Evaluation of Electric Bus Adoption in Sweden

An Interview Study of Four Swedish Cities and a Life-Cycle Cost Estimation

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Cover: An illustration of an electric bus in an urban environment, charging from a pantograph. Made by the researchers.

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Abstract

Cities worldwide are facing huge environmental challenges. Following rapid urbanization and increased traffic in city centers, noise and pollution have been seen to cause major problems. Due to bad air quality and large green house gas emissions, the Swedish government has set a goal for the transport sector to be fossil free until year 2045. To cope with these problems, electric buses have become common in the public transport in several Swedish cities (and worldwide). Umeå, Gothenburg, Landskrona and Ängelholm are four Swedish cities that have some years of experience of electric buses in the bus fleet. The study aims to evaluate the adoption process of electric buses in the aforementioned cities and hence find the main drivers, barriers and success factors for electric bus adoption. Since the cost for electric buses was found to be a barrier, the life-cycle costs has been evaluated for the electric buses in each city, including a biogas bus as a reference case.

To answer the aim, interviews were made with involved actors in the electric bus adoption in the case cities. The life-cycle cost calculations were set up based on life-cycle cost models found in the literature and values were received from the interviewees as well as from the literature. The result shows that the main drivers for bus adoption are the environmental benefits, as the reduction of local emissions and noise. The main identified barrier is the high capital costs for electric buses, but technology was also found to be a barrier. Cooperation was found to be a success factor in the case cities. Further, it was identified that a person or organization that pursued the project forward, was important. Due to the great possibilities electric buses imply, as well as battery technology development and decreased costs, electric buses are found to be a viable option in the future. The life-cycle cost results show that electric buses are competitive to a biogas bus. Slow charging at depot has the lowest cost, while fast charging and charging by the catenary (trolleybus) have about the same, or slightly higher costs, than the biogas bus. As a conclusion, there has been a fast development of the electric bus technology in recent years and the development is expected to continue the years to come. This will enable and increase the electric bus adoption in the future public transport system.

Keywords: Electric bus adoption, drivers, barriers, success factors, depot charging, fast charging, trolleybus, life-cycle costs.

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Sammanfattning

Städer världen över står inför stora klimatutmaningar. Då utvecklingen går mot en fortsatt urbanisering och ökad trafik i städerna, utgör buller och lokala utsläpp stora problem. På grund av dålig luftkvalitet och höga utsläpp av växthusgaser har den svenska regeringen beslutat att transportsektorn ska bli fossilfri till år 2045. För att hantera dessa problem har elbussar införts i ett antal städer i Sverige (och i världen). Umeå, Göteborg, Landskrona och Ängelholm är fyra svenska städer som har erfarenhet av elbussar i kollektivtrafiken. Studien syftar till att studera införandet av elbussar i de tidigare nämnda städerna och ta reda på drivkrafterna, barriärerna och framgångsfaktorerna vid implementering av elbussar i dessa städer. Då kostnaderna för elektriska bussar har visat sig vara en barriär har livscykelkostnaderna beräknats för elbussarna i varje stad, där en biogasbuss kommer att inkluderas som referens gentemot de övriga elbussarna.

För att kunna besvara syftet med studien gjordes intervjuer med de aktörer som varit involverade vid införandet av elbussar i studiens utvalda städer. Beräkningarna av livscykelkostnader har baserats på modeller för livscykelkostnader som hittats i litteraturen. De använda värdena för beräkningen av bussarnas livscykelkostnader baserades både på intervjustudien samt litteraturen. Resultatet visar att de huvudsakliga drivkrafterna är miljöfördelarna, som exempelvis minskade utsläpp och buller. De höga investeringskostnaderna har identifierats som en barriär av stor betydelse, medan de tekniska utmaningar utgör en barriär av mindre betydelse. Samarbete har identifierats som viktigt i projekt för införande av elbussar, men även drivkrafter i form av en person eller organisation. I och med de stora möjligheter som elbussar bidrar med, samt utveckligen av batterier och sänkta kostnader, ses bussar som ett rimligt alternativ för den framtida kollektivtrafiken. Resultatet från livscykelkostnaderna visar att elbussar är konkurrenskraftiga gentemot biogasbussar. Långsamladdning vid depå hade lägst kostnad medan snabbladdning och trådbuss har ungefär samma, eller lite högre, kostnad som en biogasbuss. Slutsatsen för denna studie är att den snabba utvecklingen gällande elbussar som skett de senaste åren kommer fortsätta framöver och detta kommer leda till ökat införande av elbussar i kollektivtrafiken.

Nyckelord: Införande av elektriska bussar, drivkrafter, barriärer, framgångsfaktor, depåladdning, snabbladdning, trådbuss, livscykelkostnader.

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Ellen Klein and Magdalena Lantz, Gothenburg, June 2019

Glossary

ASEK	Values that are developed by the Swedish Transport Administration for monetizing environmental impact.
Electric bus	A bus that is propelled by an electric drive line.
Deadheading	Driving back and forth to the bus depot with an empty bus.
Life-cycle cost (LCC)	Costs during the entire life-cycle.
Plug-in Hybrid Electric Vehicle (PHEV)	A vehicle that is propelled by a dual drive line, where at least one is electric.
Pantograph	Overhead charging system at the bus stop.
Power peak	A certain time during the day (usually evenings) when the highest amount of electricity is used in the city.
Public Transport Authority (PTA)	Responsible for forming regional transport supply programs, usually a municipality, a county or both.
Public Transport Operator (PTO)	Responsible for the operational part of the bus.
State of charge (SOC)	A percentage of the available capacity in a battery, where 100 percent means fully charged.
Trolleybus	An electric bus that is propelled by an overhead catenary.

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1 Introduction

The first chapter describes the background of the study followed by the aim and problem formulation. This is complemented with a section where delimitations of the study are described. Lastly, the outline of the report is presented.

1.1 Background

The world is facing large environmental challenges (UNFCC, 2018). Following rapid urbanization and increased traffic in city centers, noise and pollution have been seen to cause major problems for cities worldwide (United Nations, 2018). According to United Nations (2018), in year 2016 about 90 percent of city inhabitants worldwide respired unsafe air, leading to more than four million deaths. In Europe, transport is the main cause of air pollution in cities and contribute to 25 percent of the greenhouse gas (GHG) emissions (European Commission, 2018). Air pollution is measured using two indicators, Nitrogen Oxide (NO_x) and particles, which are emitted from the vehicle's engines and tires. These air pollutants cause diseases to humans and affect the environment negatively. In Sweden, the national goal of clean air by year 2020 will not be reached, mainly due to high concentrations of NO_x and particles in urban areas (Sveriges Miljömål, 2018).

United Nations (2018) sustainability goals for year 2030 includes improved air quality and sustainable transport systems. Accordingly, the Swedish government set a goal to decrease the GHG emissions from road transport by 70 percent until year 2030, compared to year 2010. Until year 2045, the goal for the transport sector is to be totally fossil free (Regeringskansliet, 2013). In urban areas, transportation is currently dominated by privately owned vehicles causing large emissions due to system inefficiencies. Various remedies exist, and an increasing level of public transportation has been singled out as one of the most effective solutions (Lindblom, Thyrén, Pädam, & Brundell-Freij, 2018). Today, a relatively small percentage, about four percent, of GHG emissions comes from public transport. The public transport bus fleet in Sweden has a high percentage of biogas and hydrogenated vegetable oil (HVO) buses today that release NO_x and particles that cause bad air quality (Lindblom et al., 2018; Sveriges Bussföretag, 2018). A measure to reduce the emissions and reach the goals set of zero emissions from fossil fuel is to introduce more environmentally friendly buses, that emit less, in the public transport system. Among different alternatives electric buses is often singled out as the most promising solution. Electric buses have considerably lower emissions than a conventional bus due to the electric powertrain, even though emissions from heating the bus and particles from the tires remains. Electric buses have been tested and implemented in several cities, and studies show that these can be a viable option to conventional vehicles, but the share of electric buses worldwide is still modest (Gabsalikhova, Sadygova, & Almetova, 2018; Li, Castellanos, & Maassen, 2017). In 2018 the share of electric buses in Sweden was as small as only 0,2 percent (Sveriges Bussföretag, 2018). The high investment costs and the novelty of the technology are main concerns for many cities (Clean Fleets, 2014).

Several studies have been made on electric buses, mainly focusing on the cost (Lajunen, 2018; Lajunen & Lipman, 2016; Mohamed, Ferguson, & Kanaroglou, 2018; Olsson et al., 2016). Different types of charging systems have been compared against each other as well as buses using conventional power trains (Clean Fleets, 2014; ZeEUS, 2017). Despite gaining increasing scholarly attention few articles address the adoption process of electric buses (Li et al., 2017; van der Straten, Wiegmans, & Schelling, 2007; Xylia, 2018). Mohamed et al. (2018) state that there is a lack of research about the willingness for cities to adopt electric buses and that electric bus adoption is seen to be viable in the future, but not today. Seeing to the large environmental challenges for city climate and the potential of electric buses it is thus highly interesting to investigate these adoption processes and potential barriers and by doing so might facilitate further adoption (Mohamed et al., 2018). Several cities in Sweden have electric buses in their bus fleet, some to a larger extent than others (Sveriges Bussföretag, 2018). Some Swedish cities with rather longer experience of electric buses in their bus fleet are Umeå, Göteborg, Landskrona and Ängelholm. These cities are also differing in size, geographic location and type of electric bus system (Andersson & Johansson, 2005; ZeEUS, 2017).

As of today, one such barrier is the high initial investment cost of electric bus systems, but recent research indicate that electric propulsion can be cost effective compared to a conventional bus if regarded from a life-cycle cost (LCC) perspective, especially if considering environmental cost (Lajunen, 2018). However, comparing the LCC of different propulsion systems is leagued with difficulties. Technological uncertainties such as battery lifetime and recycling obstruct LCC calculations (IVL Svenska Miljöinstitutet, 2017; Wang, Li, & Liu, 2014). As such, expanding research about LCC is necessary. At the same, the findings might prove to be valuable input towards further adoption of electric buses. Important factors such as political means, cooperation as well as drivers and barriers in project implementation are yet to be investigated thoroughly. Given this context, this study focuses on electric bus adoption from two perspectives. Firstly, from a broader perspective, where the drivers, barriers, success factors and the future for electric bus adoption will be investigated. Secondly, the more narrow perspective that regards the life-cycle costs for electric buses.

1.2 Aim & Problem Formulation

The aim of the study is to understand the adoption process of electric buses in Gothenburg, Umeå, Landskrona and Ängelholm in order to contribute to future successful adoption of electric buses in cities. Further, the aim is to evaluate the competitiveness for the electric buses in the case cities in terms of assessing the life-cycle costs (LCC). According to the aim of the study, following research questions are stated:

- What are the identified drivers, barriers and success factors for the electric bus adoption in the evaluated cities?
- Based on experiences from the evaluated cities, will electric buses be a viable option for future public transportation?
- Can electric buses be considered as competitive to conventional buses, in terms of life-cycle costs?

1.3 Delimitations

The scope of the study is delimited to four Swedish cities (Umeå, Gothenburg, Ängelholm and Landskrona), where at least a part of the bus fleet constitutes of electric buses. Only electric city buses are included in the study, thus the study excludes regional buses. Moreover, the study does not include any objective external parts that have not been a part of the electric bus project. To get an overview about the adoption process in the evaluated cities, the study takes the broader perspective and is delimited from technical details. Worth to notify is that the study investigates the experience of electric bus adoption so far, hence the scope of the study does not include future extension of the contemporary bus fleet.

Moreover, the LCC calculations do not include the manufacturing process of the bus or the batteries, neither the wages of the bus drivers. Even though the researchers of the study are aware of the fact that the bus driver's wages differ between different types of charging systems, this delimitation is in line with Lajunen (2018)'s LCC calculations of electric bus systems. Recent research has shown that the heater in the electric bus contributes to carbon dioxide emissions (Jerksjö, 2018). However, since the research still is in its infancy and hence difficult for the researchers to retrieve accurate data from the bus manufacturers, the environmental costs in the LCC calculations do not include emissions from the heater.

1.4 Outline of the Report

The second chapter describes the chosen methodology of the study. To provide some background information about the chosen topic, theory is crucial. Hence, the literature review is presented in the third chapter. Which is followed by the fourth chapter, where details about the case cities are described. The fifth chapter presents the result from the conducted interviews and the LCC calculations, which are discussed in the sixth chapter. Finally, the seventh chapter presents the conclusion of the study, where the research questions are answered.

2
Methodology

The second chapter describes the different parts of the methodology that was utilized in order to answer the stated research questions, presented in Section 1.2. Figure 2.1 shows a schematic overview of the utilized methodology.

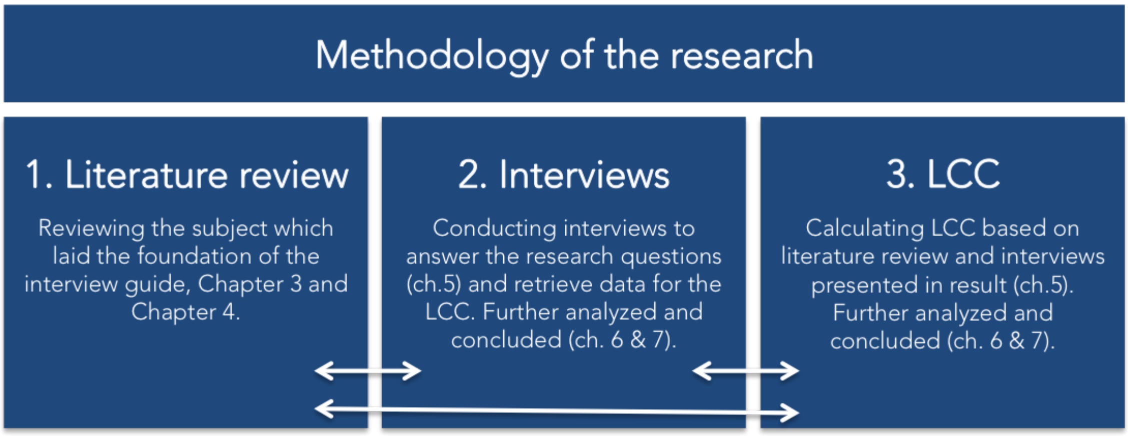

Figure 2.1: Overview of the utilized methodology.

2.1 Mixed Methods Research

Mixed methods research is utilized when both a qualitative and a quantitative data collection and analysis are needed to answer the stated research questions. The approach is nowadays widespread and commonly used (Bryman & Bell, 2011). Hesse-Biber (2017) describes the mixed methods research as a two step approach. Firstly, the qualitative part of the study was conducted, in this case the literature review and in-depth interviews. The second step, continued with the quantitative part which mainly included the life-cycle costing (LCC) calculations.

Hesse-Biber (2017) highlights that the mixed method research enables incorporation of a synergistic effect in the study, so the study provides a more comprehensive picture of the electric bus adoption. Furthermore, Hesse-Biber (2017) illuminates the possibility to include different perspectives in the study, thus take several different aspects about electric buses into account when the mixed methods research is conducted. This correlates to one of the highlighted advantages of the method called triangulation, where it is possible to use several research questions, methods and data. In addition to triangulation, complementarity is identified as another advantage in mixed methods research, which enables a more thorough understanding about the complexity of adopting electric buses (Hesse-Biber, 2017).

2.2 Literature Review

To gain knowledge and map out previous research about electric buses, the study started with a comprehensive literature review, which formed Chapter 3 and Chapter 4. Easterby-Smith, Thorpe, and Jackson (2015) describe the literature review as a three-step process. Firstly, the scope of the study needs to be clarified and includes stating the aim, research questions and identifying appropriate key words. According to the aim of the project, key words as *electric buses, charging electric buses, drivers electric buses, barriers electric buses, Swedish Public Transport System, Subsidies electric buses* and *life-cycle costing electric buses* were selected. The second step comprises searching, organizing, reading and evaluating the literature (Easterby-Smith et al., 2015). This was mainly conducted in the first couple of weeks of the study, since the researchers needed knowledge about electric buses in general and be able to ask adequate questions during the upcoming interviews, which is described further in Section 2.4. Suitable literature could be found in several different ways, for instance books, reports retrieved from Trivector and databases, such as Google Scholar. Due to the continuous development of electric buses, most of the contemporary research could be found in scientific papers, which resulted in that most of the literature was accessed from databases. Lastly, Easterby-Smith et al. (2015) describe that the third step is about writing the literature review, thus organizing and categorizing adequate theory in different themes. Even though the literature review is described as a linear three step process, it is emphasized that the process should be an iterative process, for instance the research question could be revised several times. The iterative approach is mainly incorporated in the second step (Easterby-Smith et al., 2015). This is in accordance with how the researchers of the study conducted the literature review and finally formed Chapter 3 and Chapter 4.

2.3 Multiple-Case Study

A comparative design, which means that two or more cases are compared to explain existing theory or result in new findings, are used in the study. The comparison is between four cities, hence a multiple-case study (Bryman & Bell, 2011). The first step of a case study is a thorough literature review (see Section 2.2) and clearly posed research questions (Yin, 2014). When the research objective contains the questions of "how" and "why" in the present time, case studying is a suitable method (Yin, 2014) and motivates why it is chosen for this study. A case study using more than one case, multiple-case study, is often more robust than a single case study. At the same time emphasizes Yin (2014) that a multiple-case study requires more work compared to a single case study, which was taken into consideration by the researchers.

The selection of the case cities (Umeå, Gothenburg, Landskrona and Ängelholm) was originally chosen by the consultancy firm Trivector but can be motivated from several aspects. All cities have had, since several years, electric buses in the public transport system. Moreover, Landskrona has nowadays only electric buses in the bus fleet. Furthermore, there are different types of charging systems in the evaluated case cities, which made them interesting to study and compare with each other.

2.4 Interviews

Semi-structured interviews are well established and most commonly used in qualitative interview design and was considered by the researchers to be the most appropriate interview technique for this type of study. When interviews are semi-structured a list of prepared questions, so-called an interview guide, is essential. Even though this slight preparation of questions, the procedure allows for flexibility, which means that there is opportunity to ask follow-up questions (Bryman & Bell, 2011). This in turn provides in-depth information about the four case cities. For structured interviews, the interviews need to follow a strict template and there is no room to adjust the questions according to the situation. Structured interviews seemed inappropriate for this type of study, since there are several differences between the evaluated case cities.

Before the interviews took place an interview guide was designed by the researchers shown in Appendix A, which is in line with Bryman and Bell (2011)'s recommendation for semi-structured interviews. Some differences between the four case cities were revealed when the literature review was conducted, so the interview guide was complemented with some additional questions for each case city, which once again proves that structured interviews were not adequate for the study. Except for the city specific questions, the researchers utilized the same template for all of the conducted interviews (shown in table 2.1), to achieve a valid and reliable result. To get a clear structure of the interviews, the interview guide was organized according to different subjects, as shown in Appendix A. When the researchers formed the interview guide some of the advice from Kvale (1996) were taken into consideration, like avoiding leading questions and not use a too academic language. Additionally, yes or no questions were avoided for the majority of the questions, since Kvale (1996) emphasize the importance of utilizing open ended questions in a qualitative study. To assure a correlation between the interview guide and aim of the study, the interview guide was sent to the supervisor at Trivector in advance, who provided valuable feedback. Thus, the interview guide was to some extent adjusted according to the supervisor's opinion. The interview guide was sent to the interviewee two working days before the interview took place, so the interviewee was able to be prepared for the upcoming questions.

Kvale (1996) describes the complexity of choosing the number of interviewees to

Table 2.1: Interviewed actors. PTA means public transport authority.

