The practice and application of transport electrification

Examensarbete inom högskoleingenjörsprogrammet Samhällsbyggnadsteknik

Richard Chamoun
Ahmed Elabyad

INSTITUTIONEN FÖR ARKITEKTUR OCH SAMHÄLLSBYGGNAD

CHALMERS TEKNISKA HÖGSKOLA
Göteborg, 2020
www.chalmers.se

EXAMENSARBETE ACEX20

The practice and application of transport electrification

Examensarbete inom högskoleingenjörsprogrammet

Samhällsbyggnadsteknik

Richard Chamoun

Ahmed Elabyad

Institutionen för arkitektur och samhällsbyggnadsteknik
Avdelningen för Geoteknik
CHALMERS TEKNISKA HÖGSKOLA

Göteborg, 2020

The practice and application of transport electrification

Examensarbete inom högskoleingenjörsprogrammet

Samhällsbyggnadsteknik

Richard Chamoun

Ahmed Elabyad

Examensarbete ACEX20
Institutionen för arkitektur och samhällsbyggnadsteknik
Chalmers tekniska högskola 2020

Institutionen för arkitektur och samhällsbyggnadsteknik
Avdelningen för Geoteknik
Chalmers tekniska högskola
412 96 Göteborg
Telefon: 031-772 10 00

Omslag:
(Electricity, 2018)

Institutionen för arkitektur och samhällsbyggnadsteknik
Göteborg 2020

The practice and application of transport electrification

Examensarbete inom högskoleingenjörsprogrammet Samhällsbyggnadsteknik

Richard Chamoun

Ahmed Elabyad

Institutionen för arkitektur och samhällsbyggnadsteknik
Avdelningen för Geoteknik
Chalmers tekniska högskola

SAMMANFATTNING

Transportsektorn i dagens samhälle ansvarar för stora mängder utsläpp av ljud- och luftföroreningar som är skadliga för både människa och natur. Med en växande befolkning som kommer öka behovet av transport och leda till växande städer blir det vitalt att minska användningen av fossila bränslen och öka användningen av hållbara och förnybara drivmedel i kollektivtrafiken. Ett alternativ till den traditionella dieselbussen som är framväxande är eldrivna bussar, som framstås vara betydligt energieffektivare och miljövänligare än sina konkurrenter. Implementeringen av el bussar har för tillfället skett för långsamt och i mindre skalor för att etablera sig i dagens marknad och sätta ett avtryck på städer. Främsta anledningen till detta verkar vara dess ekonomiska påfrestningar och brist på strategier till hur man på ett effektivt sätt skall genomföra omvandlingen till elektrifiering av transportsystemet.

Syftet med arbetet är att undersöka fördelarna med eldrivna bussar, hur elektrifiering av transportsystemet kommer påverka infrastrukturen i samhället samt hur genomförbart implementering av el bussar är ur ekonomiska, teknologiska samt institutionella aspekter. Arbetet avslutas med en livscykelkostnadsanalys av en elektrifierad busslinje. Syftet och frågeställningarna i rapporten besvaras genom litteraturstudier där information erhålles från högkvalitativa vetenskapliga artiklar och rapporter.

Nyckelord: el bussar, transportelektrifiering, livscykelanalys

The practise and application of transport electrification

Degree Project in the Engineering Programme
Civil and Environmental Engineering

Richard Chamoun

Ahmed Elabyad

Department of Architecture and Civil Engineering
Division of Geoteknik
Chalmers University of Technology

ABSTRACT

The transportation sector is responsible for large amounts of noise- and air pollution that are harmful to both man and nature. With a growing population that will increase the need for transport and lead to growing cities, it becomes vital to reduce the use of fossil fuels and increase the use of sustainable fuels in public transport. An alternative to the traditional diesel bus that is emerging is electric powered buses, which appear to be significantly more energy efficient and more environmentally friendly than their competitors. The implementation of electric buses has been ongoing at a slow pace and smaller scales, which is not enough to establish itself in today's market and leave an impression on cities. The main reason for this seems to be its financial strain and lack of strategies for how to effectively implement the transformation to electrification of the transport system.

The purpose of this work is to investigate the benefits of electric buses, how electrification of the transport system will affect the infrastructure in cities and how feasible implementation of electric buses is from an economic, technological and institutional perspective. The report is finalized with a lifecycle cost analysis of an electrified bus line. The purpose and question in the report are answered through literature studies where information is obtained from high-quality scientific articles and reports.

Key words: electromobility, transportelectrification, lifecycleanalysis

Innehåll

Förord

Examensarbetet omfattar 15 högskolepoäng och är en avslutande del i utbildningen Samhällsbyggnadsteknik på Chalmers tekniska högskola. Vi vill börja med att säga stort tack till vår examinator Xiaobo Qu samt Le Zhang som erbjöd välbehövlig vägledning genom arbetsprocessen och gav oss en väldigt fin idé som vi fick utveckla och arbeta på.

Vi vill även säga stort tack till våra handledare på AFRY Per Erik Lund och Gorjifar Shahriar som kunde förse oss med viktig och välbehövlig information för att kunna genomföra arbetet. Tack för ett fint välkomnande och ett mycket fint besök till företaget!

Göteborg juni 2020
Richard Chamoun
Ahmed Elabyad

1 Introduction

The transportation systems in today's urban environment are among the most important sectors to improve in order to achieve a sustainable development. Fossil fuels make up a large part of the energy use in transportation systems. Emission of greenhouse gases like carbon dioxide and air pollution in cities are direct consequences of non-sustainable usage of fuels. In Sweden, it is estimated that about 30 % of the country's total emittance of greenhouse gas originates from domestic transportations, and about 90 % of emissions from domestic transports are from road traffic (Trafikverket, 2019). These toxic particles emitted as a result of vehicles on the roads are detrimental to human health and surrounding ecosystems.

As an environmental-friendly and cost-effective transport means, electrified public transportation systems has received rising interests from many stakeholders, including consumers, automakers, and government agencies in the recent decade. The number of electric buses used for public transport has increased, both globally and in Sweden. Statistics show that from a global point of view, emissions from the transportation sector are growing substantially faster compared to other sectors and accounts for almost 25 % of emissions (Marshall, 2019). In total, buses make up only a small part of all vehicles in worldwide transportation systems, however, their environmental effects are substantial. Buses are mainly used where there is higher concentration of people, therefore the effects of noise, air pollution and emission of toxic particles are of that much significance (Marshall, 2019).

Innovative technology and advanced research have improved the possibilities for electric busses, making them considerably more energy-efficient where fossil fuels are replaced with sustainable alternatives while removing air and noise pollution. Gothenburg inaugurated its very first electric bus line in 2015, and several Swedish cities are trying out electric city buses, something that could - in the long run - change the way cities are built.

1.1 Background

As a result of the continuous exponential increase in population around the world, cities will grow and become bigger. This combined with an ongoing urbanization will lead to a significant increase in the need of transport, and therefore putting more pressure on public transport. The impact on the environment will be irreparable if emission of toxic greenhouse gases like carbon dioxide increases and continues to pollute the atmosphere. Today's conventional buses often use diesel combustion engines that release toxic particles that affects the ambient air quality in a negative way and emits large amounts of noise pollution. Decarbonization and transitioning to sustainable energy usage is with electric buses is therefore crucial.

1.2 Aim

The main issue in our report will be to evaluate the lifecycle cost for a specific electrified bus line and make comparisons with traditional buses. We will also write about what the benefits are with electric busses and feasibility of transport electrification, how electric busses for transportation systems can impact cities and applications of transport electrification.

1.3 Delimitations

Evaluation of the lifecycle cost will be for busline 55 in Gothenburg. However, values used in calculations do not reflect the exact values from busline 55 due to some information being classified. Technology replacements costs will not be taken into consideration. There are no specific geographical constraints when it comes to evaluating transport electrification and its impact on cities, discussions will be general to get a broader perspective on the prerequities. However, Sweden will be the main focus of the project.

The degree project is carried out during the study period 3-4 and is limited to 15 higher education credits.

1.4 Framing of questions

To be able to answer the main issue in the report the following information will be useful to collect:

- How will transport electrification affect the infrastructure in cities?
- Why are electric buses not implemented in more cities?
- What is the lifecycle cost of an electrified bus fleet?
- What kind of barriers exist for electric buses to be implemented?

1.5 Implementation methods

The thesis will mainly be conducted as a literature study where information will be obtained from high quality sources such as scientific reports and articles.

2 Theoretical background

2.1 The principles of electric buses

Electric buses are driven by batteries that function as the engine. These batteries come in many different sizes depending on the aim on range. Because of the current limitations of electric energy storage, it is most common that the batteries are charged regularly during the workday. The technology behind the use of electric batteries is easy to understand fundamentally but is based on advanced technical solutions that we will be investigating.

These batteries are often powered by lithium-ion because of their ability to be energetic rechargeable and these will be further discussed henceforth in the next subheading. All electric buses do not produce any emission during use and is given the name zero-emission vehicle. Furthermore, the noise emitted from the engine is drastically decreased with electric batteries. This allows the electric buses to be operated in quiet areas or even drive inside a building as shown in the project electriccitygoteborg.

2.2 Batteries

As mentioned before, lithium batteries are the most common element in electric batteries. It is because of numerous factors that gives an advantage for achieving the most efficient electric batteries and therefore also an efficient electric bus. Firstly, the lithium-ion batteries are more lightweight compared to other rechargeable batteries of the same size. The components in the electrodes is made from lightweight lithium and carbon. The lithium is a highly reactive element that allows it to store a lot of energy in the atomic bonds. That leads to a very high energy density for the lithium-ion batteries which in turn lowers the total weight for the electric vehicle. An additional advantage of the lithium-ion batteries is their ability to almost hold all its charge with minimal loses of about five percent (CEI, N.d). To put this into perspective, NiMH (nickel-metal hydride) batteries have a loss of twenty percent of the charge per month (Brain, 2006). Combine this difference with the fact that lithium-ion batteries can handle hundreds of charge and discharge cycles, and it becomes clear why it is the most common batterie in use.

Although lithium-ion batteries have a lot of good quality regarding the properties of the components there exist several weaknesses that need improvement. For example, the life span of the batteries is only around 2-3 years and it starts degrading directly after leaving the factory whether it is used or not. Furthermore, some safety measures must be applied to the circuit for maintaining the voltage and current within the safe limits. Otherwise the battery can fail if certain high temperatures is reached which leads to them bursting into flames and potentially cause even bigger damage.

2.2.1 The fundamental of lithium-ion batteries

The lithium-ion batteries can come in many different sizes depending whether it is to power a cellphone or an all-electric bus. Nonetheless on the inside they are all built the same way and look the same. One of the most important components in the battery is the temperature sensor that monitor its temperature. This information is sent to a small computer called a battery charge state monitor. It manages everything about the charging process and if the temperature reaches critical levels the computer could shut down the charging to cool down the battery. Another component is a voltage converter/regulator and a voltage tap to maintain safe levels of voltage and current and to monitor the energy capacity of the individual battery cells (Brain, 2006).

The main part of the batteries is the battery cells that commonly comes in cylindrical form. The outer case is covered in metal to handle the pressure inside the battery cells. This is possible because of a vent hole in the metal case that release some over-pressure if the battery gets heated to prevent it from exploding. Another safety measure is the PTC (positive temperature coefficient) device that keeps the battery cells from overheating. Inside the metal case is three different layers that is pressed together. They consist of a positive electrode, a negative electrode and a separator in the middle layer. This enables the battery cells to be rechargeable and the process will be explained in the next subheading.

