minute of “dead time” for charging. Battery state of charge remains between 40-80% while on route.
Overnight charging	Slow overnight charging at the depot. 4h until full charge.
Average energy consumption	0.89 kWh/km per vehicle
Heating	Integrated auxiliary fuel heater – 24kW diesel operated Eberspächer heater unit. On average this means 3.2 l / 100 km which corresponds to an additional energy overhead 0.32 kWh / km.
Total system energy consumption	1.4 kWh / km
Route distance	12.4km
Total km driven/vehicle/day	280-340km
Total daily hours of operation	19h
Successful days on route	70-80%
Environmental impact	Some 500-800 tons of CO <sub>2</sub> emissions (tank-to-wheel) were avoided in the city of Turku thanks to introduction of the e-buses, not counting emissions from the fuel heater.
Typology of the line	City centre
Topography of the line	Flat
Climate	Cold and temperate. -4°C - 17°C
TCO	0.85 eur / km total operating cost for operating the e-bus fleet
Total value of procurement	Approx. 3.8 million euros for the e-buses and charging stations

Source: Authors own, 2020. Data from: Aho, Panu. (2019). “Procurement and commissioning of electric city buses in Turku: Observations from the eFÖLI project 2015-2018”, Report from Turku University Applied Sciences, retrieved from: <https://julkaisumyynti.turkuamk.fi/PublishedService?pageID=9&itemcode=9789522167132>. And the ZeEUS 2017. ZeEUS eBus Report #2: An updated overview of electric buses in Europe, retrieved from: <https://zeeus.eu/uploads/publications/documents/zeeus-ebus-report-2.pdf>

The **City of Gothenburg** (Sweden) has performed an e-bus pilot in order to develop, test, and evaluate solutions that will contribute to the development of environmentally friendly public transportation routes throughout Europe. The pilot established a new bus route with electric buses operating at the centre of Gothenburg and established a demo area for new bus stop solutions including an indoor bus stop which

<sup>1</sup> The study officially ends in 2018, but the city has continued to use the busses.

served as a charging station and community gathering spot with cafes and other shops<sup>2</sup>. The pilot study provides thorough research on the environmental impact of switching to e-buses, focusing on noise pollution and greenhouse gas emissions.

**Table 2. Vehicle and line specifications of the Gothenburg e-bus fleet**

Pilot city	Gothenburg (Sweden)
Time period (in use)	June 2015 – 2018 <sup>3</sup>
Bus type	Volvo 10m, a concept vehicle with a centrally positioned seat for the driver and an extra-wide door.
Nr. of buses	3 fully electric (and 7 hybrids <sup>4</sup> )
Battery capacity	4 x 19 kWh
Opportunity charging	Pantograph down method. Up to 300kW. 3-4 minutes charging which enables to ride approx. 20 km.
Overnight charging	Low power plug charging for 4 hours.
Route distance	7.6 km
Average energy consumption	N/A. However, electric buses were found to be approximately 80 percent more energy-efficient than equivalent diesel buses.
Heating	Auxiliary heater Fuel (Diesel/HVO) 16 kW or Electric 7 kW
Electric motor	155kW
Total km driven/vehicle/day	156km
Total daily hours of operation	10h
Successful days on route	Service provision level of 99.68%
Environmental impact	On the test route, there was a 64.81% decrease of CO <sub>2</sub> emissions for the Electric Hybrid running on diesel and a 97.41% decrease of CO <sub>2</sub> for the electric hybrid running with renewable HVO fuel. <sup>5</sup>
Typology of the line	City centre
Topography of the line	Moderate
Climate <sup>6</sup>	Maritime climate. 0°C - 20°C

Source: Authors own, 2020. Data from: ELECTRICITY (2016). “Cooperation for sustainable and attractive public transport”, Status report, retrieved from: [http://www.goteborgelectricity.se/sites/default/files/content/u2318/electricity\\_-\\_cooperation\\_for\\_sustainable\\_and\\_attractive\\_public\\_transport.pdf](http://www.goteborgelectricity.se/sites/default/files/content/u2318/electricity_-_cooperation_for_sustainable_and_attractive_public_transport.pdf) and [http://www.goteborgelectricity.se/sites/default/files/content/PDF/volvo\\_electric\\_concept\\_bus\\_en.pdf](http://www.goteborgelectricity.se/sites/default/files/content/PDF/volvo_electric_concept_bus_en.pdf)

In 2016, the **City of Edmonton** (Canada) piloted two 12m electric buses to evaluate whether the technology used would be suitable for Edmonton’s climate and broad geographic transit service area. The focus of the study was to determine whether e-buses could reliably perform in Edmonton’s weather conditions and if so, determine if it were economically and environmentally feasible to integrate e-buses into Edmonton’s transit system. Since the study, Edmonton has commissioned the use of 40 e-buses to be used alongside the 900 diesel buses that are currently in operation.

<sup>2</sup> ELECTRICITY (2016). “Cooperation for sustainable and attractive public transport”, Status report, retrieved from: [http://www.goteborgelectricity.se/sites/default/files/content/u2318/electricity\\_-\\_cooperation\\_for\\_sustainable\\_and\\_attractive\\_public\\_transport.pdf](http://www.goteborgelectricity.se/sites/default/files/content/u2318/electricity_-_cooperation_for_sustainable_and_attractive_public_transport.pdf)

<sup>3</sup> The study officially ends in 2018, but the city has continued to use the busses.

<sup>4</sup> The rest of the table covers technical specs of the fully electric buses. However, in the Gothenburg pilot it was also found that the amount of energy used by electric hybrid buses is around 50–65 percent lower than diesel buses and that the well-to-wheel carbon dioxide emissions from electric hybrids running on HVO fuel were 97 percent lower than those from conventional diesel buses running on fossil diesel.

<sup>5</sup> The report did not include climate impact for the full battery electric bus. However, Gothenburg achieved considerable decrease in CO<sub>2</sub> emissions during the test period by using an electric hybrid bus running on HVO fuel.

<sup>6</sup> ZeEUS 2017. ZeEUS eBus Report #2: An updated overview of electric buses in Europe, retrieved from: <https://zebus.eu/uploads/publications/documents/zebus-ebus-report-2.pdf>

**Table 3. Vehicle and line specifications of the Edmonton e-bus pilots**

Pilot city	Edmonton (Canada)	
Time period (in use)	7 January 2016 - 5 February 2016 (5 weeks)	
Bus type	BYD 40 Second Generation (12m)	The New Flyer XD40 (12m)
Nr. of buses	1	1
Battery capacity	324 kWh Lithium Iron Phosphate battery (LiFePO <sub>4</sub> 324 kWh)	200 kWh Lithium-nickel-manganese-cobalt Battery (Li-ionNMC 200 kWh)
Heating	an auxiliary diesel heater	a diesel/electric heater combination
Average energy consumption	1.04 - 1.25 kWh/km	1.25 - 1.38 kWh/km
Recommended range (when e-buses should head back for a recharge at 85 and 80%)	220 - 264 km (200km manufacturer estimate)	116 - 128 km (140km manufacturer estimate)
Total km travelled during test	3,750 km	2,834 km
Opportunity charging	Pantographs installed at transit centres to provide quick charge to buses – 5 minutes per charge.	
Overnight charging	Slow trickle charging in bus garage overnight.	
Total daily hours of operation	14 – 16 hours per day	
Successful days on route	Operated most days at over 90% availability during the field trial.	
Environmental impact	When used according to the usage pattern defined by Edmonton's transit system (driving on average 49,450 km) a BYD will generate 684 TCO <sub>2</sub> e- and the NFI 776 TCO <sub>2</sub> e- respectively in lifetime emissions associated with upstream emissions from power generation.	
Typology of the line	Urban and suburban	
Topography of the line	Flat, mild hills, steep hills (up and down river valley)	
Climate	Temperate climate and known for having cold winters. Temperature extremes can reach as low as -49°C and as high as 36.7°C.	
Total system energy consumption	1.04 – 1.25 kWh/km (BYD)	1.25 – 1.38 kWh/km (The New Flyer)
Total value of procurement	\$95,566,884 for en-route charging - \$75,999,829 for trickle-charged e-buses <sup>7</sup>	

Source: Authors own, 2020. Data from: Marcon Report. 2016. "Electric Bus Feasibility Study for the City of Edmonton". Retrieved from: [https://www.edmonton.ca/documents/transit/ETS\\_Electric\\_Feasibility\\_Study.pdf](https://www.edmonton.ca/documents/transit/ETS_Electric_Feasibility_Study.pdf)

### **Primary data provided by the city**

The evaluation team was provided raw primary data about daily power usage, daily diesel consumption for the auxiliary heater, trip validation data of passenger of the e-bus pilot. This data was provided as Excel sheets. Additional information regarding the Tartu bus network and pilot were retrieved from the city officials via email. The primary data is used throughout this document where relevant.

The city had also conducted an online survey among e-bus users between 3<sup>rd</sup> and 13<sup>th</sup> of October 2019. An Excel datasheet with the collected responses was provided by the city and analysed by the evaluation team. See more in Chapter 8.1.2.

### **Data collection**

For the purposes of this evaluation additional interviews were conducted. Two types of interviews were conducted – expert interviews (N=4) and user interviews (N=50).

The expert interviews included:

- Head of the bus service provider that was responsible for the e-bus pilot.
- Lead expert of public transportation at the Tartu City Government.
- Bus driver of the e-bus during the pilot period.

<sup>7</sup> Cost represent cost for fleet of 40 e-buses over 20-year period.

- Representative of Elektrilevi, the largest electric network operator in Estonia.

The purpose of the expert interviews was twofold. First, they were important to have a holistic view of the Tartu pilot to ensure that the evaluation team has the correct understanding of how the pilot was conducted. Second, the interviews were important to provide input to the research question regarding operator experience. The interview with Elektrilevi was conducted to have a better understanding of the capabilities of charging infrastructure in Tartu. The purpose of user interviews was to collect data necessary to assess the citizens experience with the e-bus.

## Logic of the report

The first three Chapters of the report are introductory in nature. Chapter 1 provides a quick overview of the main trends for e-buses on the global and local level. Chapter 2 provides a description of the Tartu bus network and an overview of the pilot held between September 2018 – August 2019. Chapter three provides an overview of e-bus propulsion system and battery technology which are important for the discussions in the later chapters.

Chapters 4-7 follow a unified logic. The chapters begin by covering a topic based on secondary research and data from other case studies. Each of these Chapters end with a sub-chapter titled “considerations for Tartu” where the discussion and analysis are brought to the local, Tartu, context. In this manner the evaluation covers the topics: charging technology, climate and performance, environmental impact and total cost of ownership.

Chapter 8 covers the strengths and weaknesses of e-buses primarily through an analysis of data collected through user interviews and the online survey. This data is compared to a case study.

Chapter 9 is forward looking and describes the market and battery innovation trends of e-buses to provide an understanding on what to expect in the next ten years.

The document ends with a summary of the results to the guiding research questions and provides recommendations for Tartu.

## 1. Global E-bus trends

With over 425,000 e-buses deployed worldwide, it can be said that widescale integration of e-buses into public transportation is imminent<sup>8</sup>. Although roughly 421,000 of global e-buses are in China<sup>9</sup>, growth of e-buses in Europe has been significant over the past few years. For example, from 2018 to 2019, **e-buses in Northern Europe grew from 56 in operation to 467<sup>10</sup> and between 2015-2016 there was a 100% increase in overall e-bus sales in Europe<sup>11</sup>**. This growth can be attributed to the benefits of switching from traditional diesel or natural gas combustion engines to e-buses which include environmental benefits relating to lower exhaust emissions and the potential lower total cost of ownership<sup>12</sup>.

### Global Trends

- 425,000 E-buses worldwide
- Roughly 4,000 E-buses in Europe
- 100% increase in e-bus registrations in Europe from 2018-2019

Nevertheless, as e-buses are still considered an emerging technology, there is confusion as it relates to their cost and operation. As such, the initial focus for many European cities has been on pilot programs, testing the feasibility of e-buses in their respective city. With environmental pressures stacking against internal combustion engines, it is **important to explore the potential of e-buses as a cost effective and environmentally friendly alternative to current options**.

### 1.1 European trends

EU support for e-bus integration into cities is rooted in their commitment to **address climate change and leverage the economic potential of a European lead renewable energy sector**. The EU has affirmed their support for these initiatives through different strategic frameworks, particularly as it relates to **renewable energy and urban transportation**.

Starting with the **2030 climate energy framework (2014)**, the EU cites high energy prices, decreasing dependence on foreign energy sources, and the need to reduce greenhouse gases as major factors in formulating a long-term clean energy policy<sup>13</sup>. Recently, the European Commission (EC) has reaffirmed and expanded on those environmental targets in the **2018 - Vision for a long-term EU strategy for**

<sup>8</sup> Eckhouse, Brian. (2019). "The U.S. Has a Fleet of 300 Electric Buses. China has 421,000". Retrieved from: <https://www.bloomberg.com/news/articles/2019-05-15/in-shift-to-electric-bus-it-s-china-ahead-of-u-s-421-000-to-300>

<sup>9</sup> Ibid.

<sup>10</sup> Northern Europe in this scenario refers to Norway, Sweden, Finland, Denmark, and Iceland. Source information retrieved from: <https://www.sustainable-bus.com/news/electric-buses-in-north-europe-to-rise-from-56-to-467-in-one-year/>

<sup>11</sup> Perchel, Artur. (2019). "Financing schemes for bus electromobility in Europe". Covenant of Mayors' Investment Forum. Energy Efficiency Finance Market Place. Retrieved from: [https://ec.europa.eu/info/sites/info/files/2.3\\_uitp\\_perchel.pdf](https://ec.europa.eu/info/sites/info/files/2.3_uitp_perchel.pdf)

<sup>12</sup> de Pee, Arnout; Engel, Hauke; Guldemond, Marte; Keizer, Arjan; van de Staaij, Jasper. (2018). "The European electric bus market is charging ahead, but how will it develop?". McKinsey & Company article. 2018. Retrieved from: [mckinsey.com/industries/oil-and-gas/our-insights/the-european-electric-bus-market-is-charging-ahead-but-how-will-it-develop](https://www.mckinsey.com/industries/oil-and-gas/our-insights/the-european-electric-bus-market-is-charging-ahead-but-how-will-it-develop)

<sup>13</sup> EU Commission. (2014). <https://www.consilium.europa.eu/en/policies/climate-change/2030-climate-and-energy-framework/>

**reducing greenhouse gas emissions**, which outlines the EU long-term strategy for achieving net-zero greenhouse gas emissions by 2050<sup>14</sup>.

In addition to the societal benefits from these strategies, the EU also recognizes the **economic potential for developing the renewable energy sector**. For example, further investment into industrial modernization, energy transformation, circular economy, clean mobility, green infrastructure, and the bioeconomy will create new local and high-quality employment opportunities<sup>15</sup>. This is supported by actions already taken by the EU's 2020 climate and energy targets which have increased the EU labor force by 1-1.5%<sup>16</sup>.

Responsible for roughly 25% of all greenhouse gas emissions in Europe<sup>17</sup>, the **transportation sector has been targeted by EU policies as an area with high potential for achieving their economic and environmental targets**. This can be seen through the EC "European Clean Bus deployment Initiative" which creates a framework for deploying clean, alternatively fueled buses in Europe<sup>18</sup>. The EC takes a step further with the "Clean Vehicles Directive" outlining financial frameworks for EU member states to adopt which can be used to incentive the integration of environmentally friendly vehicles<sup>19</sup>. Lastly, the Sustainable Urban Mobility Plans (SUMP), is a planning concept for cities that encourage decision making across different sectors and between stakeholders for providing high quality and sustainable mobility<sup>20</sup>. Regional SUMP's are strategic documents designed to contribute to meeting European targets<sup>21</sup>.

Advances in clean energy technology have made it possible to integrate electric vehicles into public transportation systems across Europe. Considering that **urban and suburban buses account for 55.7% of all public transport journey's in Europe** (32.1 billion passenger journeys per year)<sup>22</sup>, the integration of e-buses is an opportunity to make a positive environmental and economic impact.

Support for e-bus related initiatives in the EU has been robust, resulting in numerous bus pilots and the development of e-bus strategies as it relates to charging infrastructure, best practices for different climate conditions, and synchronization of policy and strategy among relevant stakeholders. Through the EC and Horizon 2020, several projects have been funded to promote and study the deployment of E-buses in Europe. A breakdown of a few of those projects are included in Table 4. The information provided by such pilots is invaluable for cities who are considering the use of e-buses in their own public transportation networks.

---

<sup>14</sup> EU Commission Report. (2018). "2018 – Vision for a long-term EU strategy for reducing greenhouse gas emissions". Retrieved from: [https://ec.europa.eu/clima/policies/strategies/2050\\_en#tab-0-1](https://ec.europa.eu/clima/policies/strategies/2050_en#tab-0-1)

<sup>15</sup> Ibid.

<sup>16</sup> Ibid.

<sup>17</sup> Eurostat report. (2019). "Greenhouse gas emission statistics – emission inventories". Retrieved from: <https://ec.europa.eu/eurostat/statistics-explained/pdfscache/1180.pdf>

<sup>18</sup> European Commission. "European Clean Bus deployment Initiative". Retrieved from: [https://ec.europa.eu/transport/themes/urban/cleanbus\\_en](https://ec.europa.eu/transport/themes/urban/cleanbus_en)

<sup>19</sup> European Commission. "Clean Vehicles Directive". Retrieved from: [https://ec.europa.eu/transport/themes/urban/vehicles/directive\\_en](https://ec.europa.eu/transport/themes/urban/vehicles/directive_en)

<sup>20</sup> European Commission. "Sustainable Urban Mobility Plans". Retrieved from: [https://ec.europa.eu/transport/themes/clean-transport-urban-transport/urban-mobility/urban-mobility-actions/sustainable-urban\\_en](https://ec.europa.eu/transport/themes/clean-transport-urban-transport/urban-mobility/urban-mobility-actions/sustainable-urban_en)

<sup>21</sup> The Baltic Sea Region Competence Centre on SUMP. "Introduction to SUMP's". Retrieved from: <http://www.bsr-sump.eu/content/introduction-sumps>

<sup>22</sup> European Automobile Manufacturers Association. (2017) "Fact sheet: Buses". Retrieved from: <https://www.acea.be/publications/article/fact-sheet-buses>

**Table 4: Major EU funded E-bus projects**

<a href="#">EBSF-2</a> (European Bus System of the Future 2)	<a href="#">ELIPTIC</a> (Electrification of public transport in cities)	<a href="#">ZeEUS</a> – (Zero Emission Urban Bus System)	<a href="#">ASSURED</a>	<a href="#">Electric Mobility Europe</a> (EME)
<b>Duration:</b> Closed project – May 2015 – April 2018	<b>Duration:</b> Closed project – June 2015 – May 2018	<b>Duration:</b> Closed project – Nov 2013 – April 2017	<b>Duration:</b> Ongoing project – October 2017 -	<b>Duration:</b> Ongoing Project – Oct 2016 – Sept 2021
<b>Funding Entity:</b> Horizon 2020	<b>Funding Entity:</b> Horizon 2020 & CIVITAS	<b>Funding Entity:</b> EC	<b>Funding Entity:</b> Horizon 2020	<b>Funding Entity:</b> Horizon 2020 and EC
<b>Overview:</b> <ul style="list-style-type: none"> <li>Studied innovative technologies that make bus systems more attractive and efficient.</li> <li>Successfully tested technologies that reduce energy demand by 15 – 60 %<sup>23</sup>.</li> </ul>	<b>Overview:</b> <ul style="list-style-type: none"> <li>Developed new use concepts and business cases for the use of existing electric public transport infrastructure as a charging infrastructure.<sup>24</sup></li> </ul>	<b>Overview:</b> <ul style="list-style-type: none"> <li>Aims to be the main EU activity to extend the fully electric solution to the core part of the urban bus network.</li> <li>Tested e-bus systems with different charging infrastructure solutions.<sup>25</sup></li> </ul>	<b>Overview:</b> <ul style="list-style-type: none"> <li>Develops and tests high-power and superfast charging solutions for various types of heavy-duty vehicles.</li> <li>Develops charging strategies with high interoperability with different equipment<sup>26</sup>.</li> </ul>	<b>Overview:</b> <ul style="list-style-type: none"> <li>EME funds research and innovation projects focusing on the application and implementation of e-mobility.</li> <li>Creates stronger alignment of strategy and policy among relevant stakeholders.<sup>27</sup></li> </ul>

Source: Authors own, 2020

## 1.2 Estonian perspective

Estonian policies on e-mobility have so far focused on e-car mobility. Estonia was the first country in the world to set up a nationwide fast-charging network. In 2011 government organized the purchase of 507 Mitsubishi iMiEV electric cars for social work employees. The state has subsidised purchasing electric cars. The policy was introduced in 2011 but was abolished abruptly in 2014 due to lack of funding. With the loss of the subsidy the sales fell to nearly zero<sup>28</sup>. In December 2019, the Environmental Investment Centre announced a new direct grant application round for purchasing fully electric vehicles (5000 euros per car).

<sup>23</sup> European Commission. "European Bus System of the Future 2". Retrieved from: <https://cordis.europa.eu/article/id/239954-the-bus-of-the-future>

<sup>24</sup> UITP. "ELIPTIC – Electrification of Public Transport in Cities". Retrieved from: <https://www.uitp.org/eliptic-electrification-public-transport-cities>

<sup>25</sup> ZeEUS project website. "Zero Emission Urban System". Retrieved from: <https://zeeus.eu/about-zeeus/vision>

<sup>26</sup> ASSURED project website. "ASSURED" Retrieved from: <https://assured-project.eu/about/about-assured>

<sup>27</sup> EME project website. Retrieved from: <https://www.electricmobilityeurope.eu/about/>

<sup>28</sup> Tampere, Ülle. (2019). "Elektriautode uus toetusmeede avaneb tõenäoliselt juba kolmandas kvartalis". Retrieved from: <https://www.accelerista.com/uudis/eesti/elektriautode-toetusmeede/>. See also: Gnadenteich, Uwe. (2019). "Kliimaprobleemid sunnivad ka eestlased elektriautodesse". Retrieved from: <https://www.postimees.ee/6833898/kliimaprobleemid-sunnivad-ka-eestlased-elektriautodesse>

The total volume of the measure is 1.2 million Euros<sup>29</sup>. Due to great interest the measure was exhausted within 4 hours after its launch on the 17<sup>th</sup> of January 2020. The Ministry of the Environment is now working to find additional funds that could be allocated for the second call of the grant<sup>30</sup>.

City level polices have also focused predominantly on electric cars. Larger cities have offered free parking to e-car owners and in the capital city Tallinn e-cars are the only other vehicles that are allowed to drive on bus lanes. Under the project FinEstSmartMobility a SUMP has been developed for Tallinn city and the surrounding region in 2019<sup>31</sup>.

Tallinn ran a very brief e-bus pilot in May 2019. For approximately two weeks a 12m Mercedes-Benz eCitaro bus was used on lines 24 and 24A<sup>32</sup>. According to the head of the Tallinn public transportation agency (TLT) the buses could manage 140-150 km with one charge and the full charging cycle would take about 9 hours<sup>33</sup>. TLT has also stated that they plan to change to fully electric public transportation by 2035 with a fleet of approximately 650 electric buses<sup>34</sup>. Even so, in the next ten-year perspective the TLT is planning to first make a switch from diesel to gas buses. Therefore, besides the short pilot in Tallinn and the e-bus pilot in Tartu there have been no significant advancements in e-bus mobility in Estonia.

---

<sup>29</sup> Environmental Investment Centre. (2019). "EIC announces a direct grant application round for the purchasing of electric vehicles". Retrieved from: <https://kik.ee/en/article/eic-announces-direct-grant-application-round-purchasing-electric-vehicles>

<sup>30</sup> Majandus24. (2020). "Riik püüab elektriautode toetuseks raha juurde leida". Retrieved from: <https://majandus24.postimees.ee/6884311/riik-puuab-elektriautode-toetuseks-raha-juurde-leida>

<sup>31</sup> Maanteeamet. "Valmis Tallinna piirkonna säästva linnaliikuvuse strateegia". Retrieved from: <https://www.mnt.ee/et/tee/valmis-tallinna-piirkonna-saastva-linnaliikuvuse-strateegia>

<sup>32</sup> Piller, Meelis. (2019). Tallinnas testitakse elektribussi. Retrieved from: <http://www.pealinn.ee/tagid/koik/tallinnas-testitakse-elektribussi-n241334>

<sup>33</sup> Gnadenteich, Uwe. (2019). "Uuest aastast hakkab Tallinnas sõitma kümnekond elektribussi". Retrieved from: <https://www.postimees.ee/6684203/uuest-aastast-hakkab-tallinnas-soitma-kummekond-elektribussi>. See also: Tooming, Marko. (2020). "Trollid kaovad: aastaks 2035 jäävad Tallinna vaid trammid ja elektribussid". Retrieved from: <https://www.err.ee/1034364/trollid-kaovad-aastaks-2035-jaavad-tallinna-vaid-trammid-ja-elektribussid>

<sup>34</sup> ERR News. (2019). "Tallinn plaanib aastaks 2035 osta ligi 650 elektribussi". Retrieved from: <https://www.err.ee/895970/tallinn-plaanib-aastaks-2035-osta-ligi-650-elektribussi>



## 2. Tartu context

### 2.1 Bus network in Tartu

There is no municipal transportation authority in the city of Tartu. This means that the city does not own a bus fleet<sup>35</sup>. To provide public transportation, the city procures the transportation, i.e. people carrying, service from the market of transportation companies. The procurement processes have recently taken a 10-year perspective. Between 2009-2019 the city used a fleet of diesel buses run by SEBE. As of 1<sup>st</sup> of July 2019 Tartu uses a fleet of 64 gas buses run by AS GoBus. These buses are low-floored Scania buses. Two types of buses are used - 12m buses with 27 seats and 52 standing positions and 18m buses with 41 seats and 96 standing positions.