Organization	Type of organization (city)	Interviewee's Role	Place	Date
Västtrafik	PTA (Gothenburg)	Sustainability manager	In-person	2019-02-25
Umeå Kommun	Municipality (Umeå)	Public Transportation Manager	Phone	2019-02-26
Göteborgs Stad	Municipality (Gothenburg)	Project Coordinator	In-person	2019-02-27
Nobina	Operator (Landskrona & Ängelholm)	Business Development Manager	Skype	2019-02-28
Skånetrafiken	PTA (Landskrona & Ängelholm)	Sustainability manager	Phone	2019-03-01
Landskrona Stad	Municipality (Landskrona)	Traffic planner	Phone	2019-03-05
Lindholmen Science Park	Business Park (Gothenburg)	Project Manager	In-person	2019-03-06
Keolis (ÅF)	Operator (Consultant) (Gothenburg)	Previous worker at Keolis	In-person	2019-03-08
Skånetrafiken	PTA (Landskrona & Ängelholm)	Traffic developer	Email	2019-03-08
Hybricon	Manufacturer (Umeå)	CEO	Phone	2019-03-12
Volvo	Manufacturer (Gothenburg)	City Mobility Director	In-person	2019-03-18

achieve a reliable and trustworthy result. When the researchers tried to find prospective interviewees for the study, the sample was based on the literature review, where involved actors were presented for the evaluated cities (see Chapter 4). In addition to the literature review every interview ended with the question: *"Do you recommend anyone to contact for this study?"*, which means that the sample was partly based on the literature review and partly on the conducted interviews (Shown in table 2.1). The researchers noticed during the interviews that the electricity companies have an important role in electric bus adoption and thought that including them would complement the study accordingly to the research questions. Hence, electricity companies were also interviewed as shown in table 2.2 and the utilized interview guide for electricity companies is shown in Appendix B. The interviewee from Skånetrafiken was not able to answer the detail questions, so these questions were answered by email by another respondent, which is also indicated in table 2.1. Further, the interviewee at Keolis (ÅF) has long experience of the electric bus adoption in Gothenburg. However, since the interviewee recently has changed work to the consultancy firm ÅF, ÅF is indicated in brackets when referring to this interviewee.

The researchers of the report were settled in Gothenburg during the study, so when

Table 2.2: Interviewed actors at electricity companies.

Organization	Interviewee's role	Place	Date
Umeå Energi	Project Manager	Phone	2019-04-17
Göteborgs Energi	Business Developer	Phone	2019-04-18
Landskrona Energi	Project Manager	Phone	2019-04-18
Öresundskraft	Business Developer	Email	2019-04-18

the interviewees also where settled in that area, the interview took place in-person. These interviews were conducted in a good location without noise and distraction, which Easterby-Smith et al. (2015) highlighted as an important aspect to take into consideration when conducting interviews. The interviews for the three remaining cities were conducted either by phone, Skype or email, since it was both costly and time-consuming for the researchers to visit all the interviewees settled outside the area of Gothenburg. Bryman and Bell (2011) highlight that the cost aspect is one of the most common arguments for choosing telephone interviews over interviews in-person.

Telephone interviews can be advantageous when the interviewee wants to be anonymous, thus dare to participate in a telephone interview but not in an in-person interview (Bryman & Bell, 2011). As shown in table 2.1 and 2.2 the interviews took place within a time span of three weeks for the involved actors and two days for the electricity companies. The underlying reasons were that the researchers had to be flexible according to the interviewees busy schedule, as well as try to have them within an acceptable time span. The two researchers of the study alternated between each other to conduct the interviews of 30-75 minutes for the involved actors and 15-30 minutes for the electricity companies. One of the researchers asked the questions from the interview guide (Appendix A and Appendix B), while the other one took notes. All the interviews were recorded, so the researchers could fill in the gaps that were not perceived during the interview, which is in line with the recommendation provided by Seale, Gobo, Gubrium, and Silverman (2004). Worth to mention is that the interviewee was always asked in the beginning of the interview if it was fine if the researchers recorded the interview. Furthermore, Easterby-Smith et al. (2015) state that recording the interviews provides transparency to the study and prevents a biased result. To reduce language barriers all of the interviewees were held in Swedish and translated to English afterwards. Furthermore Kvale (1996) emphasizes the importance of repeating the interviewee's answer to clarify the interpretation if it seemed to be necessary, to assure certain quality of the study. This was taken into consideration when conducting the interviews.

2.5 Data Analysis

Immediately after the interviews one of the researchers listened to the recording to complement the existing gaps, as mentioned previously. Due to technological circumstances the recorder broke in the beginning of the first interview and was not able to record any of the interview. So, except for the first interview all the remaining interviews followed the same procedure when the interview was finished. Hence, after complementing existing gaps, all the interviews were compiled according to different categories, so similarities and discrepancies between the different interviews could be identified. This was not done for the interviews with the electricity companies, since they followed another interview guide. The different categories were selected according to the aim of the study, so the result clearly correlated with the research questions. The interviews were categorized according to following categories; main actors, cooperation, drivers for the adoption, choice of charging infrastructure, goals, responsibility, success factors, advantages, disadvantages/risks/barriers, future challenges, future solutions, LCC/cost and remaining information.

The categorizing process took place along with the interviewing process, which is in line with Hesse-Biber (2017)'s recommendation, who describes the data collection process and data analysis process as a simultaneous approach. Thus, it is appropriate to start analyzing the collected data, in this case the interviews, in an early stage and treat it as an iterative process which was done in the study. In addition to the categorizing process, it is suitable to write down so-called memos, or interesting findings, which was done during the data collection process (Hesse-Biber, 2017). Seale et al. (2004) illuminate that the categorization process usually includes a lot of ambiguity and stress the importance of revising the categorizing process several times. Additionally, Hesse-Biber (2017) indicates that it is crucial to distinguish the extreme cases and avoid conclusions based on deviant data, which implies that memoing is beneficial to achieve a reliable result. To assure that the data collection was interpreted in a consistent way, the researchers of the study discussed the interviews several times per week when conducting the interviews. The categorizing process continued with a comparison process, which took place when all the interviews had been conducted. The findings from the comparison process are shown in Chapter 5.

2.6 Life-Cycle Cost Analysis

A few articles dealing with life-cycle costs regarding electric buses have been constituted as a base for the life-cycle cost calculations that were made for the study (Lajunen, 2018; Lajunen & Lipman, 2016; Olsson et al., 2016). The parts from the models described in the literature that suited the case with electric buses has been complemented with environmental costs, based on values from Trafikverket (2018). A reference case for a conventional bus (biogas) was calculated in order to be compared with the different electric buses. The calculation of the life-cycle costs is found in equation 2.1 where the capital, operational and environmental costs are shown in Equation 2.2, 2.3 and 2.4. Input data for the calculations was gathered by asking interviewees as well as by reviewing the literature. The input parameters for the life-cycle cost can be found in Appendix C. Worth to notify is that only full electric buses have been included in the LCC calculations. The values that could not be found were assumed by reviewing literature and with input from the supervisors at Trivector and Chalmers University of Technology. Following assumptions have been made:

- Maintenance for charging infrastructure (depot charging and fast charging) is 3 % of the initial investment, which is in accordance with Lajunen (2018). The maintenance cost of the trolleybus is 100 SEK per meter (Kusoffsky, 2010).
- The discount rate is 3 % and consider the inflation (Lajunen, 2018).
- The salvage value in the end of the bus's life span is assumed to be zero, which is in line with Lajunen (2018).
- The life span of the battery is still uncertain, due to lack of long-term experience of electric buses. According to Norregaard, Johnsen, and Hedegaard Gravesen (2016) one can expect a life span of about 7 years. Several interviewees estimated that one battery change would be required during the bus's life span.
- The life span of the trolleybus is set to 20 years and 12 years for the other electric buses. The life span of the charging infrastructure for fast-charging and depot charging is 20 years and 40 years for the trolleybus's charging infrastructure (Andersson & Johansson, 2005; Lajunen, 2018). The biogas bus has an assumed life span of 12 years.

$$C_{lc} = C_{cap} + C_{op} + C_{env} \tag{2.1}$$

where
C_{cap} is the capital costs
C_{op} is the operational costs
C_{env} is the environmental costs

Since the investments of the buses were made in different years, described in Chapter 4, all of the investments have been recalculated until the contemporary year (2019). Hence, inflation was included for in Equation 2.2.

$$C_{cap} = (C_{bus} + C_{char}) * (1 + inflation) \tag{2.2}$$

where
C_{bus} is the investment cost for the bus
C_{char} is the investment cost for the charging infrastructure

In Equation 2.3 the majority of the parameters takes place on a yearly basis, thus d_{rate} is included in the equation. For the energy consumption, electricity costs C_{e} includes both the propulsion of the bus as well as the heater.

$$C_{op} = \sum_{j=0}^{T} (C_e + C_{mb} + C_{tax} + C_{ins} + C_{chg}) * (1 + d_{rate})^{-j} + C_{rb} \tag{2.3}$$

where
C_{e} is the electricity costs,
C_{mb} is the maintenance costs for the bus,
C_{rb} is the replacement of battery cost,

C_{tax} is the tax cost,
C_{ins} is the insurance cost,
C_{chg} is the maintenance costs for the charging infrastructure,
d_{date} is the discount rate,
T is the time period (years) of the life-cycle cost analysis

$$C_{env} = \sum_{j=0}^{T} (C_{CO2} + C_{PM} + C_{NOx} + C_{noise}) * (1 + d_{rate})^{-j} \tag{2.4}$$

where
C_{CO2} are the costs for the CO_2 emissions,
C_{PM} are the costs for particle emissions,
C_{NOx} are the costs for NO_x emissions
C_{noise} are the costs for noise
d_{date} is the discount rate
T is the time period (years) of the life-cycle cost analysis

When all the different LCCs had been calculated for the evaluated cities, sensitivity analyses were conducted. The parameters for the different scenarios in the sensitivity analyses were chosen based on the literature and interview results with input from the supervisor at Chalmers University of Technology. The parameters were mostly based on perceived uncertainties in the interviews. Table 2.3 shows the chosen parameters for the different scenarios in the sensitivity analyses.

Table 2.3: The different scenarios in the sensitivity analysis.

Analysis	**Scenario 1**	**Scenario 2**	**Scenario 3**
Life span	10 years	12 years (base value)	15 years
Environmental cost increase	Prices according to ASEK (base value)	+100%	+200%
Electricity cost increase	Prices according to Olsson et al. (2016) (base value)	+50%	+100%

2.7 Ethical Concern

When conducting a study it is important to be aware of and avoid ethical issues (Bryman & Bell, 2011; Easterby-Smith et al., 2015; Seale et al., 2004). Bryman and Bell (2011) stress four different ethical issues, namely; *harm to participants, lack of informed consent, invasion of privacy* and *deception.* To avoid harm of participants, all the interviews are anonymous in the study. Hence, the name of the interviewee is not stated in the report, only the name of the organization, the type of the organization and the interviewee's role are presented in the report. The interviewee was always informed about the anonymization in the future publication. Additionally, any personal matters were not described in the study. Since this is defined as the most unacceptable ethical issue, the researchers handled the personal data with great respect to avoid harm to participants (Bryman & Bell, 2011). The ethical issue lack of informed consent was not a point of concern, because all the interviewees were informed about the study and their specific contribution in advance. Hence, they had the possibility to neglect the participation in the study. The third ethical issue, invasion of privacy, correlates to previous issue, which also means that it was avoided in the same kind of way. The final issue, deception, is when the actual aim of the report does not correlate with the description provided by the researchers. When prospective interviewees were requested, the standardized utilized mail template clearly stated the aim of the study. In addition to that, the interview guide was sent two days in advance and the interviews started with a description of the study provided by the researchers. Thus, deception was avoided in the study.

3
Literature review

The literature review provides information about or correlated to electric buses. The chapter starts with an introduction about different types of electric buses and its charging alternatives, followed by earlier experience of electric bus adoption, a description about the Swedish public transport system, an overview about Swedish governmental subsidization for electric buses and lastly information about life- cycle costing of electric buses.

3.1 Electric Buses

An electric bus has, to some extent, an electric powertrain and is usually associated with words as green and clean, due to a decreased environmental impact compared to a conventional bus (ZeEUS, 2017). There are different types of electric buses and charging systems. Which type of electric bus system that is the most efficient is highly dependent on local conditions (Olsson et al., 2016).

Electricity is the only powertrain that full electric buses utilize. The electricity can be derived from either a battery or a catenary. For battery buses or so-called full battery electric buses there is a rechargeable battery where the energy of the propulsion system is stored chemically. If the electricity for the propulsion system is derived from the catenary, there is no need for a battery and the bus is named trolleybus. However, the trolleybus is sometimes equipped with rechargeable batteries, which are charged in motion during the ride by the overhead catenary, namely battery trolleybus (ZeEUS, 2017). In some cases, a diesel heater is installed on the bus, but it is still defined as a full electric bus (Aldenius, Khan, & Nikoleris, 2016). Furthermore, ZeEUS (2017) describes another type of electric bus, a so-called plug-in hybrid bus (PHEVs), where dual power sources propel the bus. It means that the electric propulsion system is used in combination with the combustion engine propulsion system. To recharge the battery, it is possible to connect the bus to the electric grid or use the energy that is produced by the combustion engine (Aldenius et al., 2016; ZeEUS, 2017).

3.2 Infrastructural Charging Alternatives for Electric Buses

The charging alternatives for electric buses are usually distinguished in three different categories, thus inductive charging, conductive charging and charging at depot. Inductive charging implies that the charging system is embedded in the road and the bus is charged continuously along the route with electric power that is provided from the ground by a magnetic field. Thus, the inductive charging system is favorable from an aesthetic perspective (Aldenius et al., 2016). However this technique is still rare on the market even though some European cities like Turin and Milton Keynes (England) have tried inductive charging in their public transport system (Wang et al., 2014). Conductive charging means that the bus is charged at terminus by e.g. a pantograph (fast charging) or by a catenary during the route (in motion charging of trolleybus). The most common type of charging in Sweden is depot charging during night (Aldenius et al., 2016). Since inductive charging still is unusual, the study focuses on the other charging techniques. These charging alternatives are shown in Figure 3.1 and described in following sections.

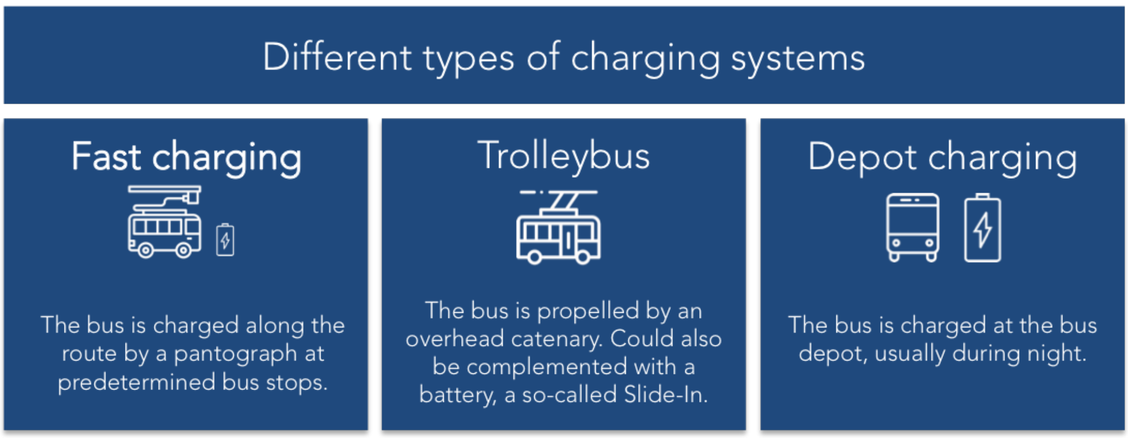

Figure 3.1: Overview of different charging alternatives for electric buses. (Englesson & Fält, 2017; Olsson et al., 2016; Tzeng et al., 2005a)

3.2.1 Fast Charging

One type of fast charging technique for electric buses is the so-called opportunity charging. It means that the battery in the bus is charged during the route at predetermined bus stops, where conductive charging stations are installed under the bus. The bus stays at the fast charging station for 10-20 seconds until the battery has enough charging power and can move on to the next predetermined bus stop with a charging station (Tzeng, Lin, & Opricovic, 2005b).

Another fast charging alternative is conductive charging by e.g. a pantograph at terminus, where the battery of the bus is recharged at the terminus for a time of about ten minutes and then can proceed the route further (Lajunen, 2018). In comparison to the opportunity charging system, this technique requires longer stops for recharging, but it does not affect the travel time for the passengers (Steen, 2017). This technique is interchangeable for both full electric buses as well as hybrid buses (Englesson & Fält, 2017).

The fast charging technique is a huge investment for a city and it also bounds the network, which means that it is both costly and rather inflexible (Steen, 2017). According to the quite short charging times either during the route or at terminus, the chargers require high power qualities (Olsson et al., 2016). However, since the battery is charged along the route it does not require a high capacity battery, hence the battery is quite small (Lajunen, 2018). The batteries for charging during the route usually have the capacity between 30-40 kWh. While the battery's capacity for charging at terminus is between 50-90 kWh. The frequent charging possibilities for fast charging buses make them a good option for routes with a high traffic demand (Olsson et al., 2016).

3.2.2 In Motion Charging of Trolleybus

Mentioned previously, the charging technique of the trolleybus means that the electricity is provided continuously from a catenary above the bus while the bus is in motion, so the bus does not require recharging stops (Englesson & Fält, 2017). This means that the charging infrastructure is fixed along the determined route (Aldenius et al., 2016). Hence, this type of public transport system is reliable, but at the same time rather inflexible (Diez et al., 2012). To increase the flexibility of the system it is possible to equip the trolleybus with an extra battery, namely battery trolleybus (Lindquist, 2016; ZeEUS, 2017). This means that the bus is able to drive outside the determined route where the infrastructure is implemented. The technique is usually referred to as the Slide-In technique (Englesson & Fält, 2017).

Two prominent arguments against trolleybuses are high infrastructural investment costs and that the implemented infrastructure is not favorable from an aesthetic point of view. At the same time, the trolleybus technique is well-tried (Englesson & Fält, 2017). In Bern (Switzerland), the catenaries of the trolleybuses are a part of the city's world heritage (Kühne, 2010).

3.2.3 Slow Charging at Depot

The buses that are charged at depot are equipped with larger batteries (250-500 kWh), since the battery's state of charge needs to be sufficient during a whole day of operation (Olsson et al., 2016). Larger batteries result in higher battery costs and larger environmental impact compared to the other charging technique's batteries (Steen, 2017). According to S. Fält it can also result in limitations when it comes to the number of passengers that the bus is able to transport (personal communication, 8th of April 2019). At the same time the flexibility increases, since recharging periods are not needed to be taken into consideration during operation (Steen, 2017). Furthermore, Lajunen (2018) describes that this technique can also be referred to as overnight charging, since slow charging at depot usually takes place during night when the bus is not in operation. However, S. Fält describes that if the bus line requires high capacity, charging during the day can sometimes be needed (personal communication, 8th of April 2019). Another aspect that is important to take into consideration when it comes to depot charging, is that the depot should be located close or in connection to the bus line. Since just driving empty buses back and forth to the charging depot without passenger, also known as deadheading, becomes quite expensive (Häll, Ceder, Ekström, & Quttineh, 2019). It takes about six hours to recharge a bus with the slow charging technique. Moreover, depot charging is usually cheaper than the fast charging technique (Lindquist, 2016).

A point of concern is that there are only a few manufacturers of these buses on the market, which also increases the uncertainty about the future of slow charging buses. Additional uncertain parameters are the life span of the battery, the actual range of the electric bus and the ability to buy spare parts for future reparation and maintenance (Englesson & Fält, 2017). One possibility is to combine fast charging during the day when the bus is in operation together with overnight charging (Lajunen, 2018).

3.3 Experience from Electric Bus Adoption

Several studies have investigated what have been the underlying factors for a successful adoption of electric buses over the last 15 years, as well as barriers that hinders adoption (Frenaij, 2014; Li et al., 2017; Mohamed et al., 2018; van der Straten et al., 2007; Xylia, 2018). van der Straten et al. (2007) state that the same enabling factors for adopting electric buses could also be found for other types of alternative powered buses, such as biogas or hybrid. The choice of bus and charging technique is to a great extent dependent on climate and topography, hence the challenges might differ between different countries as well as cities (Gabsalikhova et al., 2018).

3.3.1 What Drives Electric Bus Adoption?

It is known that electric buses during operation reduces the local emissions of NO_x and particles, as well as reducing noise. This has positive health effects on humans and also enables the city to become denser (Aldenius et al., 2016). The environmental aspects regarding reductions of local emissions and noise are considered as motivators in several studies (Frenaij, 2014; Mohamed et al., 2018; van der Straten et al., 2007; Xylia, 2018). Xylia (2018) highlights the importance of using renewable energy sources to reduce the overall emissions. Table 3.1 shows an overview of the most prominent drivers for adopting electric buses.

Table 3.1: Drivers in electric bus adoption.