2.2.2 Charge/discharge of lithium-ion batteries

The positive electrode is made from lithium cobalt oxide (LiCoO2) and becomes oxidized during charge. The main material in the negative electrode is carbon and during the charging process the oxidized ions attach itself to the reduced carbon. This chemical reaction is enabled only because of electrolyte material characteristic in the separator that firstly separates the positive and negative electrodes and secondly allows the ions to pass between the electrodes. Commonly the active material in the separator is a type of polymer with an electrolyte property. The discharge process function in the opposite manner where the lithium ions gets released from the carbon and back to LiCoO2 (Brain, 2006).

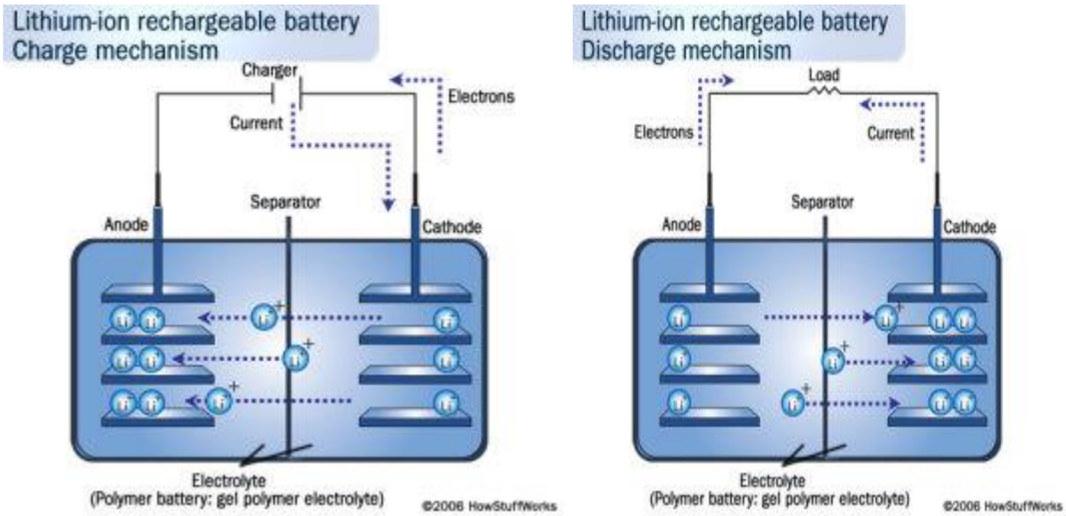

Figure 2.1. The movement of electrons during charge/discharge mechanism (Brain, 2006)

This movement of the lithium ions happens in a fast rate that leads to a fairly high voltage. For a cobalt based lithium ion batterie the voltage for every battery cell is around 3.7 volts compared to a normal AA battery that has a voltage of about 1.5 volts. This allows a battery pack of lithium-ion to come in a single cell and power small devices such as phones or combine multiple to energies an electric vehicle (Brain, 2006).

2.3 Charging of electric buses

The operation of electric buses consists of different models used to maximize the efficiency of the route based on several factors that can influence the operation. These can be the design of the battery system and the charging power requirements that affect the concept of the charging infrastructure. Therefore, it is important to focus on the operation schedule as a whole and not on specific individual routes (Lajunen, 2018).

As a research method new simulation tools for testing and evaluating the development of electric bus operation has been tested. The charging parameters are the charging method, charging power limit and the charging time. Other important parameters are the route selection that consist of the speed profile and amount of bus stops as well as the operating timetable to gather the passenger load factor and dwell time of the bus vehicle (Lajunen, 2018). The conclusion of the research results shows that the battery energy capacity and the required charging power is strongly subjected on the operating route These lead to three different charging methods used in practice based on overnight charging in the terminal, end station charging and opportunity charging alongside the route (Rogge et al., 2015). The planning phase of electric bus system is when the charging method is chosen together with individual stakeholders and the city authority. In a close collaboration they model up an in-depth study to find the ideal charging solution most suitable for the urban structure and the operating environment.

2.3.1 Overnight charging

This type of charging happens at the end of the vehicle's workday in the bus terminal. The location of the bus terminal is often in the outskirt of the city which in turn minimizes the charging infrastructures impact on the nearby environment (Rogge, 2015). The overnight charging method puts a lot of challenges on the onboard energy storage capacity because it needs to hold the energy for the whole workday. Also, the durability of the lithium-ion battery is required to perform even higher to extend the longevity of the batteries and meet the demands of overnight charging.

The process of overnight charging can be done in different strategies to cope with occasional large fleets. The charging speed in the bus depo is low with chargers at around 40-120 kW compared with at the bus stop that use overhead pantographs at around 150-500 kW (Houbbadi et al., 2019). Bus operators also need to account for maintenance and operation costs which may influence the overnight charging strategy. A research aimed to demonstrate the affect from different overnight charging strategies on the battery and their respective cost effectiveness on the operation. The conclusion was that an optimal charging strategy had the least battery capacity loss of around ten percent during ten years of operation compared to thirty percent from a so called “greedy baseline” strategy. Similar researches have been made to generate simulated models for overnight charging of electric buses and optimize the operation of this charging method.

2.3.2 End station charging

During the dwell time for the buses is an opportunity to recharge the battery so it has enough power to reach the other end station. The dwell times is typically at the last stop and is very short so the window to recharge the battery fully is small. Fast charging is a method that makes it possible to use end stations as recharging locations. It is a completely automated system using pantographs that allows for higher voltage and faster charging (Göhlich et al., 2018). This extends the daily range for the electric bus as unlimited in theory.

The charging entity has a simple high pole as infrastructure with the pantographs lowering to the vehicles roof where the charging rails is attached. The charging process is fully automatic with a two-way Wi-Fi communication contingence and the driver can always interrupt the sequence if a problem occurs (Oppcharge, 2019).

In the current situation there exist several different opportunity charging systems that is non-interoperable and aggravates the progress of electric buses (Göhlich et al., 2018). To solve this The European Automobile Manufacturers’ Association (ACEA) has recommended a standard for charging of electric commercial vehicles. These standards for opportunity charging consist of three main items. Firstly, is a contact rail that is positioned on the vehicle's roof above the front axle. Secondly is the use of pantographs lowering down from an overhead charging pole to the charging rails. Lastly is the application of a Wi-Fi protocol for communication between the bus vehicle and the charging mast (ACEA, 2017).

2.3.3 Wireless charging

There exists an additional way to charge at end station or alongside the route using an inductive system. It comprises of a coil beneath the road surface and a second matching one attached in the underside of the vehicle to allow the transmission of energy through wireless contingence (Göhlich et al., 2018). The implication of these charging infrastructure is emplaced at elected bus stops based on collected data of dwell time, frequently and how intensively at different stops. In that way the charging takes place simultaneously as the passengers is loaded and offloaded while the vehicle is fully stopped. This method is called stationary charging and is very dependent on the whole bus system design to create optimal charging stops at a high utility rate (Zicheng et al., 2018).

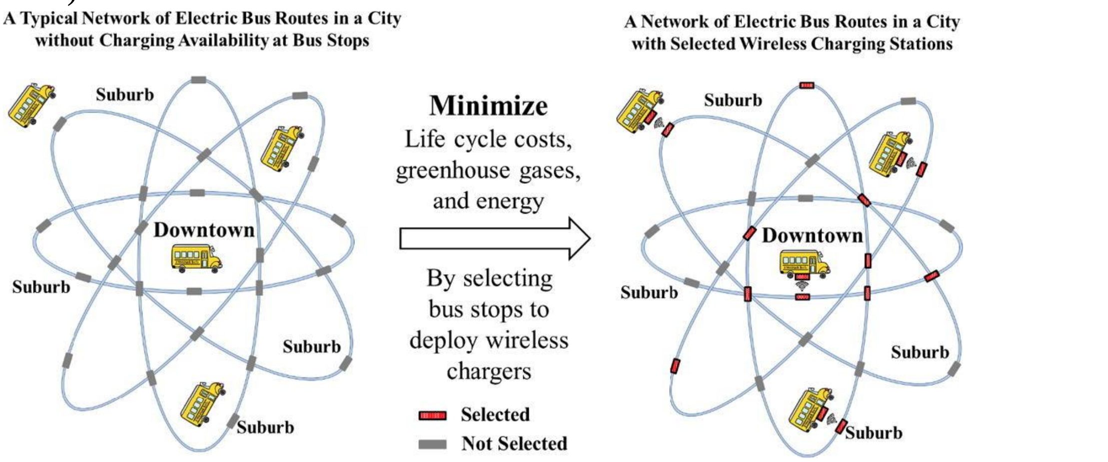

Figure 2.2. Graphic showing of selecting bus stops for wireless charging (Zicheng et al., 2018)

Wireless charging can also be used in a dynamic way when the electric vehicle is in motion. It uses the same principles as the wireless stationary charging with the utilization of inductive systems and power transmitters imbedded below the road surface. A dynamic wireless charging process diminishes some of the limitations currently associated with electric buses. These include a restricted travel distance, the need of large and expensive batteries and the long charging time which disrupts the efficiency of the bus operation (Liu et al., 2017). The two major factors this method depends on is the emplacement of the power transmitters and the battery size for the electric buses. If the deployment of power transmitters is widely spread around the bus operation, then the buses can operate with smaller batteries. By contrast larger batteries is required if the power transmitters have a low deployment unit. The relation between these two factors also affects the long-term cost of batteries or power transmitters depending on the system planning deployment. To balance this relation demands the identification of a trade-off point between the numbers of power transmitters needed and the size of batteries so that a long-term extension provides a sustainable total cost (Liu et al., 2017).

A wireless charging system is subjected to a fixed bus routing both when it comes to stationary and dynamic wireless charging. The advantages of this system include lighter bus load and in turn gives a better kilometer per kilowatt rate (De Kleine et al., 2016).

3 Results

3.1 Benefits of electric buses

Implementation of electric buses in the transport system will lead to a number of benefits from many perspectives. Major cities around the world have set environmental targets that are specifically aimed at emissions emanating from the transport sector. In these cities, strategies regarding transportation are being implemented with great regard to the electrification of transportation networks.

3.1.1 No air pollution

Improving air quality in urban environments but also overall is vital, not just from an environmental perspective but also from a health perspective. Ordinary buses with internal combustion engines that use fossil fuels emit large amounts of greenhouse gases and other dangerous pollutants (Xylia, 2018), and usually in urban environments where a lot of people reside. Incomplete combustion in regular buses are responsible for creating most of dangerous particles that pollute local air (UCSUSA, 2008). Particles that have a width smaller than 10 micrometers, also referred to as PM10, can be inhaled by humans and can adversely affect the body. Inhaling these particles can lead to cardiovascular diseases and even a higher chance of mortality (USCUSA, 2008). Air quality in everyday life is something that many may forget or do not think about, but it is something that has a major impact on human health. It is estimated that about 3.7 million premature deaths can be connected to outdoor air pollution according to the world health organization (Xylia, 2018).