Another change on the 1<sup>st</sup> of July 2019 was the complete restructuring of the bus network. The existing network was completely revamped by using mobile data, expert input and participative methods. Bus routes, the number of bus lines, and frequency of buses on said routes were changed. A good illustration of the scope of the changes is that 27 new bus stops were created, and 10 old ones became obsolete<sup>36</sup>. A guiding principle was to remove most circular bus routes and use a direct route, with more frequent buses travelling back and forth on the same route. Another change took place in January 2020 when Tartu started to use locally produced bio-methane as energy source for all city buses.

As an outcome of the restructuring the bus network in Tartu today consist of 13 bus lines plus two-night lines. There around 55 buses on route at the same time. An average bus drives around 260 km daily, most active buses cover 300km. A single bus covers on average around 96 000 – 100 000 km each year. Most bus lines operate for 19-20 hours a day.<sup>37</sup>

The shortest bus routes in the city are just below 9km. The longest back and forth route is 23km. The circular and night-time buses have the longest routes with around 30km each. The average length of all the bus lines is 15.7 km. The average length for a back and forth bus line is 13.2 km. The route distances are relevant for the discussion on charging methods in Chapter 4. See Annex 1 for a full list of bus lines and route lengths.

### 2.2 E-bus pilot in Tartu

Like many other cities in Europe, Tartu aspires to have a greener urban environment and greener transportation within the city limits. For example, in 2019 the city set up a bike sharing system, which includes e-bikes, to promote greener ways of transportation<sup>38</sup>. The city has been an is a partner in many European projects that focus on sustainable and smart cities. Even the most recent bus service

---

<sup>35</sup> This is relevant because some e-bus studies have concluded that economic feasibility due to break-even points compared to diesel or gas busses at around 16-20 years. This is longer than the procurement cycle in Tartu.

<sup>36</sup> Tartu City Government press release. (2019). "1. juulist on Tartus uuend bussid ja uus liinivõrk". Retrieved from: <https://www.tartu.ee/et/uudised/1-juulist-on-tartus-uuend-bussid-ja-uus-liinivork>

<sup>37</sup> Based on evaluation interviews.

<sup>38</sup> The Smart Bike Share contains 510 electrical bikes and 240 ordinary bikes available from 69 parking stations.

procurement was set up so that alternative technologies to diesel buses were favoured. The new gas-based bus fleet is considered a step towards a greener urban environment.

In this context, the city of Tartu also ran an e-bus pilot. Indeed, the interviewed city representative confirmed that the main motivation for the city is the reduction of pollution in the urban environment and that “[...] e-buses would enable us to remove a lot of pollution from the city”.

The pilot took place between 3<sup>rd</sup> September 2018 – 31<sup>st</sup> August 2019. The pilot was run under the BSR Electric project<sup>39</sup> financed by the Interreg Baltic Sea Programme and the regular service was partly financed by the European Development Fund. Table 5 gives an overview of the pilot.

**Table 5. Specifications of the Tartu e-bus pilot**

Pilot city	Tartu (Estonia)
Time period (in use)	September 2018 – August 2019
Bus type	Solaris Urbino 12 Electric
Nr. of buses	1
Battery capacity	200 kWh
Charging method	Depot charging, ca 5-6h needed for full charge.
Electric motor	220kW
Average energy consumption	1.14 kWh/km <sup>40</sup>
Heating	Diesel heater
Route distance	A>B Bussijaam - Raudteejaam – Bussijaam - 4,9 km A>B1 Bussijaam - Raudteejaam – Maarjamõisa - 9,1 km
Successful days on route	272 <sup>41</sup>
Average total km driven/vehicle/day	177 km <sup>42</sup> (70-90km on route <sup>43</sup> )
Typology of the line	City centre
Topography of the line	Flat
Climate	-5°C - 19°C

Source: Authors own, 2020. Data received from the City of Tartu

## **Bus**

A 12m Solaris Urbino Electric bus was used for Tartu’s pilot. The pilot operator was decided through public procurement and was won by the transportation company SEBE. SEBE rented the bus directly from Solaris to provide the transportation service during the pilot<sup>44</sup>. The bus came from Poland and was an older model that had been used as a test bus in other cities. According to the interviewed city representative the mileage at delivery was ca 50 000 km which equals around a half a year of service for regular city buses. This was also confirmed by the expert from Elektrilevi who indicated that it had been “a used bus that was by now two-generations old”. The bus had an HVAC system, a diesel heater and a 200kWh battery.

<sup>39</sup> See more at the project homepage: <https://www.bsr-electric.eu/>

<sup>40</sup> Authors calculation based on the data provided by the city.

<sup>41</sup> Authors calculation.

<sup>42</sup> Authors calculation. Takes only successful days into account.

<sup>43</sup> According to the service provider. Due to the charging solution there was a significant deadhead.

<sup>44</sup> In the evaluation interviews, both the service provider and city representative mentioned that it had been difficult to find a partner who would be willing to rent a bus short term. Most had been keen on selling the bus. This also raised the eventual cost of the pilot (see Chapter 7 on operational costs).

## ***Route***

Besides testing how an e-bus could function in Tartu's conditions the city was also interested to test out a route that had not existed before. Namely, connecting the central bus station with the trains station. The pilot line was numbered as line nr. 25.

Two routes were tested for the line. A shorter one that ran just between the bus station and train station that was 4,9km long and a longer one with an additional destination with the length of 9.1km. At one point the airport was also included in the route. The airport operates only one flight a day to Helsinki<sup>45</sup>. Outgoing flights leave at 5:20 in the morning and incoming flights arrive around 00:40. This means that the bus needs to be on the route in the city already by 3:50 in the morning. The bus leaves the airport once all disembarking passengers have gotten onto the bus. For the e-bus pilot, this caused some difficulties in overnight charging.

Therefore, differently from most bus routes the e-bus route was set up according to the arrivals and departures of trains and airplanes. This meant that the bus was infrequent and had gaps in its daily operation. The number of kilometres on route per day was around 70-90km, which was significantly lower than an average Tartu city bus (260km). The e-bus drove a total of 48,000 km during the pilot period.

## ***Charging***

The bus charging was solved without setting up permanent public infrastructure. As only one bus was used, and this was a pilot study, it did not seem reasonable for the partners involved to make additional infrastructure investments. A charger came with the rental contract and was set up at the SEBE bus depot, just outside city limits. The charging location decision was based on the idea that that is the location where the bus will be stationed the longest and would hence be a good location for depot charging. Alternatives in the city were considered, albeit no suitable alternative was found according to interviewees. Although the technology enabled three types of charging – fast, average, 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, there was a fair bit of deadhead each day as the bus depot was quite far from the route itself. While the average covered distance per day was 177km, only 70-90km of this was spent en 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.

## ***Obstructions***

The pilot faced some challenges that hindered being on the route throughout the year. There was a significant gap in operations between the 27<sup>th</sup> of October until 28<sup>th</sup> of January. The delay was caused due to a technical malfunction in the bus system. Fixing the problem took time as the local operator had to rely on Solaris engineers for repairs. Due to some communication issues and a corruption scandal of the bus provider the delay took a lot longer than expected. There was also a two-week halt in operations in January and a few days of repairs in May (charger malfunction) and August (the bus was in a minor car

---

<sup>45</sup> With the exception on Sundays when there are no flights.

crash). During these days the e-bus was replaced with a diesel bus and the bus line was serviced as usual. According to the service provider, another shortfall of the pilot was that it did not provide an accurate estimate of maintenance expenses for e-buses as this had been calculated into the rental contract as an unknown sum and the service was never needed during the pilot period.

These obstructions and challenges are instructive in two ways. First, it shows how pilots that rely on a single bus or charger are at risk of significant hindrance of operation in case of technical problems. That is, pilots with a larger e-bus fleet and other infrastructure elements are more reliable. Second, the delays in Tartu were prolonged due to the lack of relevant mechanical and maintenance staff. As this was a one of 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. This is less of a problem in contexts where the local maintenance staff has the relevant skills and tools to do the needed repairs.



The inverter transforms the direct current from the battery to alternating current, which is used by the driveline, creating mechanical energy which creates propulsion<sup>47</sup>. Further, the electric drive system allows for the regeneration of energy<sup>48</sup>. This is done through a kinetic energy recovery system (KERS) which converts mechanical energy into electrical energy and stored within the battery<sup>49</sup>. This process adds to the overall efficiency of the e-bus and is useful for urban bus routes during stop and go traffic<sup>50</sup>. In fact, electric motors have an efficiency of 85-95%, about three to four times the efficiency of internal combustion engines (ICE)<sup>51</sup>. In general, battery propulsion is more energy efficient and environmentally friendly than combustion propulsion (natural gas or diesel) but lacks the overall range compared to e-bus's traditional counter parts.

### 3.2 Battery technology

The battery pack, or battery, is the chemical storage unit for the electricity used to operate the electric motors<sup>52</sup>. At the same time, these batteries must power the auxiliary systems which include heating, cooling, ventilation, lights, telematics, multimedia, etc<sup>53</sup>. Therefore, it can be said that the battery is the most significant component for the e-bus, as it must be reliable, fast to charge, and powerful enough to meet the energetic demands for the e-bus.

Batteries used for e-buses are electrically connected by galvanic cells. A galvanic cell is a chemical device that consists of two electrodes, an anode, and a cathode<sup>54</sup>. The electrodes serve two purposes: First, the electrodes convert electric energy during the charging process, into chemical energy, which is stored within the battery. Second, this process is then reversed to dispense the energy that is stored in the battery to provide propulsion and other critical functions to the bus. This is done by converting the stored chemical energy into electric energy.

The most common battery used in e-buses are lithium ion (Li-ion) batteries. Theoretically, Li-ion batteries can combine a high specific power (300 Wh/kg), a high energy density (90-140 Wh/kg), and a low self-discharge over time<sup>55</sup>, which means they are more durable, retain a charge longer, and charge faster than conventional batteries. The main drawback for Li-ion batteries is that they are more expensive than other types of batteries, **which increases the capital expense for an e-bus.**

---

<sup>47</sup> Benz, Michael. (2015). "Techview Report – Electric Buses". Retrieved from:

[https://www.imw.fraunhofer.de/content/dam/moez/de/documents/Working\\_Paper/Working\\_Paper\\_Electric\\_Buses.pdf](https://www.imw.fraunhofer.de/content/dam/moez/de/documents/Working_Paper/Working_Paper_Electric_Buses.pdf)

<sup>48</sup> Ibid.

<sup>49</sup> Ibid.

<sup>50</sup> Ibid.

<sup>51</sup> Bourzac, K. (2013). 'Wells to wheels: electric car efficiency', Retrieved from:

<https://matter2energy.wordpress.com/2013/02/22/wells-to-wheels-electric-car-efficiency/>

<sup>52</sup> Iclodean, Calin; Cordos, Nicolae; Todorut, Adrian. (2019). "Analysis of the Electric Bus Autonomy Depending on Atmospheric Conditions". *Energies*, 12(23), 4535; <https://doi.org/10.3390/en12234535>

<sup>53</sup> Ibid.

<sup>54</sup> Benz, Michael. (2015).

<sup>55</sup> Ibid.

## 4. Charging technology

Since e-buses have a shorter range than diesel buses, the question of where, when, and how often e-buses need to charge becomes incredibly important. The two most common strategies used for charging are overnight charging (depot charging) and opportunity charging (overnight charging plus daytime recharging).

### 4.1 Charging strategies and technology

Depot charging is the simplest and most cost-effective approach as the physical structures for the bus depot already exist and requires the less equipment<sup>56</sup>. Depot charging simply involves the e-bus's battery being plugged into the depot's power grid. Depot charging generally takes place in the evenings when commuter levels are low. For bus routes that are shorter, the depot charging is the preferred method of charging as the energy demands are lower compared to a longer route<sup>57</sup>.

Opportunity charging has three main options, pantograph, plug-in, and inductive charging. Inductive charging is where a contactless electromagnetic field charges the e-bus on the route<sup>58</sup>. However, this option is more expensive and not as common<sup>59</sup>. Pantograph charging is where an e-bus is linked by a wire power source and charged on its route<sup>60</sup>. The benefit of a pantograph system is that it allows the e-bus to be partially charged along the route, extending its range, and reducing charge time. The pantograph includes an automatic connecting system, DC-conductive charging system supply equipment, fixed conductive rails attached to the roof of the vehicle, conductive poles, and communication systems<sup>61</sup>.

Further, the e-bus can be equipped with a pantograph-up system, where the pantograph is attached to the bus and it extends to the power source or a pantograph down system, where a pole mounted pantograph connects with a roof mounted charging connector on the bus (see Figure 2). In the view of the interviewed Tartu city expert the pantograph up system could be more costly as each bus would need to be equipped with the system and this increases the number of breakable components.

---

<sup>56</sup> de Pee, Arnout; Engel, Hauke; Guldemon, Marte; Keizer, Arjan; van de Staaij, Jasper. (2018). "The European electric bus market is charging ahead, but how will it develop?". McKinsey & Company article. Retrieved from: <http://mckinsey.com/industries/oil-and-gas/our-insights/the-european-electric-bus-market-is-charging-ahead-but-how-will-it-develop>

<sup>57</sup> Ibid.

<sup>58</sup> Ibid.

<sup>59</sup> Xylia, Maria; Leduc, Sylvain; Patrizio, Piera; Silveira, Semida; Kraxner, Florian. (2017). "Developing a dynamic optimization model for electric bus charging infrastructure". Retrieved from: <https://pdf.sciencedirectassets.com/>

<sup>60</sup> Clairand, Jean-Michel; Guerra-Teran, Paulo; Serrano-Guerro, Xavier; Gonzalez-Rodriguez, Mario; Escriva-Escriva, Guillermo. (2019).

<sup>61</sup> Ibid.

**Figure 2. Pantograph up vs pantograph down schematic**



Source: de Pee, Arnout; Engel, Hauke; Guldemon, Marte; Keizer, Arjan; van de Staaij, Jasper. (2018). "The European electric bus market is charging ahead, but how will it develop?". McKinsey & Company article. Retrieved from: <http://mckinsey.com/industries/oil-and-gas/our-insights/the-european-electric-bus-market-is-charging-ahead-but-how-will-it-develop>

The pantograph system is more cost intensive than the depot charging solution as it requires the creation of charging infrastructure at specific stops along the route. However, this is the preferred method for longer routes where a single charge may not be enough.

#### 4.1 Case study – Turku (Finland)<sup>62</sup>

The e-bus pilot in Turku is instructive as a lot of attention has been put on analysing the charging system and energy consumption. The e-bus fleet in Turku is operating on an opportunity charging scheme that consist of two fast charging stations located at the end-of-line stops of the route being trafficked. This means that the bus batteries are subject to frequent high-power short duration charging events (300kW, measured from the bus side). The charging solution is highly automated and uses a pantograph system. In practical operation the median active charging duration has been 3 minutes. In addition, it has been calculated that the preparation and release of the charger add approximately one extra minute to the overall charging duration.

An important nuance that came out of Turku measurements is that **the consumption measured from the buses is not the same as system level energy consumption**. Losses involved in the operation of the charging infrastructure had increased the total energy consumption by approximately 21 percent during the observation period which averages to an overhead of 0.19kWh / km. This becomes relevant when assessing the economic feasibility of an e-bus solution as it adds an additional expense to the party that directly covers all electricity related costs. Despite charging losses and fuel heater overheads the authors of the case study found e-buses to be overall more energy efficient (1.4 kWh / km) compared to diesel buses (4.2 kWh / km) and even economically feasible for the city of Turku.

---

<sup>62</sup> The information provided in this section, unless noted otherwise, comes from the following source: Aho, Panu. (2019). "Procurement and commissioning of electric city busses in Turku: Observations from the eFÖLI project 2015-2018", Report from Turku University Applied Sciences, retrieved from: <https://julkaisumyyniti.turkuamk.fi/PublishedService?pageID=9&itemcode=9789522167132>



One last thing to emphasize from the recommendations of the Turku study is that the total efficiency of an e-bus system is greatly dependant on the utilization rate of the charging infrastructure due to the fixed energy costs involved. That is, the system is more feasible with a larger fleet and continuous operation. This is also why one should not make quick judgment calls based on the single bus pilot held in Tartu.

## 4.2 Charging considerations for Tartu

Opportunity charging along the route was not used for the Tartu study, so data regarding the optimization of charging strategies along the test route in Tartu is unavailable. However, it stands to reason that opportunity charging and depot charging strategies must be considered if city of Tartu is to procure a transportation service that requires over 60 e-buses.

### ***Input from Elektrilevi***

According the representative of Elektrilevi interviewed for this evaluation the existing electric grid in Tartu is suitable for charging e-buses. In his assessment there would be no need to build a new electrical substation. According to him the grid in Tartu can supply high surges of power for on the route charging. In his expert opinion, considering current technologies, the solution of on the route pantograph charging with overnight charging has shown most promise when it comes to capital expenses (see also Chapter 7). The city would need to invest in a few on-route charging stations where many bus lines converge<sup>63</sup>. One charging station would require an investment of around 200 000 euros. Additional expenses are needed to enable the required amperage (cost calculated per ampere needed) plus set up costs (ca 20 000 euros).<sup>64</sup> The expert also recommended that an e-bus should have enough battery capacity so that the bus could do an additional round in case the charger in the end station has malfunctioned.

### ***Opportunity charging is the preferred method for most cities***

Opportunity charging is the preferred charging strategy for most cities. Despite the higher infrastructure costs (See Chapter 7) compared to depot charging, opportunity charging increases the range and reliability of e-buses as they can charge at strategic points on their route. Further, e-buses using opportunity charging do not need as big of a battery as the depot charged buses which decreases the overall cost (See Chapter 7). This was also confirmed by the interviews. Opportunity charging at end of the route was the preferred and more reliable method by all four of the evaluation interviewees because the battery size needed for a bus to service 19-20 hours straight is too heavy and expensive.

Opportunity charging seems reasonable for the Tartu bus network if one looks at the average length of a bus routes in Tartu, which is approximately 13km. This length is suitable for buses that carry small batteries and get quick charges at the end of the route. Depending on factors related to traffic conditions and the current bus routes, Tartu City should therefore consider the use of opportunity charging as a part of the procurement process for e-buses.

---

<sup>63</sup> In Tartu these stations include Lõunakeskus, Nõlvaku and Ringtee.

<sup>64</sup> However, this number is very high compared to the figures found in pilot studies analysed for this evaluation. The cost for on-route charging station in other pilots has been between 20,000 and 40,000 euros. An average figure based on this is also used in the TCO calculation in Chapter 7.

### ***Placement of charging stops can improve e-bus reliability***

The case study from Turku and Gothenburg (covered in a later section) illustrate how well-planned charging stations can keep the e-bus service reliable throughout the day. In Turku the battery state of charge remains between 40-80% throughout the day. In Gothenburg, 3-4 minutes of opportunity charging enables to ride approximately 20 km which meant that even in the case of charger malfunction at one end of the line the bus could still complete its 8 km route with only one working charger<sup>65</sup>. Naturally, this is only possible with short enough bus routes. Yet, it does show the theoretical benefits of on the route charging compared to only depot charging solution.

### ***Charging time for each e-bus will depend on route length***

Energy requirements for longer daily routes will be higher compared to the energy requirements for shorter routes. In a study which developed an optimization model for e-bus chargers in the city of Stockholm (Sweden) longer bus routes required more time at each charging station while shorter routes required a less amount of time; the mean time being 7.33 minutes<sup>66</sup>. Therefore, it will be important for **Tartu City to identify which routes will require longer charging times in order to maintain an efficient public transportation schedule.**

### ***Bus stops may require more than one charging station***

In areas where multiple bus routes converge, such as transportation hubs like bus stations or train stations, more charging stations may be required which can have an impact on the capital expenses for building the charging infrastructure. For example, in the same study based in Stockholm, it was found that in denser areas, like city centres or main transportation hubs, more charging stations were required with up to as many 7 chargers in heavily trafficked locations<sup>67</sup>. **In the case of Tartu, charging stations will have to be strategically placed to ensure timely flow of traffic and optimization of energy efficiency.** A modelling exercise is needed that considers all the bus lines, where they converge, and how often and how many buses arrive to the stations to properly plan and optimise the opportunity charging infrastructure.

---

<sup>65</sup> ELECTRICITY. (2016). "Cooperation for sustainable and attractive public transport", Status report, retrieved from: [http://www.goteborgelectricity.se/sites/default/files/content/u2318/electricity\\_-\\_cooperation\\_for\\_sustainable\\_and\\_attractive\\_public\\_transport.pdf](http://www.goteborgelectricity.se/sites/default/files/content/u2318/electricity_-_cooperation_for_sustainable_and_attractive_public_transport.pdf)

<sup>66</sup> Xylia, Maria; Leduc, Sylvain; Patrizio, Piera; Silveira, Semida; Kraxner, Florian. (2017). "Developing a dynamic optimization model for electric bus charging infrastructure". Retrieved from: <https://pdf.sciencedirectassets.com/>

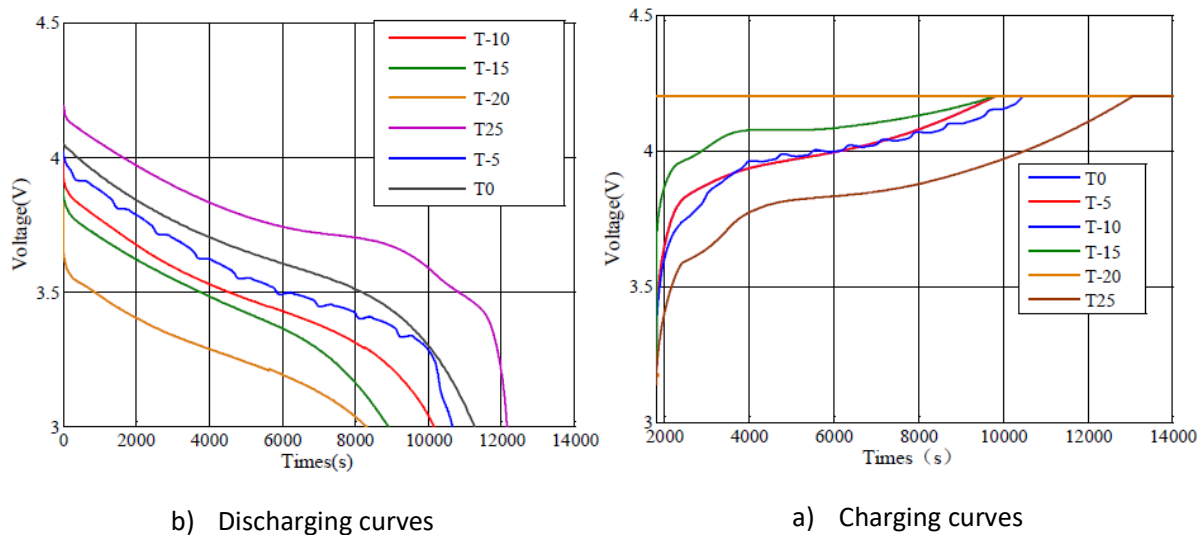
<sup>67</sup> Ibid.