Drivers	Source
Reduced local emissions	(Frenaij, 2014; Miles & Potter, 2014a; Xylia, 2018),
Reduced noise	(Frenaij, 2014; Xylia, 2018)
Political support/subsidies	(Li et al., 2017; van der Straten et al., 2007)
Gaining experience in demonstration projects	(Mohamed et al., 2018; Xylia, 2018)
Acceptance from passengers and bus drivers	(van der Straten et al., 2007)
Design/visual impact	(van der Straten et al., 2007)
Involvement of stakeholders	(Li et al., 2017)

A main point of concern regarding electric buses is the fact that it is a new and upcoming technique that lacks knowledge and experience (Clean Fleets, 2014). According to Xylia (2018), the main reason for stakeholders to participate in demonstration projects for electric buses is to gain experience about the novel technology, but other motivators for participating are also found. While actors from the academia, public transit authorities (PTA) and bus manufacturers are interested in gaining experience, municipality stakeholders are mainly interested in the environmental advantages. The bus manufacturers are also motivated by the collaboration with other stakeholders and public transport operators (PTO) are driven by being leading with new technology. Further, it was shown that the participants had an improved view of the potential of electric buses after participating in a demonstration project (Xylia, 2018). In cities where the electric buses have not been adopted, demonstration projects are motivated by Mohamed et al. (2018) to help service providers in the adoption process of electric buses. This is motivated by the fact that it provides operational data of electric buses as well as trying the operational limitations (Mohamed et al., 2018).

The visual aspect of the bus and the charging infrastructure has also an impact on the adoption of electric buses (Xylia, 2018). The charging infrastructure for electric buses requires space to a greater extent compared to conventional buses. The design of the bus is also considered to be significant, since the look of being environmentally friendly increases the acceptance (van der Straten et al., 2007). Further, van der Straten et al. (2007) state that if the technology is perceived to be easy to understand and use, it is more likely that it is accepted by bus drivers and passengers which consequently makes it as an enabler for the adoption.

Li et al. (2017) mean that public subsidies are common in cities where electric buses have been adopted and that they work as encouragement and should be available for more cities. Since subsidies facilitate to overcome high capital costs and reduces the risks of adopting new technology. Private funds are also existing, e.g. in Gothenburg, Bogota and Singapore, but is rather unusual. On the contrary, Miles and Potter (2014a) describe that subsidies are inefficient for cities to adopt electric buses and state that a risk strategy, or a new kind of risk management (as institutional structures and business models), is essential for implementing electric buses in the transit system. In the case of Milton Keynes demonstration project in England an "enabling" company purchases the buses and infrastructure and leases it to the operating company (Miles & Potter, 2014a), which is advantageous when the PTO wants to avoid the risk of new technology by giving a predetermined price. In line with this, Li et al. (2017) mean that PTOs that leases the buses and batteries avoids the risk of high investment costs and potentially inadequate batteries and means that leasing is one way of enabling bus operators to adopt electric buses.

3.3.2 Barriers in Electric Bus Adoption - and How to Overcome Them

The costs of electric buses are the main barrier for adoption, which is shown in several studies (Frenaij, 2014; Gabsalikhova et al., 2018; Li et al., 2017; Miles & Potter, 2014a; Mohamed et al., 2018; van der Straten et al., 2007; Xylia, 2018). The greatest concern in terms of cost is the capital cost, which is extensively higher than the cost of a diesel bus or biogas bus and is to a large extent dependent on the costs for the battery (Gabrielsson & Hajiakbar, 2016; Lajunen & Lipman, 2016). Even tough Lajunen (2018) identify cost reductions the last couple of years, capital cost still remains as a barrier. Another required investment regarding electric buses is the charging infrastructure, which also tend to increase the costs. Xylia (2018) states the importance of using the charging infrastructure effectively in order to use the money in the best kind of way. Further, Xylia (2018) states that the costs should be evaluated on a larger scale, since the most cost effective solution for one line might not be the case for the expanded network. Table 3.2 presents the main barriers found in in the literature.

Table 3.2: Barriers in electric bus adoption.

Barriers	Source
Technology	(Frenaij, 2014; van der Straten et al., 2007)
Operational reliability	(Li et al., 2017; Mohamed et al., 2018)
Cost (mainly capital cost and battery cost)	(Frenaij, 2014; Gabsalikhova et al., 2018; Li et al., 2017; Miles & Potter, 2014a; Mohamed et al., 2018; van der Straten et al., 2007; Xylia, 2018)
Compatibility	(Frenaij, 2014; van der Straten et al., 2007; Xylia, 2018)
Higher risks	(Frenaij, 2014; Mohamed et al., 2018)

High cost is an indication of technology challenges, which is also considered as a barrier for electric bus adoption. The technology challenges regards mostly operational reliability, which concerns among others, limited driving range, weather conditions or road conditions that affect buses with low floors (Mahmoud, Garnett, Ferguson, & Kanaroglou, 2016; van der Straten et al., 2007; Xylia, 2018). Li et al. (2017) highlight the knowledge gap about the battery functionality in cold and very warm weather. Cold climate is limiting the performance of the battery and increasing temperatures increases the degradation of the battery.

Another factor that affects the electric bus adoption is the compatibility between the new technology and the already existing one, as well as infrastructural compatibility (van der Straten et al., 2007; Xylia, 2018). If the new technology is similar to the previously used technology it might be seen as an enabler because of already existing infrastructure and knowledge. However, in the case of electric buses it is usually seen as a barrier (van der Straten et al., 2007). Furthermore, Xylia (2018) means that the variances in charging systems and powertrains and the lack of standards for compatibility, result in difficulties when mixing technologies that implies restriction in the choice of manufacturer.

Mohamed et al. (2018) identified factors related to risk, operation and cost, that hinder service providers to adopt electric buses, based on a study in Canada. These factors regard the attitude towards electric buses, operational feasibility, decision-making and building of a business case. The attitude concerns the high risks of being an early adopter, uncertain technological development and high costs. What concerns the operational feasibility are the risk of decreased service reliability, increase in fleet size, limited range, lower operational flexibility and high total cost of ownership. The decision-making process includes concerns such as risks when handling public funds and taxes. Henceforth, by using these factors Mohamed et al. (2018) have produced a framework for service providers consisting of four stages. Research and development standardization is stated to be the first stage, which is said to be done by bus manufacturers and governmental entities since they are the actors that have the capability to improve the technology. As a second stage, political support in terms of financial support and regulations, are highlighted as important due to the supplemental costs for electric bus systems. As a third stage, Mohamed et al. (2018) describe that demonstration projects contribute to increased knowledge about electric bus operation, which facilitate in the decision-making process. The fourth stage would include databanks in order to provide information about research and development as well as policy direction (Mohamed et al., 2018).

3.4 Involved Actors and Decision-Making in Swedish Public Transport System

Regeringskansliet (2010) describes that a new law about the Swedish public transport system came into force in January 2012, where the distribution of responsibility between the involved actors is clearly stated. The actor with the main responsibility is the public transport authority (PTA), which could be constituted by either a municipality, a county or a combination of the two (Regeringskansliet, 2010). The main objective for the PTA is to form so-called regional transport supply programme, which includes goals for both commercial and contracted services (Aldenius & Khan, 2017). Moreover, the passengers are also an important part of the public transport system, since they pay for the trip and express their opinions and requirements about the public transport system. The third important actor is the public transport operator (PTO), who is responsible for the operation of the public transport. The PTA is responsible for the procurement of the PTO and tries to incorporate passenger's requests about the public transport system in the contract for the PTO (Ringqvist, 2016). The procurement of the public transport system takes place within a stated time span (5-10 years) and follows the Public Procurement Act (Aldenius & Khan, 2017; Regeringskansliet, 2010). Hence, when the new procurement takes place, the old PTO could be replaced if another PTO provides a more advantageous tender (Regeringskansliet, 2010). A schematic overview of the different responsibilities between the main actors are shown in Figure 3.2.

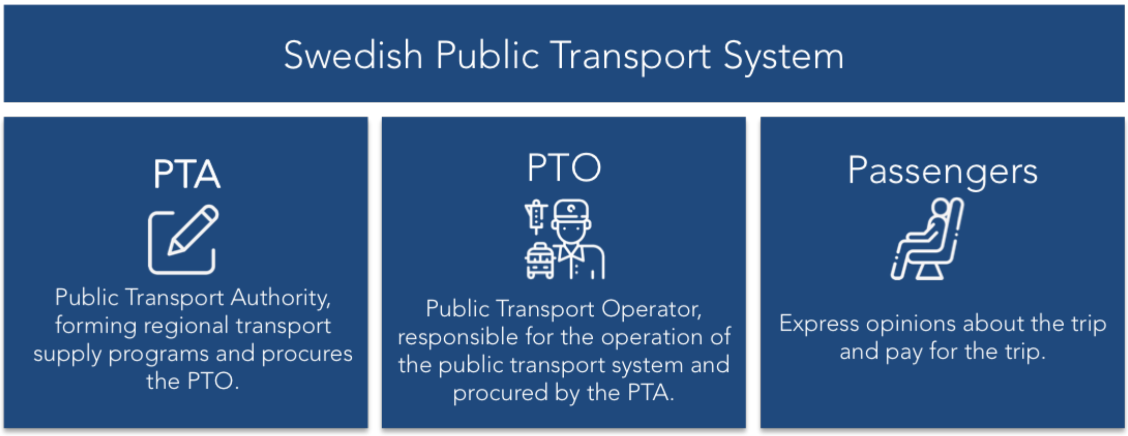

Figure 3.2: Overview of the Swedish Public Transport System, figure adjusted from Ringqvist (2016).

Nurhadi, Borén, and Ny (2014) illuminate the complexity about sustainable decision-making. Further, Xylia (2018) emphasizes the lack of procurement routines regarding the electric buses and suggests some policy instruments. For instance, more rigorous procurement standards from a life-cycle perspective, which favors sustainable powertrains over conventional powertrains. Further, due to the high capital cost of the charging infrastructure and the bus, the contract period should be long enough to show for the involved stakeholders that the investment is beneficial from an economic perspective. Finally, the network of involved actors should be expanded. For instance, involving the electricity companies when forming the procurement standards and encouraging knowledge transferring between the involved actors (Xylia, 2018).

3.5 Swedish Governmental Subsidization of Electric Buses

In Section 3.3.1, subsidies are mentioned as one of the drivers for an electric bus adoption. Therefore, following sections describe the most fundamental Swedish governmental subsidization, namely Elbusspremien, Stadsmiljöavtalet and Klimatklivet.

3.5.1 Elbusspremien

In year 2016 the subsidy for electric buses named Elbusspremien was introduced in Sweden with an intended time horizon of seven years, thus until year 2023. The main intentions were to assure a high air quality, reduce noise pollution and prevent the climate change by introducing a growing amount of electric buses on the market (Skog & Arbresparr, 2017). Several different actors are able to apply for the subsidy, e.g. municipalities, PTAs, limited companies with responsibility for the public transport system. These can receive a subsidy of 20 percent of the bus's purchase price, due to the higher investment cost of an electric bus compared to a conventional bus. Elbusspremien compromises grants for full battery electric buses, trolleybuses, battery trolleybuses and plug-in hybrid buses (Skog & Arbresparr, 2017). However, the plug-in hybrid buses are required to use electricity as the powertrain 70 percent of the operational time and are only able to gain 50 percent of the intended subsidy (Andrén & Peter, 2018).

3.5.2 Stadsmiljöavtalet

In year 2015, The Swedish Transport Administration launched the subsidy called Stadsmiljöavtalet, aiming for achieving a sustainable urban development, by increasing the number of public transport travelers and cyclists. Hence, it encourages a sustainable urban development in general, where electric buses could be one part. According to the Swedish Transport Administration's national plan, the annual budget for Stadsmiljöavtalet is one billion SEK (Trafikverket, 2017). Both municipalities and county councils have the permission to apply, but the maximum amount that could be subsidized is 50 percent of the total investment cost. Additionally, the receiver of the grant is required to do additional implementations in the city, which favor a sustainable urban development. It is important to keep in mind that electric bus systems could only be subsidized by Stadsmiljöavtalet from a larger perspective. It means that new charging infrastructure will not be subsidized, but for instance if it includes bus-only streets or bus stops it would be possible to receive the grant (Sveriges Riksdag, 2015).

3.5.3 Klimatklivet

During 2015-2018 it was possible for e.g. companies, municipalities, county councils and housing cooperatives to apply for subsidization for carbon dioxide reducing arrangement from the grant named Klimatklivet. At the moment it is not possible to apply for the grant. However, if the government follows the contemporary budget the application will open in June 2019 again (Wikholm, 2019). Naturvårdsverket initiated Klimatklivet on behalf of the government and subsidized 3207 initiatives for an amount of 4,7 billion SEK during 2015-2018. The main objective with the subsidization was to achieve one of the national environmental quality objectives, namely "Reduced Climate Impact" (Wikholm, 2018). Carbon dioxide reducing arrangements can include several different types of initiatives, but the main part of the money has subsidized initiatives for different types of charging stations for electric cars, but in some cases for electric buses (Bergman, 2018). However, Isberg et al. (2017) evaluated the impact of Klimatklivet and found that it is hard to estimate the percentage of the investment that needs to be subsidized for the investment to take place. Furthermore, Isberg et al. (2017) describe the difficulty of evaluating the total decrease of the carbon dioxide emissions for an investment, since only one part of the life cycle is subsidized. Alongside these arguments, Gustafsson (2018) concluded that Klimatklivet is inefficient for achieving the objective "Reduced Climate Impact" and states that the subsidized projects should have taken place even without the grant.

3.6 Evaluating Life-Cycle Costs

Calculating life-cycle costs is a well-recognized evaluation tool for comparison between different alternatives and can be modelled differently depending on what is analyzed (Gluch & Baumann, 2004). The life-cycle cost of electric bus systems in this study includes capital costs, operational costs and environmental costs. These costs will be explained further in the following sections.

3.6.1 Capital Costs

For the capital costs, the battery cost is the primarily reason for the increased cost for an electric bus compared to a conventional bus. The costs for batteries are dependent on the battery energy capacity and chemistry, which makes the price vary (Lajunen & Lipman, 2016). Lajunen and Lipman (2016) show that an electric bus with a high-power battery (used for fast charging) is more cost effective than a high-energy battery used for overnight charging. As a result of the technology development and higher production volumes of electric vehicles, the cost for batteries in electric buses is expected to decrease in the future (Lajunen & Lipman, 2016). In a study made by Nykvist and Nilsson (2015), the cost for lithium-ion batteries has decreased by 14 percent every year from year 2007 to 2014. According to Lajunen and Lipman (2016) it will continue to decrease by two percent every year for electric buses. Costs for electric bus systems also consist of investments for charging infrastructure and can vary for different charging types, i.e. if the buses are charged at depot, at the terminus or along the route. Investing in an electric bus system usually requires a larger bus fleet compared to investing in conventional buses, due to the charging time, which increases the cost (Lajunen & Lipman, 2016).

3.6.2 Operational Costs

Electricity consumption costs is an important cost item for the operation of electric buses. The electricity consumption depends on several things; Lajunen (2018) mentions the bus route specifications, while Olsson et al. (2016) highlight the size of the battery and the number of passenger on the bus. The cost is dependent on the price for electricity. The price for renewable electricity is today more expensive than electricity from fossil fuels, but the cost for renewable electricity is expected to be cheaper in the near future, considering statistics from several countries worldwide (IRENA, 2017). If an electric bus intends to be emission free, renewable electricity should be used. Hence, the renewable electricity price influences the operational cost (IVL Svenska Miljöinstitutet, 2017).

Electric buses have lower maintenance costs than conventional buses due to less frequent and cheaper regular maintenance of the bus fleet. Mainly because motor and transmission oils are not required for electric bus maintenance, but the cost can also vary between different electric bus systems (Gabsalikhova et al., 2018; Olsson et al., 2016). Furthermore, S. Fält emphasizes that the electric propulsion system has fewer flexible parts which implies that fewer parts can break down. Less vibrations for an electric bus, compared to a conventional bus, also results in less maintenance (personal communication, 16th of May 2019). Lajunen (2018) separates the costs for replacement of battery from the general maintenance cost and includes general repairs, spare parts and maintenance of charging devices in the cost for battery replacement. Battery replacement is expected during the lifetime of a bus, but there are uncertainties about how frequent the battery needs to be replaced. Lajunen (2018) calculates the life span for a battery based on total energy throughput, which depends on the energy capacity of the battery, charge cycles and energy throughput in operation. Olsson et al. (2016) means that a high-power battery can decrease the battery's life span, in contrast to a battery with lower power.

3.6.3 Environmental Costs

It is a complex task to monetize the environmental impact of emissions. On the one hand, it is impossible to price all aspects of environmental impacts, whereas on the other hand, one might oversimplify the calculation of environmental costs (Gluch & Baumann, 2004). Cost for carbon dioxide (CO_2) emissions has been evaluated by several researchers. In Sweden, the *ASEK values* developed by the Swedish Transport Administration, are utilized to monetize environmental impact (Trafikverket, 2018). The CO_2 emissions, whose effects on human life and environment is complex to derive, are valued and based on the governmental CO_2 tax, and not on loss of lives and climate adjustments. Earlier studies are showing lower costs for CO_2 emissions than more recent studies, which gives an indication of that the cost can possibly increase in the future (Trafikverket, 2018). NO_x, particles and noise are valued and based on negative health effects for the inhabitants, which are the costs for treatment and by losses in shorter lives (IVL Svenska Miljöinstitutet, 2017). Hence, cost estimation of local emissions (NO_x and particles) and noise depends on the amount of exposed entities. Exhausts containing NO_x and particles are non-existing for electric buses, independent of electricity source. Particles from tires are still emitted, as for conventional buses (IVL Svenska Miljöinstitutet, 2017).

The amount of generated CO_2 emissions during the lifetime for an electric bus is highly dependent on how the electricity used for propulsion, is produced. Electricity from renewable sources, such as wind and water, results in close to zero emissions, while electricity from fossil fuels results in extensively higher levels of emissions (IVL Svenska Miljöinstitutet, 2017). IVL Svenska Miljöinstitutet (2017) shows that the CO_2 emissions for an electric bus with non-renewable electricity are twice as much than for a biogas bus.

4

Case Studies

Following sections provide background information about the adoption of electric buses in the case cities. The evaluated cities are located in different parts of Sweden, further information about the geographical location is shown in Appendix D.

4.1 Gothenburg

Gothenburg is the second largest city in Sweden with a population of about 570 000 people (SCB, 2018a). The city is located on the west coast in the southern part of Sweden, as shown in Appendix D (Google maps, 2019), and results in a mild climate with a yearly average temperature of approximately seven degrees (SMHI, 2017). In connection with Volvo Ocean Race year 2015, Gothenburg introduced a new bus line named line 55 which consisted of three electric buses and seven plug-in hybrid buses (PHEV). Line 55 was a part of the cooperation called ElectriCity, a cooperation between the industry, research and society aiming for a sustainable mobility in the city. A lot of different actors have been involved in the electric bus adoption, namely as many as 15 different actors. Due to the large number of the involved actors, there has also been coordinator for the whole project, which at the moment is Lindholmen Science Park (Electricity, 2016). In year 2018, the electric bus network was further extended with two buses in line 16, so-called EL16 (Electricity, 2019b).

The report *"Samarbete för en hållbar och attraktiv kollektivtrafik"* describes that some challenges were found before the project started, such as formulating visions and setting the direction for the cooperation. Moreover, in this case it was not a common budget in the project, since all the involved actors had their own budget. Nowadays when line 55 is implemented and has been in operation for a couple of years, the main learning outcome has been that a more comprehensive stakeholder analysis should have been conducted in the initial phase of the project (Electricity, 2016). In October 2019, bus line 60 will be electrified (Västtrafik, 2018). Table 4.1 provides more details about the electric bus system in Gothenburg.

Table 4.1: Electric bus system in Gothenburg

Parameter	Characteristics in Gothenburg	Source
Number of buses	Seven PHEVs and five full electric buses	(Electricity, 2016, 2019b)
Number of bus lines	Two (line 55 and line 16)	(Electricity, 2016, 2019b)
Charging	Fast charging by a pantograph at end stops and depot charging during night.	(Electricity, 2016; ZeEUS, 2017)
PTO	Keolis (line 55) and Transdev (line 16)	(Electricity, 2016, 2019b)
Route length	15.2 km (line 55) and n.d. (line 16)	(ZeEUS, 2017)
Manufacturer	Volvo	(Aldenius et al., 2016)
Energy	Renewable energy	(Electricity, 2019a)
Main actors	Volvo, VGR, Göteborgs stad, Chalmers and Ericsson	(Electricity, 2016)
Subsidies	Klimatklivet (received 2017)	(Wikholm, 2018)

4.2 Umeå

Umeå is located in the northern part of Sweden as shown in Appendix D, which results in a cold climate with a yearly average temperature of three degrees (Google maps, 2019; SMHI, 2017). The estimated amount of the population is 127 000 people (SCB, 2018b). Aldenius et al. (2016) describe that Umeå wanted to densify the city, hence a reduction of emissions and noise was crucial to enable the densification. It was shown that electric buses could to some extent solve these problems. Thus, the start-up company Hybricon, converted two diesel buses to plug-in hybrid (PHEV) buses, which were taken in operation in year 2011. These two buses were complemented with a prototype in year 2013 and a further extension of eight electric buses was implemented in year 2014 (Aldenius et al., 2016). In June 2019 an additional adoption of 25 electric buses manufactured by VDL will be in operation in Umeå (Transportmagasinet, 2018).