There are two different types of air pollution, secondary pollution, which consists of chemical reactions due to particles in the air and primary pollution, which is released to the atmosphere. A few examples of major pollutants that can be very dangerous:

- **VOCs** – Also known as volatile organic compounds. These types of pollutants react with nitrogen oxides and form toxic ground-level ozone (USCUSA, 2008). This can cause severe damage to our respiratory systems if inhaled. VOCs that originate from buses and cars can contain benzene and acetaldehyde, which can lead to various types of cancer. In Sweden it was estimated in 2018 that the transport sector was responsible for about 9 % of total VOCs emitted. In 1990, emissions of VOCs were 91 % higher in comparison to levels in 2018, which is a significant decrease (USCUSA, 2008). This is a concrete example of how much cities can reduce emissions of environmentally harmful pollutants by means of less use of fossil fuels in transport.
- **NOx** – Similar to VOCs, nitrogen oxides can create ground-level ozone and can also form particulate matter (USCUSA, 2008). When inhaled it can lead to severe lung problems (USCUSA, 2008). They can also be harmful to the environment, when nitrogen oxides break down it can lead to both eutrophication and acidification of in land and water (Naturvårdsverket, 2019).

- **CO** – Incomplete combustion of gasoline and other fossil fuels leads to emission of carbon monoxide. It is a gas that is mainly emitted from buses and cars and is very hard to detect because of its colorless and odorless consistency (USCUSA, 2008). Carbon monoxide can stop oxygen from reaching the brain and heart if it is inhaled, which can cause severe damage to humans (USCUSA, 2008). There are strict environmental policies regarding carbon monoxide levels in the air in Sweden. Since the 1980s, levels of CO have drastically decreased, almost 80-90 percent compared to levels measured in 2018 (Naturvårdsverket, 2018).
- **SO2** – Sulfur dioxide is a pollutant that originates from using diesel in motor vehicles (USCUSA, 2008). High levels of sulfur dioxide can lead to acidification in nature and damage plants and animals (Naturvårdsverket, 2020).
- **GHG** – Greenhouse gases are well known for their climate changing effects. One of the pollutants that can be classified as a greenhouse gas and has negative effects on the environment is carbon dioxide. One of the main sources of carbon dioxide emissions occur with combustion of fossil fuels in vehicles. The reason for their contribution to climate changes has to do with their ability to absorb heat and reflect it back to the ground, which leads to increasing temperatures (Naturskyddsföreningen, n.d.).

Considering the many different pollutants that the use of fossil fuels emits, it is becoming increasingly important to electrify modern urban transportation systems. The main advantage with implementing electric buses is that the buses emits no toxic gases like NOx, VOCs and SO2. As previously mentioned, many premature deaths are related to inhalation of air pollutants from exhaust gases from motor vehicles. Eliminating these pollutants from urban areas and utilizing cleaner technology with renewable fuels can drastically reduce the environmental impact from domestic transports and at the same time create a cleaner and healthier urban environment for people.

3.1.2 Less noise pollution

Similar to air pollution, noise pollution is a major problem in urban environments due to heavy traffic during the day. The effect of noise pollution becomes significantly worse in dense urban environments. The world health organization has hinted that noise coming from traffic is an underestimated health problem that is important to consider. 30 % of people in Europe are disturbed by noise pollution originating from traffic, according to a study conducted by the WHO (Volvo, 2019). It can have significant effects both from an environmental but also a health perspective. Humans can experience heavy stress, concentration problems, sleep difficulties and even cardiovascular diseases while the natural environment and urban ecosystems can be affected by noise pollution disrupting biological processes that occur naturally and also animal life being disorientated (Marianna et al., 2017). Kantar Sifo, a market research company, conducted a study commissioned by Volvo group. The study was carried out in Gothenburg and controlled the residents' experience of noise levels in the city, results showed that seven out of ten inhabitants in the city felt disturbed by the noise levels

(Volvobuses, 2019). Majority of the residents indicated that noise emanating from traffic was the main issue, some had even experienced mental and physical complications due to noise levels (Volvobuses, 2019).

Reducing traffic noise in urban environments is crucial in order to create a sustainable and user-friendly transport system. Research in urban noise pollution has clearly shown the negative effects of unhealthy exposure to high noise levels. The noise levels emitted from buses depends greatly on the speed of the vehicle traveling. At lower speeds, for example, less than 50 km/h, the engine noise is dominant, while if the vehicle travels at speeds above 50 km/h, the tire noise becomes dominant (Volvobuses, 2019). The lower noise pollution that electric buses offer compared to motorized buses are not only advantageous from an environmental and health perspective. When planning bus routes, you want to have an optimal and unobtrusive route while having the freedom to place bus stops where the need for transport is the most. Electric buses offer that flexibility that is needed due to its significantly lower noise emittance from the vehicle when they are stationary and at lower speeds compared to traditional buses (Volvobuses, 2019).

3.1.3 Climate impact and clean energy

Reducing the use of fossil fuels is important in many aspects. Economic, ecological and social aspects regarding sustainable development are something that fossil fuels have a major impact on. As previously stated, vehicle traffic in Sweden are responsible for 90 % of emissions from domestic transports. According to a statistical report written by Sweden’s bus company which shows buses in traffic with regard to fuel in 2018, 72,5 % are powered by diesel (including biodiesel, RME/HVO) and only 0.6 % are powered by electricity (Grönlund, 2018). The use of more electric buses in the transport sector has the potential to significantly reduce dependency on fossil fuels and oil consumption. Calculations from BloombergNEF show that 500 barrels containing diesel fuel will be removed every day for every 1000 electric bus on the road powered with batteries (Transport & environment, 2018). In addition, they also estimate that electric buses will help replace 233 000 oil barrels every day.

The electric buses are significantly better when it comes to energy use and energy efficiency compared to other traditional buses. For example, there are seven electric hybrids and three full electric buses operating on route 55 in Gothenburg (Electriccity, 2016). Analyzes and studies of the bus route have proven that the electric buses can be up to 80 percent more efficient energy wise compared to diesel buses (Electriccity, 2016). The electric hybrids were estimated to utilize 50-65 percent less energy, also compared to traditional diesel engines in buses (Electriccity, 2016).

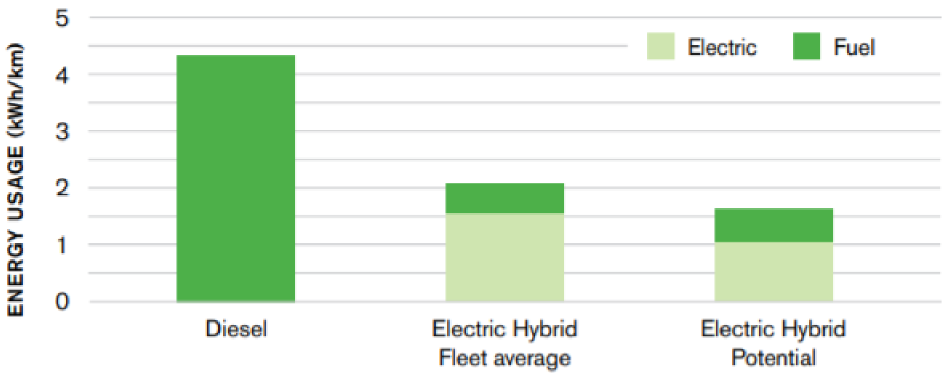

Figure 3.1. Comparison of energy usage on electric hybrid buses operating on bus route 55 and diesel bus on a similar route. Data collected from Volvo. (Electriccity, 2016).

The diesel engine in the electric hybrid buses was only used 23 % of total operation time, where the other 77 % were fully electric.

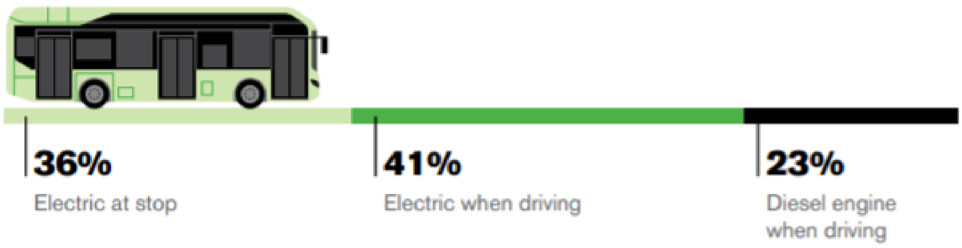

Figure 3.2. Total time spent in electric and diesel on hybrid buses on route 55. Data collected from Volvo. (Electriccity, 2016).

As previously described, fully electric buses have no emissions of toxic gases like carbon dioxide, VOCs, sulfur dioxide and greenhouse gases. The electric hybrid buses with HVO fuel proved to have a remarkably lower climate impact compared to the diesel buses, which can be explain by two main reasons. Firstly, a considerable amount of the operation time in the hybrid bus was electric and therefore less diesel fuel needed to be utilized. Secondly, HVO is a biofuel that's sustainable and renewable that uses natural ingredients and therefore has remarkably lower emittance of carbon dioxide (NESTE, n.d.). The data showed that electric hybrids that operated with HVO fuel had an astounding 97 percent lower well to wheel CO2 emission compared to a bus using fossil diesel on route 55 (Electriccity, 2016).

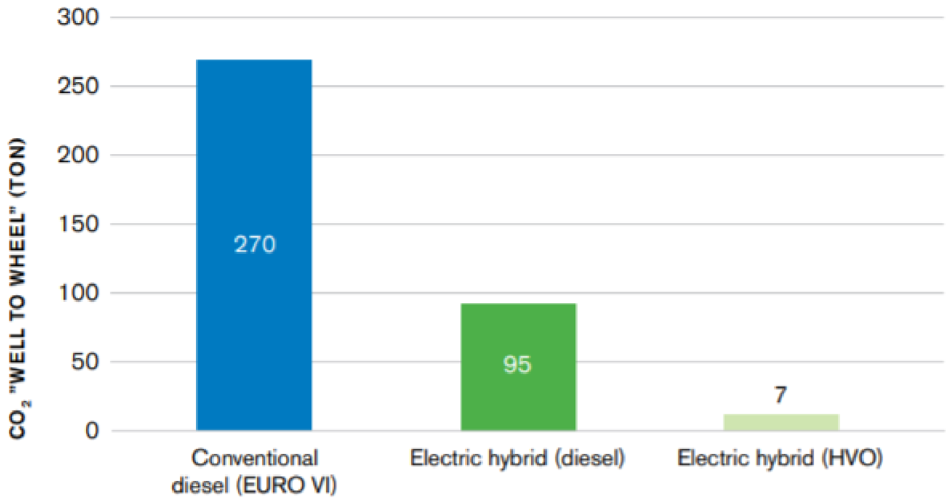

Figure 3.3. Diagram comparing carbon dioxide emissions in tons with regard to conventional diesel, electric hybrid running on regular diesel and electric hybrid operating on HVO diesel.

3.2 Feasibility of transport electrification

Mobility systems like electric buses that has the ability to utilize environmental friendly, natural and renewable energy resources like wind, solar and hydroelectric power while being high performing and cost effective has the potential to be an attractive transportation alternative (Comer, 1997). Electrification of the transport system is one of the most important challenges in modern times. It is a multifaceted challenge where many factors and aspects must be taken into consideration to obtain a solution that can satisfy today's and the future urban transport needs. In addition to technological barriers, there are also economic and political factors that need to be improved in order to make electric buses a viable and profitable option for transportation.