## 5. Climate & performance

### 5.1 Ambient temperature – Battery performance

Li-ion batteries must operate at a temperature of roughly 25 degrees Celsius to maintain the optimum level of efficiency in terms of charging and discharging rate<sup>68</sup>. Typically, the performance of Li-ion batteries will degrade at temperatures below 0 degrees Celsius. **The performance of the battery is affected in two stages, charging and discharging.** During the charging stage, cold temperatures lower the maximum charging rate available and for discharging, the voltage decreases much sooner, lowering the capacity for the battery. This relationship can be observed in Figure 3 below:

**Figure 3: Battery degradation at low temperatures**



Source: Shanshan Guo, Yun Liu and Lin Li. 2017. Study on the Performance of Lithium Ion Batteries at Different Temperatures. Atlantis press

For both curves, each line represents the ambient temperature from -20 degrees Celsius (T -20) to the optimal temperature of 25 degrees Celsius (T25). For the discharging curve, lower temperatures cause the Li-ion batteries to discharge their stored energy much sooner, shortening the range for the battery. For charging, the voltage rises very quickly and reaches the cut-off point sooner, which reduces the maximum charge rate available. **For the operation of an e-bus, these relationships translate to decreased range due to faster depletion of the battery and a diminished charge capacity.**

For higher ambient temperatures, Li-ion batteries are at higher risk of overheating. Naturally, Li-ion batteries are more prone to overheating due to the chemical processes that take place during charging

<sup>68</sup> Vilppo, Olli; Markkula, Joni. (2015). "Feasibility of electric buses in public transport". World Electric Vehicle Journal Vol 7 – ISSN 2032-6653.

and discharging<sup>69</sup>. When operating at high-temperatures, Li-ion batteries are exposed to a process called “aging” which includes two categories: cycle aging and calendar aging<sup>70</sup>. Cycle aging refers to the number of charges and discharges a battery can undergo before its capacity begins to degrade, shortening the amount of charge a battery has. Calendar aging refers to the overall lifespan for a battery. In both cases, exposure high temperature increases the aging the process, thus diminishing the capacity and lifespan of the battery.

In extreme cases, batteries operating at high temperature may create a process called “thermal runaway” where an exothermic reaction creates an uncontrolled increase in battery heat<sup>71</sup>. When the uncontrolled heat exceeds the heat endurance of batteries, fire or combustion can occur in extreme cases<sup>72</sup>.

Fortunately, e-buses are equipped with a battery management system (BMS) which includes software and hardware components that monitor the state of charge, health, temperature, and function of the battery<sup>73</sup>. Further, as the internal temperature of the battery is regulated by thermal protection and a cooling system within the battery pack, the ambient temperature has little effect on the overall temperature of the battery (i.e. if the ambient temperature is high, the internal battery pack temperature, if properly regulated, will not be affected).

## 5.2 Seasonal differences – Impact on energy expenditure

Special consideration needs to be given to the atmospheric conditions, like ambient temperature and seasonal change, and its effect on the performance of e-buses. Mentioned above, the internal temperature of an e-bus battery pack is regulated by the BMS system and is generally unaffected by the temperature outside the bus. For example, according to a bus pilot conducted in Edmonton, Canada in the winter, it was found that ambient temperature had little effect on the energy usage for **propulsion**<sup>74</sup>.

However, **energy demands from auxiliary systems, such as the HVAC system, can fluctuate in response to changes in ambient temperature**. For example, to manage the internal cabin temperature, especially in northern countries in winter or summer, an HVAC system is required to maintain a comfortable temperature for the driver and passengers. As the primary source of energy, the performance of the e-battery will be directly affected by the energy demand of auxiliary systems.

As opposed to ICE buses where the heating and cooling system uses residual heat produced from the internal combustion engine to heat the cabin, the electric motor in e-buses do not produce enough heat to capture and circulate throughout the cabin. Therefore, energy from the battery is required to operate

---

<sup>69</sup> Ma, Shuai; Jiang, Modi; Song, Chengyi; Wu Jianbo; Wang, Jun; Deng, Tao. (2018). “Temperature effect and thermal impact in lithium-ion batteries: A review”. Retrieved from: <https://doi.org/10.1016/j.pnsc.2018.11.002>

<sup>70</sup> Ibid.

<sup>71</sup> Ibid.

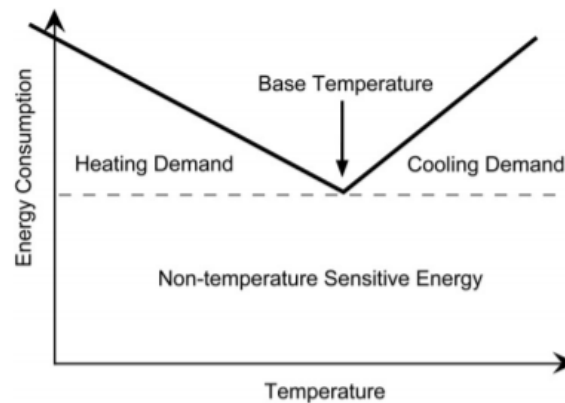
<sup>72</sup> Ouyang, Dongxu; Chen, Mingyi; Huang, Que; Weng, Jingwen; Wang, Zhi; Wang, Jian. 2019. “A Review on the Thermal Hazards of the Lithium-Ion Battery and the Corresponding Countermeasures”. *Appl. Sci.* **2019**, 9, 2483; doi:10.3390/app9122483

<sup>73</sup> Rothgang, Susanne; Rogge, Matthias; Becker, Jan; Uwe Sauer, Dirk. 2015. “Battery Design for Successful Electrification in Public Transit”. *Energies* **2015**, 8, 6715-6737; doi:10.3390/en8076715

<sup>74</sup> Marcon Report. 2016. “Electric Bus Feasibility Study for the City of Edmonton”. Retrieved from: [https://www.edmonton.ca/documents/transit/ETS\\_Electric\\_Feasibility\\_Study.pdf](https://www.edmonton.ca/documents/transit/ETS_Electric_Feasibility_Study.pdf)

the HVAC system. The theoretical relationship between ambient temperature and energy consumption can be observed below in Figure 4.

**Figure 4: Relationship between ambient temperature and energy consumption**



Source: Lee, Kyoungmo; Baek, Hee-Jeong; Cho, Chunho. (2013). "The Estimation of Base Temperature for Heating and Cooling Degree-days for South Korea". Retrieved from: <https://journals.ametsoc.org/doi/pdf/10.1175/JAMC-D-13-0220.1>

In an analysis on the effect of ambient temperature on energy demand in electric buses, it was found that the energy efficiency of e-buses decreased about 32.1% when the temperature dropped from a range of 10 - 15 degrees Celsius to a range of -5 - 0 degrees Celsius due to heating and cooling demand<sup>75</sup>. In this same analysis, it was also found that the range of e-buses were also affected by ambient temperature changes, which showed a decrease of 37.8% in range going from 10 - 15 degrees Celsius to a range of -5 - 0 degrees Celsius<sup>76</sup>. This is further corroborated in an e-bus simulation based on Berlin (Germany) bus routes and climate, where it was found that the HVAC system would require at least 1.2 kWh out of a total of 3.6 kWh to regulate the heat in extreme conditions of -17 degrees Celsius<sup>77</sup>.

While winter and summer temperature variations are the main cause for increased energy usage due to heating and cooling demands, atmospheric conditions (humidity and air density) also play a role in the energy consumption. For example, in a study conducted in Romania, it was found that when atmospheric humidity and density was higher, energy consumption was higher<sup>78</sup>. In general, increased humidity and air density creates more atmospheric resistance, requiring an increased energy output from the Li-ion battery.

Lastly, inclement weather can have a marginal impact on the energy consumption of e-buses. Given the range of factors that could impact energy consumption such as topography, snow, rain, bus stop per km,

<sup>75</sup> Henning, Mark; Thomas, Andrew; Smyth, Allison. (2019). "An Analysis of the Association between Changes in Ambient Temperature, Fuel Economy, and Vehicle Range for Battery Electric and Fuel Cell Electric Buses". Retrieved from: [https://engagedscholarship.csuohio.edu/cgi/viewcontent.cgi?article=2634&context=urban\\_facpub](https://engagedscholarship.csuohio.edu/cgi/viewcontent.cgi?article=2634&context=urban_facpub)

<sup>76</sup> Ibid.

<sup>77</sup> Gohlich, Dietmar; Kunitz, Alexander; Ly, Tu-Anh. (2014). "Technology assessment of an electric urban bus system for Berlin". Retrieved from:

[https://www.researchgate.net/publication/263224970\\_Technology\\_assessment\\_of\\_an\\_electric\\_urban\\_bus\\_system\\_for\\_Berlin](https://www.researchgate.net/publication/263224970_Technology_assessment_of_an_electric_urban_bus_system_for_Berlin)

<sup>78</sup> Varga, Bogdan Ovidiu; Mariasiu, Florin; Miclea, Cristian Daniel; Szabo, Ioan; Sirca, Anamaria Andreea; Nicolae, Vlad. 2019. "Direct and Indirect Environmental Aspects of an Electric Bus Fleet Under Service". Retrieved from:

passenger weight, and bus operator driving tendencies, it is difficult to say with certainty how energy consumption would be impacted by inclement weather like snow or rain<sup>7980</sup>.

### 5.3 Case study – Turku (Finland) and Edmonton (Canada)

By looking at other pilots held in northern climates, a clearer picture is formed on the reliability of e-buses. The cities that were chosen for case studies were Turku, Finland and Edmonton, Canada. A comparison of their climate profiles to Tartu is included in Table 6 below. The Tartu climate conditions will be evaluated in section 5.4.

**Table 6: Climate profile comparison**

City name	Turku	Edmonton	Tartu
Country	Finland	Canada	Estonia
Average high	17°C	18°C	19°C
Average low	-4°C	-10°C	-5°C
Description	Temperate weather conditions very similar to Tartu. Higher humidity given its location near the Baltic Sea. Temperature extremes can reach -35°C and as high as 35°C.	Temperate climate and known for having cold winters. Fairly dry climate receives 476.9 mm of precipitation a year. Temperature extremes can reach as low as -49°C and as high as 36.7°C.	Cold and temperate with significant rainfall averaging roughly 599 mm of rain per year. Temperature extremes can reach as low as -35°C and as high as 35°C.

Source: Authors own, 2020. Data retrieved from: <https://www.timeanddate.com/weather>

#### Case Study – Turku

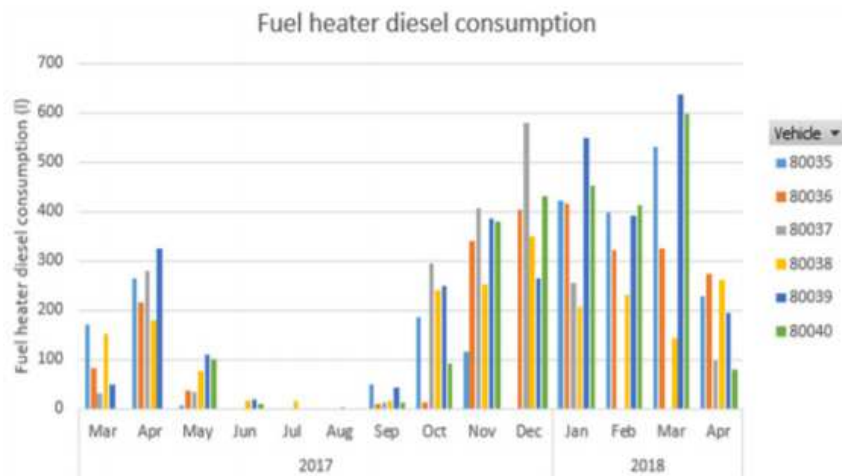
Mentioned in Chapter 5.1, energy demand will increase as the ambient temperature changes to either warmer or cooler temperatures. In the Turku study<sup>81</sup> a clear difference in consumption depending on the temperatures was found. For example, observed in Figure 5, fuel heater diesel consumption increased during the fall, winter, and spring months when ambient temperature is lower.

**Figure 5: Fuel heater consumption for Turku pilot**

<sup>79</sup> Henning, Mark; Thomas, Andrew; Smyth, Allison. (2019).

<sup>80</sup> Marcon Report. (2016). "Electric Bus Feasibility Study for the City of Edmonton". Retrieved from: [https://www.edmonton.ca/documents/transit/ETS\\_Electric\\_Feasibility\\_Study.pdf](https://www.edmonton.ca/documents/transit/ETS_Electric_Feasibility_Study.pdf)

<sup>81</sup> Aho, Panu. (2019).



Source: Aho, Panu. (2019). "Procurement and commissioning of electric city buses in Turku: Observations from the eFÖLI project 2015-2018", Report from Turku University Applied Sciences

Based on this figure, you can see the fuel consumption for the diesel heater is higher in months when the temperature is cooler which **indicates that there is a higher energy demand for heating in those months**. The study also identified a distinct decline in the number of successful days<sup>82</sup> in the winter period.

One of the main recommendations of the authors of the Turku case study stresses the importance of reliable HVAC systems: "[...], the importance of reliable HVAC system cannot be stressed enough in northern conditions, since it is a matter of passenger comfort and, perhaps even more importantly, driver's working conditions." **Therefore, this should be a reminder for future procurement processes in Tartu to also pay additional attention on the technical specifications of cabin heating and comfort.**

### Case Study – Edmonton

The Edmonton pilot was unique that the e-bus was tested in a 5-week period in January to February to test the operability of e-buses in winter conditions. Interestingly, the pilot found no direct correlation between energy usage and ambient outdoor temperatures, which occasionally reached below -20°C. There was little difference in the state of charge even during 17°C difference in ambient temperatures. The authors of the Edmonton analysis attributed the lack of effect to using diesel fired heaters and a heated parking barn which kept the batteries and other bus components warm overnight. It was estimated that in the case electric heaters had been used the range a bus is able to travel would decrease between 15-25%. Therefore, the study concluded that **it is preferable to equip electric buses with diesel heaters rather than to lose the potential range** resulting from the power consumption of electric heaters.

The study also found that other factors were more prominent in instances of increased energy consumption compared to ambient temperature. For example, in routes with a heavier morning rush, i.e. more passengers and bus stops, more energy was used. Also, elevation characteristics impacted the energy consumption of e-buses with more energy being required to propel the bus up the hill. Other factors which were identified as sources of increased energy consumption were traffic congestion,

<sup>82</sup> A day was considered successful when the bus was on the route for 275km or more.

differences between vehicles, and differences in individual driving characteristics of bus drivers. Similar factors were found to influence energy consumption also in the Turku study.

The battery compartment on board the e-buses used in the Edmonton pilot were equipped with a temperature management system that maintains its temperature at an optimal level at all times. No electric propulsion system problems (motor and battery) occurred during the field trials and all maintenance items were related to non-propulsion systems during the test period.

However, it should be noted that although there was no significant change in consumption between temperatures ca -20°C to -4°C, the pilot was only held in the winter and no comparisons were made with summer months. Therefore, there is not enough basis to assess seasonal effects on e-buses.

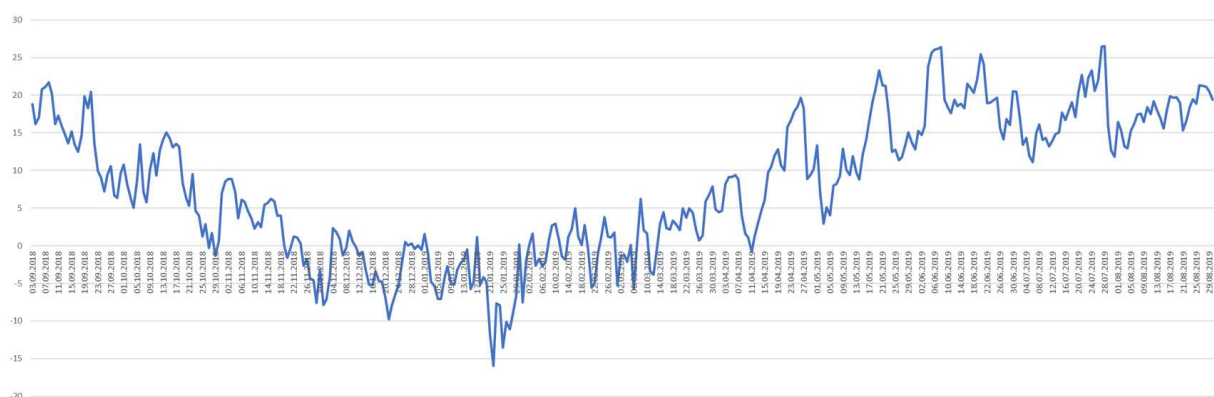
## 5.4 Climate considerations for Tartu

### ***Ambient temperature***

One of the goals of this evaluation was also to find out the relationship between energy consumption of the electric bus and outside air temperature during the Tartu pilot period. To achieve this, the energy consumption data provided by the city was put together with temperature data. The temperature data was retrieved from University of Tartu, Institute of Physics, Laboratory of Environmental Physics that measures weather data with senses on top of the Institute's roof.

The daily average ambient temperature was calculated based on a larger dataset with data points after every 5 minutes for the time period between 05:38 (when the first ticket on an e-bus was validated) and 22:15 (when the last ticket was validated) across the entire pilot period. See Figure 6.

**Figure 6: Average daily outside air temperature in Tartu (03.09.18-31.08.19)**





Source: Authors own, 2020. Data from: University of Tartu, Institute of Physics, Laboratory of Environmental Physics, retrieved from: <http://meteo.physic.ut.ee/>

Energy consumption data was calculated on the dataset provided by the city. Descriptive statistics of the resulting dataset is provided in the following Table 7. Days with 0 charging and/or km=0 were removed.

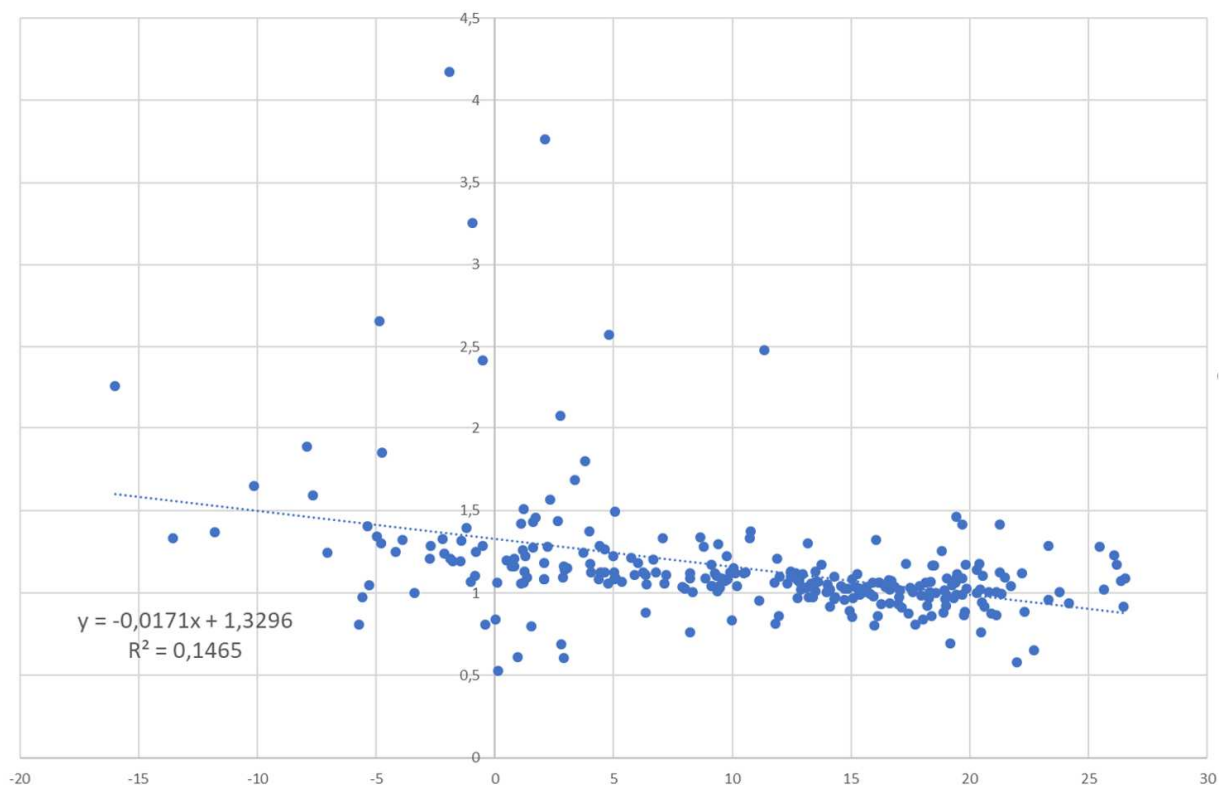
**Table 7: Data set used for the calculation**

Total data points	272
Average mileage (km/day)	177
Average charging (kWh/day)	198
Average energy consumption (kWh/km)	1.153
Total mileage (km)	48,127
Total charging (kWh)	53,731

Source: Authors own, 2020.

A linear regression method was used 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 shown on the following figure.

**Figure 7: Energy consumption (kWh/km) vs daily average temperature**



Source: Authors own, 2020. Energy consumption is measured in kWh/km and daily outside air temperature in °C.

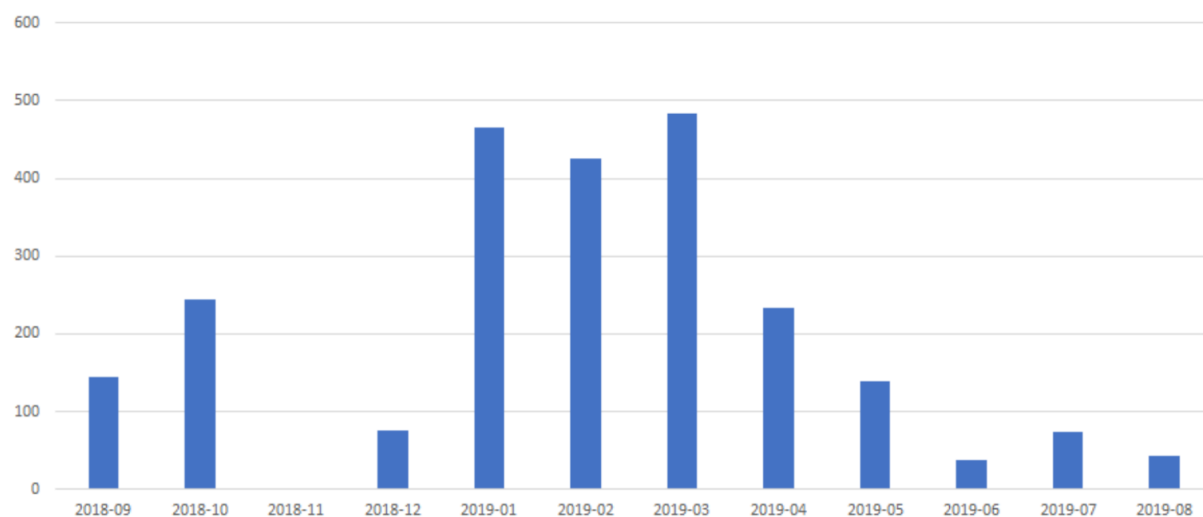
The formula for linear regression is  $y = -0,0171x + 1,3296$ , where explanatory variable  $x$  is air temperature (\*C) and, dependent variable  $y$  is energy consumption (kWh/km). The model shows that for every degree of air temperature decrease the energy consumption increases by 0,0171 kWh/km. Model's  $R^2 = 0,1465$  shows that the model may only describe 14,7% of the variation in  $y$  by the  $x$ , which is not very good and (based on the current dataset) the relationship between temperature and energy consumption is rather weak.

### ***HVAC systems will need to be carefully considered***

Considering the energy requirements necessary for an electric HVAC system, some cities have opted to include a separate, diesel heating system integrated into the e-bus. Edmonton, Turku, and Tartu have opted for this solution. While this diminishes the carbon neutral label for e-buses, diesel heating is seen as an effective solution. For example, in the Edmonton study it was decided that rather than diminish the range of buses, the study concluded that it is better to equip buses with diesel heaters. Similarly, Turku stated that is reliability of the HVAC system was vital to maintain a comfortable cabin temperature, therefore it was concluded that a diesel fuelled heater was the most reliable choice.

The bus used in Tartu's pilot study also used a diesel heater. The energy consumption of the HVAC system is also an indicator of the impact of Tartu's climatic conditions on the e-bus pilot. Figure 8. provides the monthly diesel consumption in the pilot period.

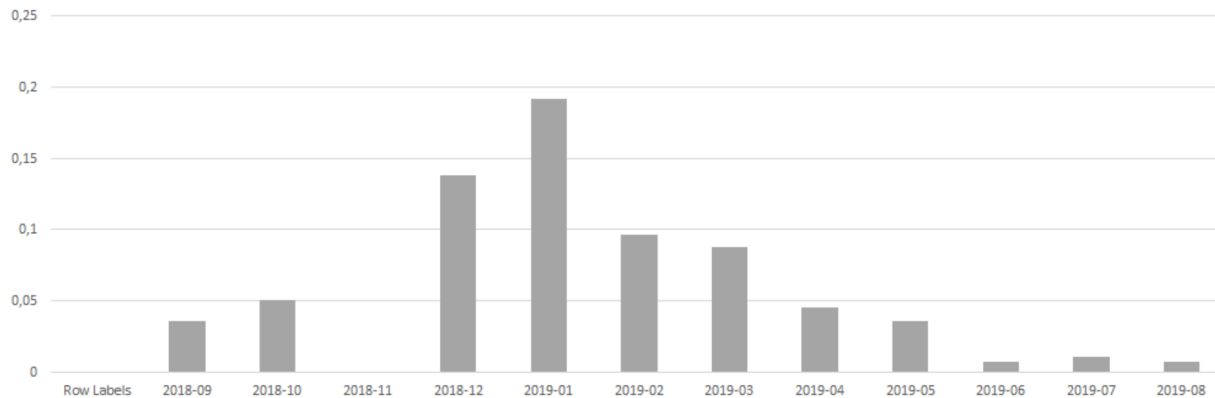
**Figure 8: Diesel consumption for HVAC (liters) by months**



Source: Authors own, 2020. Data from the City of Tartu.