The electric bus project in Umeå included a few actors, namely Ultra which is the local traffic planner, the municipality Umeå Kommun and the initiator of the project which was the local manufacturer Hybricon (Aldenius et al., 2016; Borghei & Magnusson, 2018). The municipality is the owner of both the buses and the infrastructure. Subsequently, the PTO leases the buses from the municipality (Aldenius et al., 2016). Table 4.2 provides more details about the electric bus system in Umeå.

Table 4.2: Electric bus system in Umeå

Parameter	Characteristics in Umeå	Source
Number of buses	Nine electric buses and two hybrid buses	(Aldenius et al., 2016)
Number of bus lines	Three (line 6, 9 and 80)	(ZeEUS, 2017)
Charging	Fast charging by a pantograph at selected stops and depot charging during night.	(ZeEUS, 2017)
PTO	Transdev	(Transdev, 2019)
Route length	15 km (line 6), 16 km (line 9) and 14 km (line 80)	(ZeEUS, 2017)
Manufacturer	Hybricon	ZeEUS (2017)
Energy	Renewable energy	(Umeå Energi, n.d.)
Main actors	Umeå kommun, Hybricon and Ultra	(Aldenius et al., 2016; Borghei & Magnusson, 2018)
Subsidies	Klimatklivet (received 2018)	(Wikholm, 2018)

4.3 Landskrona

Landskrona is the most southern town out of the four evaluated cities, shown in Appendix D, which generates a mild climate with an average yearly temperature of seven degrees (SMHI, 2017). The city has a population of about 46 000 people (SCB, 2018c). In 1999 the subsidy called Lokalt Investeringsprogram (LIP) was approved to some extent support a trolleybus line in Landskrona. Four years later, in 2003, the inauguration of the trolleybus line (line 3) took place. It compromised three buses, where Landskrona Stad (the municipality) was the owner of the buses and the infrastructure, Skånetrafiken was the PTA and Arriva the PTO (Andersson & Johansson, 2005). Over the years, the trolleybus line has been extended. The contemporary trolleybus line consists of four trolleybuses and one Slide-In bus, where Nobina is the PTO (Aldenius et al., 2016; Drivmo, 2019).

Drivmo (2019) describes that the whole bus fleet became electrified in January 2019. The main reason was to improve the local environment in Landskrona, thus decrease the noise and local emissions, which means that 14 new electric buses replaced the old biogas buses in the public transport network. The project has been a three- party cooperation between the municipality Landskrona Stad, the PTA Skånetrafiken and the PTO Nobina. Worth to emphasize is that Nobina has been involved throughout the whole project, thus developed the concept, being project managers for the adoption of electric buses in the city and being responsible for the operational part (Drivmo, 2019). Table 4.3 provides more details about the electric bus system in

Landskrona.

Table 4.3: Electric bus system in Landskrona

Parameter	Characteristics in Landskrona	Source
Number of buses	19 (four trolleybuses, one Slide-in bus and 14 electric buses)	(Drivmo, 2019)
Number of bus lines	Five	(Drivmo, 2019; Skånetrafiken, n.d.)
Charging	Overnight charging at depot regarding the 14 new buses and by the catenary for the trolleybuses.	(Andersson & Johansson, 2005; Drivmo, 2019)
PTO	Nobina	(Drivmo, 2019)
Route length	3 km trolleybus	(Andersson & Johansson, 2005)
Manufacturer	BYD (new buses) and Solaris (trolleybuses)	(Andersson & Johansson, 2005; Nobina, 2019)
Energy	Renewable energy	(Drivmo, 2019; Naturskyddsföreningen, 2019)
Main actors	Landskrona Stad, Skånetrafiken, Arriva (trolleybuses), Nobina (battery buses)	(Andersson & Johansson, 2005; Drivmo, 2019)
Subsidies	LIP, Stadsmiljöavtal and Elbusspremie	(Andersson & Johansson, 2005; Gomér, 2017)

4.4 Ängelholm

Ängelholm is located in the southern part of Sweden as shown in Appendix D, with a population of 41 000 people (Google maps, 2019; SCB, 2018d). It results in a pretty mild climate and a yearly average temperature of seven degrees. In 2012/2013, Skånetrafiken (the PTA) wanted to investigate the possibility of adopting electric buses on a larger scale and found out that Ängelholm was a suitable municipality (Aldenius et al., 2016; Sörensson, 2014), this because Ängelholm was in lack of biogas and the next procurement was planned to take place in 2019. Thus, it was an ideal time span of the pilot project with electric buses. Hence, it was decided in 2014 that five electric buses should be taken in operation in January 2016 in Ängelholm (Aldenius et al., 2016).

Skånetrafiken initiated the electric bus project and is seen as the main actor. However, the PTO, Nobina, has also been a part of the project, by being the purchaser of the buses. At the same time Skånetrafiken is responsible for the economic risks regarding both the charging infrastructure and the buses and has also financed the electric grid (Aldenius et al., 2016). The report *"Elbussrapport Ängelholm- första halvåret 2017"* describes the outcome of the electric bus adoption in Ängelholm, since the buses were taken in operation until the first part of 2017. The report emphasizes two major problems. Firstly, vehicle problems such as broken voltage converter and loud noise. Secondly, they encountered problems with the heaters. To increase the accessibility of the electric bus, better heaters and more easily accessible spare parts were crucial (Skånetrafiken, 2017). Subsequently, the old heaters in the bus from Valeo (Spheros) were replaced with new heaters from Reformtech (Jerksjö, 2018). Table 4.4 provides more details about the electric bus system in Ängelholm.

Table 4.4: Electric bus system in Ängelholm

Parameter	**Characteristics in Ängelholm**	**Source**
Number of buses	Five	(ZeEUS, 2017)
Number of bus lines	Three (line 1, 2 and 3)	(ZeEUS, 2017)
Charging	Overnight charging at depot.	(ZeEUS, 2017)
PTO	Nobina	(Aldenius et al., 2016)
Route length	7.1 km (line 1), 14.2 km (line 2) and 9.7 km (line 3)	(ZeEUS, 2017)
Manufacturer	BYD	(ZeEUS, 2017)
Energy	Renewable energy	(RegionSkåne, 2018)
Main actors	Skånetrafiken (Region Skåne) and Nobina	(Aldenius et al., 2016; ZeEUS, 2017)
Subsidies	n.d.	

5

Result

The fifth chapter presents the result from the conducted interviews and the life-cycle cost calculations. The first three sections are based on the conducted interviews and aim to answer the first two research questions of the study; *"What are the identified drivers, barriers and success factors for the electric bus adoption in the evaluated cities?"* and *"Based on experiences from the evaluated cities, will electric buses be a viable option for future public transportation?"*. Section 5.5 answers the third research question; *"Can electric buses be considered as competitive to conventional buses, in terms of life-cycle costs?"*, the life-cycle costs are calculated based on data from the literature review as well as the conducted interviews. Figure 5.1 shows in which city the interviewed actors have been a part of the electric city bus adoption.

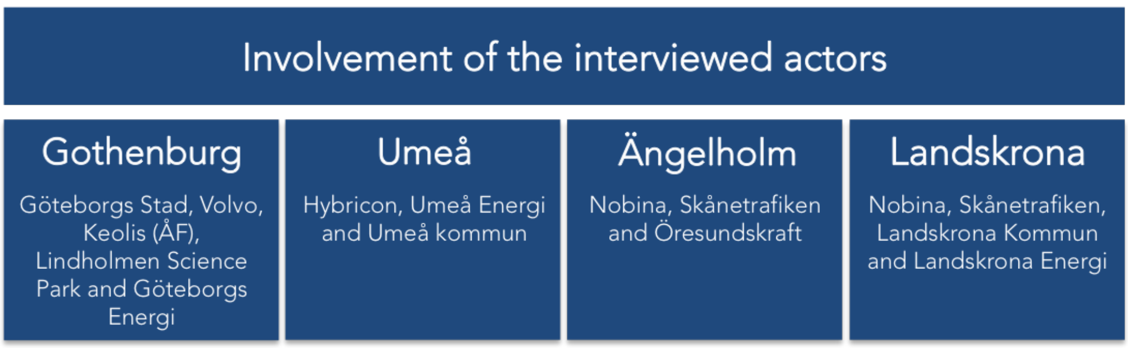

Figure 5.1: An overview of where the interviewed actors have been involved in the electric bus adoption.

5.1 Drivers when Adopting Electric Buses

Several advantages can be identified for electric buses. Figure 5.2 shows the most common advantages that were revealed and stated by the interviewed actors. For more detailed information, Appendix E shows all the perceived advantages with electric buses. Following sections describe the drivers for adopting electric buses in the case cities.

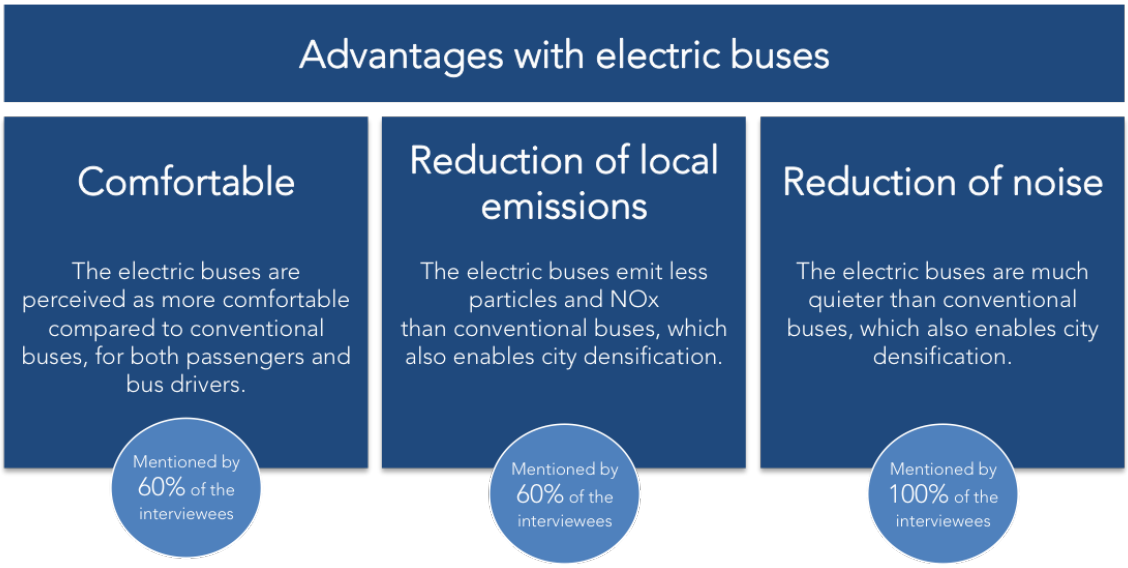

Figure 5.2: The most commonly mentioned advantages of electric buses expressed by the actors during the interviews.

5.1.1 Identified Drivers in Gothenburg

In year 2013 the county Västra Götalands Regionen (VGR) initiated the ElectriCity project. However, during the interviews with the involved actors in Gothenburg, all of them emphasized Volvo's involvement as one of the drivers for implementing line 55 in Gothenburg in conjunction with the inauguration of Volvo Ocean Race year 2015. Volvo wanted to create a demonstration arena to develop and implement electric buses in Gothenburg, where the head office is located. Thus, Volvo's strong driving force was recognized in all interviews with actors in Gothenburg. Furthermore, Lindholmen Science Park emphasizes the amazement that other cities have succeeded in the electrification of the bus system without direct correlation to the bus manufacturer. This is in accordance with Volvo's argumentation who states that they have been the project managers throughout the whole project and created a new platform for electromobility in general.

"Volvo turned about at that time [2013], and saw the potential of electrification." - Interviewee at Trafikkontoret

Of course, Volvo wanted to operate on the magnificent avenue [Avenyn, Gothenburg]. - Interviewee at Keolis (ÅF)

In addition to Volvo's power of electrifying the bus system, three of the interviewees namely Göteborgs stad, Lindholmen Science Park and Volvo, mentioned the future technology as another driver and highlighted that conventional buses as diesel and to some extent biogas buses will be replaced by the electric buses in the future, which is in line with VGR's environmental goals, mentioned by Västtrafik. Two of Västtrafik's the highlighted environmental goals are; *"All of the buses in the public transport system should be replaced by electric buses until 2030"* and *"The carbon* *dioxide emissions should be decreased with 80 percent until year 2020 with year 2006 as a reference case"*. According to these goals, Västtrafik highlighted target achievement and environmental advantages regarding emissions as drivers. The aspect of the buses being environmentally friendly was also mentioned by Keolis (ÅF).

Regarding the chosen charging infrastructure, all the respondents seem to agree with each other, thus fast-charging at terminus was the only charging alternative. According to the interviewee's different responsibilities all of them mention several drivers for implementing fast-charging at terminus in year 2015. Due to lack of space for a bus depot in the city center, deadheading was avoided by choosing an end stop solution. Furthermore, it does not require any longer recharging stops during the day, which is of high importance with respect to the high capacity of line 55. These two prominent drivers for choosing fast-charging at terminus were stated by the interviewee at Göteborgs Stad. Additionally, Volvo illuminates the importance of firstly evaluating the demand from the passengers and secondly implementing the most appropriate solution. The main objective of the electric buses was to transport passengers and not batteries, motivates the interviewee at Volvo. Hence, fast-charging at terminus was chosen over depot charging, since depot charging requires larger batteries and especially back in year 2015.

5.1.2 Identified Drivers in Umeå

Umeå is facing environmental challenges in terms of local emissions and noise pollution. Hence, improving the environmental quality standards was crucial to continue the city densification, which also generates a lot of money. To move on with the city densification a permission from the county administrative board was needed, which resulted in that Umeå Kommun started to investigate solutions for improving the air quality and noise pollution. An adoption of electric buses was identified as a solution for both of these environmental problems. Therefore, both Umeå Kommun and Hybricon highlighted that improving the local environment in terms of local emissions and noise as the major drivers for implementing electric buses in Umeå.

To reduce these negative externalities, the largest impact would be achieved if the electric buses were implemented in the most utilized bus line with the highest frequency. According to the requirements of a daily operation of approximately 21-22 hours, the only suitable solution was charging at terminus with fast charging during the day and depot charging during night.

5.1.3 Identified Drivers in Landskrona

Landskrona has long experience of electric buses, since the first trolleybuses were adopted in year 2003. Already back then, Landskrona wanted to actualize the question about environmental issues in terms of local emissions and noise in the city center and solve it by utilizing innovative solutions, such as trolleybuses. The interviewee at Landskrona Stad describes that especially one politician back then was very proactive in the environmental discussions and prioritized these questions. Even though the size of the city is small, Landskrona became famous worldwide for the new investment of trolleybuses according to the interviewee at Landskrona Stad. Thus, solving environmental issues and keeping the good reputation are identified as drivers for starting the electrification of the public transport system.

The old bus fleet in Landskrona which consisted of biogas buses needed new buses. Hence, in year 2016 Skånetrafiken initiated the project regarding replacing the existing biogas bus fleet with electric buses, since the biogas buses were identified as less efficient compared to the electric buses. Additionally, Skånetrafiken highlighted local environmental issues as a problem, such as emissions and noise, as drivers for the project, which would enable city densification to a greater extent. Landskrona Stad was very keen on keeping the good reputation about electrification of the public transport system and started to cooperate with Skånetrafiken in an early stage. Nobina, the PTO of the buses, was integrated later in the project, since Nobina also saw the environmental potential and identified electric buses as the future technology of public transport city buses. Thus, solving environmental issues, keeping the good reputation about environmentally friendly solutions in the public transport system and implementing the future technology are identified as drivers for the new electric buses in Landskrona.

Landskrona uses different charging techniques for the electric city buses; the catenary for the trolleybuses, catenary and battery for the Slide-In bus and depot charging for the recently adopted electric buses. Both the interviewee at Skånetrafiken and Nobina highlighted that they wanted to expand the existing trolleybus network for the new bus fleet but described that the municipality rejected the proposal. When the interviewee at the municipality, Landskrona Stad, was asked about the chosen charging technique the interviewee only mentioned the benefits with depot charging; as suitable for a small city like Landskrona and appropriate according to the geographical location of the city. When the researchers explicitly asked why the municipality refused to expand the existing trolleybus network, the stated reasons were that it was too expensive as well as due to political circumstances. When the proposal about expanding the contemporary trolleybus network was neglected, all the involved actors (Landskrona Stad, Skånetrafiken and Nobina) agreed on that depot charging was the best charging technique. The reason to this was that it is efficient in a small town where it is easy to find space for the depots, so deadheading could be avoided. Additionally, it does not require any infrastructural changes in the city center compared to the trolleybus network.

5.1.4 Identified Drivers in Ängelholm

Skånetrafiken wanted to gain knowledge about adopting electric buses on a larger scale, where the main intention was to scrutinize the drawbacks and the future potential of electric buses as future public transportation mode. Hence, a demonstration project about electric buses was introduced in Ängelholm, where three out of four bus lines were electrified in year 2015. Further on, environmental advantages as reduced noise pollution and decreased local emissions, which enables city densification, are also highlighted as drivers for the adoption.

Regarding the chosen charging infrastructure, in this case depot charging, was identified as the only possible solution in year 2015. Since it was a demonstration project, they wanted a rapid adoption of electric buses with enough driving range for the new electric bus lines. Due to the fact that Ängelholm is a rather small city and does not require a long driving range, charging at depot was seen as the most appropriate solution. In addition to that, it was highlighted that the PTOs usually appreciate depot charging since they are not bound to the infrastructure compared to when trolleybuses or charging at terminus are chosen.

5.2 Barriers when Adopting Electric Buses

Several different challenges and disadvantages were revealed and stated during the interviews, where the most common challenges are shown in Figure 5.3. For more details about challenges and disadvantages with electric buses, see Appendix F. The barriers of which the interviewees have identified and encountered are presented in following sections, city by city. The most commonly mentioned disadvantages are shown in figure 5.3.

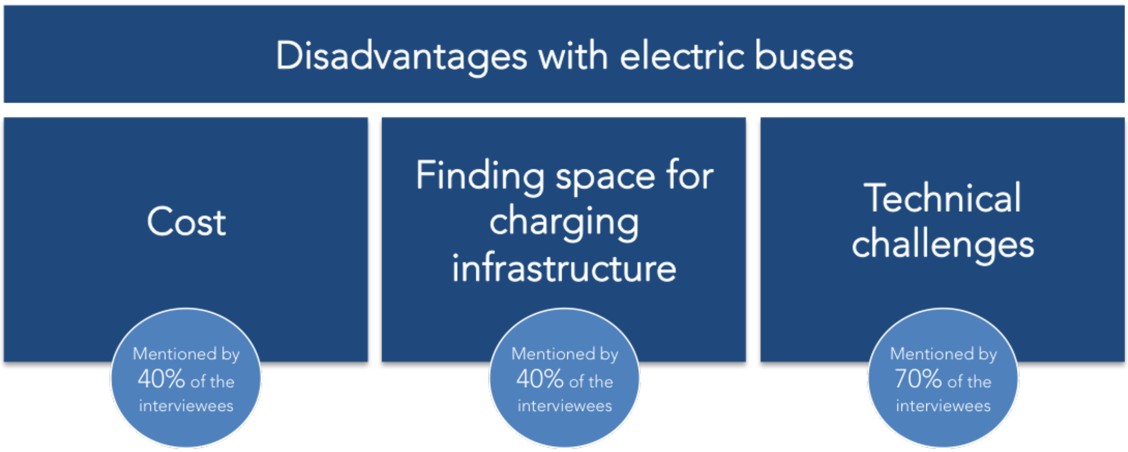

Figure 5.3: The most commonly mentioned disadvantages of electric buses expressed by the actors during the interviews.

The fact that adopting electric buses implicates the risks of introducing new technology is stated by almost all interviewees. The interviewee at Hybricon states that being among the first using this technology implies a trial and error-process which is a risk that is also a matter of expense. The public transport authority (PTA) is responsible for having the public transport in operation, and the interviewee at Västtrafik states that it is crucial that the technology works. The interviewee at

Nobina mentions the driving range and the safety of operation as uncertain parameters due to the new technology.