3.2.1 Technological challenges

Planning and developing a project with electric buses has many complex elements to consider. Batteries and other components are not the only technological challenges that exist for e-buses. Electromobility in many cities today is a relatively new phenomenon and its benefits are still unknown to many. Therefore, a lack of information on existing and future technology is a critical barrier (Sclar et al., 2019). Not having enough information can affect decision making regarding electrification of transit systems. Some decision makers for public transportation systems in cities may not even consider implementing electric buses in urban areas (Sclar et al., 2019), while other may only create a basic understanding of existing technology on electric buses like for instance capital costs, range of the buses and how the infrastructure needs to be changed and adapted to charging infrastructure needed for electromobility (Sclar et al., 2019). Both reliable and up-to-date information is crucial in order to create cost-benefit analysis that can describe the efficiency of having an electric bus transit system in an accurate way (Sclar et al., 2019).

Cities that have been successful in researching electric buses and its benefits are still uncertain regarding some aspects about the components in an electric driven bus, for example the lifecycle of electric batteries and how high or low the salvage value is for electric buses when they are decommissioned (Sclar et al., 2019). There are little to none electric buses that have been used long enough for them to be able to have reached their approximated retirement date, estimating the performance and lifespan of electric buses can therefore be difficult and problematic (Sclar et al., 2019). As previously suggested, lack of information is a crucial barrier. Long-term prognosis of e-buses, their components and their effect on societies become problematic because of lack of material and vital variables. A clear example of this is the batteries used in electric buses. Once they have reached the end of their life cycle it is difficult to properly handle and dispose of them in a way that does not cause any harm to the environment and natural habitat (Sclar et al., 2019).

Today’s electric buses that are available for use have technical specifications that can be very different from other electric buses depending on the company/manufacturer. Good research and technological advances have been made in recent years regarding the performance of electric buses, but there is still a long way to go. Limitations in performance such as ability and range are major challenges that needs to be solved in order to make electric buses operable (Sclar et al., 2019), especially in larger cities and areas where buses need to cover greater distances. According to case studies being conducted in different countries and cities around the world by the world resources institute, range capacity for electric buses in a full charge was thought to be a significant limitation for longer routes (Sclar et al., 2019). The city of Bogotá in Colombia implemented electric buses in their public transportation system during a limited time in a case study and compared them to traditional diesel buses. Results showed that the diesel buses had an average range of 440 kilometers per day while electric buses had an average range of 235 kilometers per day (Sclar et al., 2019).

There are many reasons why performance issues in terms of the range of electric buses continues to be a problem. One of the most important factors is the inconsistency of performance in batteries. Batteries generates electricity when its positive and negative terminals connect and initiate a chemical reaction to generate electrons (Helmenstine, 2019). The reason why battery performance can be so inconsistent is because of the weather. Lower temperatures affect chemical reactions and their reaction rate in a negative way by decreasing the speed of molecules, which leads to the speed of chemical reactions decreasing and therefore limiting the battery capacity (Helmenstine, 2019). Warmer temperatures can also have a negative impact on battery range, for example the need of air condition for passengers during warmer days requires large amounts of electricity and can have a significant effect on the battery (Sclar et al., 2019).

In addition to capacity limitations with battery due to various causes such as weather conditions and range difficulties, how the topography is in cities is something that can also have a big impact on electric buses and its power capabilities. In the previously mentioned case studies that had been directed by the world resources institute, many cities reported that steep hills and terrain were problematic and performance limiting for electric buses (Sclar et al., 2019). Buses that are unable to maintain necessary velocities can cause delays by not being able to reach every bus stop in time, which can then lead to dissatisfaction among the people in the city.

As previously stated, implementation of electric buses in the transportation sector is something that is relatively new. From a technological standpoint, something new often means that manufacturers and scientists constantly need to test new solutions and experience a learning curve in order to see what can work as a viable option. The components in electric buses are different compared to traditional buses and they therefore need different types of designs. Electric buses have not reached the large-scale use and production needed for high-quality standards to exist globally. Some cities that had tried pilot programs to see how e-buses would perform described that structural damage and other problems like broken suspension valves occurred due to the fact that some electric buses were simply not built properly enough to handle roads (Sclar et al., 2019). The market for electric buses is still growing but is not yet established in countries around the world like the market for traditional buses is, therefore it is easier for larger companies to control the market which leads to options being limited in certain cities.

3.2.2 Financial Challenges

In today's society, most things come down to financing and capital costs, and electric buses are no exception. The main difference between electric buses and conventional buses that many cities struggle with economically is the initial cost of the bus. High initial costs for electric buses leads to difficulties in mass-producing the buses to increase usage in public transit systems while also trying to develop and improve the technology. The high initial costs that comes with electric buses can be explained by various reasons: an up and coming market, geographical limitations, and many uncertainties with existing technology (such as components) are few among many mentionable factors (Sclar et al., 2019). Bloomberg new energy finance states that the battery in electric buses is a big reason for its high price. Although it has been reported that battery prices have fallen significantly in the last decade (almost 80 %) and electric buses are improving (Sclar et al., 2019). Many experts agree that the market will continue to grow and become bigger. The electric buses will be able to compete with traditional buses, however, how much time it will take until we get there is something that is extremely hard to predict.

Obtaining a clear overview and an approximate average price for electric buses is also relatively difficult to predict. There are several different factors that affects prices, the battery has the biggest impact on pricing but technical specifications on the bus, which manufacturer and where they are based are also major factors as to why the prices of electric buses can vary a lot. In order for electric buses to become a reality in many cities, transport authorities must first have sufficient capital to finance such a project and change in transportation systems. Not only is it necessary to have enough capital to buy the buses, but also to make sufficient adjustments to infrastructure and make it adapted to electromobility. All the preparations required, such as improving electric systems and underground connections before an optimal charging infrastructure can be introduced is crucial to consider.

It takes a lot of planning and work to build and operate suitable charging stations for the electric buses. Deciding who manages the charging infrastructure and can provide capital needed can also be demanding. The expenditure in this area is something new to take into account from an economic perspective. For instance, public transportation authorities are not responsible for supplying electricity and adapting infrastructure to electric buses, changing infrastructure in larger scales comes at a very high cost. Conventional companies that manufactures buses are usually not in charge of establishing charging stations for the vehicles. Both private stakeholders and government agencies need to work and plan together for everything to work properly (Sclar et al., 2019).

3.2.3 Institutional challenges

In addition to technological and economical challenges, there are also institutional barriers that needs to be taken into account if electric busses shall become a reality in many cities. Transit agencies and manufacturers have numerous barriers that can make it hard to accomplish a successful implementation of electric buses. Public transit agencies that are secluded financially or physically often have difficulties obtaining while simultaneously maintaining electric buses in transportation systems (Sclar et al., 2019). For example, during its lifespan the buses will need maintenance and possible repair of its technical components and the like. Cities that do not have local or regional manufacturers that can provide the necessary spare parts when needed can suffer extra expenses and reduced availability of buses (Sclar et al., 2019). Due to the fact that electric buses are still a relatively new and emerging technology, many new technical and economic aspects need to be taken into consideration. Therefore, it becomes increasingly difficult for e-bus manufacturers to try and establish themselves in more cities.

Political aspects are also something that has a major impact on the implementation of electric buses. It is crucial to have political support and to have politicians that have enough knowledge about the technology to be able to make decisive decisions based on good grounds. Cities that have tried to implement electric buses in their transportation systems in order to replace conventional diesel buses often mentioned that governmental incentives and strategies that could guide and help the process in both local and national levels was lacking (Sclar et al., 2019). Transit agencies that are initiating projects in preparation for electric buses have found that having no strategies to help with electromobility in cities or additional options for funding made it problematic to establish proper short- and long-term plans.

Today, there are still many reasons why cities continue to use diesel and natural gas buses and perhaps avoid electric-powered buses. It is difficult to argue that electric buses are advantageous to implement now, and it is hardly preferable from an economic point of view. Some cities still have subsidies, such as price advantages for natural gas and diesel buses that can discourage application of electric buses.

3.3 Impact on cities

Diesel buses still make up most of the public transport in cities all around the world. As previously mentioned, this kind of transportation produces enormous emissions and greenhouse gases, one 16 m long urban bus consumes 40.000-liter diesel per year which is equivalent to 100-ton CO2 (Glotz-Richter et al., 2016). Specially in urban environments with high population density will this lead to health issues due to air pollution. The transition from diesel to electric buses will bring a huge shift in the transport operation and provide an impact on many different aspects. The electrification of the transport system will bring new challenges to overcome, such as higher pressure on the electric grid network in the city. This is only one of many things that will alter the city to adjust for the requirements of electric buses.

3.3.1 Sustainable transport system

All around Europe countries have set up targets to reduce the emission from the transportation sector that currently accounts for one quarter of all greenhouse gas emissions in Europe (UITP, 2019). The goal in many cities such as London, Paris and Gothenburg are to bring this number to zero to achieve a zero-emission transport system. A side effect of an improved operation is a more attractive transportation system that will lead to an increased public use and less individual car usage. The electrification of urban transport system has all the means to improve the mobility and accessibility for the citizens in their day-to day life.

A sustainable transport system means the planning include developed strategies that is integrated in various aspects such as understandings of mobility, urban development, transportation and individual behavior. This covers all types of sustainable transportation methods such as walking, cycling and public transport. Journeys made with buses is the most trivial in every transportation system around the world and it makes up for about 80 percent of all public transportation (Glotz-Richter et al., 2016). This makes the bus sector a powerful role to make significant change by improving technologies and shifting to electric buses.

Indeed, the very purpose of a sustainable transport system is to reduce the amount cars that contribute to social congestion in cities. An electrification of the bus fleet will contribute to great marketing for the transport system and by highlighting the improvement this will bring to the dynamism and modernism to the citizens lives will indicate these companies care about their customers. In France, RAPT made a survey about their electric buses to the travelers and 93 percent answered that it enhanced the image of the operator (UITP, 2019). An attractive bus network has the means to make the whole city attractive by changing the current norms of mobility and create a more integrated transport system.

3.3.2 City infrastructure

The transition from diesel driven to electrification does not equal changing a bus with another one, as a matter of fact the whole system of transportation goes through a modification. The introduction of a new technology influences everything from the vehicle design to the application of bus stops while also bringing in new components to consider such as charging infrastructure. Furthermore, this is a unique opportunity to change the general principles of urban transportation and to elevate the cityscape by signifying a new modern urban object.

A major asset of electric buses is the eradication of pollutions emitted during use. These include the removal of both noise and air deterioration previously causing urban disturbances. Instead these drawbacks have been converted to provide innovative design solutions such as an indoor bus stop (Electricitygoteborg, 2016). This leads to a better product for the customers, in this case they are totally sheltered from the weather and can enjoy a better interior design while also being able to board the bus as they please. In the long run an integrated mobility system with various transportation modes and services to move around the city will reduce people's dependence on the car (Sweco, 2018). Consequently, the urban planning will outgrow the car which in turn will change the way our cities are designed.

As mentioned in previous subheading there currently exist three ways to charge an electric bus. These are plug, pantographs and inductive wireless charging, each has its own infrastructure with designated power levels from low to high depending on fast charging or overnight charging. Firstly, overnight charging will demand an upgrading of the bus depo to include enough charging space for the whole electric fleet. The refurbishment requires large investments and the most part of it is for a large set of chargers and the accompanied charging intelligence. Depo charging is limited to low power charging which does not call for a higher demand on the electric grid.