Figure 8, is somewhat misleading however as it does not take into account the days the bus was out of order in November and most of December. Figure 9. provides a better visualisation of the diesel consumption in HVAC as it is presented relative to the actual mileage during each month.

**Figure 9. Relative diesel consumption for HVAC (l/km) by months**



Source: Authors own, 2020. Data from the City of Tartu.

These figures show, unsurprisingly, that diesel consumption for the HVAC went up during the colder months. The average diesel consumption for the HVAC system across the pilot year was 0.04l/km which is a similar figure to the diesel consumption by HVAC systems in the Turku pilot (0.032l/km).

Unless significant technological advances are made in Li-ion batteries that allow them to operate an HVAC system without significantly diminishing the range, it is likely that Tartu needs to consider the use of a diesel or HVO heaters as an auxiliary heat solution in future e-bus pilots or fleets.

#### ***E-buses are reliable in cold weather***

E-buses are equipped with a BMS which helps regulate the internal temperature of the Li-ion battery and insulates it against the outdoor temperature. If the BMS is functioning properly, the ambient temperature will not impact the performance of the Li-ion battery. However, if energy consumption of the e-bus battery can vary from season to seasons based on the energy demand from for auxiliary components, like the HVAC system, to maintain the internal temperature of the bus.

For example, in the Edmonton pilot, no direct correlation was observed between energy usage and ambient outdoor temperatures, which occasionally reached below -20°C. There was little difference in the state of charge even during 17°C difference in ambient temperatures. The authors of the Edmonton analysis attributed the lack of effect to using diesel fired heaters and a heated parking barn which kept the batteries and other bus components warm overnight. It was estimated that in the case electric heaters had been used the range a bus is able to travel would decrease between 15-25 percent. Therefore, the study concluded that it is preferable to equip electric buses with diesel or HVO heaters rather than to lose the potential range resulting from the power consumption of electric heaters.

## 6. Environmental impact of an e-bus fleet

One of the most compelling arguments in favour of e-buses is the positive environmental impact of replacing a polluting urban bus fleet with a fleet of e-buses. In fact, the road transport sector is one of the largest net contributors to carbon emissions, accounting for nearly 13% of total particulate emissions globally and 25% of total greenhouse gas emissions in Europe<sup>83</sup>. As most urban public transportation fleets are equipped with ICE buses, e-buses in public transport offer an effective and immediate solution to replace fossil fuels in a significant way.

In addition to improving air quality there is also a potential reduction in noise pollution. Reducing noise pollution can add to the overall quality of life for city dwellers who live or work near bus routes. Therefore, the introduction of an e-bus fleet is a way to address global concerns arising from greenhouse gas emissions, but also achieve localized benefits as it relates to the overall health and well-being of citizens.

However, it is important to note that biogas buses have much stronger environmental benefits compared to diesel buses. As Tartu has transitioned to an entirely biogas fleet, other cases and examples will be brought into this section to give a more realistic idea of the environmental impact of e-buses compared to the current technology in use.

### 6.1 Primary pollutants and their impact

In general, the primary pollutants generated by ICE buses include carbon dioxide (CO<sub>2</sub>), nitrogen oxide (NO<sub>x</sub>), particulate matter (PM), and noise pollution<sup>84</sup>. For the purposes of this analysis, these pollutants can be organized into two categories: The first category includes CO<sub>2</sub>, NO<sub>x</sub>, and PM and can be described as emissions created by the combustion of fossil fuels. Second, noise pollution can be described as a localized negative externality created by the operation of buses in an urban setting. Both categories, while different in their scope and effect, are both detrimental to the overall quality of life for city dwellers.

It has been well documented that emissions (CO<sub>2</sub>, NO<sub>x</sub>, PM) from ICEs have detrimental health consequences to people at a local level and contribute to the greenhouse production which has negative environmental effects both locally and globally. At a singular level, ICE emissions have been linked to different health issues. For example, according to the World Health Organization (WHO), transport related emissions have been linked to increased risks of mortality and respiratory morbidity as well as increased allergic responses<sup>85</sup>. Additionally, in a report by the International Council on Clean Energy Transportation (2019), it was found that ambient air pollution is the leading environmental health risk factor globally, resulting in roughly 3.5 million premature deaths in 2017 due to stroke, ischemic heart disease, pulmonary

---

<sup>83</sup> Varga, Bogdan Ovidiu; Mariasiu, Florin; Miclea, Cristian Daniel; Szabo, Oan; Sirca, Anamaria Andreea; Nicolae, Vlad. (2020).

“Direct and Indirect Environmental Aspects of an Electric Bus Fleet Under Service”. *Energies*, 13, 336; doi:10.3390/en13020336

<sup>84</sup> Ibid.

<sup>85</sup> WHO. (2005). “Health effects of transport-related air pollution”. Retrieved from:

[http://www.euro.who.int/\\_data/assets/pdf\\_file/0006/74715/E86650.pdf](http://www.euro.who.int/_data/assets/pdf_file/0006/74715/E86650.pdf)

disease, lung cancer, respiratory infections, and diabetes<sup>86</sup>. On a macro level, emissions from transportation related activity in Europe is responsible for almost 25% of all greenhouse gas emissions in Europe, which is linked with global warming and climate change<sup>87</sup>.

Noise is a major environmental issue which mainly affects those living in an urban environment. According to a WHO report on noise pollution, most assessments have focused on the annoyance of noise pollution to the extent that it can disturb different activities<sup>88</sup>. However, noise pollution has been known to have detrimental health impacts in areas where noise producing stressors are most condensed. For example, in an assessment of the environmental burden of disease (EBD) due to environmental noise, it was found that due to environmental noise in Western Europe, amounted to 1-1.6 million DALYs<sup>89</sup> or healthy life years lost every year due to environmental noise<sup>90</sup>. In other words, factors like heart disease, cognitive impairment in children, sleep disturbance, tinnitus, and general annoyance are exasperated by noise pollution, leading to premature death or lost years of quality, healthy life.

## 6.2 Case study – Edmonton (Canada) & Gothenburg (Sweden)

An inevitable obstacle in the procurement of an e-bus fleet is the reality that, as of right now, ICE buses are a reliable and relatively cheap solution to meet the transportation needs of a city. However, **in a time when more information is available about the adverse effects of air and noise pollution, city leaders must consider the impact it will have on the well-being of their citizens.** Therefore, it is important to factor the potential impact of reducing noise and air pollution when evaluating the cost for procuring a fleet of e-buses. Both the Edmonton and Gothenburg cases studies provide an in-depth analysis of the environmental impact of replacing ICE buses with e-buses. Edmonton provides a thorough analysis on greenhouse gas reduction and Gothenburg focuses on noise pollution and the reduction of noise at different speeds. Therefore, both cases will be used in this section to illustrate the potential impact of integrating an e-bus fleet. Further, additional case studies will be used where relevant.

### 6.2.1 Emission reduction

---

<sup>86</sup> Anenberg, Susan; Miller, Joshua; Henze, Daven; Minjares, Ray. (2019). "A Global Snapshot of the Air Pollution-Related Health Impacts of Transportation Sector Emissions in 2010 and 2015".

<sup>87</sup> Pietrzak, Krystian; Pietrzak, Oliwia. (2019). "Environmental Effects of Electromobility in a Sustainable Urban Public Transport". Retrieved from: <https://www.mdpi.com/2071-1050/12/3/1052/html>

<sup>88</sup> WHO. (2011). "Burden of disease from environmental noise". Retrieved from: [https://www.who.int/quantifying\\_ehimpacts/publications/e94888.pdf?ua=1](https://www.who.int/quantifying_ehimpacts/publications/e94888.pdf?ua=1)

<sup>89</sup> The EBD is expressed as disability-adjusted life years (DALYs) which is the sum of potential years of life lost due to premature death and the equivalent number of years lost because of being in a poor state of health or disability. See more: WHO. (2011).

<sup>90</sup> Ibid.

While there have been several e-bus pilots in cities around Europe, to date there still has been no city to transition to a completely carbon neutral e-bus fleet<sup>91</sup>. Therefore, most of the information regarding the reduction in emissions from urban transport systems rely on data that has been collected from limited pilot studies and simulations, so it is difficult to say what the real-world impact will be. Fortunately, the city of Shenzhen, China has launched a completely electric fleet of buses, making it an ideal focus study for measuring the environmental impact.

At the end of 2017, Shenzhen China, a city of 12 million people, had 16,359 e-buses in operation. At the time, this made Shenzhen the only city in the world to use a completely electric bus-fleet<sup>92</sup>. The environmental impact observed over the last three years has been significant, with the amount of fuel used in public transportation, PM emissions, CO<sub>2</sub> emissions, and less coal used due to energy savings per km for e-buses compared to diesel buses. A summary of the results can be observed in Table 8 below.

**Table 8: Shenzhen China Environmental impact indicators**

Indicator	Result
<b>Fuel consumption</b>	Fuel consumption in public transportation has been reduced by more than 95%
<b>Energy savings</b>	E-buses consume 72.9% less energy than diesel buses, resulting in 366,000 tons of coal saved annually, substituted by 345,000 tons of alternative fuel
<b>CO<sub>2</sub> emissions</b>	Reduction of 48% CO <sub>2</sub> emissions which amounts to 1.353 million tons of CO <sub>2</sub> emissions annually
<b>Smog producing emissions (CO, VOC, NOx, PM)</b>	Reduction of 431.6 tons annually for smog producing emissions

Source: Authors own, 2020. Data retrieved from: Institute of Transportation and Development Policy (2018). "China Tackles Climate Change with Electric Buses". Retrieved from: <https://www.itdp.org/2018/09/11/electric-buses-china/>

Based on the results from Table 8, the integration of e-buses in Shenzhen has been successful in reducing harmful emissions and increasing energy savings. It is important to note that the scope and impact of this study are much different compared to Europe. For example, the number of e-buses in operation in Shenzhen is roughly 4x greater than all the e-buses currently used in Europe. Further, as fuel used for electricity production varies from country to country – i.e. the share of coal used for electricity generation compared to renewable sources – the outcome will likely be different in Tartu.

However, small scale pilots and simulations in EU cities show what the potential impact for e-bus adoption could be. For example, the ZeEUS project (mentioned in the background section) tests and studies e-buses in cities around the EU and has observed promising results as it relates to the reduction of CO<sub>2</sub> emissions. A summary of a few studies is included in the Table 9.

Based on the limited results from each pilot, there were significant reductions in CO<sub>2</sub> emissions which supports the results from Shenzhen that e-buses reduce the amount of CO<sub>2</sub> emissions in an urban setting. What is more, the savings from fuel saved for each city is substantial which underscores the cost savings potential for an all-electric bus fleet.

<sup>91</sup> According to the "European Green City Initiative", Dutch cities Eindhoven and Helmond are the closest cities to transition to an entirely electric bus fleet. Retrieved from: <https://ec.europa.eu/environment/europeangreencapital/dutch-cities-eindhoven-and-helmond-roll-out-largest-electric-bus-fleet/>

<sup>92</sup> Institute of Transportation and Development Policy (2018). "China Tackles Climate Change with Electric Buses". Retrieved from: <https://www.itdp.org/2018/09/11/electric-buses-china/>

**Table 9: E-bus pilots in Europe and their results /environmental impact**

City, Country	Pilsen, CZ <sup>93</sup>	Bonn, DE <sup>94</sup>	Eindhoven, NL <sup>95</sup>
<b>Average temperature (C°)</b>	2° - 10°	-2° - 23°	0° - 23.4°
<b>Number of buses used</b>	2	6	43
<b>Bus model &amp; length</b>	ŠKODA Perun E-Bus; 12m	Sileo S12; 12m	VDL Citea SLFA-E181 electric; 18m
<b>Duration</b>	May 2015 - April 2017	April 2016 - March 2018	Dec 2016 - Sept 2017
Operational conditions			
<b>Typology</b>	City centre, suburban	City centre, suburban	City centre, suburban
<b>Topography</b>	Hilly	Mostly flat, moderate hills	Flat
<b>Length</b>	6km	17km	4.4-12.3km
<b>Average speed</b>	25km/h	16.6km/h	18.5 – 27.5km/h
<b>Total daily hours of operation</b>	7.5-18.5h	13.5h	20h
<b>Total daily km driven (per vehicle)</b>	80-200 km	200km	200 km – max 300km
<b>Average number of passengers</b>	1258	7250	11,500 per line
Results			
<b>Diesel fuel saved (assuming 38l/100km)</b>	17,852 litres	93,736 litres	1,298,586 litres
<b>Distance travelled</b>	46,980km	246,674km	3,417,331km
<b>CO<sub>2</sub> prevented from emissions</b>	6,149kg <sup>2</sup>	99,809kg <sup>2</sup>	1,167,054kg <sup>2</sup>

Source: Authors own, 2020. Data from ZeEUS project reports, retrieved from: <https://zeeus.eu/publications>

While the examples in Table 9 are convincing, they only discuss the amount of CO<sub>2</sub> that will be prevented by replacing diesel buses with e-buses. They do not account for biogas buses, which are more environmentally friendly than diesel buses. In a report on Swedish public transportation, data from bus operations in Sweden were compared, including emissions per energy source during the use phase (while the bus is driving) for a 12m city bus. The results of the study can be observed in Table 10.

<sup>93</sup> ZeEUS local brochure – Pilsen. (2018). Retrieved from: <https://zeeus.eu/uploads/publications/documents/zeeus-city-sheet-pilsen-en-final.pdf>

<sup>94</sup> ZeEUS local brochure – Bonn. (2018). Retrieved from: <https://zeeus.eu/uploads/publications/documents/zeeus-city-sheet-bonn-en-final.pdf>

<sup>95</sup> ZeEUS local brochure – Endhoven. (2018). Retrieved from: <https://zeeus.eu/uploads/publications/documents/zeeus-city-sheet-eindhoven-en-final.pdf>

Based on the results in Table 10, diesel is by far the most polluting energy source. For NO<sub>x</sub>, HC/VOC, and PM, biogas produced more polluting emissions than diesel fuel but was significantly out produced regarding CO<sub>2</sub> emissions. In this case, e-buses, which were equipped with bio-diesel heaters, outperformed both bus options for each category. However, it is important to note that the electricity produced to charge e-buses was from wind and bio-diesel which was produced from slaughterhouse waste<sup>96</sup>. If electricity from the grid was produced using only fossil fuels, then the pollution per charge from e-buses would be higher.

**Table 10: Emission per energy source during the use phase of a 12m bus when used in Swedish public transportation**

Emission	Diesel + FAME <sup>97</sup>	Biogas	Electric + HVO	% Change for e-bus compared with diesel	% Change for e-bus compared with Biogas
NO <sub>x</sub> (g/km)	0.8	1	0.1	-87.50%	-90%
HC/VOC (mg/km)	254.9	363.4	6	-97.65%	-98.35%
SO <sub>2</sub> (mg/km)	3.45	17.4	-	-	-
PM (mg/km)	17.6	22.7	0.01	-99.94%	-99.96%
CO <sub>2</sub> e (g/km)	1108.9	27.4	2.3	-99.79%	-91.61%

Source: Authors own, 2020. Data from: Boren, Sven. (2019). "Electric buses' sustainability effects, noise, energy, use, and costs" International Journal of Sustainable Transportation. Retrieved from: <https://doi.org/10.1080/15568318.2019.1666324>

In the case of biogas, carbon dioxide emissions are considered carbon neutral as the fuel source originates from an open carbon cycle. In other words, biogas does not take away or add to carbon emissions. In other greenhouse gas polluting emissions, biogas is on par with natural gas and diesel emissions<sup>98</sup>. So, while CO<sub>2</sub> emissions significantly decrease, other polluting emissions remain the same if not higher than diesel buses.

E-bus environmental impact largely depends on the fuel source which is used to power the electrical grid – if fossil fuels are used there will be more pollution, if renewable sources are used there will be less pollution. Therefore, it is necessary to consider the fuel sources used to power an electrical grid.

The Edmonton study does a good job providing an analysis of a realistic CO<sub>2</sub> reduction based on replacing diesel buses and their power demand from the electrical grid. Observed in Table 11, Edmonton study compares their current CO<sub>2</sub> emissions from the electrical grid to what it will be in twenty years. The twenty-year mark was used as that is the life cycle of the electric buses they are testing.

Due to governmental targets to reduce greenhouse gas emissions from coal, the Canadian provincial government indicated that Alberta (state Edmonton is in) will ban coal power plants completely by 2030

<sup>96</sup> Boren, Sven. (2019). "Electric buses' sustainability effects, noise, energy, use, and costs" International Journal of Sustainable Transportation. Retrieved from: <https://doi.org/10.1080/15568318.2019.1666324>

<sup>97</sup> FAME (Fatty acid methyl ester) is a component used in fossil diesel for dedicated diesel engines (like trucks and buses) to increase fuel performance. Retrieved from: Boren, Sven. 2019.

<sup>98</sup> Tõnissoo, Tõnis. (2012). "Feasibility study on the introduction and use of biogas buses in the Tartu City". Retrieved from: [https://www.tartu.ee/sites/default/files/uploads/Transport/bbb\\_Feasibility\\_study\\_on\\_use\\_of\\_biogas\\_buses.pdf](https://www.tartu.ee/sites/default/files/uploads/Transport/bbb_Feasibility_study_on_use_of_biogas_buses.pdf)



and transition to more environmentally friendly options like hydro power<sup>99</sup>. Based on these productions, it is estimated that greenhouse gas emissions from electrical generation will decrease from 64,249,608 tons to 48,475,834 tons in 2034, a decrease of 24.55%.

The grid intensity is important to note because it will impact the overall amount of greenhouse gas emissions produced by electric buses over the next twenty years. According to the report, an e-bus operating during the study would emit approximately 38-44% less CO<sub>2</sub> than diesel buses and by 2034, an e-bus will emit 72-74% less CO<sub>2</sub>. Accounting for the diesel heaters used by the e-buses in the studies<sup>100</sup>, a diesel heated e-bus would reduce the greenhouse gas footprint by 60% over a 20-year period<sup>101</sup>.

**Table 11: Projected grid intensity for 2013 and 2034**

	Year 2013 grid intensity				Year 2034 Grid intensity			
	Installed Capacity	% of total capacity	Production (MWh/year)	GHG (TCO <sub>2</sub> e/year)	Installed Capacity	% of total capacity	Production (MWh/year)	GHG (TCO <sub>2</sub> e/year)
<b>Coal</b>	6271	42	44441574	53329888	0	0	0	
<b>Cogeneration combined</b>	4245	28	22683582	9527104	7527	30	52749216	22154671
<b>Cycle</b>	843	6	3175412	133673	7471	30	45812172	19241112
<b>Simple cycle</b>	804	5	2288988	1258943	2939	12	12872820	7080051
<b>Hydro</b>	894	6	1840388		1894	8	3981946	0
<b>Wind</b>	1459	10	3476388		3777	15	8933360	0
<b>Other</b>	423	3	2430795		1343	5	7764689	0
<b>Total</b>	14939	-	80337127	64249608	24951	-	132114203	48475834

Source: Authors own, 2020. Data from: Marcon Report. (2016). "Electric Bus Feasibility Study for the City of Edmonton".

Retrieved from: [https://www.edmonton.ca/documents/transit/ETS\\_Electric\\_Feasibility\\_Study.pdf](https://www.edmonton.ca/documents/transit/ETS_Electric_Feasibility_Study.pdf)

The main takeaway from the environmental assessment is that future trends suggest that electricity generation will become more environmentally friendly over the next 20 years in Edmonton. Therefore, the environmental impact for switching to e-buses will increase during their life cycle, hence further extending their environmental benefits into the future.

### 6.2.1 Noise pollution reduction

In general, electric motors emit a less noise than their ICE counterparts. This is in large part due to the fact the electric motors do not emit a low frequency noise (LFN) as ICE motors do. LFN is defined by its pervasiveness, as it can penetrate buildings, walls, glass, and travel far distances. As a result, LFN is identified as the main source for noise pollution in urban settings.

<sup>99</sup> Marcon Report. (2016). "Electric Bus Feasibility Study for the City of Edmonton". Retrieved from:

[https://www.edmonton.ca/documents/transit/ETS\\_Electric\\_Feasibility\\_Study.pdf](https://www.edmonton.ca/documents/transit/ETS_Electric_Feasibility_Study.pdf)

<sup>100</sup> According to the report, e-buses outfitted with diesel heaters consume 412 litres of diesel per year.

<sup>101</sup> Ibid.

Performance indicators for measuring noise pollution emitted from buses include interior and exterior noise measurements. Interior measurements assess the noise in the cabin of the bus and how it impacts the bus operator and bus commuters. Exterior noise refers to how the noise is impacting people outside of the bus.

When idling (not moving) e-buses are much quieter compared to other ICE buses. This is the case for both external noise measurements and internal noise measurements<sup>102</sup>. For example, in a study conducted in Edmonton, Canada, it was found that interior and exterior noise for e-buses were much quieter (see Table 12 below).

**Table 12: Interior & Exterior noise level comparison**

Performance parameter	Diesel	Electric
Interior noise at idle, dBa	54.9	47.2
Exterior noise at idle, dBa	58.5	49

Source: Authors own, 2020. Data from: Marcon Report. 2016. "Electric Bus Feasibility Study for the City of Edmonton".

Retrieved from: [https://www.edmonton.ca/documents/transit/ETS\\_Electric\\_Feasibility\\_Study.pdf](https://www.edmonton.ca/documents/transit/ETS_Electric_Feasibility_Study.pdf)

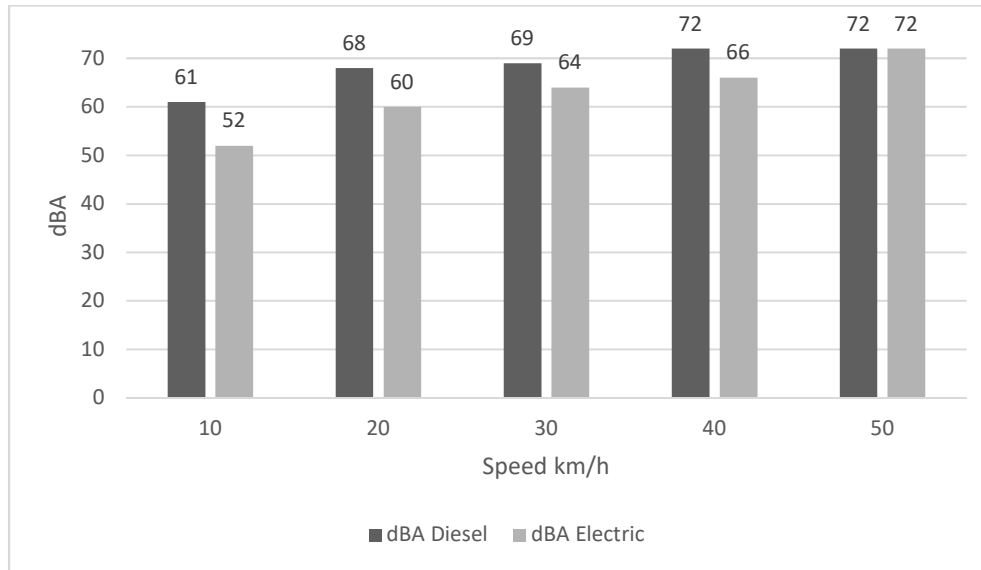
The comparison shows that e-buses are roughly 5-10 dBa quieter than ICE buses while idling. This was shown to be the case in separate studies conducted in Gothenburg, Sweden<sup>103</sup> and a study comparing e-bus user preferences in eight Swedish municipalities<sup>104</sup>. However, when the e-bus accelerates or is travelling at higher speeds, it was found that the difference in dBa between e-buses and diesel buses decreases to the point where both buses are equally as loud. Figure 10 shows this relationship below as measured by outdoor noise.

**Figure 10: Relationship between speed and outdoor noise level**

<sup>102</sup> Ibid.