5.2.1 Identified Barriers in Gothenburg

During the beginning of the adoption of electric buses in Gothenburg, the bus drivers were very skeptical about the new technology and what it would imply to drive electric buses. Recruiting bus drivers was also a challenge, according to the PTO in Gothenburg, where the main barrier was the uniform route line it would imply to drive the electric buses. It required hard work to convince the future bus drivers to choose electric buses over conventional buses. The bus driver's time is also increasing since stops for charging at terminus are required, which can make drivers wages higher for an electric bus system. Additionally, Västtrafik highlighted that there is a general problem of recruiting bus drivers, even for other buses than electric buses.

Challenges with the batteries in several different aspects were emphasized during a couple of interviews. The interviewee at Västtrafik mentions the problems regarding mineral extraction for the battery production as well as the recycling of the battery. Further, it is stated that the battery production is energy demanding. Lindholmen Science Park states that the battery technology is a challenge due to the complexity and the high cost, which also increases the risks further. The weight of the bus is dependent on the batteries, and heavy buses have been highlighted as a challenge by the interviewees at both Lindholmen Science Park and Göteborgs Stad. There have also been concerns of the buses being too quiet due to the electrical propulsion system. The terminus at Lindholmen implied some risks since the bus is occupying an area where buses have not been in operation before and where many vulnerable road users as pedestrians and cyclists move.

There have also been challenges regarding space for the charging infrastructure, which was indicated by most of the interviewed actors in Gothenburg. This means that it was an important factor when choosing the location for the charging infrastructure at Lindholmen in Gothenburg. Moreover, the interviewee at Volvo also stated the challenges of constructing the electric grid at the bus stops. According to the interviewee at Keolis (ÅF), the charging infrastructure results in a less flexible bus network.

5.2.2 Identified Barriers in Umeå

The bus supplier, Hybricon, and the municipality in Umeå, Umeå Kommun, point out that adopting electric buses is expensive, especially when they started in year 2014. At that time, they did not get any subsidy for the investment. This applies especially when not accounting for the positive local environmental impact. The more demanding charging times of an electric bus leads to an impaired efficiency in traffic, which increases the expense for the bus drivers as well as the number of buses. Furthermore, the interviewee at Hybricon remarks that the adoption was restrained by the challenge in finding bus drivers that are interested in learning the new way of driving. The lack of interest has led to inadequate feedback, which could have been helpful for this type of project.

Characteristic for Umeå is the extreme weather conditions with low temperatures and a lot of snowfall, which has been a major challenge. It has been problematic for the bus drivers charging the buses at the terminus, since the tolerance is low when setting up the bus, which was stated by the interviewee at Umeå Kommun. This was mainly due to the ice on the ground, which makes the bus slide. According to Hybricon, the cold weather is also problematic for the climate inside the bus since the doors are open often, which makes the bus more energy demanding, hence more expensive.

5.2.3 Identified Barriers in Landskrona

The PTO, Nobina, and the PTA, Skånetrafiken, in Landskrona mean that the main disadvantages are the decreased uptime, which increases bus driver times due to longer charging times and a larger bus fleet. Knowledge about reparation of the electric buses among mechanics is also constrained, hence identified as a barrier.

The interviewee at Skånetrafiken stressed that the battery production is problematic, who means that the life cycle impact is both environmentally poor as well as bad in a human right's perspective. The production of batteries should not be neglected and the requirement of minerals as cobalt should be further investigated. Further, the interviewee said that child labor is common in the production, which is stated to be a major problem. The interviewee at Landskrona Stad described that the electric buses are heavier than conventional buses, which means that this must be considered when building roads and designing the superstructures. It was also mentioned that electric buses, and especially the trolleybuses, are somewhat locked to the network to a larger extent than conventional buses.

5.2.4 Identified Barriers in Ängelholm

As for the case of Landskrona, the PTO and PTA in Ängelholm means that the main disadvantage is the decreased uptime, which increases bus driver times due to longer charging times and additional buses. A risk they considered was the driving range, which has been shorter than expected. Further, Nobina means that the programs that control the door opening as well as the heating can be problematic since it is the first generation and it has to be set up manually, which has resulted in a generally worse indoor climate in the buses delivered from the bus manufacturer Build Your Dreams (BYD). They have also had some issues with delivery delays which is largely due to lack of retailers for spare parts since the electric buses are tailor-made for the city. This brings on challenges regarding spare parts when the buses need reparation, because retailers are restrained. Knowledge about reparation among mechanics is also constrained.

Except from the battery production challenges mentioned by Skånetrafiken (see paragraph two in Subsection 5.2.3), they encountered some problems with a collapse of the batteries which all had to be changed after three years. Skånetrafiken meant that this was due to mishandling in some way, but the specific problem is unknown. According to Nobina, a charging station was also shutdown. Even though everything was included in the insurance, it led to waiting times for spare parts.

5.3 Success factors in the electric bus adoption

The following section presents the success factors, stated and revealed, by each interviewed actor in the study (except for the electricity companies), shown in table 5.1. The stated success factors refer to the answers of the interview question *What success factors have you identified in the project?* The revealed success factors have been identified through the data analysis, conducted by the researchers.

5.3.1 Cooperation

The most prominent success factor identified among the interviews has been cooperation, since four of the interviewees expressly said that the cooperation in the project was a success factor (shown in table 5.1). Interviewee at Nobina mentioned that having one project manager has been a success factor, while a revealed success factor during the interview at Volvo was a neutral coordination group. These success factors could also to some extent be derived to cooperation. The number of involved actors varies to a large extent between the evaluated cities. Gothenburg is quite unusual since about 15 different actors have been involved in the project. To enhance the cooperation in the project, a neutral coordination group has been involved throughout the whole project, which has arranged meetings with the main actors on a monthly basis. Today, Lindholmen Science Park works as the neutral coordination group, who emphasizes understanding for each actor, openness towards each other, daring to think outside the box and suggest new ways to work as key factors for successful cooperation. In addition to this, several different interviewees in Gothenburg mentioned the importance of sharing the same vision and having a strict deadline, which in this case was the inauguration of Volvo Ocean Race in year 2015.

"A strict deadline has contributed to the fact that there has been a clear focus, what happens and when. When you have this kind of cooperation with many different actors that have different backgrounds, then having such a clear objective makes it easier to pursue the issue and focus." - Interviewee at Volvo

Table 5.1: Identified success factors from the interviews.

Stakeholder	Stated success factors	Revealed success factors
Göteborg Stad	Quiet and vibration-less buses, comfortable for bus drivers and passengers	All stakeholders having separate budgets, clear distribution of responsibility
Västtrafik	Satisfied bus drivers and passengers, better working environment that makes the profession more attractive	Stepwise movement towards adoption to avoid risks, leasing the buses from the manufacturer (Volvo), clear distribution of responsibility
Lindholmen Science Park	Cooperation, having a neutral coordination group, go outside the comfort zone, sharp deadline, common vision	Clear distribution of responsibility
Volvo	Sharp deadline, common vision and goal	Clear distribution of responsibility, neutral coordination group
Keolis (ÅF)	Cooperation, different colors on the bus, feedback from the bus drivers	The inauguration of Volvo Ocean Race 2015, clear distribution of responsibility
Umeå Kommun	Cooperation, enough supply of renewable electricity	One dedicated project manager, clear distribution of responsibility
Hybricon	Knowledge	Located in the vicinity of Umeå city, clear distribution of responsibility
Nobina	One project manager	Clear distribution of responsibility, starting the project with a letter of intent
Skånetrafiken	Bus drivers and passengers are satisfied, reduced emissions	Joint working groups
Landskrona Stad	Fulfilling the environmental goals, cooperation (three-party cooperation)	Politician with high ambitions, keep the good reputation about being the first adopter in Skåne

The interviewee at Keolis (ÅF) illuminates that personal chemistry seems to be an important factor. At the same time, the interviewee at Volvo describes that a lot of involved actors have emphasized that personal chemistry is crucial for a successful cooperation. However, the interviewee at Volvo highlights that almost the whole original team is nowadays replaced by new people.

"Some call it "Göteborgsanda" [Gothenburg Spirit], or something. Keolis also had a similar project in Stockholm, which did not work that well to be honest. (...) It is about finding some people who are enthusiastic and personal chemistry is extremely important. And then if it was luck or if it was created it is difficult to say, but we succeeded. One problem was never anyone else's problem, it was our problem. Just such a thing. (...) We all met little by little, we teamed up very well together. It depends on the people who are in the team." - Interviewee at Keolis (ÅF)

In comparison to Gothenburg, the remaining evaluated cities, namely Landskrona, Ängelholm and Umeå, have had significant fewer involved actors in the project. Landskrona Stad thinks that the three-party cooperation has worked well since they have been few involved. This is in accordance with the answer from interviewee at Nobina, who describes that it is harder to cooperate with an increasing number of involved actors. Moreover, Nobina thinks that it is beneficial to include and interact with the PTOs, which also is in line with Skånetrafiken's opinion. Furthermore, the interviewee at Skånetrafiken describes that the politicians also is an important part in the cooperation and highlights that it has been much harder to implement the buses in Landskrona compared to Ängelholm, due to political circumstances. At the same time, Landskrona Stad describes that the politicians have always been striving for the same goal as the other actors in the three-party cooperation.

The interviewee at Umeå Kommun states that cooperation has been a success factor and thinks that it has been important that one project manager has managed the whole implementation. Even though the construction process could be both complicated and time-consuming, the implementation of the electric buses has worked out well according to the interviewee at Umeå Kommun. Furthermore, as already mentioned by the involved actors in Landskrona and Ängeholm, Umeå Kommun highlights the importance of including and interact with the PTO, in this case Transdev. While the interviewee at Umeå Kommun says that the cooperation has been a success factor, the interviewee at Hybricon sees the gained knowledge as the success factor of the project.

5.3.2 Working Environment

Several different interviewees emphasize that electric buses contribute to a better working environment for the bus drivers, but also a better experience for the passengers. In comparison to a conventional bus, the electric bus is quiet and vibration-less, which is seen as the main reason for the improved working environment. As mentioned previously in Section 5.2.1 and 5.2.2, it has been generally hard to recruit bus drivers. However, while the recruitment seemed to have been tough for Gothenburg and Umeå, the outcome in both cities looked somewhat different. Keolis (ÅF) in Gothenburg explains that they had a hard time to convince bus drivers to drive line 55 but that the drivers were very satisfied when they finally chose to be a part of the project. As shown in table 5.1, several actors in Gothenburg emphasized the improved working environment, while nobody in Umeå highlighted it as a success factor.

It was hard to recruit bus drivers to only drive the same bus line for three years, [boring]. I tried to pitch several different things like: driving students, drive at Avenyn [the magnificent street in Gotheburg], drive on a bridge with sea view, drive at Lindholmsallén [Bus Rapid Transit street] - Interviewee at Keolis (ÅF)

5.3.3 Responsibility

None of the interviewees stated explicitly that the distribution of the responsibility was a success factor. On the other hand, the distribution of responsibility was mentioned as an important part of the project during several different interviews as shown in table 5.1. Hence, it was revealed as an important factor for the success of the electric bus adoption. In Gothenburg, the different responsibilities were clearly stated, e.g. Västtrafik vouched for the bus stops and leased the buses from Volvo, Göteborgs Stad vouched for the land and Göteborgs Energi vouched for the electric grid and the charging infrastructure. This could have been an area of conflict, but everything worked out well. Additionally, it has not been a common budget for the project in Gothenburg and all the different actors have financed their own part.

It was almost a prerequisite, that you had such a loosely coupled project and did not put together a huge project with funding and everything...it would have taken too long. Now, in the ElectriCity cooperation, every actor pays for their own part and we have a quite small common budget, just for the coordination group. But otherwise, we have not a common budget. Everybody must pay for their own part and are expected to contribute in a good and positive way. - Interviewee at Göteborg Stad

Nobina describes that a contract, so-called a letter of intent, was initially signed between Skånetrafiken and the municipality in both Landskrona and Ängelholm, where the different responsibilities were stated. Nobina was incorporated later in the project and has since then managed the whole implementation of electric buses in both Landskrona and Ängelholm. Hence, an additional contract was added for Nobina afterwards. In Landskrona, the municipality has financed the infrastructure. Nowadays, the electric buses in both Ängelholm and Landskrona are owned by Nobina. However, when the contemporary contract terminates, Skånetrafiken will repurchase the buses from Nobina which is according to the additional contract about electric buses between Nobina and Skånetrafiken. Thus, it has been a clear distribution of responsibility in both Landskrona and Ängelholm. Moreover, it has also been a clear distribution of responsibility in Umeå, where the municipality has constructed the charging infrastructure, ordered the buses and financed the buses and Umeå Energi has been responsible for the electric grid.

5.4 Future Development of Electric Buses

All the interviewees are positive to the development of electric buses in the public transport system, and the majority see few problems with an electric bus adoption. In contrast to some years ago, there is no doubt if electric buses are capable to work in operation, even though some challenges can be identified. The PTA in Gothenburg, Västtrafik, sees a hindrance when the demand of electric buses will increase and the production will not immediately meet the requirements due to slow conversion in production. Furthermore, the interviewee means that electrification of city buses will enable for increased use of biofuels in the transport sector in general, for instance regional buses.

"I also believe that, especially in countries like China where the air quality is bad and they have major health problems, the electric drive will be very important. I believe that the electric drive will be part of the solution for the future problems and an important piece of a puzzle in the adjustment towards renewable and that a future transport system has features of electric drive." - Interviewee at Skånetrafiken

"Look at China, it is full throttle at the electric bus side! Europe has been slow, but we [in Umeå] started early. The industry is forced in that direction but sometimes it hurts to redirect for new technology. Not everybody is in a hurry, because maybe they do not want to. There is no reverse, it is only one way forward. This technique will become a leader." - Interviewee at Hybricon

To achieve the optimal operation with electric buses, the interviewee at Keolis (ÅF) emphasizes the importance of accurate planning of charging stations, with regards to topography of the city and weight of the bus and plan extra time in the operating schedule. An example given by the interviewee is to avoid placing a charging station on top of a hill, since this affects the battery's capacity. Further, the interviewee at Keolis (ÅF) describes that getting a building permit for the charging stations in the city should not be taken for granted. As mentioned previously in Section 5.2.2 the weather has been a point of concern in Umeå. For the future adoption of the 25 electric buses that will be delivered in June 2019, the asphalt at charging stations will be heated and roofs will be installed to avoid problems when charging the buses. At the same time, the conversion to a fully electrified city raises questions of whether the electric grid will have the capacity to provide enough power for the charging stations. Interviewee at Göteborgs Stad illuminates the problems that might occur at certain times during the day, when all the buses need charging at the same time, also known as power peaks.

"Electricity is extremely effective, but the production of electricity... the challenge is to store it, so the overproduction of electricity during the night that is not used. Sometimes you need to get rid of it when it costs money. The challenge is to store electricity and to provide enough electricity. We have noticed that in our small facilities that we have built there is a large amount of current that needs to come through." - Interviewee at Nobina

All the interviewed electricity companies think that it is feasible for the electric grid to provide enough renewable electricity for the electric buses even in the future, but identify some challenges. If everything in a city is supposed to be electrified (like industries and cars) in the future, a major point of concern is the electric power supply during so-called power peaks. These power peaks usually take place during evenings, when people come home and start using the electricity for e.g. lighting and cooking. The interviewees at Umeå Energi, Öresundskraft and Göteborgs Energi highlight the importance of charging the electric cars during night when the demand for electricity is rather low. Further, the interviewee at Landskrona Energi suggests that electricity should be more expensive when the demand is high and vice versa. Regarding the price of the future renewable electricity, the interviewee at Umeå Energi thinks that the prices will fluctuate to a greater extent compared to the contemporary prices. Since renewable energy sources as solar- and wind power do not have that reliable supply of electricity as for instance nuclear power. Moreover, all the electricity companies describe that the client should incorporate them in an early stage of the project, since everything is about planning and finding suitable locations for charging stations in the city.

Traditionally, we have had a client and supplier relationship. They send an order, where it is stated that they want electricity to a certain place and how much etc. and we try to expand the cooperation since everything is about planning in advance.
- Interviewee Umeå Energi

The battery is crucial for the electric bus to operate, but is also a critical issue. According to interviewee at Volvo, in the future development of the batteries, the capacity of the battery will increase, while the weight will decrease. However, how fast the development will proceed is still uncertain. Apart from this problem, the battery production and its use of child labour and raw materials, is also stated as a future issue. The interviewee at Skånetrafiken, states that they will make demands for cobolt-free batteries. Further, Skånetrafiken mentions that they are involved in a research project where they evaluate the life cycle impact on human rights and materials during the production of batteries. The interviewee at Umeå Kommun describes that they have discussed the possibilities of reusing old batteries for other purposes, as for residential areas. In Gothenburg, they have given the first exhausted battery for solar cells to a new built residence in the city.

Table 5.2: The contemporary contract periods in the evaluated cities.

City	Termination of contract [year]
Gothenburg	2021
Umeå	2022
Ängelholm	2021
Landskrona	2024

As already mentioned, all the interviewees think that the future public transport system will be electrified, but it is obvious that it does not exist one optimal solution of charging technique. Skånetrafiken, Hybricon and Lindholmen Science Park describe that a mix of different charging techniques is the optimal solution for an electrified public transport system. The interviewee at Lindholmen Science Park highlights that electric buses that are charged at depot allows for flexibility, while fast-charging may be more suitable for a shuttle bus. This is in accordance with the interviewee at Västtrafik's opinion, who thinks that it is important to take the local context into consideration when adopting electric buses. Both Nobina and Skånetrafiken mention that the Slide-In technique is advantageous when it comes to optimizing the bus driver's expenses during charging and is more flexible compared to a trolleybus. Additionally, both Nobina and Landskrona Stad describe that the trolleybus is a very controversial charging technique since it is costly and unfavourable from an aesthetic point of view. A technique which is not used in the public transport in any city is the inductive charging. During the interviews with Nobina, Skånetrafiken and Umeå Kommun, this was mentioned as an up coming technique, but is not sufficiently good to be used in operation yet.

"It is hard to say that it looks beautiful with an overhead catenary in the city, but if there are tracks underneath, it looks fantastic. If it is a tram, so to say. But when you have a trolleybus you have the double. You have the electricity supply and the earth connection in each wire. If you drive in two directions, then there are four wires and I guess that is what uglifies the city." - Interviewee at Nobina

Electric buses open up for new opportunities for the city, as mentioned previously. In Umeå, the main reason for adopting electric buses was that they enable city densification. The possibilities to plan the city differently will increase. Ideas about indoor charging stations and depots in buildings was mentioned by interviewees from Göteborg Stad and Keolis (ÅF). The buses could also drive through buildings and stop by the entrance to shopping centers. Interviewee at Keolis (ÅF) believes that bus stops will create venues for people to meet and means that free wifi and possibilities for people to charge their phones are essential.

5.5 Life-Cycle Costs of Electric Buses

Following sections describe the life-cycle costing (LCC) result for one electric bus and its charging infrastructure in the evaluated cities, as well as a biogas bus as reference. Important to keep in mind is that the intention of the LCC result is to provide an overview of the case cities and show the environmental cost compared to the operational and capital costs. Further, the assumed life spans for the evaluated bus systems differ between the case cities. Since the life span of the trolleybus is assumed to 20 years and its charging infrastructure to 40 years, while for the other buses it is 12 and 20 years respectively. These life spans are used as base values for the sensitivity analysis, shown in Figure 5.4. Since the evaluated bus systems have different life spans, the result is presented on a yearly basis.

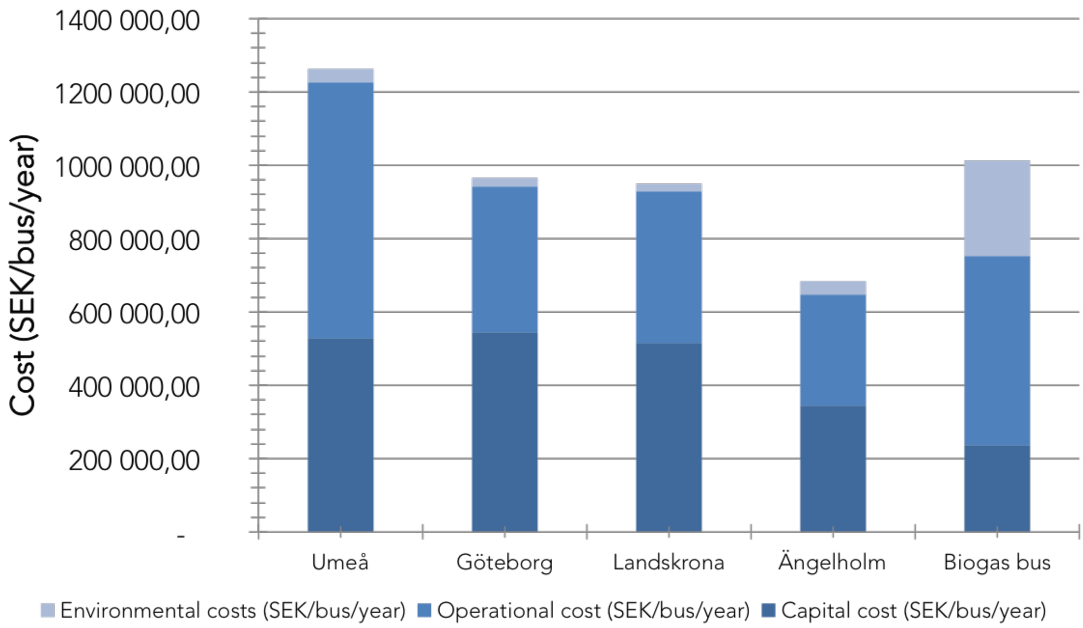

Figure 5.4: Yearly cost of the LCC calculations.

