ERASMUS UNIVERSITY ROTTERDAM
Erasmus School of Economics
Bachelor Thesis Economics and Business Economics

The opportunities and challenges of implementing zero-emission buses in public transport in The Netherlands

Name student: Heleen Koch
Student ID number: 495169
Supervisor: G. Mingardo
Second assessor: S. J. Vermeulen
Date final version: August 15th, 2021

Acknowledgements

During the thesis process, I have received worthful support and advise from my supervisor, Dr. Giuliano Mingardo, for which I would like to thank him. Additionally, I would like to thank all interviewees from Arriva, GVB and RET for participation and providing detailed information about the implementation of zero-emission buses at their companies. The interviewees are in no way responsible for the content, I will take full responsibility for this thesis' content.

Abstract

In this research, I examine what the opportunities and challenges are of implementing zero-emission buses in public transport in The Netherlands. Zero-emission buses result in lower greenhouse gas emissions. The usage of renewable electricity sources provides an opportunity to further reduce emissions. In The Netherlands, mostly battery electric buses are used as zero-emission buses due to the high costs of fuel cell buses. The low range of battery electric buses is a challenge but expected to be overcome by developments regarding the batteries and fast charging facilities in the future. Rising electricity demand can be a challenge, but agreements with network providers might avoid electricity shortage. In cities, location scarcity is observed, but may be avoided by agreements with municipalities. Costs of zero-emission buses are high, but Dutch public transport companies manage to cope with these by concessions and subsidies offered by third parties.

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1. Introduction

Over the last few decades, greenhouse gas emissions have increased and contributed significantly to climate change (Kennedy et al., 2009). Greenhouse gas emissions negatively affect air quality (Althor et al., 2016). Every year, approximately five million people die as a result of air pollution, making it the number four leading cause of death in the world (Ritchie & Roser, 2017). Roughly nine percent of all deaths are due to air pollution (Ritchie & Roser, 2017). In The Netherlands in 2018, the total greenhouse emissions were 179.99 metric tons of carbon dioxide equivalent ($MtCO_2e$) (World Resources Institute, 2021). Transportation-related greenhouse gas emissions totalled 30.83 $MtCO_2e$, accounting for 17.1% of all greenhouse gas emissions in The Netherlands (World Resources Institute, 2021). Because transport-related emission account for a large portion of the total greenhouse gas emissions, making transportation more sustainable can make a significant difference in greenhouse gas emissions.

The European Commission has set a goal for the European Union to be climate neutral by 2050, which implies that no net greenhouse gas emissions are permitted (European Commission, 2021). To reach this goal, the European Commission has also set a target particularly for transport: new vehicles are not allowed to emit any greenhouse gases by 2035 (European Commission, 2021). In order to reach these goals, every country must contribute. Therefore, several governmental and public transport parties have come to an agreement in The Netherlands. From 2025 onwards, all new bought public transport buses must be zero emission (Interprovinciaal Overleg et al., 2016). Additionally, only zero-emission buses will be permitted to operate by 2030 (Interprovinciaal Overleg et al., 2016).

In the past, almost all public transport buses were fossil fuelled, causing high greenhouse gas emissions with the use of transport. To make the usage of public transport more sustainable, zero-emission buses should be deployed. Zero-emission buses do not emit any greenhouse gases during their operation, contrary to fossil fuelled buses. There exist two kinds of zero-emission buses, namely battery electric buses and fuel cell electric buses (Islam & Lownes, 2019). In case of battery electric buses, the energy is stored in a battery which needs to be charged via an extern mechanism (Mahmoud et al., 2016). For the use of hydrogen fuelled electric buses, the vehicle is fuelled with hydrogen, which is then turned into electricity (Islam & Lownes, 2019).