<sup>103</sup> Electricity report. (2016). "Cooperation for sustainable and attractive public transport". Retrieved from: [https://www.electricitygoteborg.se/sites/default/files/content/u2318/electricity\\_-\\_cooperation\\_for\\_sustainable\\_and\\_attractive\\_public\\_transport.pdf](https://www.electricitygoteborg.se/sites/default/files/content/u2318/electricity_-_cooperation_for_sustainable_and_attractive_public_transport.pdf)

<sup>104</sup> Boren, Sven; Nurhadi, Lisiana; Ny, Henrik. 2016. "Preferences of Electric Buses in Public Transport; Conclusions from Real Life Testing in Eight Swedish Municipalities". Retrieved from: <https://www.diva-portal.org/smash/get/diva2:911643/FULLTEXT01.pdf>



Source: Authors own, 2020. Data retrieved from: Electricity report. (2016). "Cooperation for sustainable and attractive public transport". Retrieved from: [https://www.electricitygoteborg.se/sites/default/files/content/u2318/electricity\\_-\\_cooperation\\_for\\_sustainable\\_and\\_attractive\\_public\\_transport.pdf](https://www.electricitygoteborg.se/sites/default/files/content/u2318/electricity_-_cooperation_for_sustainable_and_attractive_public_transport.pdf)

When compared to biogas buses, the results are about the same. According to a report on Swedish transportation options, biogas buses were louder than their e-bus counterpart<sup>105</sup>. In the same report, it was noted that the model of biogas bus used in the study had a cooling fan which added to the exterior noise, the results of this study are included in Table 13.

**Table 13: Exterior noise measurements during acceleration and constant speeds**

Bus powered by	0 to 35 km/h average noise dba	30 km/h average noise	40 km/h average noise	50 km/h average noise
Electricity	68.6	65.4	70.4	73.6
Biogas	73	67.6	70.3	74.3
Biogas + cooling fan	75.2	N/A	73.9	78

Source: Authors own, 2020. Data retrieved from: Boren, Sven. 2019. "Electric buses' sustainability effects, noise, energy, use, and costs" International Journal of Sustainable Transportation. Retrieved from: <https://doi.org/10.1080/15568318.2019.1666324>

The noise results from Table 13 corroborate the results from Figure 10 which show that at lower speeds, e-buses have less noise emissions compared to diesel and biogas buses but reach noise parity between 40-50 km/h.

Even though outdoor noise levels reach noise parity at 50 km/h (see Figure 10 for average speeds in case studies), it must be taken into consideration that in most cases, buses in an urban setting generally travel

<sup>105</sup> Boren, Sven. 2019. "Electric buses' sustainability effects, noise, energy, use, and costs" International Journal of Sustainable Transportation. Retrieved from: <https://doi.org/10.1080/15568318.2019.1666324>

between 15 – 30 km/h. Therefore, it can be expected that in most cases, the noise levels will be lower than ICE buses.

### 6.3 Environmental considerations for Tartu

Based on the scenarios discussed in previous sections, it can be said with confidence that integrating an e-bus fleet will have environmental benefits for Tartu. From the perspective of the decision makers in Tartu, those environmental benefits would need to be weighed against the economic feasibility. Viewed in this context, several environmental benefits have been identified in this section that could have an impact in Tartu.

#### ***Transitioning to an e-bus fleet will have an immediate impact on reducing polluting emissions***

Environmental benefits are one of the most convincing arguments for switching to an e-bus fleet. In all the case studies observed, there has been a reduction in harmful emissions from ICE buses. What is more, the immediacy of the impact is perhaps one of the selling points for reaching EU environmental targets. For example, in Shenzhen China, which has had e-buses in operation since the end of 2017, has already seen a reduction of 1.353 million tons of CO<sub>2</sub> emissions (see primary pollutants section). Further, even the small-scale pilots referenced in Table 9 show a significant decrease in CO<sub>2</sub> emissions and other greenhouse gas emissions.

#### ***Noise pollution from public transportation will decrease***

Based on the results from Gothenburg and Edmonton, it is highly likely that replacing ICE buses with e-buses will decrease noise pollution. Based on the case studies in Gothenburg and Edmonton, e-buses, while idling emit much less noise compared to ICE vehicles. Despite the noise advantage levelling out at 50km/h (see Figure 10) it can still be expected that noise pollution will drop in Tartu. For example, during rush hour or in congested areas in the city centre, it can be expected that the buses will spend more time below the 50km threshold and will idle longer at stop lights, therefore resulting in lower noise pollution.

#### ***Reduction of noise pollution will lead to a more comfortable journey***

Based on the user experiences from Gothenburg and Edmonton, noise pollution lead to a more enjoyable journey. According to survey results from Gothenburg, the e-bus route was rated very highly for its low noise level. In a similar survey conducted in the Edmonton study, 73% of passengers rated the e-bus noise levels as being better than the diesel buses. Further, bus operators indicated that the noise level for the e-bus as a positive indicator compared to the diesel buses. While the results were for passengers in different cities, they are consistent as it relates to fact that lower noise levels lead to a more enjoyable journey which is encouraging for the City of Tartu. See also Chapter 8 for more information on user and bus operator experiences.

#### ***Equipping diesel heaters on the e-bus will create polluting emissions***

An unfortunate side-effect of having to use a diesel-powered HVAC system is that it will create polluting emissions which would technically make the e-buses “almost carbon neutral”. For example, in the Edmonton study, it was estimated that e-buses would burn 412 litres of diesel a year which amounts to

1.51 tons of CO<sub>2</sub>. However, as Tartu City is considering the use of e-buses in ten years, it is possible that Li-ion battery technology could improve to the point where it is feasible to power an HVAC system without the need of an auxiliary heater. This would need to be evaluated at the time of procurement.

#### ***Future environmental targets will enhance the benefit of e-buses***

Like the EU, the state of Alberta has well defined environmental targets for transitioning to renewable energy sources (see Chapter 1). Seen in Chapter 6.2.1, those environmental targets are expected to increase the CO<sub>2</sub> emission reductions from switching from a diesel bus to an e-bus. Following the same logic, if the EU continues to adhere to their environmental targets, it can be expected that the emissions created from producing electricity will also decrease, therefore enhancing the environmental benefit of e-buses in the future.

#### ***Estonia's climate goals should be considered***

According to the “Estonian national energy and climate plan 2030<sup>106</sup>”, Estonia’s goal is to decrease greenhouse gas emissions by 80% by 2050 compared to 1990 levels. The main polluting industries that are being targeted are electricity production, heating sector, and transportation. Of the two polluting sectors, **electricity production and transportation** are the most significant to e-buses. Similar to the Edmonton study (see Chapter 6.2.1), Estonia’s clean energy targets will make e-buses more energy efficient by 2030. For example, based on current trends, it is projected that by 2030, **greenhouse gas emissions in the energy sector will decrease by roughly 25%**, which corresponds with a 15% increase in shares of renewable energy used for energy production by 2030<sup>107</sup>. Assuming that these targets are accurate and Tartu transitions to 100% renewable electricity production, it can be said that integrating e-buses in 2030 will be environmentally feasible.

---

<sup>106</sup> Estonia's Communication to the European Commission under Article 9(1) of Regulation (EU) 2018/1999. (2018). “Estonian national energy and climate plan (NECP 2030)”. Retrieved from: [https://ec.europa.eu/energy/sites/ener/files/documents/ec\\_courtesy\\_translation\\_ee\\_necp.pdf](https://ec.europa.eu/energy/sites/ener/files/documents/ec_courtesy_translation_ee_necp.pdf)

<sup>107</sup> Ibid.

## 7 Total cost of ownership

Total cost of ownership (TCO) is the generally accepted methodology for comparing the costs of two vehicles<sup>108109110</sup>. TCO involves the assessment of the costs for the lifetime of the vehicles, taking into consideration the acquisition price and the operation and maintenance costs. Using TCO in the context of e-buses compared to other ICE vehicles is advantageous for decision makers as it allows them to estimate the costs of procurement over a lifetime of use rather than the immediate investment price<sup>111</sup>.

In addition to calculating life-time costs, the TCO method allows the decision maker to identify specific costs related to each vehicle, for example, battery costs would be related to e-buses while the cost of refuelling would be applied to an ICE bus. This last point is the core of the TCO analysis, it is vitally important to identify the specific costs as it relates to either ICE vehicles or e-buses as these components will provide the basis for the comparison. For example, a relevant cost for an e-bus would be the charging infrastructure while the wages paid to the bus driver are irrelevant as it would most likely be the same for both.

To help identify the separate components for e-buses and ICE buses, the costs for each component can be organized into capital expenses (CAPEX) and operational expenses (OPEX). In general, CAPEX expenses are the upfront costs to procure the buses i.e. cost of one e-bus where the OPEX are the costs incurred in daily operation of the bus like wages, fuelling/charging costs, etc. Combined, the CAPEX and OPEX will form the TCO cost.

### 7.1 TCO – Cost components

Before a comparison of ICE vehicles and e-buses can be made, the cost components over the lifetime of operation must be organized into CAPEX and OPEX. In the context of e-buses, CAPEX generally refers to the upfront costs associated with purchasing the e-bus (including the battery price) and the charging infrastructure costs. OPEX costs can include numerous components, including driver wages, energy costs (price of electricity vs diesel or biogas), maintenance and repairs etc.

The main differences in cost include the charging infrastructure for the e-bus and fuel source, which is either fuel or electricity. Table 14 shows the general components without specific cost calculations considered, this is because regional differences and laws can impact the overall cost for e-buses or ICE vehicles in the form of tax incentives, subsidies, fuel price etc. For example, fuel costs tend to vary from

---

<sup>108</sup> Gölich, Dietmar; Kunith, Alexander; Ly, Tu-Anh. 2014. "Technology assessment of an electric urban bus system". Retrieved from:

[https://www.researchgate.net/publication/263224970\\_Technology\\_assessment\\_of\\_an\\_electric\\_urban\\_bus\\_system\\_for\\_Berlin](https://www.researchgate.net/publication/263224970_Technology_assessment_of_an_electric_urban_bus_system_for_Berlin)

<sup>109</sup> Keizer, Arjan; Engel, Hauke; Guldmond, Marte; van de Staaij, Jasper; de Pee, Arnout. 2018. "The European electric bus market is charging ahead, but how will it develop?". McKinsey Energy insights

<sup>110</sup> Pihlatie, Mikko; Ranta, Mikaela; Rahkola, Pekka; Ponomarev, Pavel. 2016. "Feasibility of electric buses in Tromsø". Retrieved from: <https://www.vtt.fi/inf/pdf/technology/2019/T348.pdf>

<sup>111</sup> Aho, Panu. (2019). "Procurement and commissioning of electric city busses in Turku: Observations from the eFÖLI project 2015-2018", Report from Turku University Applied Sciences, retrieved from:

<https://julkaisumyynti.turkuamk.fi/PublishedService?pageID=9&itemcode=9789522167132>

year to year based on market factors that could impact oil price. Further, some countries may have more stringent emission taxes in place for ICE vehicles which could impact operating costs.

**Table 14: Basic overview of CAPEX and OPEX for e-buses and ICE vehicles**

Cost type	E-bus	ICE bus
<b>CAPEX</b>		
Vehicle	✓	✓
Charging infrastructure	✓	-
<b>OPEX</b>		
Maintenance and service	✓	✓
Fuel	-	✓
Electricity	✓	-

Source: Authors own, 2020 \*If an e-bus uses a diesel-powered HVAC system, then it will accrue a small cost for fuel to operate. However, as the amount is so small, it was left out of this example.

For ICE buses, the TCO components are less complex compared to e-buses. In general, ICE buses have the initial investment of the bus, with no additional costs<sup>112</sup> other than the OPEX. OPEX accounts for general maintenance costs and fuel costs which are subject to change depending on market conditions.

It is important to note that, while both ICE buses, biogas and diesel buses vary in cost. Biogas buses have a similar price breakdown compared to diesel buses except the investment cost for biogas buses are generally 10-25% more expensive than diesel buses but have a substantial cost savings in fuel price. However, there may be additional infrastructure and transportation costs for biogas fleets depending on the local areas ability to produce, transport, and refuel a biogas bus. In a study done in Liège, Belgium found that the average difference in purchase price for biogas buses compared to e-buses was roughly 38,000 Euros. A breakdown of the costs is included in Table 15 below.

**Table 15: Comparison of Biogas bus to diesel bus for Liège Belgium based on 20-year life cycle (Euros)**

	Bus powered by diesel	Bus powered by biogas
Type of cost	Single bus	Single bus
Price for bus	250,000	287,500
Cost for using the bus	967,140	989,360
<i>Cost of fuel</i>	562,140	465,750
<i>Cost of maintenance</i>	405,000	486,000
<i>Cost of infrastructure</i>	-	37,610
<b>Total</b>	<b>2,184,280</b>	<b>2,266,220</b>

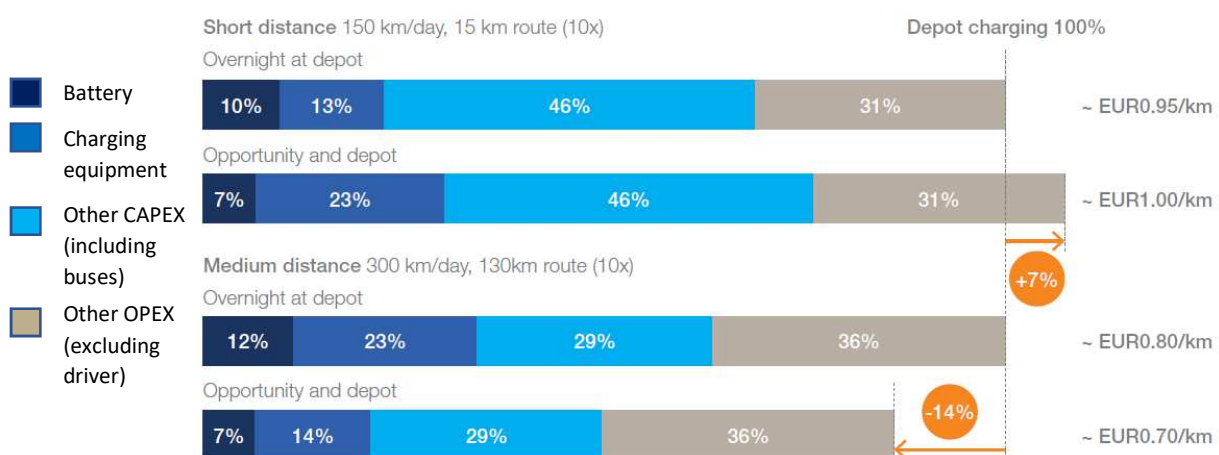
Source: Authors own, 2020. Data retrieved from: Mostert, Martine. (2013). "The economic and environmental feasibility of biogas buses in Liège". Retrieved from:  
<https://orbi.uliege.be/bitstream/2268/128673/1/The%20economic%20and%20environmental%20feasibility%20of%20biogas%20buses%20in%20Li%C3%A8ge-BIVEC.pdf>

<sup>112</sup> Biogas buses may require additional fueling infrastructure if it does not exist at the time of procurement.

For e-buses, there are additional costs to consider. In general, e-buses have a higher CAPEX compared to ICE buses, this is mostly due to the charging infrastructure needed and the higher costs of Li-ion batteries. Starting with the battery costs, Li-ion batteries represent a third of the total costs for e-buses<sup>113</sup>. For example, in a report by Boston consulting, it was found that the battery pack, including the cell and battery installation, constitute for roughly 35% of the cost for a battery electric vehicle<sup>114</sup>. Further, depending on local needs, the length of the route and the frequency of stops needed to charge may necessitate a different battery size. In general, smaller batteries are less expensive and are used for shorter bus routes or longer bus routes with more charging stops. Large batteries are more expensive and can be used for long and short routes and charged less frequently.

Additionally, charging strategies can be different from city to city which will impact the cost of the battery i.e. depot charging vs opportunity charging (See Chapter 4). For example, a bus using depot charging will generally charge overnight and expend its energy during the day. To operate an entire day without stopping to charge requires a larger battery with a higher capacity, this option can be used on short (150km) or longer routes (300km)<sup>115</sup>. For opportunity charging which includes depot charging and mid-day charging on the route, a smaller battery is used with a short (150km) or long range (300km) capability and while it has a lower battery cost, has a higher infrastructure cost for on route charging<sup>116</sup>. A cost comparison between the two charging strategies for short- and long-range trips is included below in Figure 11.

**Figure 11: Cost comparison between charging strategies**



<sup>113</sup> Laizans, Aigars; Graurs, Igors; Rubenis, Aivars; Utehin, George. (2016). "Economic Viability of Electric Public Buses: Regional Perspective". Retrieved from:

[https://www.researchgate.net/publication/293195329\\_Economic\\_Viability\\_of\\_Electric\\_Public\\_Buses\\_Regional\\_Perspective](https://www.researchgate.net/publication/293195329_Economic_Viability_of_Electric_Public_Buses_Regional_Perspective)

<sup>114</sup> Kupper, Daniel; Kuhlmann, Kristian; Wolf, Sebastian; Pieper, Cornelius; Xu, Gang; Ahmad, Justin. (2018). "The Future of Battery Production for Electric Vehicles". Boston Consulting Group.

<sup>115</sup> de Pee, Arnout; Engel, Hauke; Guldmond, Marte; Keizer, Arjan; van de Staaij, Jasper. (2018). "The European electric bus market is charging ahead, but how will it develop?". McKinsey & Company article. Retrieved from: <http://mckinsey.com/industries/oil-and-gas/our-insights/the-european-electric-bus-market-is-charging-ahead-but-how-will-it-develop>

<sup>116</sup> Ibid.



Source: de Pee, Arnout; Engel, Hauke; Guldmond, Marte; Keizer, Arjan; van de Staaij, Jasper. (2018). "The European electric bus market is charging ahead, but how will it develop?". McKinsey & Company article.

As observed in Figure 11, this TCO analysis for charging strategies shows that for shorter routes, depot charging is 5-10% cheaper than opportunity charging. However, for a medium distance route, opportunity charging is the cheaper method as this strategy only requires a small (less expensive) battery and a cheaper, 50kW charger while depot charging would require a larger, 150kW charger<sup>117</sup>.

Including the separate charging infrastructure into the costs for an e-bus will provide a more accurate representation of what both the CAPEX and OPEX will be. In a study based on the experiences of 5 cities in Sweden, e-buses (including depot and opportunity charging) were compared to biogas buses and diesel buses for a bus route in Karlskrona, Sweden. The results of the study can be found below in Table 16.

**Table 16: Cost comparison between Biogas, Diesel, E-bus depot, and E-bus opportunity**

Cost parameter	Biogas	Diesel	Electric (Depot charge + HVO)	Electric (Opp. Charge + HVO)
Procurement price (MSEK)	2.4-2.6	2.1-2.3	3.6-4	3.3-3.6
Energy (SEK/kWh)	1.25	1.44	1.05	1.05
Fueling/charging station (kSEK)	48-53	24-27	290-610	434-500
Extra battery (MSEK year 2023)	-	-	.7-.9	.5-.7
Planned maintenance (kSEK/year)	72-80	52-58	65-71	78-86
Helping maintenance (kSEK/year)	133-147	117-130	119-132	137-152
Uncertainty (+/-MSEK/year)	0.6	0.5	0.7	0.5

Source: Authors own, 2020. Data retrieved from: Boren, Sven. (2019). "Electric buses' sustainability effects, noise, energy, use, and costs" International Journal of Sustainable Transportation. Retrieved from: <https://doi.org/10.1080/15568318.2019.1666324>

The findings from Table 16 further establishes the CAPEX differences between e-buses and ICE buses. In general, these costs will remain consistent from city to city as the largely depend on the costs for the e-bus and the infrastructure costs. According to the study, it was found that e-buses with opportunity charging were the cheapest option for Karlskrona and therefore feasible.

However, there will be greater variability from city to city as it relates to the OPEX and should be noted that the operational expenses for Tartu will likely be different. Therefore, it is important to understand the local context for energy production in Tartu in order to accurately calculate the energy consumption cost.

## 7.2 TCO of Tartu bus-fleet

As was mentioned in Chapter 2.1 the city of Tartu procures its bus service and does not own a bus fleet itself. Therefore, the city operates with procurement agreements. This means that a pure TCO calculation of a bus or bus fleet is less meaningful for the city as its procurement process will always depend on price

<sup>117</sup> de Pee, Arnout; Engel, Hauke; Guldmond, Marte; Keizer, Arjan; van de Staaij, Jasper. (2018). "The European electric bus market is charging ahead, but how will it develop?". McKinsey & Company article. 2018. Retrieved from: [mckinsey.com/industries/oil-and-gas/our-insights/the-european-electric-bus-market-is-charging-ahead-but-how-will-it-develop](https://mckinsey.com/industries/oil-and-gas/our-insights/the-european-electric-bus-market-is-charging-ahead-but-how-will-it-develop)

quotes and terms of the procurement. TCO models are primarily used by companies that directly own the buses. That being said, the TCO calculation is still the best tool available to provide an indication of economic feasibility.

For the evaluation task at hand, the fact that the city procures a service, meant that the city does not have first-hand data on all cost elements. This complicates the analysis for Tartu bus fleets as some of the data is considered a business secret by the service providers.

Table 17 provides an overview of the yearly average cost for the city for the attainment of the bus service. Since 2011 the cost per. km has been adjusted quarterly each year. The adjustment involves a calculation based on the consumer price index, average salaries in the sector (bus drivers), market price for biogas based on GET Baltic stock prices, and a coefficient.

**Table 17: Average Eur per. km of city of Tartu bus transportation as per procurement contracts**

Year	Diesel	Gas	Electric
2011	1.665	-	-
2012	1.778	-	-
2013	1.825	-	-
2014	1.839	-	-
2015	1.814	-	-
2016	1.752	-	-
2017	1.852	1.304	-
2018	1.947	1.418	-
2019	2.047	1.498	-
2020	-	1.462	4.59

Source: Authors own, 2020. Data retrieved from the city of Tartu.

Based on the data provided by the e-bus pilot, the question *“How does the cost of the electric bus used in the pilot compare to today’s cost for diesel buses and gas-fuelled buses?”* it can be said that the e-bus, as operated in the pilot, is significantly more expensive than the biogas and diesel bus options. However, it is the evaluation team’s opinion that the result is unreliable and does not accurately assess the TCO for e-buses in a way that can be compared to biogas or diesel buses.

The large cost difference reflected in Table 17 can be largely attributed to the timeline and scope of the pilot in Tartu. We know that from the analysed case studies and the current procurement timeline for biogas buses in Tartu, that the lifespan of bus fleets can last 10-20 years. Further, it has been established that e-buses have higher CAPEX, but lower OPEX compared to ICE buses. Therefore, after the first year, the cost per/km will drop. Taken together, this indicates that the longer the e-bus fleet is in operation, the more competitive the price will be. Considering that €4.59/km only reflects the costs of a one-year pilot study, the evaluation team feels that the cost does not accurately represent the real costs for an e-bus fleet in Tartu.

Moreover, input data is changing every day (electricity/fuel prices, bus prices, battery prices, etc.) which will make the data used in the Tartu pilot obsolete. Therefore, the research questions regarding the economic comparison of different buses should be reformulated in a way which answering them would be meaningful and usable.

As an alternative solution the evaluation team provided a flexible Excel model to the city of Tartu that allows the user to create “profiles” for different bus types and other relevant data, and compares them

side-by-side. This way the model inputs and assumptions could be updated at any time with relevant data, making the model a dynamic, useful tool for future comparisons. While the current data does not allow for an accurate assessment on TCO for e-buses compared to biogas buses, the Excel model can be used to provide a more accurate assessment of the procurement costs over the lifetime of its use.

The model is able to take cost assumptions for a diesel bus, biogas bus, electric bus with depot charging, and electric bus with depot charging and two pantograph charging poles and apply them to the route lengths, fuel costs, and energy consumption measurements from Tartu. The rationale for each cost can be seen in the Annex 2. Further, the model assumes an operating period of 15 years, with a distance of 100,000km per year for one bus. The results from the model and the comparison can be seen in Table 18 below.