According to Figure 5.4, showing the yearly cost of the buses, the most expensive electric bus costs slightly more than 1,2 MSEK per year while the least expensive cost about 0,7 MSEK per year. The cost for the biogas bus is in between that range, about 1 MSEK per year. The most expensive bus is using the fast charging technique, which is also used by the second most expensive bus. The least expensive electric bus is found in Ängelholm, which is using a depot charging system. The investment costs are higher for all electric buses, which is about the double for the major part, compared to the biogas bus. Another major difference between the electric buses and the biogas bus, is the environmental costs, which is much higher for the biogas bus. If not considering the environmental costs, the biogas bus is among the cheapest alternatives, while it becomes the second most expensive when considering the environmental costs. The result, in exact numbers, is found in Appendix C.

The daily driven distance per bus differs between the evaluated cities, as stated in Appendix C. Hence, Figure 5.5 shows the LCC per driven kilometer for one bus. The main difference compared to 5.4 is that the bus in Gothenburg is the most expensive, while the second most expensive bus is the trolleybus in Landskrona. The biogas bus and the bus in Umeå have the same cost per driven kilometer, while the bus in Ängelholm is still the least expensive according to the LCC calculations.

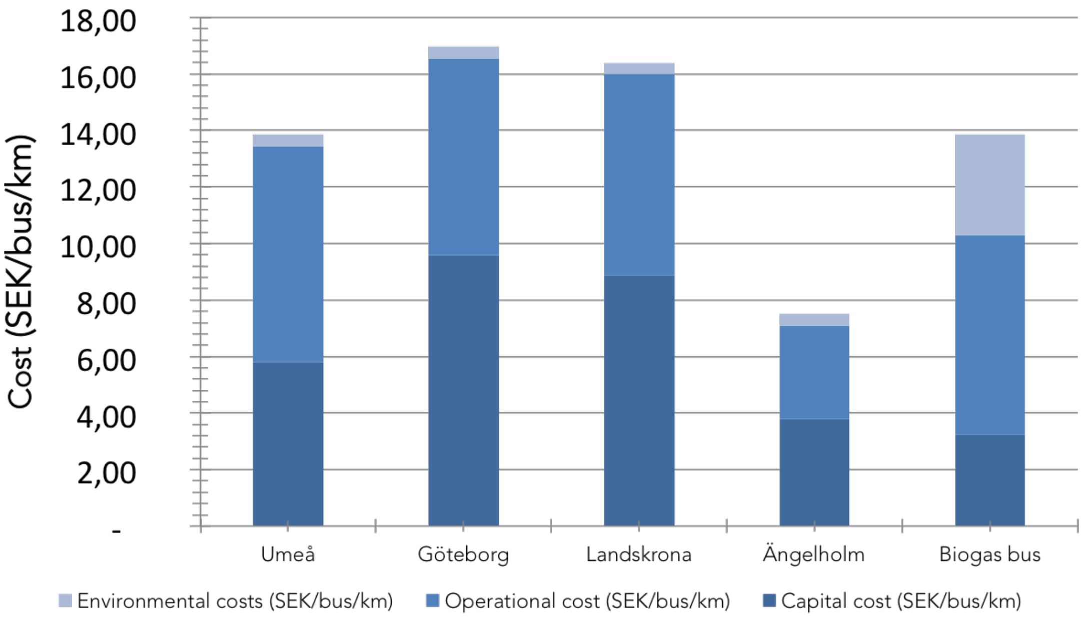

Figure 5.5: Cost per driven kilometer for the LCC calculations

5.5.1 Sensitivity Analysis - Life Span

Due to the lack of experiences of electric buses, their life span is still an uncertain parameter for cost calculations. During the interviews with involved actors, the opinions about how long-lived the electric buses are differed between 10-15 years. The biogas bus is included in the analysis, to be compared with the cost differences for an electric bus. Since the trolleybuses in Landskrona are expected to have a longer life span, about 20 years, they are not included in the sensitivity analysis. Moreover, the life span expectation for the trolleybus in Landskrona is less uncertain, since the trolleybuses have been in operation since 2003.

As seen in the Figure 5.6 the cost per driven kilometer decreases linearly as the life span increases. The trend is similar for all cities and is showing that the longer the life span, the more cost effective is the bus. The analysis shows that an electric bus in Gothenburg is slightly less expensive if it would have a life span of 15 years, than a bus in Umeå with a life span of 10 years. Further, the analysis shows that an electric bus with a life span of 15 years is less expensive compared to a biogas bus with a life span of 10 years. The results from the sensitivity analysis for life span are found in Appendix G.

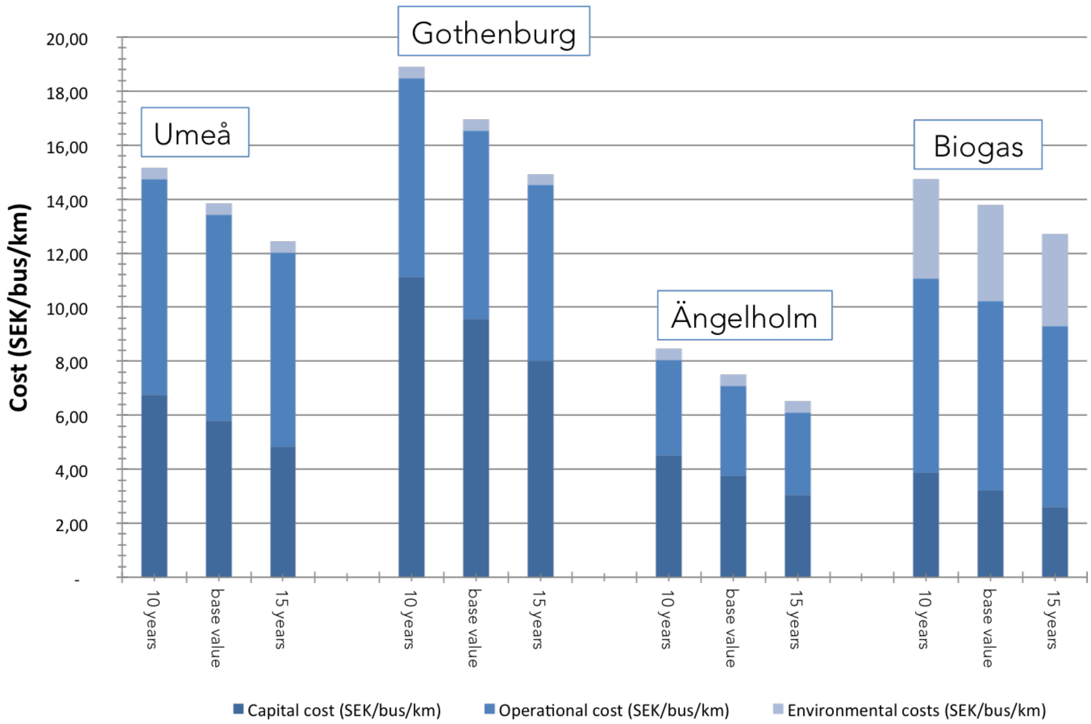

Figure 5.6: LCC calculations with different life spans.

5.5.2 Sensitivity Analysis - Increased Environmental Costs

The positive environmental aspects of electric buses regarding emission and noise pollution are also positive from a cost perspective, which can be seen in Figure 5.4 and 5.5. Since the electric buses emits less pollutants, the environmental costs for the electric buses do not change to that large extent as the biogas bus. Due to urbanization and increased traffic as well as future environmental goals that leads to tightened requirements, the environmental costs are expected to increase soon, according to Section 3.6.3. Hence, a sensitivity analysis of environmental cost increase is interesting.

Figure 5.7 shows that an increase of environmental costs by 100 percent will make the biogas bus the most expensive alternative, but has still about the same cost as the electric bus in Gothenburg. When increasing the environmental costs by 200 percent, the costs per kilometer increases to 21 SEK for the biogas bus, while the second most expensive bus has a cost of 17 SEK/km. The results from the sensitivity analysis for environmental cost increase are found in Appendix G.

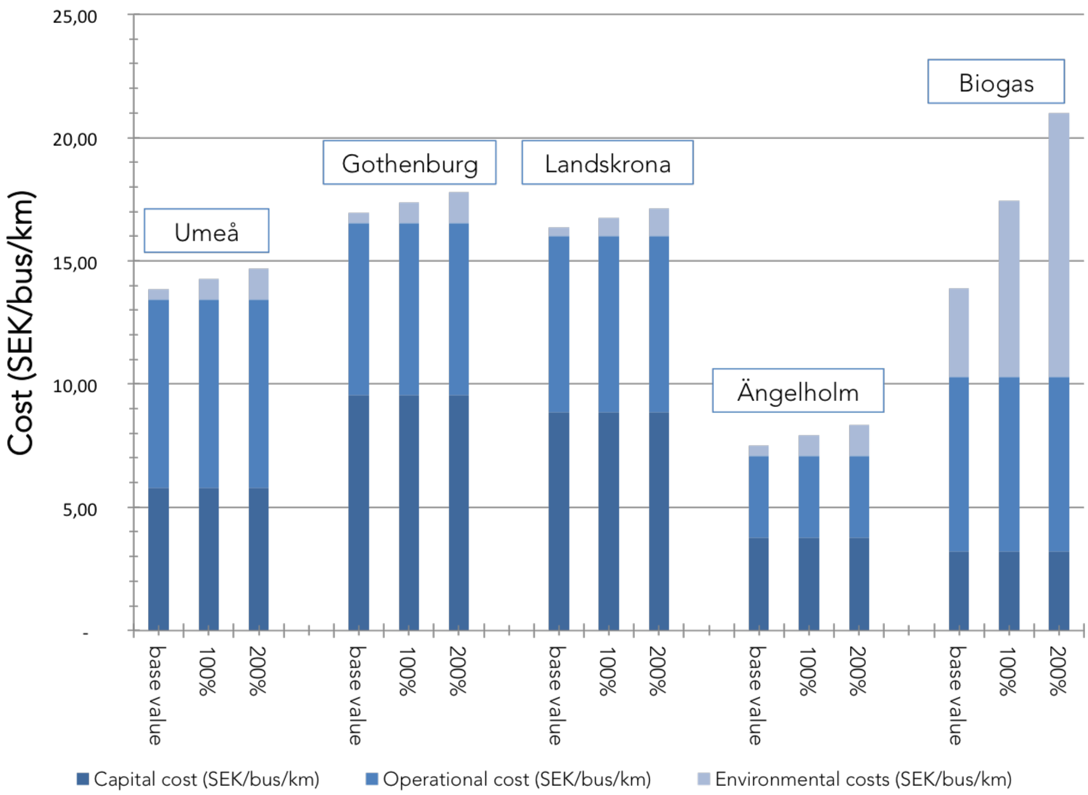

Figure 5.7: LCC calculations for increased environmental costs.

5.5.3 Sensitivity Analysis - Increased Electricity Costs

The electric buses are highly dependent on the supply of renewable electricity, in order to be environmentally friendly. The interviews with the electricity companies indicated an increased cost for renewable electricity, since the demand will grow when the city becomes increasingly electrified. Hence, a sensitivity analysis of increased energy cost seemed interesting.

As seen in Figure 5.8 the cost increases linearly by the electricity cost increase, except for the biogas bus since it is not dependent of electricity cost changes. For the base values, the electric bus in Umeå is slightly less expensive than the biogas bus. When increasing the energy costs by 50 percent almost all the electric buses, except for the buses in Ängelholm, will be more expensive than the biogas bus. An increase of 100 percent implies that the electric buses are more expensive compared to the biogas bus, where the cost for the biogas bus is 4 SEK/km less than the most expensive electric bus. The results from the sensitivity analysis for energy cost increase are found in Appendix G.

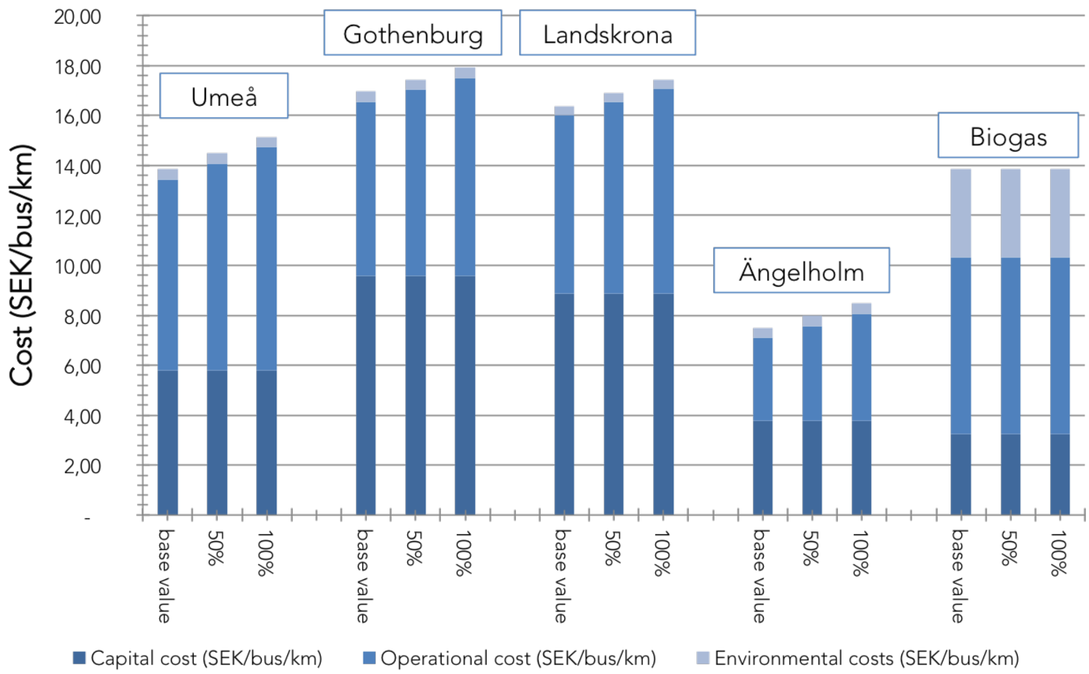

Figure 5.8: LCC calculations for increased electricity costs.

6

Discussion

The sixth chapter provides a discussion of the result described in this study and how it correlates to theory. The first section (Section 6.1) focuses on discussing the research question *"What are the identified drivers, barriers and success factors for the electric bus adoption in the evaluated cities?"*, the second section (Section 6.2) focuses on discussing the question *"Based on experiences from the evaluated cities, will electric buses be a viable option for future transportation?"* while the third section (Section 6.3) provides a discussion about the estimated life-cycle costs. Finally, the fourth section (Section 6.4) includes reflections about the chosen methodology.

6.1 Incentives for Adopting Electric Buses

The general impression of the involved actors in electric bus adoption is their positive approach regarding the development of electric buses. It is apparent that the opportunities for a continuing adoption of electric buses are great and that, at the time being, the development takes place in a rapid pace. Worries about the buses not working in operation belongs to the past. Having some years of experience, the operation of the electric buses is getting more well-known. Adopting electric buses has been a learning by doing process in all cities, as it was expressed by the bus manufacturer in Umeå. A few years ago, the operational feasibility was a barrier and an insecurity for those implementing electric buses. Now, when the buses have been in operation for some years, it seems like the operational feasibility is not that huge barrier anymore. We think that this has been an important step towards large-scale adoption. Passengers and bus drivers seem to have gained an increased understanding about electric buses during the past years, which has favored the adoption. The results give insight about how bus drivers have changed their view from being skeptic to appreciating this new technology and its many advantages. Acceptance from passengers and bus drivers has also been identified in the theory as a success factor, which indicates that this is important in electric bus adoption.

A characteristic of the electric bus adoption in Gothenburg is that several more actors have been involved in the implementation process, compared to the other case cities. The bus manufacturer, Volvo, has specifically seemed to have a great importance in the project implementation. Probably due to its location and that the company is well established in Gothenburg. By contributing with a strong driving force, as a large company, the risk that it implies to try new technology is not too critical to venture new technology. In similarity to Gothenburg, the bus manufacturer in Umeå, Hybricon, is also located nearby the city, but has not had the same prerequisites, like experience and economy. These factors seem to be important in this type of project. On the other hand, BYD, the Chinese bus manufacturer for the buses in Ängelholm and Landskrona, has not been involved at all, which confirms that it is not necessary to have a close collaboration with the bus manufacturer to realize an electric bus adoption. As Volvo has been a driver for electric buses in Gothenburg, a similar pattern of drivers has been identified in the other cities. The trolleybus implementation in Landskrona was stated to be realized due to a politician that was very proactive environmentally friendly solutions in public transport. In Umeå it seems like strong ambitions from the municipality, together with collaborations with the nearby bus manufacturer, have been important for that adoption. In Ängelholm, the PTA also seems to have been striving very hard for electric bus adoption. This makes us think that some kind of driving force, a person or an organization, is needed in every adoption.

The electric bus and its charging infrastructure have earlier been considered more expensive than conventional buses, and have been seen as, and still is to some extent, one major barrier for electric bus adoption. The high costs with a novel technology, have likely been the most prominent barriers. Subsidies are common worldwide as well as in Sweden and works as an auxiliary means to overcome the high costs. The opinions whether they are a sufficient means differ in the literature. Li et al. (2017) says that subsidies have been available in cities that have adopted electric buses and that it could be available for more cities, since it works as encouragement. When Landskrona implemented the trolleybus in year 2003 it was partly subsidized, and we think that it enhanced the implementation process to a great extent. However, the interview study indicates that subsidies have not been crucial for the other implementations in the case cities. Umeå, that was the early adopter of electric buses, indicated that subsidies would have been helpful for them at that time, but it did not restrain them from implementing electric buses. This is what makes us believe that other drivers, such as fulfilling environmental goals and enable city densification, are stronger and more important. Thus, we think that subsidies for electric buses may have been crucial back in the days when Landskrona implemented the trolleybus, but nowadays subsidies seem more helpful than compulsory for realize an electric bus implementation. At the same time, it is important to highlight that subsidies might be helpful for other cities that might not have similar conditions and possibilities as the case cities in this study and should therefore continue to support new technology. Miles and Potter (2014b) describe that subsidies are inefficient and that it is more important if the PTO or PTA can lease the buses to avoid unexpected costs due to new technology. Hence, we suspect that a contributor to the successful electric bus adoption in Gothenburg might have been the economic support from Volvo. Västtrafik has leased the buses from Volvo, hence not been required to buy the buses, which have not implied as large risks as it could have elsewise.

Cooperation in electric bus adoption projects has been identified as important. The number of involved actors has varied to a large extent between the case cities, but the number of involved actors does not likely affect if the project succeeds or not. Nobina, the PTO in Landskrona and Ängelholm, remarks that being less involved actors in this kind of project is better and easier, while Gothenburg has had several involved actors which all have been very positive to the cooperation in the project. It proves that a successful cooperation seems to be dependent on every situation and not on the number of involved actors. Factors such as a neutral coordination group, clear distribution of responsibility and no common budget seem to be important for a good cooperation. It also seems important to have an understanding towards other actors to have an easy implementation. At the same time, we believe that it is likely that an electric bus adoption can be realized even though the cooperation is not optimal, it might just take longer time.

6.2 Electric Buses in Ten Years

Electric buses will probably be the future technology for the future public transport system, as previously mentioned. However, the remaining point of concern is to adopt electric buses on a larger scale. Landskrona is the only case city with a full electric bus fleet. Ängelholm has electrified almost the whole public transport system and will probably electrify the whole public transport system in the next procurement period, year 2021. Umeå has long experience of electric buses and will continue to extend the existing electric bus fleet in June 2019. Even though Gothenburg also has extension plans for the electrification of the bus fleet, there are only five full electric buses in the contemporary bus fleet. It implies that it is much easier to implement electric buses in smaller towns as Ängelholm and Landskrona, compared to a big city as Gothenburg. This argument is further backed up with data from the conducted interviews (see Appendix F), where it is shown that only involved actors in Gothenburg stated "Finding space for charging infrastructure" as a disadvantage with electric buses. According to this, we think that the share of electric buses in the bus fleet will continue to develop and probably in a more rapid pace in the smaller cities compared to larger cities.