On the other hand, opportunity charging has a much higher power level requirement to make fast charging available. Another factor is adjusting the electric energy supply to provide this energy to the bus stops along the line. Additional infrastructure is the charging infrastructure at different bus stops. To make this all possible the city must find the appropriate and available space for all these infrastructures among the general road traffic. Another solution would be to separate the charging spots, so the charging process is not disturbed by being blocked by parking vehicles or stopping the traffic flow. If the charging is located at the end stations, then several charging positions may be needed for an effective charging time. Generally, the new demand for floor space in bus operation increase by 15-30 percent (UITP, 2019). This is based on the number of bus lines using the stop and the frequency depending on the schedule. In collaboration between the city and its energy provider and the public transport company the bus network must be designed to identify suitable spaces, especially if it is a large-scale deployment.

The charging infrastructure itself and the positioning have a direct impact on the bus stop design. The conductive charging poles for pantographs and their respective electric substation provide a visual experience on the surrounding environments. That is why cities adjust their design to fit in with the visual identity of the city. Additionally, the installation of charging infrastructure also requires space underground for infrastructure foundation which in turn could breach safety and space regulations. This is especially prevalent for inductive charging that use heavy underground construction work and sub-surface space for the charging devices. Moreover, the installation must take account of ground stability requirements for the planned positioning of the charging spot. As said inductive system crave a lot of ground working which demand substantial amount of excavation. On the plus side the inductive charging system does not impact the visual image of the city in anyway and provide easy approaches for the electric buses.

3.3.3 Electric grid

Today the transport sector stands for a third of all energy consumed and rely mostly on liquid fossil fuel. The electrification of transport system and increased practice of electric vehicles such as cars and buses will create the need for reinforcement on the electric grid to power all electric bus fleets and make way for fast charging. The energy supply is not unlimited and city together with the transport administration need to make sure the power access covers the city and the bus network without interruptions. Indeed, this various hugely depending on geographic location but to achieve a sustainable transition to electrification the electricity needs to be produce by renewable methods such as wind, solar, bioenergy and water. Henceforth the electricity production will depend on these technologies to meet the demand which is set to be 32 percent renewable of total energy consumption by 2030 (EC, 2018). Politicians in the EU are developing new energy market structures to integrate the renewable electricity generating with applicable infrastructure to unify different markets across borders.

The electric demand varies greatly during different times of the day, for example during the evening most people are home and begin charging their electric vehicle or the bus fleet using overnight charging. This asserts for the electric grid to always have power available which in turn puts great pressure on the storage capacity in the electric grid. A disadvantage electricity is that it cannot be stored directly in the electric grid and a conversion phase is needed. It is possible to store electrostatic energy in capacitors or conductive coils, yet the capacity of these solutions is very limited and cannot maintain durable operation (Robyns et al., 2016). Another more common solution for supporting the grid is stationary storage devices such as battery systems in residential homes to shift the local consumption of electricity to be more decentralized. These utility-scale battery systems have the right properties such as quick deploy time and exceptional scalability and is a promising solution to support the grid.

To manage the future needs of electricity the battery technologies must improve and drastically find new ways to lower the energy cost and make battery storage systems economically viable and more suited for bulk power management. Currently pumped hydro storage (PHS) is commonly used in this quantity storage but the low energy density and geographic restrictions makes it less favorable to accommodate future communities. Battery electric storages has been on the rise since the introduction of electric vehicles and several different battery systems have been developed and improved. Additional to the above-mentioned energy cost reduction the performance of these battery electric storages is improving. The cost reduction lithium-ion system is anticipated to almost double the lifecycle values of today and have the potential to reach 19 100 equivalent full cycles by 2030 (IRENA, 2017). The combined effect of reduced capital cost and advancement in performance will exhilarate further development and deployment of battery electric storage to create a cost-effective service for the electric grid system.

The electrification of transport system will not only develop services to the electric grid but also bring changes to the fundamentals of electric grid. Vehicle-to-grid (V2G) is one of these transformative usages of both electric vehicles and grid system. The concept behind it is that taking advantages of parked electric vehicles connected to a charging infrastructure and allowing them to provide the grid with power if needed. This is intended to create flexibility in the power grid while also creating an influential role for the owners of electric vehicles, especially private cars which is in use only 10 percent of the time (IRENA, 2017). By implementing load management, the charging time can occur in an off-peak period or supply back to the power grid in high demand hours. Ideally this technology enables for a controllable two-way electrical flow between the vehicle and grid. However, in order to promote the V2G technology widely in the society includes to reckon with customers preference and restriction on the electric grid. By effectively addressing these issues the electric mobility will be more optimized and allow for energy use in smart way.

Researchers have brought up their worries about uncontrolled electric vehicle charging and the impact it has on electrical transformers life (Sorrentino et al., 2014). They have agreed on intelligent control strategies applied on the electric grid system is the next generation technology to cope with the changes in demand. Today the electric grid has many disadvantages functions and inefficient ways to convey electricity. For example, the existing grid have no way to recover wasted heat and about 8 percent of the output is lost in the transmission lines (Farhangi, 2010). The future electric grid called "Smart grid" is set to deal with the major inadequacies of the existing grid. It will completely revolutionize the communicative systems of the grid and will have self-healing and resilience to system deviation properties. The transition will initially begin with implementation of distributed control and monitoring systems within the existing electric grid. Over time the functional growth of these intelligent systems will allow for the usage to shift to the new smart grid. In turn the smart grid is set to define new ways of distributing and transact energy with each other by utilizing two-way communication, digital network, self-monitoring and self-healing and adaptive with pervasive control. This way the smart grid should not be a replacement but a complimented service to the existing grid.

The concept of smart grid will contribute to the necessary technology required for V2G. Together they are going to simplify the implementation of electric vehicles with the embodiment of smart grid integrated and interconnected through cable highways for data, command and power exchange.

3.3.4 Planning and operation

One of the most general challenges the municipality and transport companies face when implementing an electrified transport system and specifically a bus system is planning the operation and modifying the network. The appropriated charging method needs to be evaluated based on the routes and depending on low or high charging power have various influence on the schedule and require different infrastructure such as a depo upgrade or a charging mast positioned out in the streets. The driving capacity of the electric bus plays a huge roll on the decision of charging strategy and a cooperation between transport companies and vehicle manufacturers is of the essence to allow for applicable design.

The driving capacity determines the maximum range of distance the bus can drive on fully charged batteries. This in turn varies based on numerous road condition factors such as the route topology and complexion, weight of the vehicle, number of passengers, driving style and weather conditions. A close interaction during the design phase between the before said parties will allow additional perspective on certain aspects. These include the average and maximum kilometers per day, serving scheduling, position of the bus depo and position of the opportunity charging equipment and availability of power supply for charging equipment (UITP, 2019). A study was carried out in Barcelona to simulate the operation of fully electric buses on two routes, one was a horizontal flat route and the other was vertical and mountainous route. The result showed that the flat route needed two opportunity charging stations, one at each end. On the other hand, the vertical route only required one at its lowest station (UITP, 2019). An extensive planning of operation leads to a more effective implementation of electric buses.

The single handedly biggest factor is the chosen battery sizes. A large battery often used in depo charging strategy contribute to more weight on the total vehicle weight and the space taken by the battery can reduce the number of passengers the bus can handle. Henceforth, the operator may need to run extra buses or order larger buses to maintain the same service. Meanwhile, full opportunity charging systems can take advantages of smaller batteries and carry more passengers but for a shorter time. One operation is never same as the next one and therefore the urban density and travel demand must be broken down to ensure the electric vehicles meets the demand, because “There is no one size fits all approach” (UITP, 2019).

The electrification of transportation brings with unfamiliar technology for the staff members. That is why the training of bus drivers and bus maintenance staff is an important part of the deployment on electric buses. The new requirement includes safety aspect in terms of maintenance but also in case of failures or emergencies. This includes training first responders such as firemen, police and other rescue service on electric vehicle properties and function of the related charging equipment in case of accidents. The training of all staff involved in the operation is a vital part of the planning phase to assert a basic knowledge. This include city authorities and manufacturers to provide safety specification sheet and training programs (UITP, 2019).

3.4 Line 55

Bus route 55 is an electrified route and extends between two different campuses belonging to Chalmers university of technology named lindholmen and johanneberg. There are seven electric hybrid b uses and three fully electric buses operating on the route. The charging is carried out at the beginning and at the end of the journey, the process is called opportunity charging and only takes 3-4 minutes for the buses to acquire enough energy for the entire bus route (Electricity, 2016). Total length of the route is 7.6 kilometers from start to end station and similarly from end station to start. It is estimated that out of 35 000 planned trips, only 120 of them were cancelled due to various reasons (Electricity, 2016). The electric buses that operates on route 55 are equipped with a technology called zone management system (Electricity, 2016). It controls the velocity of buses in different areas and can for example manage what engine the bus is utilizing depending on where it is. Buses operates on lower speeds in areas with a higher number of pedestrians and cyclist. When it comes to the electric hybrid buses, the system has the ability to identify zero-emission areas and only utilize electric batteries in order to minimize air and noise pollution (Electricity, 2016). Maintenance of the buses is carried out at the Volvo Bus Experience centre with a depot and workshops available. Components mounted on the roof of the buses combined with specially designed platforms makes it simple and efficient for maintenance (Electricity, 2016).

Picture 1. Overview image at bus stops along the route.

3.5 Lifecycle cost analysis

The benefits electric buses can offer from an environmental perspective are limitless, but its technological and economical barrier are something that must be considered. Thus, it is important to be able to examine all relevant aspects and quantify the results to compare alternatives and get a good overview of viable options. A LCCA can provide an advanced and detailed analysis of economic aspects while considering the entire life span of the bus. Calculations will take multiple cost structures into account in order to get an accurate evaluation of the life cycle cost and make it possible to compare all parameters. The calculations will be separated into two different categories: capital costs and operation costs.

3.5.1 Methodology and framework

Equations and methods used are based on Antti Lajunens paper "Lifecycle costs and charging requirements of electric buses with different charging methods". It is vital to estimate the parameters with precision and provide reasonable values of variables used in calculations to obtain a successful analysis. Values that were provided and used in calculations were estimated by an expert in the field, the values do not reflect the exact numbers for bus line 55 due to some of the information being confidential.

The time period for the lifecycle cost analysis is set to 10 years. Carbon dioxide emission costs are not taken into consideration due to the electric buses not having any emission of the greenhouse gas, CO_2 emissions that originate from manufacturing are also not taken into account in calculations. Variable costs that can change over time such as energy and maintenance costs as a result of various reasons are considered constant over the 10-year period. If the buses are assumed to be used the entirety of its lifespan then the salvage value is set to be zero.

3.5.2 Capital cost

The capital costs are composed of the purchase cost of a bus, recovery value of charging devices and buses, initial cost of charging device and the number of buses in one fleet (Lajunen, 2018). The equation is as follows:

$$C_{capital} = N_{buss} * C_{buss} + C_{charge} - C_{SV} \quad (1)$$

N_{buss} = Number of buses
C_{buss} = Initial cost of a bus
C_{charge} = Initial cost of charging component
C_{SV} = Recovery value of buses and charging devices

The number of buses is estimated to be 10 and the purchase cost of an electric bus is estimated to be around SEK 6.5 million. Initial cost of charging component is set to be SEK 150 000. The salvage value depends on how long the bused is used relative to its service life. Salvage value will be calculated for year 1-10 to see how the capital costs are affected.