**Table 18: Cost comparison for bus options in Tartu**

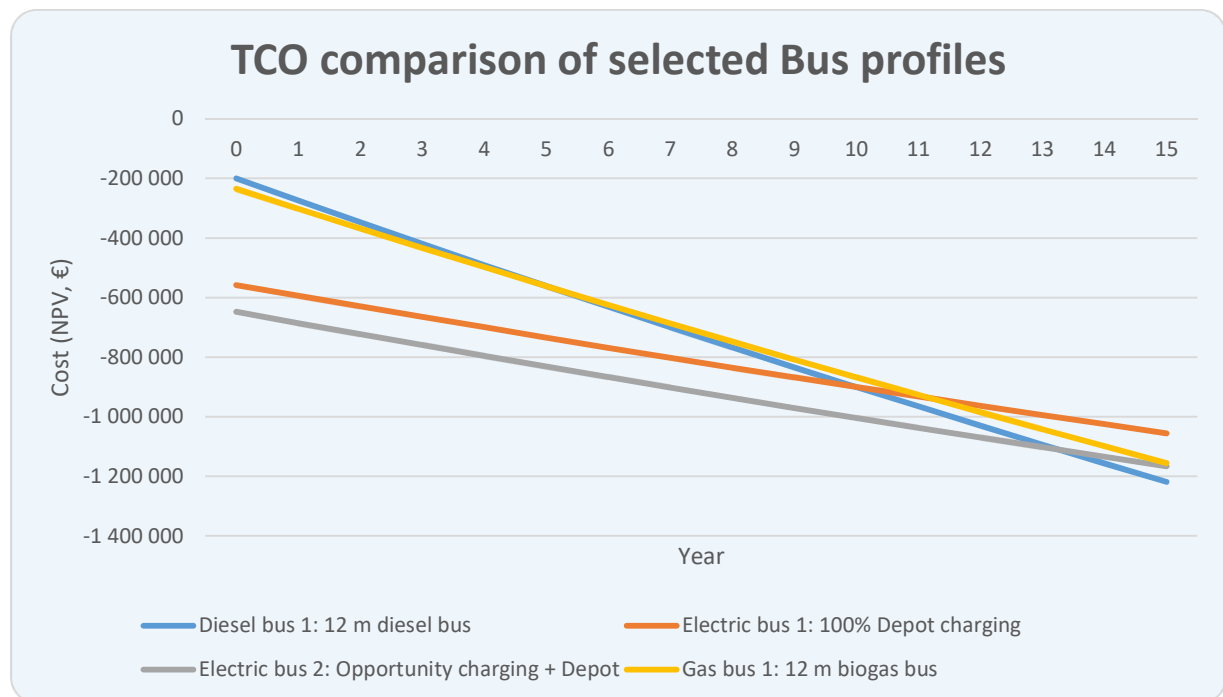
	<i>Diesel bus: 1 x 12m bus</i>		<i>Biogas bus: 1 x 12 m bus</i>		<i>Electric bus: 1 x 12m depot charged bus</i>		<i>Electric bus: 1 x 12m depot charge + opportunity charging with 2 pantograph posts</i>	
<b>Cost</b>	<b>Value</b>	<b>Unit</b>	<b>Value</b>	<b>Unit</b>	<b>Value</b>	<b>Unit</b>	<b>Value</b>	<b>Unit</b>
<b>CapEx (per bus)</b>								
<i>Aquisition cost of a bus</i>	200,000	€	235,000	€	553,000	€	553,000	€
<i>Infrastructure (charging/refueling)</i>	0	€	0	€	5,000	€	95,000	€
<b>OpEx (per bus)</b>								
<i>Fuel/energy cost</i>	1.258	€/l	0.949	€/kg	0.09	€/kWh	0.09	€/kWh
<i>Fuel/energy consumption</i>	0.391	l/km	0.391	kg/km	1.14	kWh/km	1.14	kWh/km
<i>Maintenance costs (fixed)</i>	5,000	€/year	6,951	€/year	6,000	€/year	7,500	€/year
<i>Maintenance costs (variable)</i>	0.2	€/km	0.23	€/km	0.16	€/km	0.16	€/km
<i>OpEx 1: HVAC (diesel)</i>	-	-	-	-	0.04	€/km	0.04	€/km
<b>TCO (NPV)</b>	<b>1,218,824</b>	<b>€</b>	<b>1,155,895</b>	<b>€</b>	<b>1,055,960</b>	<b>€</b>	<b>1,155,895</b>	<b>€</b>
<i>including:</i>								
<i>Initial investment</i>	200,000	€	235,000	€	558,000	€	648,000	€
<i>Cash Flow during the period (NPV)</i>	1,018,824	€	920,895	€	443,028	€	463,627	€

Source: Authors own, 2020. The rationale for the figures can be found in Annex 2.

According to this model, when comparing single buses, an e-bus with depot charging is shown to be the most cost efficient over a 15 year period, with a total of €1,055,960 in expenses followed by the e-buses with a depot charger and two pantograph chargers and the biogas bus. The diesel bus is the least cost effective in a 15-year period. Applying this data to Figure 12 and comparing them over a 15-year period, an e-bus with 100% depot charging reaches price parity with a diesel and biogas bus in 9-10 years and 12-13 years with an e-bus with opportunity and depot charging options.

Adjusting for the missing data in the Tartu pilot, the model has produced a scenario which shows that e-buses, used over a 15-year period, are less expensive than diesel and biogas options. **Based on the results under the conditions outlined in Annex 2, it can be said that operating an e-bus in Tartu is economically feasible.**

**Figure 12: TCO comparison of bus profiles**



Source: Authors own, 2020

However, there are some limitations with the model, first, this model compares the cost of only one bus, not a fleet of buses. In the case of e-buses which may need extensive infrastructure upgrades due to the chargers, the cost for an entire fleet may be entirely different than what is represented in Table 18. Further, the charging infrastructure will largely depend on local conditions in Tartu such as access to the electrical grid along the bus stops, upgrades needed to bus depots to accommodate chargers, and identifying which routes are best suited for opportunity charging. This is a modelling exercise that needs to be conducted before 2029. However, the model provided by this evaluation can be updated with the appropriate total investment costs of fleets and chargers, so as new data becomes available, the model will be able to produce more accurate cost estimates for Tartu.

### 7.3 Cost considerations for Tartu

#### ***Consider the capabilities of local bus operators***

In case the Tartu city procurement process will remain the same in 2029, i.e. a passenger carrying service will be procured instead of a fleet of buses, and there is a will to change to electric transportation, the city government should already indicate this to the bus companies a few years in advance. It takes time for fleet operating companies to restructure their bus fleets and to build relevant expertise, e.g. maintenance and driving skills, and capacity. A sudden investment into an entire fleet based on a different technology can be a hurdle for some transport providers, especially considering that e-buses are still more expensive per unit than ICE buses. The interview with the service provider for the e-bus pilot also revealed that for

them e-buses are not yet an economically viable solution if the procurement contract is only for 8-10 years. As was shown in the calculations above the breakeven point for some e-buses comes at year 12-13. In other words, the longer the procurement period the more economically attractive is the e-bus alternative to bus service providers.

***Consider opting for an environmentally friendly fuel source for the heating system***

While a diesel heater was used in the e-bus pilot, there are certainly more affordable and environmentally friendly fuel options which will reduce the costs for e-buses. For example, if the on-board heater used bio-diesel or biogas, similar to what is used for biogas buses, it would be cheaper and bring down the OPEX costs for e-buses.

***Optimize the charging strategy to maximize the cost effectiveness***

The charging infrastructure represents a significant cost to the e-bus procurement. For example, the number and length of bus lines will determine the amount of charging stations needed, therefore it is dependent on the city transportation authority to develop a system that maintains the optimum level of efficiency in terms of cost and service.

***Fuel sources for energy production may change the charging costs for e-buses***

Due to environmental targets set by the EU and Estonia, it is likely that fuel sources for electricity production will change over the next ten years. For example, oil shale, which is the predominant fuel source for electricity production in Estonia, may be used less in favor of cheaper, environmentally friendly fuel sources, driving down the cost of charging an e-bus.

## 8 Strengths and weaknesses of e-buses

Table 19 highlights the general strengths and weaknesses of e-buses compared to internal combustion buses.

**Table 19: Strengths and weaknesses of electric and ICE buses**

	Electric buses	Internal combustion buses
<b>Strengths</b>	<ul style="list-style-type: none"> <li>• Lower CO<sub>2</sub> emissions</li> <li>• Produces less noise pollution</li> <li>• Lower maintenance and service costs</li> <li>• Increased energy efficiency through regenerative braking</li> </ul>	<ul style="list-style-type: none"> <li>• Lower capital expenses than e-buses</li> <li>• Low-risk – Have been in operation for decades</li> <li>• Better suited for cold climates – capture heat generated from engine to heat cabin</li> <li>• Better range than e-buses</li> </ul>
<b>Weaknesses</b>	<ul style="list-style-type: none"> <li>• Higher capital expenses compared to ICE buses</li> <li>• Auxiliary systems, like HVAC system, deplete battery faster</li> <li>• Lower range compared to ICE buses</li> <li>• Additional infrastructure necessary for charging equipment</li> <li>• Climate conditions can increase the energy demand in e-buses</li> </ul>	<ul style="list-style-type: none"> <li>• More noise pollution compared to E-buses</li> <li>• Produces more greenhouse gases</li> <li>• Biogas and diesel are more expensive than charging for e-bus</li> <li>• Operation and maintenance costs are higher compared to e-buses</li> </ul>

Source: Authors own, 2020.

The aim of the rest of this chapter is to provide input regarding user and operator experience in order to provide an answer to the research question *“What are the strengths and weaknesses of the electric bus in terms of user and operator perspective compared to diesel and gas buses?”*

### 8.1 User experience

#### 8.1.1 Results of street interviews

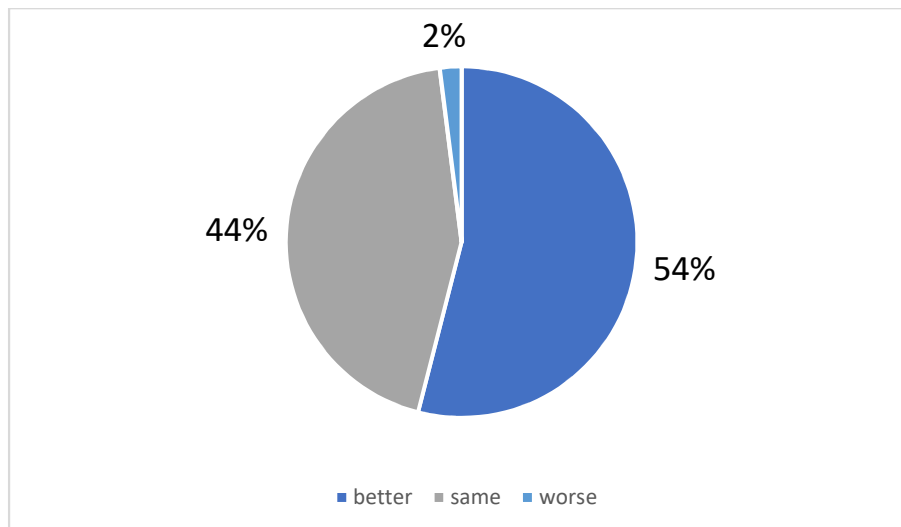
To map user experiences interviews were conducted with Tartu bus users between 10-16<sup>th</sup> of January 2020<sup>118</sup>. A short and structured interview was conducted with those who had used the e-bus<sup>119</sup>. The average age of respondents was 37 and most respondents (N=34) use the city bus service daily. Almost all the respondents (98%, N=49) were pleased with their experience with the e-bus. More than half of the

<sup>118</sup> The interviews were conducted at bus station on three separate occasions. On the 10<sup>th</sup> of Jan. people were interviewed at the ‘Kesklinn (I-V)’ bus stations. On the 13<sup>th</sup> of Jan. interviews were conducted at ‘Kuperjanovi’ and ‘Vabaduse puistee’ bus stations. On the 16<sup>th</sup> of Jan. interviews were conducted at the ‘Raudteejaam’ and once again at the ‘Kesklinn’ bus stations.

<sup>119</sup> Roughly 150 contacts were made to identify 50 people who had used the electric bus. The sample per question varies between 48-50 because some respondents preferred not to answer certain questions. It must be noted that the interviews were conducted five months after the e-bus pilot ended. Furthermore, in July 2019 a completely new bus-network was set up with a fleet of gas busses. Therefore, it should be kept in mind that the responses were not given during or immediately after using the e-bus and that potentially there could have been confusion between the different types of busses that had been used in the city in the past months.

respondents (54%, N=27) found the e-bus experience better than a regular bus experience, albeit given the small sample the difference is minimal as almost the same amount of respondents (N=22) found the experience to be the same, see Figure 13.

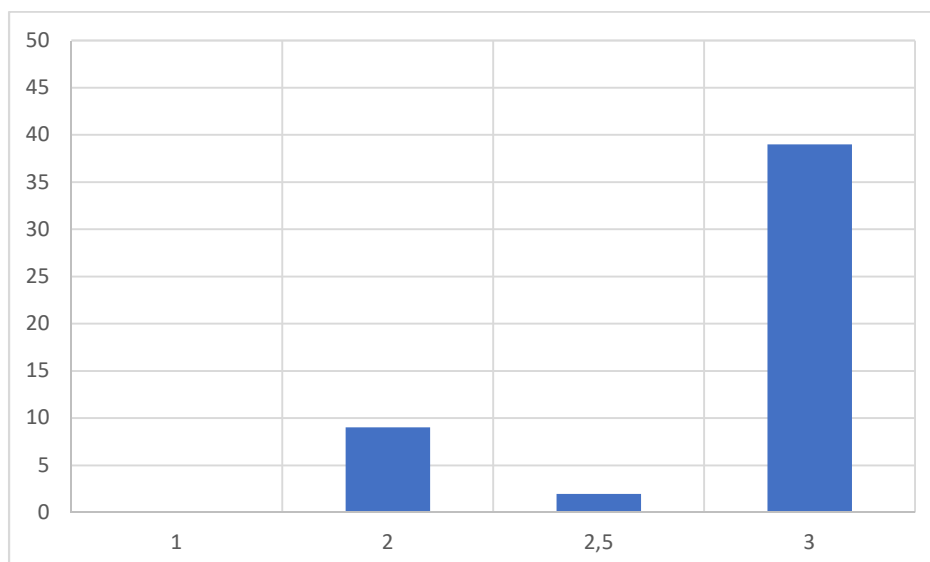
**Figure 13: “Was the e-bus experience better, the same or worse compared to a regular bus?” (N=50)**



Source: Authors own, 2020.

The interviewees were also asked to score the e-bus comfort and convenience (while taking into account temperature, noise level and convenience of the interior) on a scale of 1 to 3. Most (N=39) rated the e-bus with the maximum score while nobody gave it the smallest score. The results are presented in Figure 14.

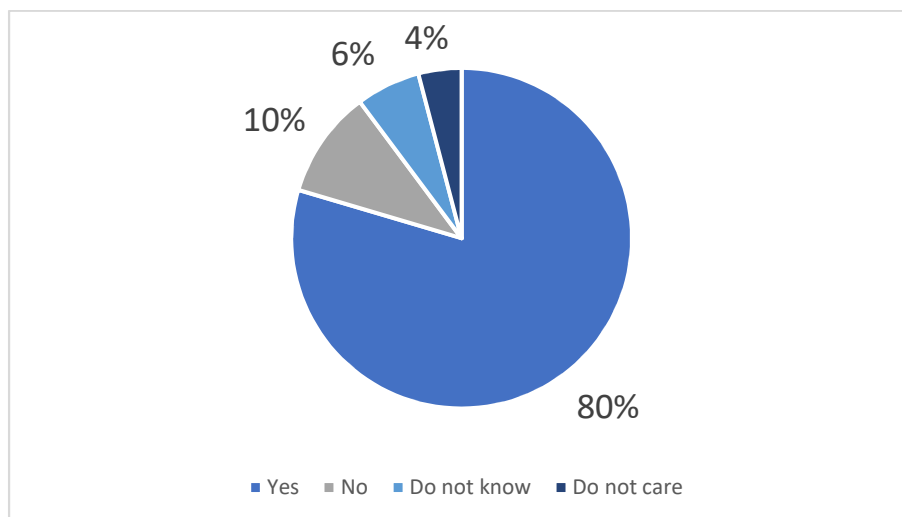
**Figure 14. Scores given to the comfort and convenience of the e-bus (N=50)**



Source: Authors own, 2020.

Most respondents (80%, N=39) said that they would prefer e-buses to the current bus-fleet. At the time of this questionnaire the city was already using a fleet of gas buses.

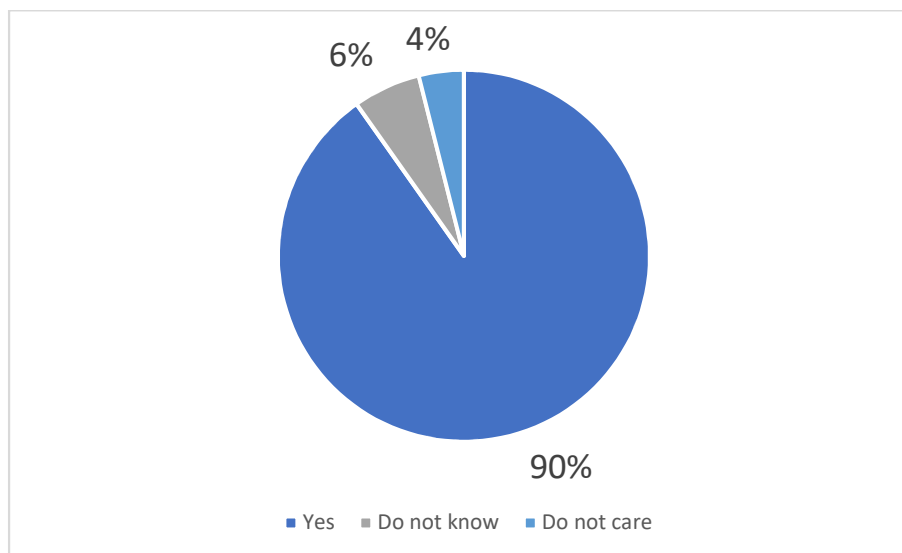
**Figure 15: “Would you prefer e-buses to the current bus-fleet?” (N=49)**



Source: Authors own, 2020.

Nearly all respondents (N=46) thought that e-buses have a positive effect on the environment, see Figure 16.

**Figure 16: “Do e-buses have a positive impact on the environment in your opinion?” (N=49)**



Source: Authors own, 2020.

While the short interview conducted on the streets shows a generally favourable picture towards e-buses it does not allow to go deeper with the analysis and pinpoint what is really behind the user's experience. Therefore, the following Chapters will also cover an analysis of an online survey and compare the results with user surveys conducted elsewhere.



### 8.1.2 Results of online survey

An online survey for e-bus users was open on the city of Tartu homepage between 3<sup>rd</sup> and 13<sup>th</sup> of October 2019. A press release was done to announce the survey and it was shared in the city's social media channels. Participation in the survey was encouraged with prizes.

It must be noted that the results of this survey are only valid among the sample of respondents and cannot be expanded to the population. No methodological sampling was used and the access to the survey was limited to those with enough computer literacy to fill an online survey. No background characteristics, e.g. age, were collected from the respondents<sup>120</sup>. Nonetheless, a quantitative content analysis of the survey questions provides some insights to the user experience of the e-bus pilot. Altogether 103 responses were collected. For this analysis N=102 was used as one of the responses was a clear duplicate. The survey consisted of three open ended questions which are analysed below.

#### ***Difference between e-buses and internal combustion buses***

First, the survey respondents were asked "Is there a difference for you between an electric bus or a bus that uses some other fuel (for example diesel, natural gas)? What is the difference?". To analyse the first half of the question the replies were transformed into a closed question format with the options "Yes", "No", "Do not know".

Some respondents claimed that there was no difference for them (13%, N=13). This can be understood from the user perspective that for some the most important thing is to reliably get from one destination to another. One response was categorized as "Do not know".

Most respondents (86%, N=88) claimed that there indeed was a difference. These replies were further categorized as "Yes" and "Yes (negative)". Altogether N=11 respondents saw the difference as negative and described e-buses as a worse option. Most of these responses (N=8) were related to the understanding that gas buses are environmentally friendlier, and that oil shale is a polluting energy source. Two respondents also mentioned reliability issues, which likely is related to the technical difficulties experienced during the pilot and one had complaints regarding the HVAC system. Most respondents (76%, N=77) saw a positive difference in the bus types by clearly indicating a preference towards e-buses.

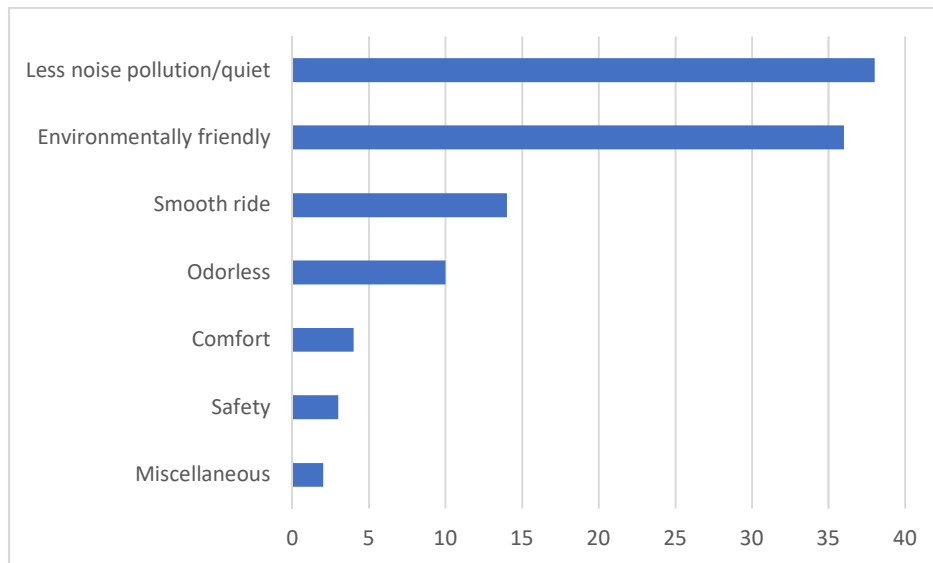
To analyse the positive differences of e-buses compared to other bus types<sup>121</sup> data-driven categorization was used on the positive (N=77) responses. The keywords have been visualized in Figure 17.

---

<sup>120</sup> For example, based on the previous experience of the evaluation team it can be expected that the elderly are less inclined to fill in online surveys. However, the elderly are presumably one of the main groups who use public transportation. Therefore, it could be expected that the elderly are underrepresented in this sample.

<sup>121</sup> It should be noted that in some cases the benefits of e-buses were clearly articulated vis-a-vis gas and diesel buses, whereas in some cases (regarding the environment) benefits of both e-buses and gas buses were articulated vis-a-vis diesel busses.

**Figure 17: “What is the difference?” (N=77)**



Source: Authors own, 2020.

Observed in figure 17, the most important characteristics of e-buses for the respondents are the reduction of noise pollution (N=38) and environmental benefits (N=36). Interestingly, it could be seen that some respondents used the keywords in a more general sense while others described how the city air in Tartu would be cleaner or that they would get less noise from the streets into their apartments. Some respondents emphasized that environmental considerations are important to themselves personally and they make cautious environmental choices (e.g. they would not use a diesel bus). The third most popular characteristic was the smoothness of the ride with e-buses. However, it seems that the term is very much linked with the quietness of the ride - all but one respondent, who mentioned the smoothness of the ride, also mentioned the quiet nature of it. Nevertheless, it is clear from some of the responses that the braking system of e-buses was the reason why the rides had been smooth. For some respondents the important difference came from the lack of diesel or gas smells. Somewhat surprisingly safety was also mentioned by a few respondents. One of them explained their fears regarding gas-tank explosions<sup>122</sup> and another attributed safety to the smoothness of the ride as there is a smaller threat to fall during braking.

### ***Strengths and weaknesses of the pilot's e-bus***

Secondly, all the respondents were asked: “What did you enjoy the most about Tartu’s e-bus and what bothered you the most?” The responses to this question could be divided into two - to those that were related to the e-bus user experience and the specific model of the bus and to those related to the structure of the pilot. All in all, 24% (N=24) of all the respondents claimed that nothing bothered them at all.

Even more so than with the first question the main benefit seen by the users was the quietness of the e-bus (46%, N=47). A surprisingly large segment of respondents (18%, N=18) mentioned that the e-bus had been cleaner than regular buses. It is hard to assess whether this was an objective feeling and the pilot

<sup>122</sup> The respondent also mentioned the gas bus explosion in Stockholm, March 2019, as an example. See more at International Fire and Rescue Services (2019). “The cause of the Stockholm CNG bus explosion has now been determined”, available at: <https://www.ctif.org/news/cause-stockholm-cng-bus-explosion-has-now-been-determined>

bus was indeed cleaned more thoroughly or it can be attributed to something else in the bus design. Some respondents thought it might have been because of less users on this line. Other positive comments involved aspects of the bus design – its modernity, colour, comfort, lighting system, spaciousness, seats design.

Many respondents provided answers that had less to do with the electric technology of the bus and more with the bus route, schedule, and cost. The piloted line had not existed before the and therefore the respondents also used the opportunity to give feedback to this new service line. For example, 19% (N=19) of all the responses mentioned the free bus fare as a positive element to the experience. Altogether around 36% (N=37) of the respondents provided feedback on either the route or schedule of the bus. Among the positive comments (N=17) the most positive replies referred to the fact that the bus schedule had been set up based on train connections, therefore reducing the wait time, and making the commute convenient. Among the negative (N=23) comments, most were related to the frequency of buses on the route. Few respondents pointed out that they could only use the bus rarely as it was on a route that was not as relevant to their commute. The negative comments can also be seen in a positive light that with more frequent e-buses on more lines the people would have been even more pleased. However, there are a few responses worth highlighting. It seems that a few users had experienced unexpected route and schedule changes during the pilot. This is an indication that during such pilots it might be better to stick to one constant route or to pay additional attention on communication activities in case the route is changed during the pilot. People need a reliable service to get to their destination.