When a city starts to investigate what type of charging that is optimal for their city it is important to take the local context into consideration. This means that parameters as capacity in terms of frequency of the bus line, how densely populated the city is, climate and topography could be decisive factors for the choice of charging infrastructure. In this study, it has been shown that larger cities, as in this case Umeå and Gothenburg, have chosen fast-charging, while smaller towns as Ängelholm and Landskrona implement depot charging during night instead. The choice with depot charging could be motivated by several different arguments, like; it is easier to implement, the bus line does not require that high frequency, it is easier to find space for the bus depot in connection to the bus line so deadheading could be avoided and according to the LCC calculations it is cheaper (see Figure 5.5). Depot charging is the most common type of charging today and it is likely that depot charging will continue to grow, due to the rapid development of the batteries. Both theory and the conducted interviews show that the batteries will become cheaper, lighter and more efficient in the future. Hence, it seems as the battery cost that was highlighted by both Miles and Potter (2014a) and Li et al. (2017) as a barrier is not going to be a main point of concern in the future. The interviewees that have been involved in the adoption in Landskrona have expressed appreciation for the trolleybus. This type has a rather long life span and is very reliable and the Slide-In bus allows for some flexibility in the network. At the same time, when the electric bus fleet was extended in January 2019, depot charged buses were chosen over an extension of the contemporary trolleybus network. Even though both the PTA, Skånetrafiken, and the PTO, Nobina, promoted the trolleybus. The main reason seems to be the cost which is in accordance with the LCC calculations of the study (see Figure 5.5), where it is shown that the trolleybus in Landskrona is more expensive compared to other electric buses. For larger cities it is more likely that they will mix different charging techniques which also was mentioned in the conducted interviews with the involved actors. However, important to keep in mind is the compatibility, highlighted as a barrier by Xylia (2018), van der Straten et al. (2007) and Frenaij (2014), which implies that when mixing technologies it may result in an impeded pace of the electric bus adoption. Thus, we think that smaller cities will probably continue to implement depot charged buses, while bigger cities, where higher capacity of the bus line is needed, fast-charging technique is the most suitable. In addition to that, we think that when it is needed, mixing different charging alternatives could be an option even though it requires more time for the implementation. The trolleybus is reliable and appreciated but since the batteries have become much better in terms of efficiency and weight, we think that it is likely that the trolleybus in Landskrona will be replaced by depot charged buses when the next procurement takes place in year 2024.

It was found during the interviews that one of the most prominent disadvantages with electric buses is the cost (see Figure 5.2), which is in line with the theory where cost is stated as a main barrier in the electric bus adoption (Frenaij, 2014; Gabsalikhova et al., 2018; Li et al., 2017; Miles & Potter, 2014a; Mohamed et al., 2018; van der Straten et al., 2007; Xylia, 2018). The LCC calculation shows that the capital cost for an electric bus and charging infrastructure is much higher than for a conventional bus, but including cost for environmental impacts results in smaller differences of the total costs. This is important to include, especially since one of the major drivers for implementing electric buses seems to be that the electric buses are environmentally friendly. For instance, advantages as reduced noise and reduced local emissions were both mentioned in the theory as well as stated in the interviews (see Figure 5.2) (Frenaij, 2014; Miles & Potter, 2014a; Xylia, 2018). These two advantages enable city densification, which will be even more important in the future, due to the rapid urbanization. According to these arguments, the future cities will probably continue to adopt electric buses even though the capital cost is higher now. Since cities in the future are hopefully motivated to create a livable environment and reduce negative externalities as local emissions and noise.

The procurement of the contemporary public transport system needs to follow the public procurement act, which could be disadvantageous when it comes to the procurement of the electric buses. During the conducted interviews it was emphasized that the life span of the bus still is an uncertain parameter, where the interviewees stated a life span between 10-15 years. Furthermore, Xylia (2018) describes that it is probably longer than for a conventional bus. At the same time, the electric buses's life span is usually longer than the procurement period and has a higher capital cost than conventional buses. Hence, to promote sustainable alternatives in the public transport system, as electric buses, the procurement standards should if possible be changed. Many of the contemporary electric bus projects are demonstration projects, as in Ängelholm and Gothenburg, hence do not need to follow the public procurement act. Thus, to extend the electric bus adoption on a larger scale in the future, we believe that the procurement routines need to be changed. For instance longer contract periods, which is in line with Xylia (2018)'s research. Moreover, during the interviews with the electricity companies it was highlighted that accurate planning is of high importance. They think that it would be beneficial to include them in an early stage of the electric bus adoption process to be able to plan the electric grid in the most optimal way. This is in line with Xylia (2018) who also thinks that it would be advantageous to include the electricity companies when forming the procurement standards. Thus, to enable a sustainable decision-making for the future public transport system, we think that tailor-made procurement standards for electric buses are needed.

It is important to remember that there are still some technological challenges with electric buses, which were both found in the literature as well as stated during the conducted interviews with the involved actors (see Figure 5.3) (Li et al., 2017; Mohamed et al., 2018). For instance, uncertainties about the operational reliability, thus the actual driving range of the battery bus. According to the contemporary development of the battery, it seems like the batteries become more efficient and cheaper every year. It also implies that the prominent disadvantage "Technical challenges" (Figure 5.3) that was highlighted as one of the most important disadvantages during the interviews, will probably play a minor role in the future.

Hopefully, all the city buses in the future will be electric. Hence, people will just say bus when they mean an electric bus. Moreover, if all the buses are electric in the future, they will hopefully open up for new routes. As an example, since they are emission free and silent it would be possible for the electric buses to drive inside shopping centers. Then, we hope that the visitors in the shopping center will choose the bus over the car.

6.3 Life-Cycle Costing, a Sustainable Evaluation Tool

The result from the LCC is showing that electric buses are competitive to a biogas bus. The major part that affects the costs for the electric buses are the capital costs, that are about the double compared to the biogas bus. What is competitive for the electric buses are the environmental costs, that are about tenfold smaller than for the biogas bus. This confirms that the environmental costs are important to include in order to give a fair estimate of the costs. The environmental costs have been quantified to be possible to include and this gives values that might represent the real cost. Hence, this cost item might be much lower or much higher. As the CO_2 emission costs are based on taxes (see Section 3.6.3) and not costs for climate adaption due to changed climate, cost for recovery after climate disasters nor loss of lives, the value is probably underestimated. As the CO_2 emissions might be valued higher in the future, as well as NO_x and particles, the electric bus would be even more competitive to conventional buses, which was shown in the sensitivity analysis for the environmental costs (see Figure 5.7).

The costs for the electric buses in Ängelholm have a cost about the half of the other electric buses. What differentiates Ängelholm's electric bus system compared to the other cities is that it is charging at depot and has consequently required less complicated infrastructure in the city. Since the maintenance cost, each year, for the charging infrastructure is based on the investment, this becomes lower for a cheaper charging infrastructure. Further, the buses are produced by a Chinese bus manufacturer, BYD, who might already have a production on a larger scale and can therefore give a lower price. The electric bus in Gothenburg gives the highest cost per kilometer, which might partly be due to that its daily route is shorter than the other buses' routes and consequently the capital cost and maintenance is higher for each kilometer. The maintenance cost is not dependent on total driven kilometer, which it could be considered to be. The higher cost for Gothenburg can probably also depend on that only the full electric buses on route 55 (three out of ten) are included in the cost calculations. This means that the charging infrastructure investment, that is used by all ten buses, is only considered as an investment for three buses.

The results from the sensitivity analysis are in line with what the researchers of the study expected. Regarding the changes of lifespan, this shows that a longer lifespan results in lower costs. Anyhow, it is important for an investor to consider this uncertain parameter when setting up a budget. As it is important to consider environmental costs, it is also important to consider that they might increase in the future. The higher the cost is for NO_x, particles, CO_2 and noise, the more expensive becomes the biogas bus compared to the electric buses. This can work as an incentive for cities when considering adopting electric buses. On the contrary, what tell against electric buses, are the renewable electricity prices that might increase. This was indicated when interviewing the electricity companies and is also a possible scenario according to us. This is based on that we believe that the city will become electrified and lead to power peaks, which might result in cost fluctuations. Thus, an increase of renewable electricity prices during power peaks would lead to that the electric buses are not that competitive anymore. If one might consider both environmental cost increase and electricity cost increase, both types will be more expensive, and one might hope that the most environmentally friendly alternative will be chosen. At the same time describes IRENA (2017) that the price of renewable electricity is expected to decrease in the near future. Since this is the opposite compared to what was found during the interviews it shows that this parameter is still uncertain.

6.4 Reflections About the Chosen Methodology

It is important to reflect about the method that has been used to reach the result. Doing interviews imply many advantages, but also disadvantages, mainly depending on the asked questions, but also the role of the interviewee, the knowledge of the interviewers and the available time. The interview guide included many questions, which restrained the interviewers to go into detail in some subjects, in order to complete all the questions. This might also have restrained the interviewers from clarifying ambiguities and other answers from the interviewees. The interview guide could have been developed further to give space for the most important questions. Further, the choice to include four cities in the study, implies that the scope became very comprehensive and resulted in a quite general study.

There are several different roles among the interviewees. Important to keep in mind is that every actor answer the questions from their perspective. For instance, a sustainability manager might emphasizes the environmental parts, while a project manager highlights the managerial parts of the project. Moreover, when it comes to the detailed question the numbers could be biased since the interviewee might want to depict the bus in the most optimal way. To avoid a biased result for the LCC calculations, we tried to compare the stated numbers by the interviewee with the existing numbers in the literature.

As mentioned earlier, the costs for electric buses have been, and are still to some extent, a point of concern in adoption of electric buses. This is the main reason why the LCC is included in this study. Since the environmental aspects of electric buses is one of the main advantages and the argument for adoption on large scale, this was considered important to include in the calculations. Furthermore, since there are many uncertain parameters to account for, it seemed interesting to make analysis of when using different values for some parameters. The desire of the LCC was to get an estimate of the cost within a limited range of time, hence some parameters have been excluded. The LCC gives an indication of costs for different charging infrastructure systems and are compared against a conventional biogas bus. Drivers expenses, battery production (and its environmental impact) and the heater (and its emissions) should not be considered unimportant but have been excluded due to time and knowledge limitations. Anyhow, it is important to keep in mind that these parameters also affect the LCC, especially the environmental costs. Further, since the LCC includes environmental costs, it is considered as a useful and suited tool for comparing electric buses with a biogas bus.

7

Conclusion

In this chapter we conclude our findings to the research questions.

What are the identified drivers, barriers and success factors for the electric bus adoption in the evaluated cities? The most prominent driver for an electric bus adoption has been found to be the environmental benefits, as the reduction of local emissions and noise. By reducing these negative externalities, it opens for possibilities to densify the city. When it comes to the existing barriers for electric bus adoption, the high capital cost compared to conventional buses cannot be neglected at the moment. Further, the development of the technology has proceeded in a rapid pace the last couple of years, but the technology is still in its infancy, which means that the technology barrier remains to some extent. Uncertainties such as the actual life span of the bus and the battery's efficiency and reliability still exist. It seems like cooperation is important for a successful electric bus adoption, but the number of involved actors seems to play a minor role. Instead, factors as a clear distribution of responsibility, sharing the same vision, be understanding towards the other actors and providing feedback seem to be of higher importance. A driving force, a person or organization, was also identified as important for an electric bus adoption.

Based on experience from the evaluated cities, will electric buses be a viable option for future transportation? It is evident that electric buses will be the future technology for the public transport system, thus it is a viable option for the future. The electric buses contribute to more livable cities due to its environmental advantages. Over the past years, the passengers and the bus drivers have started to accept and appreciate the new technology. At the same time, there is a rapid development of the batteries and it is likely that the price of the batteries will continue to decrease. However, since there is a general electrification trend of cities now, it is possible that the price of renewable energy starts to fluctuate and raise during power peaks.

Can electric buses be considered as competitive to conventional buses, in terms of life-cycle costs? In general, electric buses can be considered competitive to conventional buses in terms of costs, but differences in charging systems are identified. While the cost for the electric bus system in Ängelholm is extensively lower than the reference case, the biogas bus, the fast charging buses in Umeå and Gothenburg as well as the trolleybus in Landskrona have about the same cost. As the environmental cost might increase, due to the climate change, and the capital costs of electric buses might decrease, due to the future large scale production, we believe the electric buses will be even more competitive in the future.

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A

Appendix A - Interview Guide

Introducing questions

- What is your background?
- What is your occupation and for how long have you worked with electric buses?

Background of the project

- Why did you start to invest in electric buses? How did you make this decision?
- Why did you choose the implemented charging infrastructure?
- What did you identified as the main advantages with electric buses and its charging infrastructure?
- What did you identified as the main disadvantages with electric buses and its charging infrastructure?
- What types of objectives were chosen for the project? Why these objectives? Did you achieve these objectives?
- What types of risks were identified in the project? Have any of the identified risks happened?
- What did the implementation phase of the project look like from the beginning to the end (barriers, initiatives etc.) ?

Cooperation in the project

- Which actors have been a part of the project? Has the involvement changed over time?
- How has you been involved in the project?
- How has the cooperation been with the other involved actors in the project?
- Hur har ansvarsfördelningen sett ut? Varför ser den ut på det sättet?
- Would you define it as a successful cooperation with the other actors?
- What did the contemporary contract for electric buses look like? What is the contract period?

Outcome of the project

- How has the reliability of the electric buses been?
- Did you evaluate the life cycle costs of the electric buses?
- Who has paid for the electric buses?
- Has any parts been subsidized? If yes, do you think the implementation of electric buses has happened even without subsidization?

Future

- What success factors have you identified in the project?
- Did you identified anything you could have done differently?
- Do you plan to continue investments of electric buses, in that case what type of strategy do you use?

- What do you think about the technological development of electric buses, any new techniques?
- What do you think about the future development of electric buses in Sweden, Europe and the world?

Detail questions

- Do you know the average energy consumption for propelling the bus in normal use (standard value is 2 kWh/km)?
- What is the investment cost of the bus and the charging infrastructure?
- What is the estimated life span of the bus and the battery?
- Did you estimate the decrease of NOx, carbon dioxide and particles in the city after the implementation of electric buses?
- How do you insure the buses and what is the insurance cost?
- What is the annual maintenance cost for the electric buses?
- How many batteries has the bus? What is the effect of the batteries? What is the cost of a new battery?
- What is the tax for the electric buses?
- Do you have an estimation of the salvage value?

Landskrona

- Why did you choose to invest in depot charging during night instead of expand the contemporary trolleybus network?
- What type of heater is installed in the bus?
- What type of battery is installed in the bus?

Ängelholm

- Why did you change the batteries in the buses?
- What type of battery is installed in the bus?

Gothenburg

- There have been several different involved actors in Gothenburg, do you think it has affected the project?

Umeå

- Why did you choose to invest in VDL's buses instead of Hybricon's buses, for the buses that will be implemented in June 2019?

Finalizing questions

- Anything you would like to add that has not been mentioned during the interview?
- Do you recommend anyone to interview for this study?
- Could we contact you for additional questions?

B

Appendix B - Interview Guide, electricity companies

- What challenges have you encountered so far regarding the electricity supply to the electric buses' charging stations?
- What are the prospects for an electricity supply with renewable energy?
  - Regarding complete electrification of public transport in your city?
  - Regarding large-scale electrification of the transport sector (passenger cars, public transport)?
- What future challenges do you identify regarding the electricity supply to the electric buses' charging stations?
- What do you think is important to consider in order to avoid these problems?
- How has the cooperation worked with the other actors in the electric bus implementation?
- What did your involvement look like in the implementation?
- What do you think about the price development of electricity (both renewable and non-renewable)?

C

Appendix C - Data for life cycle-costing

Appendix C shows the data that has been utilized for the life-cycle costing (LCC). In the calculations inflation has been taken into account as well as the discount rate, as described in 2.6

Table C.1: Data for life cycle costs calculations in Umeå.

Parameter	Value	Reference/comment
Route [km/day]	250	(ZeEUS, 2017)
Number of full electric buses	9	Interviewee Umeå kommun
Energy consumption [kWh/km]	2	Interviewee Umeå kommun
Fuel price [SEK/kWh]	0,75	(Olsson et al., 2016)
Investment bus+infrastructure [MSEK]	60	Interviewee Umeå kommun
Investment bus [MSEK]	5	(Gabrielsson & Hajiakbar, 2016)
Lifespan bus [year]	12	(Lajunen, 2018; Lajunen & Lipman, 2016)
Lifespan infrastructure [year]	20	(Lajunen, 2018)
Insurance [SEK/year]	38889	Interviewee Umeå kommun
Maintenance bus [SEK/year]	100000	(Lajunen, 2018; Olsson et al., 2016)
Maintenance infrastructure [SEK/year]	450000	(Lajunen, 2018)
Effect batteries [kWh]	80	Interviewee Umeå kommun
Cost battery [SEK/kWh]	10000	(Lajunen, 2018; Olsson et al., 2016)
New battery [SEK]	800000	Multiplied values above
Tax [SEK/year]	984	Interviwee Nobina and Skånetrafiken
Environmental cost (noise)[SEK/km]	0,5	(IVL Svenska Miljöinstitutet, 2017)
Capital cost [SEK/bus/lifetime]	6 349 782	
Operational cost [SEK/bus/lifetime]	8 349 680	
Environmental cost [SEK/bus/lifetime]	454 151	
LCC [Cost/bus/lifetime]	15 153 614	
Cost [SEK/bus/year]	1 262 801	
Cost [SEK/bus/km]	14	

Table C.2: Data for life cycle costs calculations in Gothenburg (line 55).

Parameter	Value	Reference/comment
Route [km/day]	156	(ZeEUS, 2017)
Number of electric buses	3	Interviewee Göteborgs stad
Energy consumption [kWh/km]	1,5	Interviewee Volvo, (Electricity, 2016)
Fuel price [SEK/kWh]	0.75	(Olsson et al., 2016)
Investment bus [MSEK]	5	Interviewee Göteborgs stad
Investment infrastructure [MSEK]	6	Interviewee Göteborgs stad
Lifespan bus [year]	12	(Lajunen, 2018; Lajunen & Lipman, 2016)
Lifespan infrastructure [year]	20	(Lajunen, 2018)
Insurance [SEK/year]	45000	Based on interviews with Skånetrafiken
Maintenance bus [SEK/year]	100000	(Lajunen, 2018; Olsson et al., 2016)
Maintenance infrastructure [SEK/year]	189730	(Lajunen, 2018)
Effect batteries [kWh]	76	Interviewee Volvo
Cost battery [SEK/kWh]	10000	(Lajunen, 2018; Olsson et al., 2016)
New battery [SEK]	760000	Multiplied values above
Tax [SEK/year]	984	Interviwee Nobina and Skånetrafiken
Environmental cost (noise)[SEK/km]	0,5	(IVL Svenska Miljöinstitutet, 2017)
Capital cost [SEK/bus/lifetime]	6 535 135	
Operational cost [SEK/bus/lifetime]	4 764 829	
Environmental cost [SEK/bus/lifetime]	283 390	
LCC [Cost/bus/lifetime]	11 583 355	
Cost [SEK/bus/year]	965 280	
Cost [SEK/bus/km]	17	

Table C.3 shows the data for Landskrona. Even though the contemporary trolley-busline has five buses (one slide-in), the total number of buses was three when the investment took place, hence the chosen number for the calculations.

Table C.3: Data for life cycle costs calculations in Landskrona (line 3, trolleybus).

Parameter	Value	Reference/comment
Route [km/day]	159	Interviewee Skånetrafiken
Number of buses	3	(Andersson & Johansson, 2005)
Energy consumption [kWh/km]	1,83	Interviewee Skånetrafiken
Fuel price [SEK/kWh]	0,75	(Olsson et al., 2016)
Investment bus [MSEK]	5,05	(Andersson & Johansson, 2005)
Investment infrastructure [SEK]	21,65	(Andersson & Johansson, 2005)
Lifespan bus [year]	20	Interviewee Skånetrafiken
Lifespan infrastructure [year]	40	Interviewee Skånetrafiken
Insurance [SEK/year]	45 000	Interviewee Skånetrafiken
Maintenance bus [SEK/year]	100 000	Interviewee Skånetrafiken
Maintenance infrastructure [SEK/year]	300 000	(Gabrielsson & Hajiakbar, 2016)
Tax [SEK/year]	984	Interviwee Nobina and Skånetrafiken
Environmental cost (noise)[SEK/km]	0,5	(IVL Svenska Miljöinstitutet, 2017)
Capital cost [SEK/bus/lifetime]	10 287 758	
Operational cost [SEK/bus/lifetime]	8 283 081	
Environmental cost [SEK/bus/lifetime]	431 707	
LCC [Cost/bus/lifetime]	19 002 546	
Cost [SEK/bus/year]	950 127	
Cost [SEK/bus/km]	16	

Table C.4: Data for life cycle costs calculations in Ängelholm.