New innovations such as zero-emission buses can be difficult to adopt, but if implemented successfully they can open doors to new possibilities. Multiple studies on the separate components of electric buses have been conducted. However, no analysis has been done about the whole case: the knowledge about various components of zero-emission buses in combination with the actual implementation of zero-emission buses in real-life. Therefore, in this research it will be investigated what the challenges and opportunities are of implementing zero-emission buses in public transport in The Netherlands. The research question is:

“What are the challenges and opportunities of implementing zero-emission buses in public transport in The Netherlands?”

This research consists of multiple components. First, a review of the literature is performed to figure out what is already known in the literature. Subsequently, the methodology is presented which describes the type of research, how the data is collected and how the data is analysed to get results. The results are presented in the section after the methodology. The paper ends with the conclusion and recommendations for further research.

2. Literature Review

2.1 Emissions

Chan et al. (2013) concluded from their research that fuel consumption causes the biggest part of total life cycle emissions of buses. Therefore, if a change in fuel consumption is possible, a relatively large share of life cycle emissions could be omitted. Lajunen and Lipman (2016) mention that fuel cell electric buses and battery electric buses do not emit anything directly once they are in use. Pollutions in the form of emissions are only created during the production of these vehicles (Lajunen & Lipman, 2016). This can be convenient for areas where emissions are usually high, such as densely populated cities. By introducing these zero-emission buses, air in these areas will become cleaner, which will have a positive impact on the residents' health conditions (Xylia et al., 2019).

Even though zero-emission buses do not have direct emissions during operation, the operation of these buses often have indirect emissions (Mahmoud et al., 2016). It depends on the electricity sources what the size of emissions is. Hydrogen is not available right from nature and thus needs to be produced (Nikolaidis & Poullikkas, 2017). Hydrogen can be for example produced by fossil fuels; however, these fuels are not environmentally friendly and emit greenhouse gases (Nikolaidis & Poullikkas, 2017). Mahmoud et al. (2016) mention that the more renewable energy is used as electricity source, the lower the emissions will be. Usage of renewable energy will have the most positive effect on the environment compared to other possible energy sources (Mahmoud et al., 2016).

A study conducted by Abdul-Manan (2015) shows that the probability that battery electric buses cause a decrease in greenhouse gas emissions is 90 percent. Next to this, the results show that with the use of battery electric buses approximately 43 percent of emissions can be reduced compared to the usage of fossil fuelled buses during the buses total lifecycle. If battery electric buses are in use, the usage of fossil fuels will decrease and thus the production of such fuels also decrease (Zhou et al., 2016). Due to less needed fossil fuel production, a decrease of approximately 40% in greenhouse gases emitted during the production of these fossil fuels is also expected (Zhou et al., 2016). A comparison between battery electric vehicles and hybrid electric vehicles is made in the research by Abdul-Manan (2015). With the applicable conditions on the different sorts of vehicles during the year of the research, it seemed like replacing hybrid electric vehicles with battery electric vehicle could be more polluting, in terms of total greenhouse gas emissions, than keeping the hybrid electric vehicles (Abdul-Manan, 2015). The emissions of hybrid electric vehicles were 15 percent lower compared to replacing these with battery electric vehicles (Abdul-Manan, 2015). This is mainly due to the further stage the development of hybrid vehicles is in (Abdul-Manan, 2015). Additionally, new infrastructure is needed for battery electric vehicles, which is not the case for hybrid electric cars. This new infrastructure is expensive. Therefore, Abdul-Manan (2015) recommends that battery electric buses should not replace the hybrid vehicles but should only replace the vehicles which are fully fossil fuelled. Hybrid electric vehicles can be effective, since the infrastructure does not need to be adapted, and the emissions of such vehicles are already relatively low compared to fully fossil fuelled vehicles (Abdul-Manan, 2015). The most important key for battery electric vehicles to be successful, is that energy sources will become cleaner. This is also emphasized by Zhou et al. (2016); electric battery buses cause a decrease in emissions, but if you want to make the usage of battery electric buses more beneficial, the electricity needs to become greener. Zhou et al. (2016) also add that a loss in electricity during charging needs to be minimised, to keep the emissions as low as possible. Abdul-Manan (2015) mentions that countries which have little renewable energy to their access, might be better off by investing in renewable energy sources than in battery electric vehicles. Since then, not only transport, but also non-transport sectors could emit less pollutants (Abdul-Manan, 2015).