### ***The future of e-buses in Tartu***

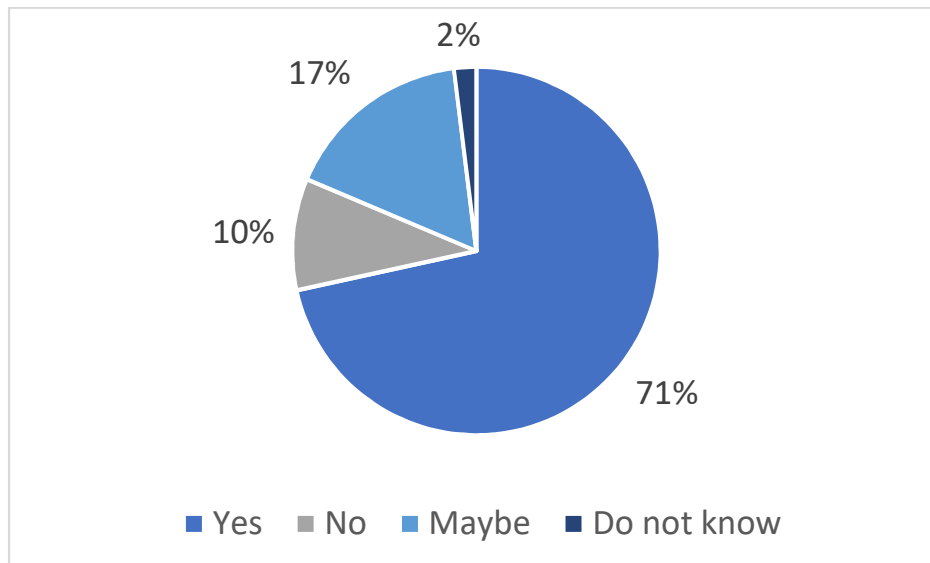
Lastly, the respondents were also asked: “In your opinion, should all Tartu city buses be electric in 10 years’ time?”. To illustrate the sentiment, the open-ended replies were transformed into closed responses. As can be seen in Figure 16 most respondents were supportive of electrification of the public transport. Furthermore, around 25% of the respondents (N=18) who have been categorized as “Yes” (N=73) emphasized their response by using the word “certainly”<sup>123</sup>. Few of the respondents would have liked to see the change sooner, in a 5 years perspective.

Whereas the positive sentiment was obvious, the replies categorized under “Maybe” were more conditional. The conditions included concerns regarding the source of electricity, the reliability of e-buses, advancements in technology and economic feasibility. Some respondents were in general in favour of the idea, but only under the conditions that green electricity would be used or that it has been confirmed that the e-buses would be the most environmentally friendly solution available, especially compared to biogas. Others mentioned that the bus fleet could be changed partially, but not in its entirety. For example, one respondent saw a diversity of buses as a guarantee that the bus service will be reliable even if there are malfunctions in the electric grid. A few respondents were in favour of the idea if it has been confirmed that e-buses can reliably function during winter. Another two of the respondents were more aware of the current state of e-bus technology and mentioned aspects related to battery size, optimal driving range, and cost of the technology, but if these challenges are overcome in the next 10 years, then they would be for the idea.

---

<sup>123</sup> EST: „kindlasti“

**Figure 18: “Should all Tartu city buses be electric in 10 years' time?” (N=102)**



Source: Authors own, 2020.

10% of the respondents gave a straightforward reply that could be categorized as a “No”. The reasons for being critical to the idea were somewhat similar to the concerns of those in the “Maybe” category, but their verdict was clearly against the idea. Oil shale as a pollutive energy source was one of the main reasons for being against changing to a fleet of e-buses. Two respondents claimed that the ecological footprint of e-vehicles is larger than diesel-based transportation. The respondents in this category mentioned gas or hydrogen buses as better alternative for Tartu.

To sum up, most of the respondents were favourable towards a bus fleet composed of e-buses and this is an indication of public support to the idea, albeit keeping in mind the limited sample. However, the concerns and criticism of the people belonging to the “Maybe” and “No” camps need to be addressed if indeed the city changes to an electric transportation system. Cost efficiency and environmental impact calculations would be needed in 10 years’ time to assure a broader support from the public. A similar recommendation was made in the Turku study: “For the general acceptance of e-buses, PR management is of utmost importance. When an e-bus is being maintained or serviced for whatever reasons, the general public will blame this on the new technology, even if the root cause is trivial in nature.”<sup>124</sup>

## 8.2 Operator experience

For a better understanding of the operator experience three interviews were conducted with people closest to the e-bus pilot:

- Head of the bus service provider that was responsible for the e-bus pilot

<sup>124</sup> Aho, Panu. (2019). “Procurement and commissioning of electric city busses in Turku: Observations from the eFÖLI project 2015-2018”, Report from Turku University Applied Sciences, pp. 11

- Lead expert of public transportation at Tartu City Government
- Bus driver of the e-bus during the pilot

These interviews provided insight to the operator experience of an e-bus. The main message from the service provider and bus driver was that the operator user experience was much better compared to a diesel or gas bus. All three interviewees emphasized aspects related to noise reduction and how this impacts the working environment of the bus driver. According to the bus driver it is physically exhausting to spend a full workday in a vibrating bus cockpit. He even jokingly added that “If it were possible, I would only drive this kind of bus every day. Diesel is like night and day compared to the e-bus.” He added that the biogas buses are akin to diesel buses when it comes to engine noises and driving comfort. Just as was emphasized by bus users in the online survey the bus driver also emphasized the smoothness of acceleration and ability to drive very precisely with an e-bus.

Another benefit that was mentioned by the bus driver was the cleaner and more convenient way of fuelling the bus as there are no diesel smells and the bus only needs to be unplugged from the e-charger in the morning. The latter is relevant during winter when with diesel buses one might need to spend time to warm up frozen oils.

According to all three of the interviewees the biggest challenge in integrating a fleet of e-buses are technological, e.g. the current battery size and cost of investments. The key question is how much energy a bus can take with it in the morning to service the line reliably. Additionally, both the service provider and the bus driver also mentioned challenges regarding integrating newer technologies. According to the bus driver, so-called “old school” drivers might struggle with learning the nuances of smart e-bus systems, especially if they provide information to the driver with digital screens compared to analogue switches. This means that whenever there is a transition between e-buses and ICE buses significant trainings should be held to the driving staff. This also reflects to the Turku case study where it was identified that the energy consumption per. bus ride also depended on the specific bus driver.

### 8.3 Case study - Edmonton (Canada)

The evaluation team also investigated user satisfaction information from previous e-bus studies. A good source of information is the Edmonton e-bus pilot where special attention was paid to customer satisfaction. In their case, printed questionnaires were distributed to passengers on board the e-buses. In total, 2,825 questionnaires were collected during the pilot.

A large segment of respondents (78.1%) found that the local transportation company should purchase e-buses. Younger age groups, full-time employed and students were most favourable to the purchasing of e-buses. Interestingly, 64% of the respondents also indicated a readiness to pay more for the bus service (average tolerated increase of 8.8%) to enable the local transport provider to purchase e-buses. From a noise perspective, 73% of respondents evaluated the electric bus as being better than the other buses

they are familiar with. The same was true for fumes (73%) and smoothness of ride (66%). Furthermore, 80% of the respondents found the e-buses to have a comfortable temperature.<sup>125</sup>

Public transportation survey in Gothenburg also showed higher user satisfaction for the bus line that was operated by electric and electric hybrid buses than for public transportation in general (very satisfied 73% vs 56%). In addition, comparisons were made to a different route run on diesel. In the survey they found that a total of 74% of passengers agreed fully with the statement "I find the noise level on board comfortable" on the e-bus line, compared with 29 percent on the other route.<sup>126</sup>

The Edmonton study also included pre- and post-pilot interviews and focus groups with bus operators and mechanical and maintenance staff involved with the pilot. While the results were specific to the bus models (e.g. poor build quality of a bus) and pilot (e.g. short duration) there are a few elements worth pointing out. The bus drivers once again saw good acceleration, smooth ride and quietness as benefits of the e-buses. The maintenance staff pointed out that e-buses might need audible alarms for the safety of garage personnel. The maintenance staff also expected the maintenance to be theoretically easier as the buses have fewer components, and these tend to be larger and therefore probably rebuildable and e-buses have less fluids meaning fewer leaks and a cost reduction in maintenance oils. One of the main take ways of the Edmonton study was that "adequate training will be key to ensuring staff buy-in and a smoother integration of the new technology"<sup>127</sup>. As the e-bus technology has some fundamental differences to ICE buses it is important to consider the time and extra costs involved in training both the bus drivers and mechanical staff.

In conclusion, these user and operator perception findings from Edmonton and Gothenburg are in-line with the surveys and interviews conducted in Tartu and validate the findings in Chapters 8.1 and 8.2. It can be said that based on data from across pilots e-buses are always hailed for their quiet nature and environmentally friendly image.

---

<sup>125</sup> Marcon Report. (2016). "Electric Bus Feasibility Study for the City of Edmonton". Retrieved from: [https://www.edmonton.ca/documents/transit/ETS\\_Electric\\_Feasibility\\_Study.pdf](https://www.edmonton.ca/documents/transit/ETS_Electric_Feasibility_Study.pdf)

<sup>126</sup> ELECTRICITY (2016). "Cooperation for sustainable and attractive public transport", Status report, pp. 17

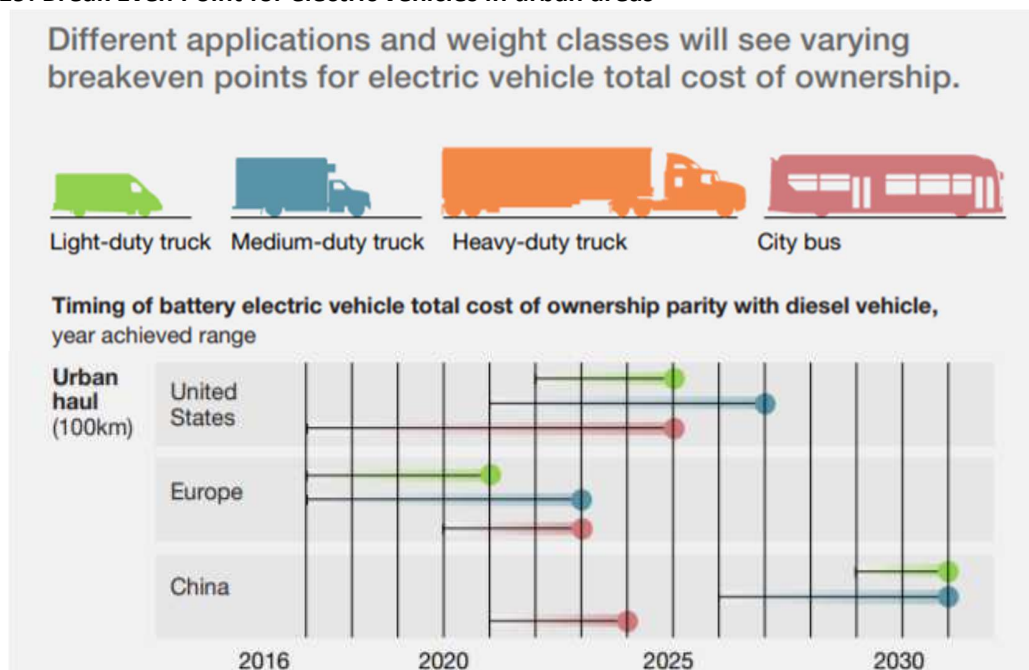
<sup>127</sup> Marcon Report. 2016., pp. 5:1-5:7

## 9 The future of electric buses - key trends

Despite positive environmental benefits for the use of e-buses in public transportation, the cost benefits remain unclear. High-capital expenses for e-buses, including the charging infrastructure and battery prices, are cost prohibitive in most parts of the world. Further, concerns related to the range and reliability of e-buses compared to diesel or natural gas buses can also make public transportation authorities hesitant to procure an entire e-bus fleet.

However, recent trends indicate that total cost for e-buses are expected to drop significantly within the next 10-20 years. For example, in a report by the McKinsey Center for Future Mobility, it was predicted that by 2023 the TCO for e-buses in an urban environment compared to diesel buses would hit their “breakeven point” meaning, the TCO for e-buses would equal diesel buses (See Figure 19)<sup>128</sup>.

**Figure 19: Break Even Point for electric vehicles in urban areas**



Source: Heid, Bernd; Hensley, Russel; Knupfer, Stefan; Tschiesner, Andreas. (2017). “What’s sparking electric-vehicle adoption in the truck industry?”. Retrieved from: <https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/whats-sparking-electric-vehicle-adoption-in-the-truck-industry>

It is also expected that between 2025-2030 electric buses will have a TCO advantage over diesel buses. Despite the favourable forecast, the reality of the situation today is that in most cases, e-buses are more expensive than their diesel or natural gas counterparts.

This raises the question, if TCO for e-buses in public transportation is higher than most bus options right now, why are e-bus procurements growing so rapidly? The answer to this question has several

<sup>128</sup> Heid, Bernd; Hensley, Russel; Knupfer, Stefan; Tschiesner, Andreas. (2017). “What’s Sparking Electric-Vehicle Adoption in the Truck Industry?”. McKinsey Center for Future Mobility. Retrieved from: <https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/whats-sparking-electric-vehicle-adoption-in-the-truck-industry>

dimensions, one of which being political. For example, EU policies and green energy initiatives have been driving demand for environmentally friendly transportation options (See Chapter 1). There is also the city branding and image component where EU cities would like to brand themselves as having environmentally friendly transportation options.

However, future trends for e-buses in public transportation show that the affordability of e-buses are likely to drop in the near future, making a compelling case for e-bus procurement. Future trends can be broken into two sections: First, **current market trends are driving down the costs for e-buses**. Second, **technological innovation in Li-ion batteries will make e-buses more affordable in the future**.

## 9.1 Market trends for electric buses

Demand for e-buses into public transportation is increasing. This is supported by the fact that e-buses constitute the fastest-growing part of the EV market, **with a compound annual growth of 100% from 2013 – 2018 compared to 60% for electric vehicles**<sup>129</sup>. Despite conventional wisdom – that cheaper, comparable products are more competitive – there is broad political support in Europe for an environmentally friendly mobility option which is driving the growth of the e-bus market.

Political influences, international strategies, and cultural preferences are helping to shape the view that clean mobility options are the future of public transit and should take priority over the economic considerations<sup>130</sup>. This is further supported by international strategies, including the **2018 - Vision for a long-term EU strategy for reducing greenhouse gas emissions** (referenced in Chapter 2), as well as the robust support that has been given towards testing, studying, and evaluating e-buses.

In addition to the EU, the general public is overwhelmingly supportive for these environmental initiatives. For example, in a 2019 Eurobarometer survey commissioned by the European Commission, **90% of respondents agree that the EU must ensure access to clean energy and encourage a move away from fossil fuels towards energy sources with low greenhouse gas emissions**<sup>131</sup>. Further, **90% of the respondents in the same survey believe the EU should empower cities and local communities to move towards clean energy sources**<sup>132</sup>.

Bolstered by this support, the market for e-buses is growing with the number of e-buses ordered in Europe doubling in 2017 compared to 2016<sup>133</sup>. Also, there is a clear preference for e-buses compared to other electric public transportation options (See Figure 20).

---

<sup>129</sup> Heid, Bernd; Kasser, Matthias; Muller, Thibault; Pautmeier, Simon. (2018). "Fast Transit: Why Urban E-buses lead Electric-Vehicle Growth". McKinsey Center for Future Mobility.

<sup>130</sup> Ibid.

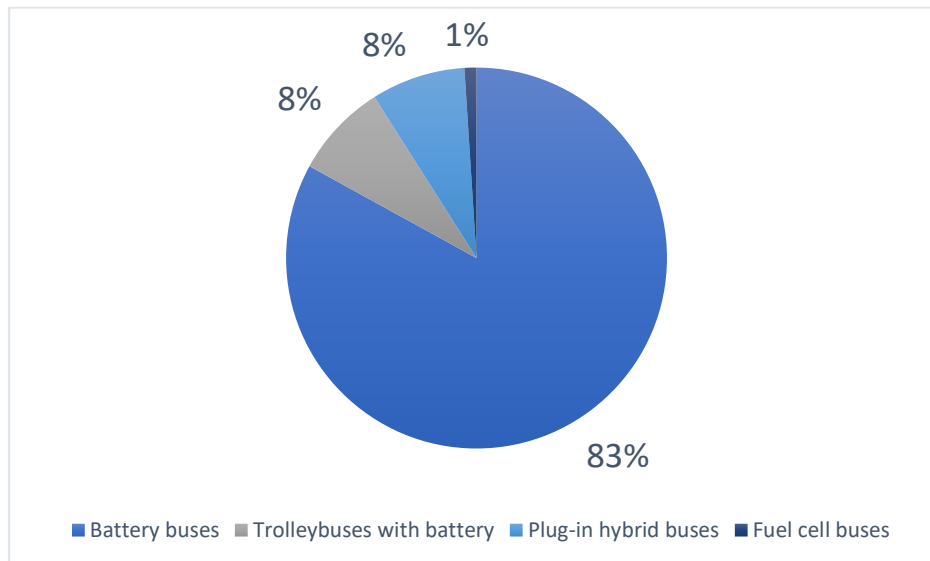
<sup>131</sup> European Commission. (2019). "Special Eurobarometer 492 – Europeans' attitudes on EU energy policy". Retrieved from: <https://ec.europa.eu/commfrontoffice/publicopinion/index.cfm/survey/getsurveydetail/instruments/special/surveyky/2238>

<sup>132</sup> Ibid.

<sup>133</sup> Muzi, Nico. (2018). "Electric buses arrive on time". Retrieved from: <https://www.transportenvironment.org/publications/electric-buses-arrive-time>



**Figure 20: Order of electric buses in 2017 per technology**



Source: Authors own, 2020. Market data sourced from Transport & Environment (2018). "Electric buses arrive on time – Marketplace, economic, technology, environmental and policy perspectives for fully electric buses in the EU". Retrieved from: [https://www.euractiv.com/wp-content/uploads/sites/2/2018/11/2018\\_11\\_electric\\_bus\\_paper\\_final.pdf](https://www.euractiv.com/wp-content/uploads/sites/2/2018/11/2018_11_electric_bus_paper_final.pdf)

In a report by the McKinsey Center for Urban Mobility, it is estimated that in Europe, the number of e-buses in cities will grow by **18% per year and that by 2030, e-buses will account for three-quarters of annual urban bus sales**<sup>134</sup>. From the perspective of bus suppliers (manufacturers), this indicates that the market will continue to grow and based on economic theories like competition-driven pricing<sup>135</sup>, e-bus manufacturers will try to grab the largest share of the growing e-bus market, **driving the cost down**.

## 9.2 Battery innovation trends

The battery pack for a battery electric vehicle, including e-buses, is one of the most expensive components for the entire vehicle, representing 35% of the total cost<sup>136</sup>. Interestingly, compared to internal combustion engine vehicles, EVs are roughly 35% more expensive<sup>137</sup>. **Taken together, this indicates that the difference in cost between e-buses and their internal combustion counterparts is largely determined by the cost of the battery.**

<sup>134</sup> Heid, Bernd; Kasser, Matthias; Muller, Thibault; Pautmeier, Simon. (2018). "Fast Transit: Why Urban E-buses lead Electric-Vehicle Growth". McKinsey Center for Future Mobility.

<sup>135</sup> Competition-driven pricing is a method of pricing in which the seller makes a decision based on the prices of its competition. Typically, this methodology focuses on how that price will achieve the most profitable market share. In general, competitive pricing drives down the cost of a good to achieve the greatest market share. Retrieved from: <https://www.investopedia.com/terms/c/competition-driven-pricing.asp>

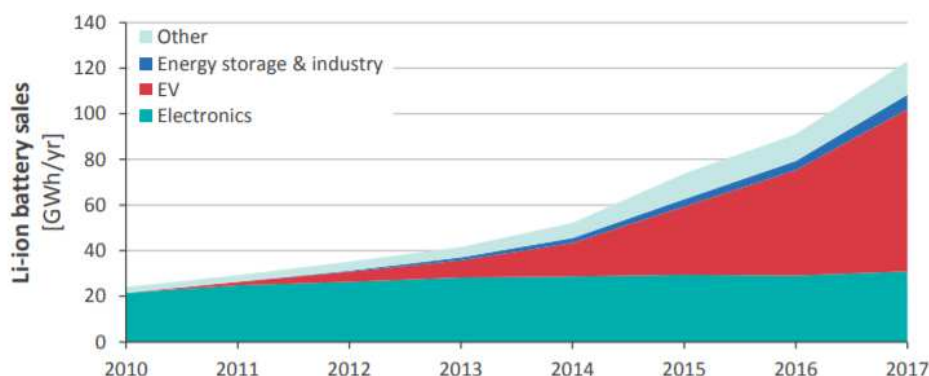
<sup>136</sup> Kupper, Daniel; Kuhlmann, Kristian; Wolf, Sebastian; Pieper, Cornelius; Xu, Gang; Ahmad, Justin. (2018). The Future of Battery Production for Electric Vehicles". Boston Consulting Group.

<sup>137</sup> Ibid.

Li-ion batteries are the battery of choice for most e-buses and it is expected to be so in the future (See Chapter 3.2). However, to have a full understanding the factors that influence the price for Li-ion batteries, it is important to have a macro perspective of the entire Li-ion market.

Li-ion batteries were first introduced into the mass market in 1990 and have been used in such applications as electronics, medical devices, and power tools<sup>138</sup>. By 2010, Li-ion batteries reached an annual market value of about 6.5 bn euros largely because of portable electronics<sup>139</sup>. Since 2010, Li-ion growth for electronics slowed to roughly 6%. However, for **EVs and stationary storage applications, the market share of Li-ion batteries grew from about 5% to 60% between 2010 – 2017**<sup>140</sup> (See Figure 19).

**Figure 19: Global historical annual growth of Li-ion batteries in main market segments**



Source: Tsiropoulos, I; Tarvydas, D; Lebedeva, N. (2018). "Li-ion batteries for mobility and stationary storage applications". JRC science for policy report. Retrieved from:

<https://publications.jrc.ec.europa.eu/repository/bitstream/JRC113360/kjna29440enn.pdf>

The growth in Li-ion applications for EVs has coincided with a significant drop in price in the batteries. For example, the price for Li-ion batteries has dropped 87% percent from \$1,100 kWh in 2010 to \$156 kWh in 2019<sup>141</sup>. In a Bloomberg New Energy Finance report, it is projected that the cost for Li-ion batteries will continue to drop and reach roughly \$74kWh - \$61 kWh by 2030 (See Figure: 20). What is more, achieving a battery price of \$100/kWh is seen as the point in which EV will start to reach price parity with internal combustion engines which is predicted to happen as soon as 2024<sup>142</sup>. Based on these estimates, it can be said that e-buses could achieve a price advantage over internal combustion options by 2030.

A large portion of the drop in price can be attributed to market conditions and business strategies, however, innovation in the battery industry has also impacted the total cost. For example, growing research and innovation activity as measured by an increasing number of patents in the Li-ion industry

<sup>138</sup> Tsiropoulos, I; Tarvydas, D; Lebedeva, N. (2018). "Li-ion batteries for mobility and stationary storage applications". JRC science for policy report. Retrieved from:

<https://publications.jrc.ec.europa.eu/repository/bitstream/JRC113360/kjna29440enn.pdf>

<sup>139</sup> Ibid.

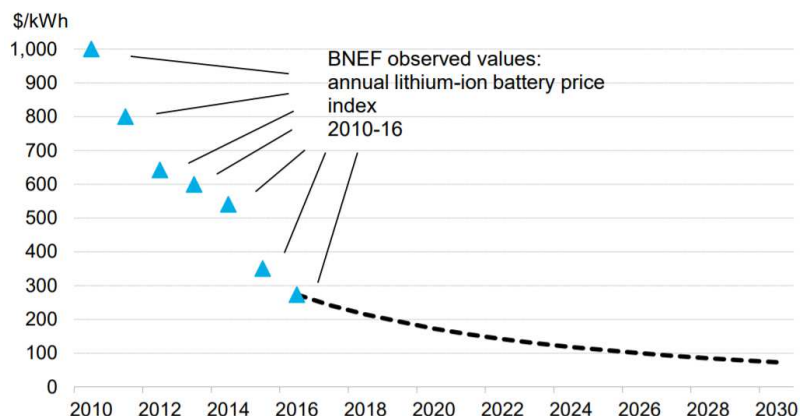
<sup>140</sup> Ibid.