Parameter	Value	Reference/comment
Route [km/day]	250	(ZeEUS, 2017)
Number of electric buses	5	(ZeEUS, 2017)
Energy consumption [kWh/km]	1,5	Interviewee Nobina,(Skånetrafiken, 2017)
Fuel price [SEK/kWh]	0.75	(Olsson et al., 2016)
Investment bus [SEK]	3 831 800	Interviewee Skånetrafiken
Investment infrastructure [MSEK]	1	Interviewee Skånetrafiken
Lifespan bus [year]	12	(Lajunen, 2018; Lajunen & Lipman, 2016)
Lifespan infrastructure [year]	20	(Lajunen, 2018)
Insurance [SEK/year]	45 000	Interviewee Skånetrafiken
Maintenance bus [SEK/year]	100 000	Interviewee Skånetrafiken
Maintenance infrastructure [SEK/year]	30 000	(Gabrielsson & Hajiakbar, 2016)
Effect batteries [kWh]	276	Interviewee Skånetrafiken
New battery [SEK]	800 000	Interviewee Skånetrafiken
Tax [SEK/year]	984	Interviwee Nobina and Skånetrafiken
Environmental cost (noise)[SEK/km]	0,5	IVL Svenska Miljöinstitutet (2017)
Capital cost [SEK/bus/lifetime]	4 133 875	
Operational cost [SEK/bus/lifetime]	3 628 218	
Environmental cost [SEK/bus/lifetime]	454 151	
LCC [Cost/bus/lifetime]	8 216 245	
Cost [SEK/bus/year]	684 687	
Cost [SEK/bus/km]	8	

Table C.5: Data for life cycle costs calculations for the reference case (biogas bus).

Parameter	Value	Reference
Route [km/day]	200	Assumed by researchers
Fuel price [SEK/km]	5,58	(IVL Svenska Miljöinstitutet, 2017)
Investment bus [MSEK]	2,7	(Gabrielsson & Hajiakbar, 2016)
Lifespan bus [year]	12	Assumed by researchers
Insurance [SEK/year]	6 800	Interviewee Nobina
Tax [SEK/year]	984	Interviewee Nobina
Maintenance [SEK/year]	175 000	(Gabrielsson & Hajiakbar, 2016)
NOx emissions [SEK/km]	0,01320	(IVL Svenska Miljöinstitutet, 2017; Trafikverket, 2018)
CO2 emissions [SEK/km]	0,25080	(IVL Svenska Miljöinstitutet, 2017; Trafikverket, 2018)
PM emissions [SEK/km]	0,02568	(IVL Svenska Miljöinstitutet, 2017; Trafikverket, 2018)
Noise [SEK/km]	4	(IVL Svenska Miljöinstitutet, 2017)
Capital cost [SEK/bus/lifetime]	2 830 824	
Operational cost [SEK/bus/lifetime]	6 198 289	
Environmental cost [SEK/bus/lifetime]	3 117 063	
LCC [Cost/bus/lifetime]	12 146 176	
Cost [SEK/bus/year]	1 012 181	
Cost [SEK/bus/km]	14	

D
Appendix D - Map of Sweden

Figure D.1: Map of the investigated cities. Figure adjusted from Google maps (2019).

E
Appendix E - Advantages electric buses

Advantages/actors	Trafikkonoret	Västtrafik	Lindholmen Science Park	Volvo	Umeå Kommun	Hybricon	Nobina	Skånetrafiken	Landskrona Stad
NOx-emission	x	X	X			x			X
Noise reduction	x	x	X	X	x	x	X	X	X
Energy efficiency			x						X
Comfortable	x	x			x			X	x
Reputation									x
Appealing					x				
Security									
Spacious									
Environmentally friendly					x			x	
Try new technology	X			x				x	
CO2- emission		x	x						X
Particles	x								
Interior driving	x		X	X	x				
Emissions		x	X	X		x	X		x
City densification	x		x		x	X	X		x
Better working environment		x			X				x
Cheaper maintenance					X			X	
Reduce car dependency						X			
Connecting hubs						X			
Reliable								X	
Lower operating cost								X	
Easy to handle	x								

X= Stated during interview; x=revealed during interview

Figure E.1: Stated and revealed advantages of electric buses

F

Appendix F - Disadvantages electric buses

Disadvantages/actors	Trafikkonoret	Västtrafik	Västtrafik	Lindholmen Science Park	Volvo	Umeå Kommun	Hybricon	Nobina	Skånetrafiken	Landskrona Stad
Sceptisism bus drivers	X				x	X	x			
Technical challenges	X		x		x	x	X	X	x	
Battery production		X							X	
Battery recycling		X								
Battery technique			x			x		x		
Dead heading		X								
Space for charging		X	X	X	X					
Electric power supply/power requirement	x			X						
Locking the route network					X			X		X
Placement of the end stop (indoor bus stop)	x		X		X					
Cost			x			X	X		X	
Decreased efficiency						X				
Requirement of more buses						X		X	x	
Difficult to drive						X				
Difficult to charge						X				
Weather conditions						X	x			
Driver expenses					x			X		
Performance during winter									X	
Weight										X
X=Stated during interview; x=revealed during interview										

Figure F.1: Stated and revealed disadvantages of electric buses

G

Appendix G - Result from the sensitivity analyses

G.1 Umeå

	Lifespan		
Scenarios	10 years	base value	15 years
	10	12,00	15
Capital cost (SEK/bus/lifetime)	6 173 399	6 349 782	6 614 356
Operational cost (SEK/bus/lifetime)	7 269 789	8 349 680	9 854 406
Environmental costs (SEK/bus/lifetime)	389 191	454 151	544 668
LCC (SEK/bus/lifetime)	13 832 378	15 153 614	17 013 430
Capital cost (SEK/bus/year)	617 340	529 148	440 957
Operational cost (SEK/bus/year)	726 979	695 807	656 960
Environmental costs (SEK/bus/year)	38 919	37 846	36 311
Cost (SEK/bus/year)	1 383 238	1 262 801	1 134 229
Capital cost (SEK/bus/km)	6,8	5,8	4,8
Operational cost (SEK/bus/km)	8,0	7,6	7,2
Environmental costs (SEK/bus/km)	0,4	0,4	0,4
Cost (SEK/bus/km)	15,2	13,8	12,4

Figure G.1: Results from life span sensitivity analysis - Umeå

	Environmental cost increase		
Scenarios	base value	100%	200%
	0,50	1,00	1,50
Capital cost (SEK/bus/lifetime)	6 349 782	6 349 782	6 349 782
Operational cost (SEK/bus/lifetime)	8 349 680	8 349 680	8 349 680
Environmental costs (SEK/bus/lifetime)	454 151	908 303	1 362 454
LCC (SEK/bus/lifetime)	15 153 614	15 607 765	16 061 916
Capital cost (SEK/bus/year)	529 148	529 148	529 148
Operational cost (SEK/bus/year)	695 807	695 807	695 807
Environmental costs (SEK/bus/year)	37 846	75 692	113 538
Cost (SEK/bus/year)	1 262 801	1 300 647	1 338 493
Capital cost (SEK/bus/km)	5,80	5,80	5,80
Operational cost (SEK/bus/km)	7,63	7,63	7,63
Environmental costs (SEK/bus/km)	0,41	0,83	1,24
Cost (SEK/bus/km)	13,8	14,3	14,7

Figure G.2: Results from environmental cost increase sensitivity analysis in Umeå

	Energy cost increase		
Scenarios	base value	50%	100%
	0,78	1,17	1,56
Capital cost (SEK/bus/lifetime)	6 349 782	6 349 782	6 349 782
Operational cost (SEK/bus/lifetime)	8 349 680	9 058 156	9 766 633
Environmental costs (SEK/bus/lifetime)	454 151	454 151	454 151
LCC (SEK/bus/lifetime)	15 153 614	15 862 090	16 570 566
Capital cost (SEK/bus/year)	529 148	529 148	529 148
Operational cost (SEK/bus/year)	695 807	754 846	813 886
Environmental costs (SEK/bus/year)	37 846	37 846	37 846
Cost (SEK/bus/year)	1 262 801	1 321 841	1 380 881
Capital cost (SEK/bus/km)	5,80	5,80	5,80
Operational cost (SEK/bus/km)	7,63	8,27	8,92
Environmental costs (SEK/bus/km)	0,41	0,41	0,41
Cost (SEK/bus/km)	13,8	14,5	15,1

Figure G.3: Results from energy cost increase sensitivity analysis in Umeå

G.2 Gothenburg

	Lifespan		
Scenarios	10 years	base value	15 years
	10	12,00	15
Capital cost (SEK/bus/lifetime)	6 324 324	6 535 135	6 851 351
Operational cost (SEK/bus/lifetime)	4 191 987	4 764 829	5 563 031
Environmental costs (SEK/bus/lifetime)	242 855	283 390	339 873
LCC (SEK/bus/lifetime)	10 759 165	11 583 355	12 754 255
Capital cost (SEK/bus/year)	632 432	544 595	456 757
Operational cost (SEK/bus/year)	419 199	397 069	370 869
Environmental costs (SEK/bus/year)	24 285	23 616	22 658
Cost (SEK/bus/year)	1 075 917	965 280	850 284
Capital cost (SEK/bus/km)	11,1	9,6	8,0
Operational cost (SEK/bus/km)	7,4	7,0	6,5
Environmental costs (SEK/bus/km)	0,4	0,4	0,4
Cost (SEK/bus/km)	18,9	17,0	14,9

Figure G.4: Results from life span sensitivity analysis in Gothenburg

	Environmental cost increase		
Scenarios	base value	100%	200%
	1	1	2
Capital cost (SEK/bus/lifetime)	6 535 135	6 535 135	6 535 135
Operational cost (SEK/bus/lifetime)	4 764 829	4 764 829	4 764 829
Environmental costs (SEK/bus/lifetime)	283 390	566 781	850 171
LCC (SEK/bus/lifetime)	11 583 355	11 866 745	12 150 136
Capital cost (SEK/bus/year)	544 595	544 595	544 595
Operational cost (SEK/bus/year)	397 069	397 069	397 069
Environmental costs (SEK/bus/year)	23 616	47 232	70 848
Cost (SEK/bus/year)	965 280	988 895	1 012 511
Capital cost (SEK/bus/km)	9,6	9,6	9,6
Operational cost (SEK/bus/km)	7,0	7,0	7,0
Environmental costs (SEK/bus/km)	0,4	0,8	1,2
Cost (SEK/bus/km)	17,0	17,4	17,8

Figure G.5: Results from environmental cost increase sensitivity analysis in Gothenburg

	Energy cost increase		
Scenarios	base value	50%	100%
	1	1	2
Capital cost (SEK/bus/lifetime)	6 535 135	6 535 135	6 535 135
Operational cost (SEK/bus/lifetime)	4 764 829	5 096 396	5 427 963
Environmental costs (SEK/bus/lifetime)	283 390	283 390	283 390
LCC (SEK/bus/lifetime)	11 583 355	11 914 922	12 246 489
Capital cost (SEK/bus/year)	544 595	544 595	544 595
Operational cost (SEK/bus/year)	397 069	424 700	452 330
Environmental costs (SEK/bus/year)	23 616	23 616	23 616
Cost (SEK/bus/year)	965 280	992 910	1 020 541
Capital cost (SEK/bus/km)	9,6	9,6	9,6
Operational cost (SEK/bus/km)	7,0	7,5	7,9
Environmental costs (SEK/bus/km)	0,4	0,4	0,4
Cost (SEK/bus/km)	17,0	17,4	17,9

Figure G.6: Results from energy cost increase sensitivity analysis in Gothenburg

G.3 Landskrona

	Environmental cost increase		
Scenarios	base value	100%	200%
	1	1	2
Capital cost (SEK/bus/lifetime)	10 287 758	10 287 758	10 287 758
Operational cost (SEK/bus/lifetime)	8 283 081	8 283 081	8 283 081
Environmental costs (SEK/bus/lifetime)	431 707	863 414	1 295 121
LCC (SEK/bus/lifetime)	19 002 546	19 434 253	19 865 960
Capital cost (SEK/bus/year)	514 388	514 388	514 388
Operational cost (SEK/bus/year)	414 154	414 154	414 154
Environmental costs (SEK/bus/year)	21 585	43 171	64 756
Cost (SEK/bus/year)	950 127	971 713	993 298
Capital cost (SEK/bus/km)	8,9	8,9	8,9
Operational cost (SEK/bus/km)	7,1	7,1	7,1
Environmental costs (SEK/bus/km)	0,4	0,7	1,1
Cost (SEK/bus/km)	16,4	16,7	17,1

Figure G.7: Results from environmental cost increase sensitivity analysis in Landskrona

	Energy cost increase		
Scenarios	base value	50%	100%
	0,78	1,17	1,56
Capital cost (SEK/bus/lifetime)	10 287 758	10 287 758	10 287 758
Operational cost (SEK/bus/lifetime)	8 283 081	8 899 300	9 515 519
Environmental costs (SEK/bus/lifetime)	431 707	431 707	431 707
LCC (SEK/bus/lifetime)	19 002 546	19 618 765	20 234 983
Capital cost (SEK/bus/year)	514 388	514 388	514 388
Operational cost (SEK/bus/year)	414 154	444 965	475 776
Environmental costs (SEK/bus/year)	21 585	21 585	21 585
Cost (SEK/bus/year)	950 127	980 938	1 011 749
Capital cost (SEK/bus/km)	8,9	8,9	8,9
Operational cost (SEK/bus/km)	7,1	7,7	8,2
Environmental costs (SEK/bus/km)	0,4	0,4	0,4
Cost (SEK/bus/km)	16,4	16,9	17,4

Figure G.8: Results from energy cost increase sensitivity analysis in Landskrona

G.4 Ängelholm

	Lifespan		
Scenarios	10 years	base value	15 years
	10	12,00	15
Capital cost (SEK/bus/ lifetime)	4 112 954	4 133 875	4 165 257
Operational cost (SEK/ bus/lifetime)	3 223 676	3 628 218	4 191 910
Environmental costs (SEK/ bus/lifetime)	389 191	454 151	544 668
LCC (SEK/bus/lifetime)	7 725 820	8 216 245	8 901 836
Capital cost (SEK/bus/ year)	411 295	344 490	277 684
Operational cost (SEK/ bus/year)	322 368	302 352	279 461
Environmental costs (SEK/ bus/year)	38 919	37 846	36 311
Cost (SEK/bus/year)	772 582	684 687	593 456
Capital cost (SEK/bus/km)	4,5	3,8	3,0
Operational cost (SEK/ bus/km)	3,5	3,3	3,1
Environmental costs (SEK/ bus/km)	0,4	0,4	0,4
Cost (SEK/bus/km)	8,5	7,5	6,5

Figure G.9: Results from life span sensitivity analysis in Ängelholm

	Environmental cost increase		
Scenarios	base value	100%	200%
	0,5	1,0	1,5
Capital cost (SEK/bus/lifetime)	4 133 875	4 133 875	4 133 875
Operational cost (SEK/bus/lifetime)	3 628 218	3 628 218	3 628 218
Environmental costs (SEK/bus/lifetime)	454 151	908 303	1 362 454
LCC (SEK/bus/lifetime)	8 216 245	8 670 396	9 124 548
Capital cost (SEK/bus/year)	344 490	344 490	344 490
Operational cost (SEK/bus/year)	302 352	302 352	302 352
Environmental costs (SEK/bus/year)	37 846	75 692	113 538
Cost (SEK/bus/year)	684 687	722 533	760 379
Capital cost (SEK/bus/km)	3,8	3,8	3,8
Operational cost (SEK/bus/km)	3,3	3,3	3,3
Environmental costs (SEK/bus/km)	0,4	0,8	1,2
Cost (SEK/bus/km)	7,5	7,9	8,3

Figure G.10: Results from environmental cost increase sensitivity analysis in Ängelholm

	Energy cost increase		
Scenarios	base value	50%	100%
	0,78	1,17	1,56
Capital cost (SEK/bus/lifetime)	4 133 875	4 133 875	4 133 875
Operational cost (SEK/bus/lifetime)	3 628 218	4 159 576	4 690 933
Environmental costs (SEK/bus/lifetime)	454 151	454 151	454 151
LCC (SEK/bus/lifetime)	8 216 245	8 747 602	9 278 959
Capital cost (SEK/bus/year)	344 490	344 490	344 490
Operational cost (SEK/bus/year)	302 352	346 631	390 911
Environmental costs (SEK/bus/year)	37 846	37 846	37 846
Cost (SEK/bus/year)	684 687	728 967	773 247
Capital cost (SEK/bus/km)	3,8	3,8	3,8
Operational cost (SEK/bus/km)	3,3	3,8	4,3
Environmental costs (SEK/bus/km)	0,4	0,4	0,4
Cost (SEK/bus/km)	7,5	8,0	8,5

Figure G.11: Results from energy cost increase sensitivity analysis in Ängelholm

G.5 Biogas bus

	Lifespan		
Scenarios	10 years	base value	15 years
	10	12,00	15
Capital cost (SEK/bus/lifetime)	2 830 824	2 830 824	2 830 824
Operational cost (SEK/bus/lifetime)	5 253 692	6 130 601	7 352 491
Environmental costs (SEK/bus/lifetime)	2 671 204	3 117 063	3 738 324
LCC (SEK/bus/lifetime)	10 755 721	12 078 488	13 921 639
Capital cost (SEK/bus/year)	283 082	235 902	188 722
Operational cost (SEK/bus/year)	525 369	510 883	490 166
Environmental costs (SEK/bus/year)	267 120	259 755	249 222
Cost (SEK/bus/year)	1 075 572	1 006 541	928 109
Capital cost (SEK/bus/km)	3,9	3,2	2,6
Operational cost (SEK/bus/km)	7,2	7,0	6,7
Environmental costs (SEK/bus/km)	3,7	3,6	3,4
Cost (SEK/bus/km)	14,7	13,8	12,7

Figure G.12: Results from life span sensitivity analysis for a biogas bus

	Environmental cost increase		
Scenarios	base value	100%	200%
	4	9	13
Capital cost (SEK/bus/lifetime)	2 830 824	2 830 824	2 830 824
Operational cost (SEK/bus/lifetime)	6 198 289	6 198 289	6 198 289
Environmental costs (SEK/bus/lifetime)	3 117 063	6 234 126	9 351 189
LCC (SEK/bus/lifetime)	12 146 176	15 263 238	18 380 301
Capital cost (SEK/bus/year)	235 902	235 902	235 902
Operational cost (SEK/bus/year)	516 524	516 524	516 524
Environmental costs (SEK/bus/year)	259 755	519 510	779 266
Cost (SEK/bus/year)	1 012 181	1 271 937	1 531 692
Capital cost (SEK/bus/km)	3,2	3,2	3,2
Operational cost (SEK/bus/km)	7,1	7,1	7,1
Environmental costs (SEK/bus/km)	3,6	7,1	10,7
Cost (SEK/bus/km)	13,9	17,4	21,0

Figure G.13: Results from environmental cost increase sensitivity analysis for a biogas bus

	Energy cost increase		
Scenarios	base value	50%	100%
	-	-	-
Capital cost (SEK/bus/lifetime)	2 830 824	2 830 824	2 830 824
Operational cost (SEK/bus/lifetime)	6 198 289	6 198 289	6 198 289
Environmental costs (SEK/bus/lifetime)	3 117 063	3 117 063	3 117 063
LCC (SEK/bus/lifetime)	12 146 176	12 146 176	12 146 176
Capital cost (SEK/bus/year)	235 902	235 902	235 902
Operational cost (SEK/bus/year)	516 524	516 524	516 524
Environmental costs (SEK/bus/year)	259 755	259 755	259 755
Cost (SEK/bus/year)	1 012 181	1 012 181	1 012 181
Capital cost (SEK/bus/km)	3,2	3,2	3,2
Operational cost (SEK/bus/km)	7,1	7,1	7,1
Environmental costs (SEK/bus/km)	3,6	3,6	3,6
Cost (SEK/bus/km)	13,9	13,9	13,9

Figure G.14: Results from energy cost increase sensitivity analysis for a biogas bus