Salvage value after t years for the **buses**:

$$C_{SV,bus} = \frac{t}{10} * \ C_{buss} = \frac{t}{10} * 6\,500\,000 * (1 + d_{rate})^{-j} \ (2)$$

1 year

$C_{SV} = \frac{9}{10} * 6\,500\,000 * 10 * \ (1 + 0{,}05)^{-1} = 55\,714\,285{,}71\ kr \ (3)$

2 years

$C_{SV} = \frac{8}{10} * 6\,500\,000 * 10 * \ (1 + 0{,}05)^{-2} = 47\,165\,532{,}88\ kr \ (4)$

3 years

$C_{SV} = \frac{7}{10} * 6\,500\,000 * 10 * \ (1 + 0{,}05)^{-3} = 39\,304\,610{,}73\ kr \ (5)$

4 years

$C_{SV} = \frac{6}{10} * 6\,500\,000 * 10 * \ (1 + 0{,}05)^{-4} = 32\,085\,396{,}52\ kr \ (6)$

5 years

$C_{SV} = \frac{5}{10} * 6\,500\,000 * 10 * \ (1 + 0{,}05)^{-5} = 25\,464\,600{,}41\ kr \ (7)$

6 years

$C_{SV} = \frac{4}{10} * 6\,500\,000 * 10 * \ (1 + 0{,}05)^{-6} = 19\,401\,600{,}31\ kr \ (8)$

7 years

$C_{SV} = \frac{3}{10} * 6\,500\,000 * 10 * \ (1 + 0{,}05)^{-7} = 13\,858\,285{,}94\ kr \ (9)$

8 years

$C_{SV} = \frac{2}{10} * 6\,500\,000 * 10 * \ (1 + 0{,}05)^{-8} = 8\,798\,911{,}706\ kr \ (10)$

9 years

$C_{SV} = \frac{1}{10} * 6\,500\,000 * \ (1 + 0{,}05)^{-9} = \ 4\,189\,957{,}955\ kr \ (11)$

10 years

$C_{SV} = \frac{0}{10} * 6\,500\,000 * \ (1 + 0{,}05)^{-10} = 0\ kr \ (12)$

Salvage value after t years for the **charging devices**:

$$C_{SV} = \frac{t}{10} * \ C_{charging\ device} = \frac{t}{10} * 150\,000 * (1 + d_{rate})^{-j} \ (13)$$

1 year

$C_{SV,chg} = \frac{9}{10} * 150\,000 * 10 * \ (1 + 0{,}05)^{-1} = 1\,285\,714{,}29\ kr \ (14)$

2 years

$C_{SV,chg} = \frac{8}{10} * 150\,000 * 10 * (1 + 0{,}05)^{-2} = 1\,088\,435{,}38\ kr$ (15)

3 years

$C_{SV,chg} = \frac{7}{10} * 150\,000 * 10 * (1 + 0{,}05)^{-3} = 907\,029{,}48\ kr$ (16)

4 years

$C_{SV,chg} = \frac{6}{10} * 150\,000 * 10 * (1 + 0{,}05)^{-4} = 740\,432{,}23 kr$ (17)

5 years

$C_{SV,chg} = \frac{5}{10} * 150\,000 * 10 * (1 + 0{,}05)^{-5} = 587\,644{,}625\ kr$ (18)

6 years

$C_{SV,chg} = \frac{4}{10} * 150\,000 * 10 * (1 + 0{,}05)^{-6} = 447\,729{,}24\ kr$ (19)

7 years

$C_{SV,chg} = \frac{3}{10} * 150\,000 * 10 * (1 + 0{,}05)^{-7} = 319\,806{,}60\ kr$ (20)

8 years

$C_{SV,chg} = \frac{2}{10} * 150\,000 * 10 * (1 + 0{,}05)^{-8} = 203\,051{,}80\ kr$ (21)

9 years

$C_{SV,chg} = \frac{1}{10} * 150\,000 * (1 + 0{,}05)^{-9} = 96\,691\ kr$ (22)

10 years

$C_{SV,chg} = \frac{0}{10} * 150\,000 * (1 + 0{,}05)^{-10} = 0\ kr$ (23)

Total capital costs:

$$C_{capital} = N_{buss} * C_{buss} + C_{charge} - C_{SV,total} \quad (24)$$

$$C_{SV,total} = C_{SV,Bus} + C_{SV,chg} \quad (25)$$

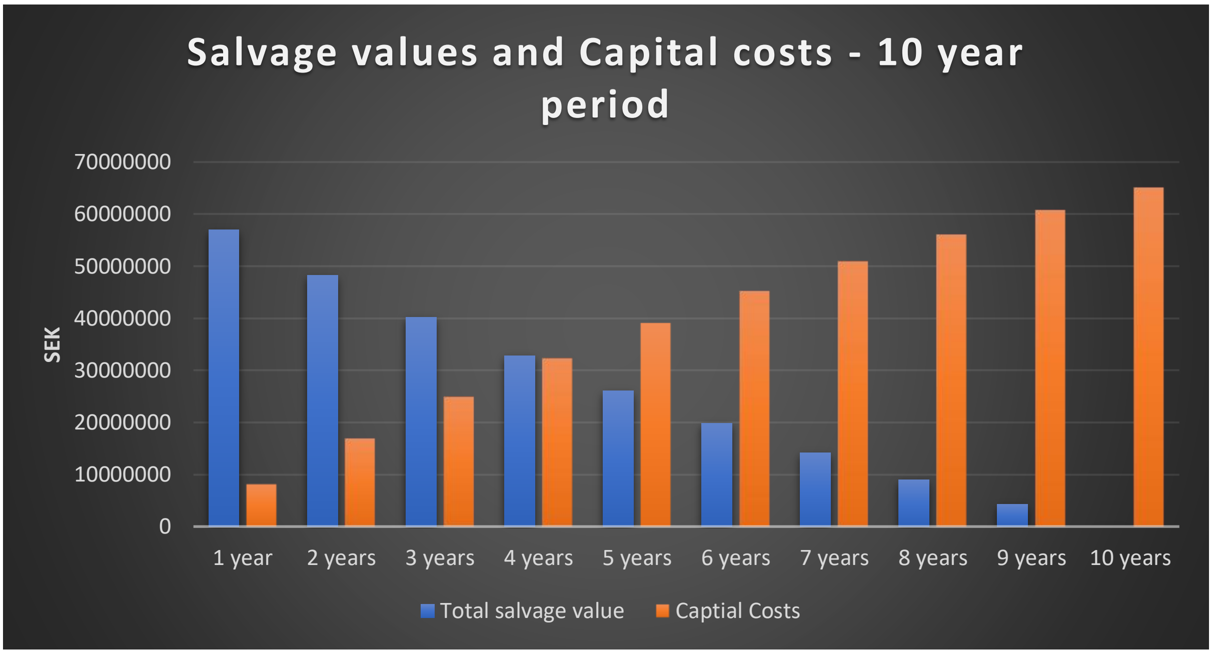

Diagram 1. Capital costs and salvage values per year.

As presented in the diagram, it is evident that the salvage values decreases the longer the buses are used, which causes the capital cost to rise each year. The capital costs are highest when the buses have reached the end of their life span, causing the salvage value to be nullified.

3.5.3 Operation cost

The operation cost consists of CO2 emissions costs, maintenance, and energy costs for a bus fleet. The following equation describes annual operation costs:

$$C_{OP} = \sum_{j=0}^{T} (N_{bus} * D_j \left(C_{nrj_j} + C_{m_j} + C_{co2_j}\right) + C_{chg} * m_{chg}) * (1 + d_{rate})^{-j} \quad (26)$$

D_j = Yearly driven distance

C_{nrj_j} = Energy cost

C_{m_j} = Maintenance cost

C_{co2_j} = Carbon dioxide emission cost

m_{chg} = Charging device maintenance cost factor as percentage

d_{rate} = Discount rate

T = Time interval for the analysis

An approximate driven distance for the bus line is around 65 000 km per year, energy cost is 1,5 sek/kWh and maintenance cost are 2 sek per kilometer driven with a discount rate of 5 %. Cost factor for charging device maintenance cost is set to 3 %. Time interval for the analysis is as previously mentioned set to 10 years.

Initial operation cost

$$C_{OP}=\sum_{j=0}^{10}(10*0(1{,}5+2+0)+150\,000*0{,}03)*(1+0{,}05)^{-0}=0\ (27)$$

Operation cost after 1 year

$$C_{OP}=\sum_{j=1}^{10}(10*65\,000(1{,}5+2+0)+150\,000*0{,}03)*(1+0{,}05)^{-1}$$
$$=2\,170\,952{,}38\ kr\ \ (28)$$

Operation cost after 2 years

$$C_{OP}=\sum_{j=2}^{10}(10*65\,000(1{,}5+2+0)+150\,000*0{,}03)*(1+0{,}05)^{-2}$$
$$=2\,067\,573{,}70\ kr\ (29)$$

Operation cost after 3 years

$$C_{OP}=\sum_{j=3}^{10}(10*65\,000(1{,}5+2+0)+150\,000*0{,}03)*(1+0{,}05)^{-3}$$
$$=1\,969\,117{,}81\ kr\ (30)$$

Operation cost after 4 years

$$C_{OP}=\sum_{j=4}^{10}(10*65\,000(1{,}5+2+0)+150\,000*0{,}03)*(1+0{,}05)^{-4}$$
$$=1\,875\,350{,}29\ kr\ (31)$$

Operation cost after 5 years

$$C_{OP}=\sum_{j=5}^{10}(10*65\,000(1{,}5+2+0)+150\,000*0{,}03)*(1+0{,}05)^{-5}$$
$$=1\,786\,047{,}90\ kr\ (32)$$

Operation cost after 6 years

$$C_{OP}=\sum_{j=6}^{10}(10*65\,000\ (1{,}5+2+0)+150\,000*0{,}03)*(1+0{,}05)^{-6}$$
$$=1\,700\,998\ kr\ (33)$$

Operation cost after 7 years

$$C_{OP}=\sum_{j=7}^{10}(10*65\,000(1{,}5+2+0)+150\,000*0{,}03)*(1+0{,}05)^{-7}$$
$$=1\,619\,998{,}09\ kr\ (34)$$

Operation cost after 8 years

$$C_{OP} = \sum_{j=8}^{10} (10 * 65\,000(1{,}5 + 2 + 0) + 150\,000 * 0{,}03) * (1 + 0{,}05)^{-8}$$
$$= 1\,542\,855{,}33\ kr \quad (35)$$

Operation cost after 9 years

$$C_{OP} = \sum_{j=9}^{10} (10 * 65\,000(1{,}5 + 2 + 0) + 150\,000 * 0{,}03) * (1 + 0{,}05)^{-9}$$
$$= 1\,469\,386{,}02\ kr \quad (36)$$

Operation cost after 10 years

$$C_{OP} = \sum_{j=10}^{10} (10 * 65\,000(1{,}5 + 2 + 0) + 150\,000 * 0{,}03) * (1 + 0{,}05)^{-10}$$
$$= 1\,399\,415{,}26\ kr \quad (37)$$

Total operation cost

$$C_{OP,total} = 17\,601\,694{,}77\ kr \quad (38)$$

Diagram 2. Operation costs during the life span of the bus

Diagram 3. Cumulative operation cost over 10 years.

The difference between regular operation cost and cumulative operation cost is that in the cumulative operation cost the yearly driven distance increases 65 000 km per year, so for example the second year instead of calculating with a yearly driven distance of 65 000 km, the distance is multiplied by 2.