<sup>141</sup> Henze, Veronica. (2019). "Battery Pack Prices Fall as Market Ramps up with Market Average at \$156/kWh in 2019". BloombergNEF. Retrieved from: <https://about.bnef.com/blog/battery-pack-prices-fall-as-market-ramps-up-with-market-average-at-156-kwh-in-2019/>

<sup>142</sup> Ibid.

estimates a reduction of cost by roughly 2% per 100 patents<sup>143</sup>. Combined with over 30,400 new patent families in battery technology in 2017 alone<sup>144</sup>, it can be expected that the price for Li-ion batteries will continue to drop.

**Figure 20: Observed values of annual lithium-ion battery price index**



Source: Curry, Claire (2017). "Lithium-ion Battery Costs and Market". Retrieved from: <https://data.bloomberglp.com/bnef/sites/14/2017/07/BNEF-Lithium-ion-battery-costs-and-market.pdf>

Technological advancements have been primarily focused on improving the chemistry of the cathodes, anodes, and electrolytes as well as other material components of the EV battery packs<sup>145</sup>. For example, increasing the chemical density of an anode and cathode will also increase the capacity of the battery, improving the range of the e-bus. In another example, it has been found that silicon is much better at absorbing lithium ions as graphite (charging phase), so companies have been "peppering" silicon into graphite plates in order to increase the charge rate for Li-ion batteries<sup>146</sup>. Further, innovation in the manufacturing of new batteries during the production stage are also driving down the cost for Li-ion batteries in EVs<sup>147</sup>.

Lastly, synergies within the Li-ion market and related applications, including electronic devices, are expected to make Li-ion batteries more efficient and cost effective<sup>148</sup>. For example, the development of photovoltaic charging along bus routes may also impact the total cost for Li-ion batteries in e-buses. As growth in the Li-ion market increases (Figure 19), it can be expected that innovation in this market will continue to drive the cost of e-buses down.

<sup>143</sup> N. Kittner, F. Lill, D.M. Kammen, (2017). "Energy storage deployment and innovation for the clean energy transition, *Nature Energy*", 2: 1–6, doi:10.1038/nenergy.2017.125.

<sup>144</sup> Thissandier, Fleur; Baron, Nicholas. (2018). "Status of the Battery Patents – Status of Patenting Activity – April 2018". Retrieved from: <https://www.knowmade.com/wp-content/uploads/2018/04/Status-of-the-Battery-Patents-2018-FLYER.pdf>

<sup>145</sup> Hensley, Russel; Newman, John; Rogers, Matt. (2012). "Battery Technology Charges Ahead". *McKinsey Quarterly*. Retrieved from: <https://www.mckinsey.com/business-functions/sustainability/our-insights/battery-technology-charges-ahead>

<sup>146</sup> Rath, Akshat. 2019. "How we get to the next big battery breakthrough". Retrieved from: <https://qz.com/1588236/how-we-get-to-the-next-big-battery-breakthrough/>

<sup>147</sup> Tsiropoulos, I; Tarvydas, D; Lebedeva, N. (2018).

<sup>148</sup> Ibid.

## 10. Results and recommendations

In summary, the purpose of this evaluation was to assess the e-bus pilot in city of Tartu and the future potential of e-buses for Tartu based on six research questions. The following presents the results and recommendations:

### 1. What technical e-bus solutions would be the best and most effective for Tartu?

The charging infrastructure needed for a fleet of e-buses poses a significant challenge for cities. In addition to the high CAPEX for the e-bus charging system, there is also the question of identifying when, where, and how to integrate the charging technology into the bus system. From the standpoint from a city official, the solution to integrating an e-bus into public transportation would involve the charging strategies identified in Chapter 4 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 a higher infrastructure cost as the charging station needs to be built along the bus route however it extends the e-bus range, making them more reliable. Depot charging is less expensive but less reliable for longer routes. The Edmonton, Turku, and Gothenburg case studies used a combination of opportunity and depot charging as their strategy of choice. This seems to be the common technical solution as it ensures e-bus range reliability and has multiple charging options in case an e-bus needs a lastminute charge or a charging strategy is down for maintenance.

Regarding effectiveness, a combination of depot and opportunity charging has proven to be effective in increasing the reliability of e-buses and has been found to be economically feasible in Turku and Edmonton. While opportunity charging was not tested in Tartu, it seems reasonable for the Tartu bus network if one looks at the average length of a bus routes which is approximately 13km. This length is suitable for buses that carry small batteries and get quick charges at the end of the route. **Therefore, opportunity charging combined with overnight depot charging are the most effective charging methods identified in this study.**

#### ***Recommendation: An assessment of the current bus routes and electrical grid is needed in Tartu***

To identify the best combination of opportunity charging and depot charging stations, it is important for Tartu to evaluate the current bus route and infrastructure. Factors related to traffic, length and duration of bus routes will need to be considered to identify which bus routes would be suitable to opportunity charging and which routes would be suitable for depot charging. Further, access to the electrical grid as it relates to bus routes will also need to be considered to identify where to put opportunity charging stations for buses which can be on the route or at the end of a bus route. It is also possible bus routes may have to be changed to accommodate charging systems. **Therefore, it is recommended that an analysis of the e-bus system be conducted to identify where charging stations should be placed.**

### 2. How does the cost of the electric bus used in the pilot compare to today's cost for diesel buses and gas buses?

The data from the e-bus pilot in Tartu indicate that e-buses are significantly more expensive than biogas and diesel buses. However, it is the opinion of the evaluation team that the results do not accurately reflect the real costs for operating an e-bus in Tartu. The conditions for the bus pilot were atypical of a

public transportation procurement as the acquisition cost and operational cost only reflect the year in which the pilot was in operation, not the entire lifetime of operation.

To adjust for the pilot data, an Excel model was created that allows the user to input cost data for different bus profiles and compare them over a longer period. In this evaluation the model was used to compare buses on a hypothetical 15-year period by using input data from the city and secondary sources. According to this modelling experiment, an e-bus with depot charging is shown to be the most cost efficient over a 15-year period followed by the e-buses with a depot charger and two pantograph chargers and the biogas bus. The diesel bus is the least cost effective in a 15-year period. Further, it was found that an e-bus with 100% depot charging reaches price parity with ICE buses in 9-10 years and an e-bus with opportunity and depot charging options reach price parity with ICE buses in 12-13 years. These results are consistent with the findings from the Turku and Edmonton case study where price parity with ICE buses was achieved between 12-20 years.

Based on this information, the research question can be answered in two ways: An answer based only on the pilot data or the information from the model. If interpreting the pilot data literally, it was found that the €/km for the e-bus used in the pilot was significantly higher than diesel and biogas buses in Tartu and therefore not feasible. However, by adjusting the model to reflect a more realistic interpretation of cost elements, e-buses were found to be cheaper than diesel and biogas buses and therefore the more feasible option. It is the opinion of the evaluation team that the model cost calculation for an e-bus in Tartu provides a more realistic outcome. Therefore, it can be said that using the current data assumptions, and adjusting the operational time frame to 15 years, e-buses compared to ICE buses are economically feasible.

***Recommendation: Continue to use the model to test different cost scenarios***

The evaluation team provided a flexible Excel model to the city of Tartu that allows the user to create “profiles” for different bus types and other relevant data, and compares them side-by-side. This way the model inputs and assumptions could be updated at any time with relevant data, making the model a dynamic, useful tool for future comparisons. For example, if the acquisition cost of an e-bus decreases in the next ten years, that cost can be integrated into the model to calculate a new cost comparison. Therefore, it will be in Tartu’s best interest to continue to use the model as new information becomes available in order to have the most up to date cost information.

**3. What are the strengths and weaknesses of the electric bus in terms of user and operator perspective compared to diesel and gas buses?**

User and operator experiences for the Tartu bus pilot were assessed through interviews with bus users and operators. Further, the results of the online survey used by the city of Tartu were also analysed.

The main results of the evaluation team interviews (N=50) were as follows:

- 54% of respondents rated the e-bus experience as **better** than the current buses; 44% said it was the same; 2% said it was worse.
- 80% of respondents said they would **prefer e-buses** to the current fleet; 10% said no; 6% said they do not know; 4% they do not care.
- 90% of respondents said e-buses have a **positive impact on the environment**; 6% do not know; and 4% said they do not care.

The main results of the online survey (N=102) were as follows:

- 76% of the respondents saw a **positive difference** between e-buses and internal combustion buses. The most common reasons for this were the quieter bus ride and environmentally friendly nature of e-buses.
- Likewise, 46% of the respondents claimed that what they enjoyed the most was the **quiet nature of the e-bus**. A surprisingly large segment, 18%, of respondents mentioned that the e-bus had been **cleaner** than regular buses. 24% of all the respondents claimed that **nothing bothered them** about the e-bus pilot. Among the negative comments, most were related to the **frequency of buses** on the route and not so much about the e-bus technology.
- 71% of the respondents agreed with the statement that all city buses in Tartu **should be electric in 10 years' time**. Those in the "Maybe" or "No" camps were mostly concerned with cost efficiency and environmental impact, 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.

The user experience results were in-line with survey results from the Edmonton and Gothenburg pilots. It can be said that based on data from across pilots e-buses are very much hailed for their quiet nature.

Operator experience was assessed by interviewing people (N=3) who were closest to the e-bus pilot. 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 the drivers to effectively use the new technology.

***Recommendation: Consider public sentiments, not just the cost***

The survey responses revealed that most of the respondents saw e-buses as a positive addition to the public transportation system. This indicates that a portion of Tartu's citizens understands and appreciates the use of an environmentally friendly transportation system. However, in order to assure a greater public acceptance, the city would need to make sure to communicate clearly the cost and environmental benefits compared to the current biogas fleet as some scepticism was already identified with the interviews and survey.

**4. How will the electric buses operate in Tartu's climatic conditions?**

Secondary and primary research indicates that climate conditions will not have a significant impact on the performance of the e-bus. 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.

In the Tartu pilot, a linear regression model was used to compare the ambient temperature data to the energy consumption data provided by the city. It was found that there was a weak correlation between ambient temperature changes and energy consumption in e-buses. **This indicates that ambient temperature has little impact on the energy performance of the e-bus used in the pilot.**

This can be attributed to two factors: First, the Li-ion battery is equipped with a battery management system (BMS) which insulates the battery from outside temperatures. Second, a diesel heater was used for the pilot so battery would not be responsible for powering the HVAC system.

It is important to note that the **energy demand for heating increases significantly in the winter months**. This is expected as more heat is needed to maintain a comfortable cabin temperature for the bus operator and commuters.

***Recommendation: Re-evaluate heating options in ten years***

Based on current data, diesel or biodiesel powered heating systems is the solution of choice for e-buses operating in cold weather climates. As a consequence, such heating systems create air pollution, this diminishing the positive effects from using an e-bus. Therefore, it is recommended to assess what heating options are available for e-buses at the time of procurement as there may be other options that do not impact the battery performance or cause air pollution.

**5. What important technological innovations are expected for electric buses in the next decade?**

Improvements to Li-ion batteries are predicted to dramatically decrease the cost of Li-ion batteries over the next ten years, making the CAPEX for e-buses cheaper. **The technological innovation can be attributed to two main components: innovation to the battery chemistry and innovation in the processes of the manufacturing plants for Li-ion batteries.**

Market trends in the e-bus market are also decreasing the cost of Li-ion batteries. Demand for e-buses have been steadily increasing. From the perspective of bus suppliers (manufacturers), this indicates that the market will continue to grow and based on economic theories like competition-driven pricing, e-bus manufacturers will try to grab the largest share of the growing e-bus market, **driving the cost down.**

Taken together, it is estimated that the **costs for Li-ion batteries will continue to drop, enabling e-buses to reach price parity with ICE buses between 2024 and 2030.**

***Recommendation: Stay up to date on Li-ion and e-bus trends***

Technology development in Li-ion batteries and the growth in demand for e-buses is driving down the costs for e-buses. Given the rapid change in cost seen over the last decade is expected to continue. Therefore, it is important to keep track of these changes because it may impact the cost of e-buses in the future and make e-buses an economically viable option for Tartu by 2029.

**6. Is the use of electric buses today and in 2029 economically and environmentally feasible?**

Based on the results of the pilot in Tartu, it is difficult to say whether the use of e-buses today would be economically or environmentally feasible. The circumstances under which the bus pilot was conducted were atypical for a public transportation procurement and may have impacted the overall price per km for e-buses. Assuming the data that was used in the evaluation team model is accurate, it can be said that the use of a e-buses in Tartu today is economically feasible. Looking ahead to 2029, the cost for e-buses is expected to drop further, therefore it can be said that by 2029 it is highly likely that e-buses will be economically feasible in Tartu.

Environmentally, the report shows that ICE buses produce harmful greenhouse gas emissions. Comparing only the operation of the bus (i.e. emissions from an ICE bus during operation to an e-bus), **our results**

**indicate that e-buses are less harmful for the environment.** However, the electricity necessary for charging the e-bus still creates pollution and Estonia still predominantly relies on oil shale which is highly polluting. **Therefore, changing to an e-bus fleet today would reduce the CO<sub>2</sub> levels in Tartu, but the pollution would still take place near the power plants.**

Environmental feasibility in 2029 will depend on whether Estonia can reduce its dependence on oil shale for electricity production. In Estonia, based on current trends, it is projected that by 2030, **greenhouse gas emissions in the energy sector will decrease by roughly 25%**, which corresponds with a 15% increase in shares of renewable energy used for energy production by 2030. **Assuming that these targets are accurate and Tartu transitions to 100% renewable electricity use, it can be said that integrating e-buses in 2029 will be environmentally feasible.**

***Recommendation: Consider renewable energy options for charging buses in 2029***

Estonia reaching their environmental targets by 2029 is not guaranteed and if oil shale continues to be the primary source of electricity production, then potential positive impact that comes from switching to a fleet of e-buses may be mitigated. Therefore, the evaluation team recommends that the city of Tartu considers the use of electricity produced from renewable sources or incorporate solutions like wind and solar collectors at charging stations, to charge e-buses.



## Annex 1 – Tartu city bus lines and their distances

Line number	Direction	Line description	Distance per route (km)
1	A>B	FI - Nõlvaku	8,5
	B>A	Nõlvaku - FI	8,9
2	A>B	Lõunakeskus - Kannikese - Nõlvaku	13,9
	B>A	Nõlvaku - Kannikese - Lõunakeskus	13,6
3	A>B	Zoomeedikum - Nõlvaku	11,1
	B>A	Nõlvaku - Zoomeedikum	11,4
4	A>B	Ringtee - Kummeli	8,6
	B>A	Kummeli - Ringtee	8,7
5	A>B	Turu - Annelinn - Ihaste-Annelinn-Turu	18,8
6	B>C>A	Roheline park - Zoomeedikum - Lõunakeskus	11,9
	A>C>B	Lõunakeskus - Zoomeedikum - Roheline park	12,6
7	A>B	Ringtee - ERM - Kaupmehe	11,0
	B>A	Kaupmehe - ERM - Ringtee	11,3
8	A>B	Kvissentali - Roopa	11,2
	B>A	Roopa - Kvissentali	11,3
9	A>A	Ringliin 1	29,2
9A	A>A	Ringliin 2	29,0
10	A>B	Kvissentali-Annelinn - Ringtee - Rdt. jaam	22,9
	B>A	Rdt. jaam - Ringtee - Annelinn - Kvissentali	22,6
11	A>B	Kasteheina - Lõunakeskus	15,1
	B>A	Lõunakeskus - Kasteheina	15,2
12	B>A	Lõunakeskus - Kasteheina	12,5
	A>C>B	Kasteheina - Haigla - Lõunakeskus	13,2
13	A>B	Kasteheina - Puidu	15,4
	B>A	Puidu - Kasteheina	14,8
21	A>B>C	Ööliin	32,4
22	A>B	Ööliin	29,4

## Annex 2 – Rationale for cost components used in the TCO model

### Diesel

1. **Acquisition of bus:** SEBE interview gives approximate cost of €200,000 per bus. Data from Swedish study (Karlskrona) says range for diesel bus acquisition cost are €192,007.12 – €210,298 with average cost being €201,152.56<sup>149</sup>. Therefore, €200,000 will be used for the cost of bus.
2. **Fuel/energy cost:** Most recent diesel fuel price (08.4.2020) is 1.258 €/l<sup>150</sup>.
3. **Fuel Consumption:** Fuel consumption based on SmartEnCity project statistics for Tartu. Diesel fuel consumption is 39.5 l/100km<sup>151</sup>. As model is calibrated for l/km, consumption is set at .391/km.
4. **Fixed Maintenance costs:** Fixed costs were taken from TCO calculations based on bus route in Karlskrona<sup>152</sup>. The planned costs (fixed costs) were used for the cost. The average planned cost = €5,024.27. Listed price in model is €5,000 rounded to nearest thousandth.
5. **Variable Maintenance costs:** Variable maintenance costs taken from Turku case study which lists O&M costs represented as a function of Euro/km<sup>153</sup>. Price used from study is .20/km.

### Biogas

1. **Acquisition of bus:** Data from biogas statistics available on SmartEnCity website and Karlskrona study used to approximate cost for biogas bus. According to the site, investment for biogas buses are 20-25% higher than diesel, therefore, a 20% increase would be €240,000<sup>154</sup>. Average from the Karlskrona study is €229,155 euros. The average between the two is €234,577, rounded to nearest thousandth is €235,000.
2. **Infrastructure cost:** Infrastructure cost was left out. As Biogas buses are already in use, it is assumed that the cost for biogas infrastructure has already been invested.
3. **Fuel/energy cost:** Based off current compressed biogas prices which is .949 €/kg<sup>155</sup>.
4. **Fuel/energy consumption:** Same as diesel consumption rate. Per Tartu 2012 report<sup>156</sup> and SmartEnCity, fuel consumption rates are roughly the same compared to diesel which is .391/km.
5. **Fixed Maintenance costs:** Fixed maintenance costs based on Karlskrona study. Average fixed costs from Karlskrona study is €6,951 per year for planned (fixed) costs. Rounded to nearest thousandth is €7,000.

---

<sup>149</sup> Boren, Sven. (2019). "Electric buses' sustainability effects, noise, energy, use, and costs" International Journal of Sustainable Transportation. Retrieved from: <https://doi.org/10.1080/15568318.2019.1666324>

<sup>150</sup> Diesel prices, 08.10.2020. Taken from: <https://www.mylpg.eu/stations/estonia/prices/>

<sup>151</sup> SmartEnCity. (2019). "Gas buses in the whole city of Tartu". Retrieved from: <https://smartencity.eu/about/solutions/gas-buses-in-the-whole-city-of-tartu/>

<sup>152</sup> Boren, Sven. (2019).

<sup>153</sup> Aho, Panu. 2019. "Procurement and commissioning of electric city busses in Turku: Observations from the eFÖLI project 2015-2018". Report from Turku University Applied Sciences. Retrieved from: <https://julkaisumyynti.turkuamk.fi/PublishedService?pageID=9&itemcode=9789522167132>.

<sup>154</sup> SmartEnCity. (2019).

<sup>155</sup> Current biogas price taken from: <https://www.gaas.ee/en/for-business/compressed-natural-gas/>

<sup>156</sup> Tõnissoo, Tõnis. 2012. "Feasibility study on the introduction and use of biogas buses in the Tartu City". Retrieved from: [https://www.tartu.ee/sites/default/files/uploads/Transport/bbb\\_Feasibility\\_study\\_on\\_use\\_of\\_biogas\\_buses.pdf](https://www.tartu.ee/sites/default/files/uploads/Transport/bbb_Feasibility_study_on_use_of_biogas_buses.pdf)

6. **Variable Maintenance costs:** Tartu 2012 report shows maintenance and repair costs being .230/km. Therefore, .230/km is used.

### E-bus with depot charging

1. **Acquisition of bus:** SEBE interview indicated price for e-bus is approx. €600,000. However, this does not differentiate between depot and opportunity charging. Best assumption is that it would fall under depot as no pantograph charging was used in the pilot. Cost of depot e-bus with bio diesel heater from Karlskrona study average is €346,218 per depot bus. The Tromsø study lists price of one bus with battery size of 250 kWh, as roughly €485,000<sup>157</sup>. The Edmonton case study has price of €779,140<sup>158</sup>. The average of all four is €552,589. In this case, €553,000 (rounded to nearest 1,000) will be used as approximate cost using depot charging.
2. **Infrastructure cost:** Infrastructure cost is difficult to predict as it depends on the current depot state. If depot can easily be outfitted with chargers, then infrastructure costs are cheaper. However, if other changes are needed, it may become more expensive. Based on 2015 report on feasibility of e-buses in public transport, depot chargers were roughly €5,000 each<sup>159</sup>. Swedish report includes ranges of costs and other studies do not have specific charger costs included. Therefore, €5,000 will be used for price of charger.
3. **Fuel/energy consumption:** Consumption rate of 1.14 kWh/km based off Tartu pilot results.
4. **Fuel/energy costs:** Energy costs in Estonia are generally .09 - .07 Euros per kWh. Used € .09 for electricity cost<sup>160</sup>.
5. **Fixed Maintenance costs:** Fixed costs based on Karlskrona study. Swedish study has fixed maintenance costs which are approximately €6,000 per year<sup>161</sup>.
6. **Variable Maintenance costs:** Variable costs are from Turku study which is .16 €/km<sup>162</sup>. For Turku, only maintenance and charger maintenance were calculated as fuel/electricity was already included in the model.
7. **HVAC cost:** The diesel heating system will accrue fuel costs to operate. The consumption rate of the HVAC system was used from the Turku study. The consumption rate is .032l/km<sup>163</sup> and the current cost of diesel is €1.258/l, which was converted into a per km cost of €0.040256/km. Rounded to the nearest 100<sup>th</sup>, you get €0.04/km. Therefore, €0.04/km was used in the OPEX cost calculation to accommodate for HVAC expenses on e-buses.

---

<sup>157</sup> Pihlatie, Mikko; Ranta, Mikaela; Rahkola, Pekka; Ponomarev, Pavel. 2016. "Feasibility of electric buses in Tromsø". Retrieved from: <https://www.vtt.fi/inf/pdf/technology/2019/T348.pdf>

<sup>158</sup> Marcon Report. (2016). "Electric Bus Feasibility Study for the City of Edmonton". Retrieved from: [https://www.edmonton.ca/documents/transit/ETS\\_Electric\\_Feasibility\\_Study.pdf](https://www.edmonton.ca/documents/transit/ETS_Electric_Feasibility_Study.pdf)

<sup>159</sup> Vilppo, Olli; Markkula, Joni. 2015. "Feasibility of electric buses in public transport". World Electric Vehicle Journal Vol 7 – ISSN 2032-6653.

<sup>160</sup> Raudjärv, Rita; Kuskova, Ljudmilla 2011. "Is Energy Cheap or Expensive?". Quarterly Bulletin Of Statistics Estonia. Retrieved from: <https://www.stat.ee/dokumendid/64159>

<sup>161</sup> Boren, Sven. (2019).

<sup>162</sup> Aho, Panu. 2019. "Procurement and commissioning of electric city busses in Turku: Observations from the eFÖLI project 2015-2018". Report from Turku University Applied Sciences. Retrieved from: <https://julkaisumyyniti.turkuamk.fi/PublishedService?pageID=9&itemcode=9789522167132>.

<sup>163</sup> Ibid.

## E-bus opportunity charging

1. **Acquisition of bus:** Same calculation as depot charging. Cost for the bus will be €553,000.
2. **Infrastructure cost:** Per Karlskrona study, average infrastructure cost for opportunity charging was €45,700<sup>164</sup>. In the interview with Elektrilevi, they cite cost of €200,000 per pantograph charging pole however this price seems very high compared with other case studies. Given these differences, €45,000 was used as the assumption for pantograph charging. Depot charging can be equipped with pantograph charger as well. However, it will be assumed that slow charger will be used when buses aren't in use. Therefore, depot charger will be same as above. With two pantograph chargers needed, one at each end stop, plus depot charging calculation is as follows:  $45,000 + 45,000 + 5,000 = €95,000$ .
3. **Fuel/energy consumption:** Consumption rate of 1.14 kWh/km based off Tartu pilot results.
4. **Fuel/energy costs:** Energy cost kept the same as in depot charging.
5. **Fixed Maintenance costs:** Maintenance costs based off Karlskrona study<sup>165</sup>. Average fixed operation and maintenance is €7,499 but rounded to €7,500 in the model.
6. **Variable Maintenance costs:** Variable Maintenance of .16 €/km based on Turku study. .12 (Charger maintenance) + .04 (maintenance costs) = .16/km per year<sup>166</sup>.
7. **HVAC cost:** Same as for e-bus with depot charging

---

<sup>164</sup> Boren, Sven. (2019).

<sup>165</sup> Boren, Sven. (2019).

<sup>166</sup> Aho, Panu. 2019.