Year	D_j
1	65 000 km
2	130 000 km
3	195 000 km
4	260 000 km
5	325 000 km
6	390 000 km
7	455 000 km
8	520 000 km
9	585 000 km
10	650 000 km

3.5.4 Lifecycle cost

The total life-cycle cost can be calculated by adding the capital costs and operation costs according to the following equation:

$$C_{LC} = C_{CAP} + C_{OP} = 65\,150\,000 + 17\,601\,694 = 82\,751\,694\ kr \quad (39)$$

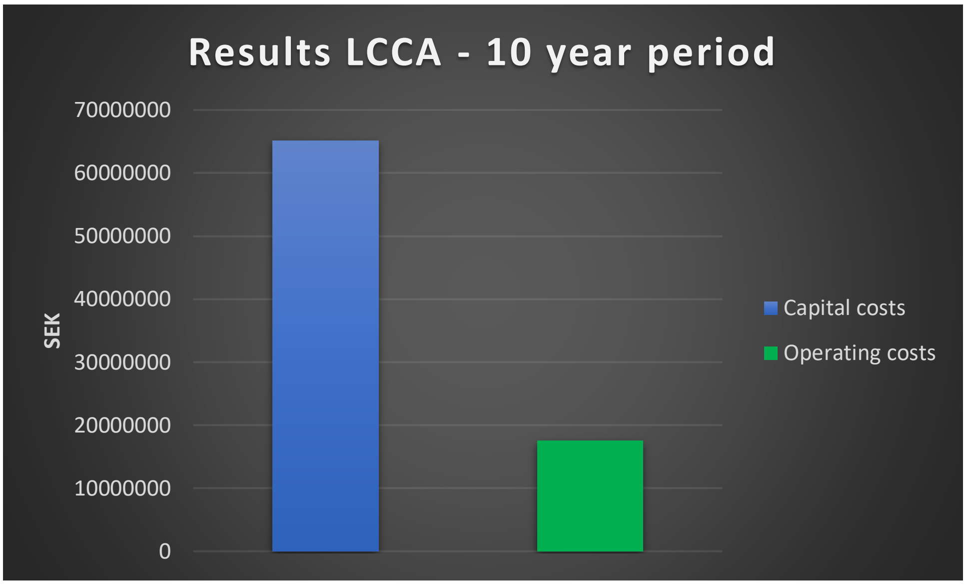

Diagram 2. The total lifecycle cost for a bus fleet of 10 buses with an acquisition cost of SEK 6.5 million per bus

According to calculations, the total life cycle cost for a bus fleet of 10 buses with a time period of 10 years is SEK 82 751 694. Or in other currencies, 7 850 910 €/8 607 770 $. The capital costs for the electric bus fleet accounted for approximately 80 % of the total life cycle cost. A major reason as to why the capital costs are so high for e-buses compared to other conventional buses is their high initial cost, as it was expected.

The analysis was based on a bus fleet only composed of 10 buses, which has a vital effect on the final lifecycle cost. A larger bus fleet would have resulted in a substantially larger lifecycle cost. Major cities with high urban populations often require larger bus fleets in order to meet the need for transportation. For example, if the bus fleet was composed of 25 buses instead, then the capital and operation costs would be remarkably higher.

It may be advantageous to consider how the lifecycle cost is for only one electric bus in order to adequately compare the results of the lifecycle costs with other types of buses.

$$C_{capital,10\,years} = 1 * 6\,500\,000 + 150\,000 - \ 0\ kr = 6\,650\,000\ kr\ (40)$$

$$C_{OP,total} = 1\,791\,442\ kr\ (41)$$

$$C_{LC} = C_{CAP} + C_{OP} = 6\,650\,000 + 1\,791\,442 = 8\,441\,442\ kr\ (42)$$

According to an analysis in a study conducted by professors in different universities where they compared the life cycle cost between a diesel and electric bus showed that the total lifecycle cost for a diesel bus was approximately 560 000 € (Potkany et al., 2018). The study was based on a similar method to the one used in this analysis and also had a 10-year time period with a similar distance traveled per year and discount rates. The diesel bus was a Mercedes – Benz, Merkavim Pioneer and had an acquisition cost of 234 000 €, which is about 2,45 million SEK. Total lifecycle cost for the diesel bus landed on approximately 560 000 € (5.9 million SEK). Comparing the LCC for the diesel bus and electric bus in this analysis based on given parameters, the difference is 240 251 €.

4 Discussion

4.1 Benefits of electric buses

The environmental goal set on reducing emissions in urban areas and slowly get rid of fossil fuel is largely dependent on the transport sector which represent almost a third of all greenhouse related emissions worldwide. The benefits also include air quality improvements and elimination of noise pollutions and toxic gases which also bring forward health improvements. But some cities have already implemented electrified buses to their transport system, have they reported these benefits or even additional benefits caused by electric buses?

The only major city worldwide with a full electric bus fleet is Shenzhen in China. Between 2011 and 2017 the Shenzhen eastern bus company transformed all its diesel buses to electric ones and currently has the world's largest electric bus fleet. The reported benefits were huge, only one year after the shift to electric buses the average amount of fine particles (PM2.5) had reached 26 micrograms per cubic meter according to a report made by Shenzhen human settlement and environment commission in 2018 (Zhong et al., 2019). This result was the cleanest air quality in Shenzhen in 15 years and put them sixth overall in the country's list monitoring air quality index. The benefits of electric buses have proven them self in many cases, most notably as mentioned in Shenzhen. An additional benefit was that over 5.000 private car owners in the city shifted over to electric buses (ISGF, 2018). Resulting in less traffic congestion and CO2 emission from cars and improving the overall urban life.

The major benefit of electric buses is the sustainability it brings to the transport system while also contributing to the life quality. But the deployment of electric buses is not the only solution in dealing with air quality and emissions in urban area. The electrification should only be one part of the zero-emission goal and in addition provide a more sustainable mobility strategy to help cities become a healthier place to live in.

Another huge benefit of electric vehicle is so called eCAVs standing for electric, connected, automated vehicles. The primary aim is to assist humans in driving, but it can also be utilized as a tool for improving traffic conditions by streamlining traffic flow breakdown. The design of eCAVs focus on both the perspective of vehicle manufacturers and transportation managers and users. That is achieved by forming based car models on the future automated electric vehicles and emphasizing the aforesaid design on high level of automation which leads to efficient and energy saving traffic operation (Qu et al., 2020).

4.2 Feasibility of transport electrification

The technology has already been implemented by numerus different companies in many cities and proven feasible. The problem is that the situation differs enormously and which in turn demand an in-depth feasibility study on the most appropriate technology given the local context. To allow for the whole transport system to be electrified then the current technological, economical and institutional challenges need to be dealt with and improved to simplify the implementation of electrification.

The technology behind electric buses is relatively new and even if it is feasible it still has some limitations. The main component in electric buses is the battery and currently the majority is made of lithium-ion. It has a lot of attribute advantages over other electric batteries but still retracted by the limited range and efficiency. The freshness of the battery technology has not enabled manufacturers complete knowledge about the lifecycle of electric batteries and henceforth hindered the trouble shooting and improvement of electric batteries. But with today's material and design of lithium-ion battery it is expected to reach the maximal potential in the next years (Saft, 2017). The next step is both improving and introducing the next generation lithium-ion battery and testing of new technology that can transform the electric transportation. Currently research is being made on a new kind of battery called solid-state batteries that changes the liquid electrolyte to solid one and possibly result in higher energy density and power density (Janek et al., 2016). But the concept is condemned with a lot of prejudice and misjudgments and still need work on some key issues. The point is that both battery manufacturers and researcher know the current standard of batteries needs to improve and will determine if the electrification process will be a success.

Tied with improved battery technology is reduced overall cost for an electric bus. The financial challenges are not only the initial cost for the vehicle and the city authority need a capital for constructing the new infrastructure to create the basic functions of electromobility. Of course, a lack of knowledge will lead to further financial costs and ineffective implementation. Therefore, it is advised for city authorities to hire consultants from so-called sister cities with previous experience on electrifying the transport system and provide technical dimension for electric buses. This include for the city authority to make institutional arrangements for smother electrification process and combat the financial challenges.

In today's situation it is hard to argue for an economic advantage of electric powered buses over diesel powered buses. An institutional action to counter this is to offer state subsidies for transport companies on acquisitions of electric buses and covering the added cost. In Sweden bus operators can seek a premium on 40 percent of the additional cost compared to a similar size diesel bus (Trafikverket, 2019). This does not result in the same impact as the previously mentioned situation in Shenzhen where the city council together with the national government subsidized half of the total initial cost of every electric bus (ISGR, 2018). The institutional role has the power to elevate the electrification process or to repress the shift. The goals of achieving a zero-emission transport sector is only a distant dream if not the right initiative is taken by all parts involved. This goes from manufacturers providing better technology to authorities and transport companies fulfilling the potential and standardizing the technology for a more sustainable transportation.

4.3 Impact on cities

The long-term effect of electrified buses and transport system is a healthier life in the city core and drastic decline in emissions while also changing the operation of transport and the visual image it possesses. The impact can be divided in two part where one is about the impact of the technology and can be determined beforehand. That is regarding the no emission and noise pollution part, but the second part is how the electrification of transport system impacts the city in terms of day to day life. This is more complex to answer because today there only exist one city in the world with a fully electric transport system, Shenzhen in China. There exist many disparities between China and Sweden so the chosen approach and result may not be same, yet it is still the only place with knowledge about the impacts on cities.

According to report made by Bloomberg new energy finance the electric buses will save about 270.000 barrels of diesel every day worldwide and provide a bigger impact than electric cars have on cities (Prosser, 2019). This will make cities less dependent on sourcing fossil fuel and instead shift to locally produced electricity. But in order to really fulfill the potential of transport electrification this power needs to come from renewable sources. Instead the risk of only moving the pollution from the city and placing in them in areas around coal plants will arise other problems. The stress electric buses put on electric grid in the city has proven to be minimal. Mostly because the electric demand is low during the night and the electric buses run through the day and charge during the night.

The transport challenges today consist of weak safety, large traffic congestions and in need of changes to become more sustainable. All this undermines the lives of everyone in major cities. Every year 1.25 million people die from traffic accidents and another 50 million gets injured while also being the leading cause of death for people under the age of 45 (Qu et al., 2020). The human factor is the main cause for these accidents and in order to fight the transport challenges new technological innovations have been brought forward. Future electric vehicles will have the ability to communicate with infrastructure controls by V2G but also to other individual vehicles through vehicle-to-vehicle (V2V).

4.4 Lifecycle cost analysis

In order to have the possibility to compare electric buses from technical, economic and environmental perspectives and make comparisons relative to other alternative buses, an LCCA had to be conducted. The method gave us a detailed and multifaceted view where we could take multiple cost structures into account and then quantify the result. The capital costs in computations helped us obtain both a short-term and long-term perspective in the analysis by including the initial costs of the bus and its charging components while also including the residual value and how it was affected over the life span of the bus. Calculations showed that the capital costs were very high and made up the majority of the total life cycle cost.

On the other hand, operation costs included yearly driven distances, energy and maintenance costs. The energy costs that were estimated to be 1.5 SEK/kWh and the maintenance costs 2 SEK/kilometer driven were assumed to be constant for the entire time period in the calculation, so we did not take into account variations in price due to various factors which could have had a noticeable effect on the total operation cost after 10 years. Equations for technology replacements costs were not included in computations due to lack of information regarding how to calculate the replacement function, F_r, indicating battery replacement. The parameter has an output of 0 or 1 and determines if replacement costs related to technological components in the bus will be taken into account or not, which can increase the final lifecycle cost. All values obtained in calculation were only guideline values and not specific values for bus line 55, resulting in the final life cycle cost being largely theoretical.

5 Conclusion

The purpose of this report was to investigate the benefits of electric buses, how feasible it is to implement the use of electric driven buses in urban transport systems and the potential impact they can have on cities. The report was finalized with a lifecycle cost analysis on an electrified bus line. Through our analysis, we can conclude that the implementation of electric buses has enormous potential to decrease dependency on fossil fuels in transit systems and improve the urban environment for both people and nature. The significant improvement electric buses offer when it comes to reduction in noise and air pollution are advantageous from many aspects. Recent projects, such as the one carried out by electricity in Gothenburg with bus line 55 has shown great promise and has proven that electrifying bus lines in smaller scales is a feasible option today. However, the technology still needs more time and resources to be able to develop, expand and make it a viable option and competitive in more cities compared to other traditional buses. There are still many technological, economical, and institutional barriers that needs to be taken care of and considered to improve the possibilities and prerequisites for electromobility.

5.1 Suggestions for future work

Implementing electric buses is a complex objective with many different factors that needs to be taken into consideration. Analyzes and conclusion in the report have been general and do not give a clear picture of the feasibility of electric buses. There is a lot of room for further research and in-depth studies to analyze how institutional, economic, and technological challenges can be improved. A more detailed lifecycle analysis can also be carried out, taking into account more factors such as perhaps larger bus fleets, a longer life span of buses, the variability in different parameters in order to further analyze the economic factors that are so central in electric buses.

6 References

Trafikverket. (2019). *Transportsektorns utsläpp.* Retrieved from: https://www.trafikverket.se/for-dig-i-branschen/miljo---for-dig-i-branschen/energi-och-klimat/Transportsektorns-utslapp/

Marshall, A. (2019). *Why electric buses haven't taken over the world – yet.* Retrieved from: https://www.wired.com/story/electric-buses-havent-taken-over-world/

Xylia, M. (2018): *Towards electrified public bus transport – The case of Stockholm.* Doctoral Thesis. Department of Energy Technology. KTH Royal Institute of Technology, SE-100 44, Stockholm, Sweden, 2018, 77 p.

Union of concerned scientists. (2008). *Cars, Trucks, Buses and Air pollution.* Retrieved from: https://www.ucsusa.org/resources/cars-trucks-buses-and-air-pollution

Naturvårdsverket. (2019). *Fakta om kväveoxider i luft.* Retrieved from: https://www.naturvardsverket.se/Sa-mar-miljon/Klimat-och-luft/Luftfororeningar/Kvaveoxider/

Naturvårdsverket. (2019). *Utsläpp av kolmonoxid till luft.* Retrieved from: http://www.naturvardsverket.se/Sa-mar-miljon/Statistik-A-O/Kolmonoxid-utslapp-till-luft/

Naturvårdsverket. (2017). *Utsläpp I siffror.* Retrieved from: https://utslappisiffror.naturvardsverket.se/Amnen/Andra-gaser/Svaveldioxid/

Naturvårdsverket. (2018). *Fakta om kolmonoxid i luft.* Retrieved from: https://www.naturvardsverket.se/Sa-mar-miljon/Klimat-och-luft/Luftfororeningar/Kolmonoxid/

Naturvårdsverket. (2020). *Fakta om svaveldioxid i luft.* Retrieved from: https://www.naturvardsverket.se/Sa-mar-miljon/Klimat-och-luft/Luftfororeningar/Svaveldioxid/

Naturskyddsföreningen (n. d.). *Därför förändras klimatet.* Retrieved from: https://www.naturskyddsforeningen.se/globaluppvarmning

Volvobuses. (n. d.). *How electric buses can address noise pollution.* Retrieved from: https://www.volvobuses.com/en-en/news/2019/sep/electric-buses-can-address-noise-pollution.html

Jacyna, Marianna., Wasiak, Mariusz., Lewczuk, Konrad., & Karon, Grzegorz. (2017). Noise and environmental pollution from transport: decisive problems in developing ecologically efficient transport systems. Vol. 19 Issue 7, 2017. Retrieved from: https://www.jvejournals.com/article/19371/pdf

Grönlund, Anna. (2019). *Statistik om bussbranchen.* Sveriges bussföretag. Retrieved from: https://www.transportforetagen.se/globalassets/rapporter/buss/190827-statistikrapport2019final.pdf?ts=8d79ff6569b3d00

Transport & Environment (2018). *Electric buses arrive on time: Marketplace, economic, technology, environmental and policy perspectives for fully electric buses in the EU.* Retrieved from: https://www.transportenvironment.org/sites/te/files/publications/Electric%20buses%20arrive%20on%20time.pdf

Electricity (2016). *Cooperation for sustainable and attractive public transport.* Retrieved from: http://www2.trafikkontoret.goteborg.se/resourcelibrary/Statusrapport_2016_short_ENG_.pdf

Potkany, Marek., Hlatka, Martina., Debnar, Marek. & Hanzl, Jiri. (2018). Comparison of the life cycle cost structure of electric and diesel buses. doi: 10.17818/NM/2018/4SI.20

NESTE (n.d.). *Lägre utsläpp med Neste MY Förnybar Diesel (HVO).* Retrieved from: https://www.neste.se/neste-my-hvo/hvo

Sclar, Ryan., Gorguinpour, Camron., Casellanos, Sebastian., & Li, Xiangy. (2018). *Barriers to adopting electric buses.* World resources institute. Retrieved from: https://wrirosscities.org/sites/default/files/barriers-to-adopting-electric-buses.pdf

Helmenstine, Anne. (2019). Why Batteries Discharge More Quickly in Cold Weather. *ThoughtCo.* Retrieved from: https://www.thoughtco.com/why-batteries-discharge-quickly-cold-weather-607889

Marshall, Brain (2006). Howstuffworks. https://electronics.howstuffworks.com/everyday-tech/lithium-ion-battery1.htm

CEI, Clean energy insitution. Undated. University of Washington. Retrieved from: https://www.cei.washington.edu/education/science-of-solar/battery-technology/

Houbbadi, Adnane. Trigui, Rochdi. Pelissier, Serge. Redondo-Iglesias, Eduardo. Bouton, Tanguy. (2019). Optimal Scheduling to Manage an Electric Bus Fleet Overnight Charging. https://www.mdpi.com/1996-1073/12/14/2727

Rogge, Matthias. Wollny, Sebastian. Sauer, Dirk U. (2015). Fast Charging Battery Buses for the Electrification of Urban Public Transport—A Feasibility Study Focusing on Charging Infrastructure and Energy Storage Requirements. https://www.mdpi.com/1996-1073/8/5/4587

Göhlich, D., Fay, T., Jefferies, D., Lauth, E., Kunith, A., & Zhang, X. (2018). Design of urban electric bus systems. Cambridge university press. https://www.cambridge.org/core/journals/design-science/article/design-of-urban-electric-bus-systems/1C0E4AA05F6E1FBF8A545E13F6A8D2DE

Zhicheng, Bi. De Kleine, Robert. A. Keoleian, Gregory. (2016). Integrated Life Cycle Assessment and Life Cycle Cost Model for Comparing Plug-in versus Wireless Charging for an Electric Bus System. https://onlinelibrary.wiley.com/doi/epdf/10.1111/jiec.12419

Zhaocai, Liu. Ziqi song, Yi He. (2017). Optimal Deployment of Dynamic Wireless Charging Facilities for an Electric Bus System. https://journals.sagepub.com/doi/pdf/10.3141/2647-12

Glotz-Richter, Michael. Koch, Hendrik. (2016). Electrification of Public Transport in Cities.
https://www.sciencedirect.com/science/article/pii/S2352146516304227

UITP. Union internationale des transports publics. (2019). The impact of electric buses on urban life. https://www.uitp.org/sites/default/files/cck-focus-papers-files/UITP-policybrief-June2019-V6%20WEB%20-%20OK_0.pdf

Electricity. (2016). Forskning för hållbara städer. Retrieved from: https://www.electricitygoteborg.se/forskning

Sweco. (2018). Many european cities are undergoing a transport revoultion. https://www.sweco.se/en/news/press/2018/many-european-cities-are-undergoing-a-transport-revolution/

EC. European commission. (2018). In-depth analysis in support of the commission communication. *A Clean Planet for all A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy.* https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en.pdf

Benoît, Robyns. Christophe, Saudemont. Daniel, Hissel. Xavier, Roboam. Bruno, Sareni. Julien, Pouget. (2016). [Electronic]. Electrical Energy Storage in Transportation Systems. Wiley-ISTE. pp. 1-18

IRENA. International renewable energy agency. (2017). Electricity storage and renewables: Cost and markets to 2030.
file:///C:/Users/ahmed/Downloads/IRENA_Electricity_Storage_Costs_2017.pdf

Sorrentino, Marco. Rizzo, Gianfranco. Sorrentino, Luca. (2014). A study aimed at assessing the potential impact of vehicle electrification on grid infrastructure and road-traffic greenhouse emissions.
https://www.sciencedirect.com/science/article/abs/pii/S0306261914000592

Farrhanghi, Hassan. (2010). The path of the smart grid. Retrieved from: https://ieeexplore.ieee.org/abstract/document/5357331

Zong, Jonathan. (2019).Thatsmags. Shenzhen Had the Cleanest Air in 15 Years in 2018. Retrieved from:
https://www.thatsmags.com/china/post/26603/shenzhen-having-cleanest-air-in-15-years

ISGF. Indian smart grid forum. (2018). Electric Bus Revolution of Shenzhen City in China. Retrieved from: https://indiasmartgrid.org/reports/ISGF%20-%20Visit%20to%20Shenzhen%20Eastern%20Bus%20Company%20Ltd%20on%2016th%20April%202018.pdf

Saft. (2017). Three battery technologies that could power the future. Retrieved from: https://www.saftbatteries.com/media-resources/our-stories/three-battery-technologies-could-power-future

Janek, Jurgen. Zeier, G.Wolfgang. (2016). A solid future for battery development. Retrieved from: https://www.nature.com/articles/nenergy2016141.pdf

Trafikverket. (2019). Elbussar I Sveriges kollektivtrafik. *En kartläggning av Trafikförvaltningen Stockholm, Skånetrafiken och Västtrafik utifrån fyra perspektiv.* https://www.trafikverket.se/contentassets/2cf6ea91cdba4601bc36afa31b549c5d/rapport--elbussar-i-sveriges-kollektivtrafik.pdf

Prosser, Marc. (2019). China's electric buses save more diesel than all electric cars combined. Retrieved from: https://singularityhub.com/2019/04/22/chinas-electric-buses-save-more-diesel-than-all-electric-cars-combined/

Lajunen, Antti. (2018). Aalto University, Department of Mechanical Engineering, PO Box 14300, FI-00076. *Lifecycle costs and charging requirements of electric buses with different charging methods.*

Qu, Xiaobo. Yu, Yang. Zhou, Mofan. Lin, Ching-teng. Wang, Xiangyu. (2020). Jointly dampening traffic oscillations and improving energy consumption with electric, connected and automated vehicles: A reinforcement learning based approach. Applied Energy, 257, 114030.