In short, zero-emission buses do not have operational emissions. However, if the electricity sources are not renewable, emissions are still involved and changing to zero-emission buses will not have that big of an effect in total lifecycle emissions.

2.2 Electricity sources and electricity efficiency

As more vehicles are electrically driven, the demand of electricity for transport is increasing. That might seem favourable considering the increasing emissions due to fossil fuels. Nonetheless, if the energy sources are not renewable enough, the usage of electricity will not cause a decrease in emissions (Mahmoud et al., 2016). For example, only 18.8% of the electricity was generated with renewable sources in The Netherlands in 2019 (CBS, 2020). Fossil fuels produced the other almost 76% of the electricity (CBS, 2020). In 2019, electricity contributed for 18.5% to the total greenhouse gas emissions in The Netherlands (CBS, 2021). This last percentage will decrease if the electricity source becomes greener.

Song et al. (2018) address that electricity loss should be taken more into account. Electricity stations are not as efficient as possible. If the electricity efficiency will not increase, the emissions of diesel buses are likely to be lower compared to the emissions of the electric buses (Song et al., 2018). Bi et al. (2015) mention that there is a difference in charging efficiencies between two possible charging options for electric buses. Therefore, which charging option to use should be carefully considered. Plug-in charging is expected to be five percent more efficient compared to the wireless charging option. The plug-in charging option is expected to have an efficiency of 90% and the wireless charging option an efficiency of 85% (Bi et al., 2015). Next to this, electricity sources should be more environmentally friendly in order to decrease emissions created by public transport. This can be reached by using for example more solar photovoltaics (Song et al., 2018).

Another problem that might arise, is that in relatively colder countries, electricity is also needed to heat the bus itself and not only to charge the bus (Lajunen & Lipman, 2016). This causes that less energy remains for the transport service of the bus, resulting in an lower range (Lajunen & Lipman, 2016). Furthermore, an electricity deficit for hydrogen fuelled buses may be caused by the scarce availability of hydrogen, which is needed in fuel cells to generate electricity (Hua et al., 2014). At a hydrogen station in the United States, distributed liquid hydrogen and hydrogen generated by an electrolyser on solar energy are combined (Hua et al., 2014). By doing so, an amount of almost 600 kilograms of hydrogen per day is created (Hua et al., 2014).

To summarize, electric buses might seem sustainable. However, if electricity is produced with fossil fuels, it contributes for a significant share to total greenhouse emissions. Therefore, renewable electricity sources should be used as much as possible. Additionally, electricity efficiency should be optimized in order to prevent electricity deficits.

2.3 Necessary infrastructure changes for charging and refuelling zero-emission buses

One of the main bottlenecks for implementing a zero-emission bus policy is the changes needed in infrastructure (Hua et al., 2014). These changes are expensive. For battery electric buses a special infrastructure design is needed, so that there can be optimal use of the buses and for trying to minimize time waste as much as possible. Lajunen and Lipman (2016) suggest fast charging for battery electric buses made possible by special infrastructure design. This is because buses will be able to operate longer during the day. Next to this, electric buses are reliant on the power grids. If there is a power failure, electric buses will eventually not be able to operate any longer (Lajunen & Lipman, 2016).

Li (2014) also recommends fast charging for battery electric buses. However, Li (2014) recommends fast charging only for densely populated areas, since less space is needed for the infrastructural changes for fast charging. Fast charging is more expensive. If there is a lack of money or high electricity price, fast charging is not favoured (Li, 2014). In that case, slow charging might be a solution, because that occurs during the night when electricity demand is relatively lower (Li, 2014). Therefore, electricity costs will be lower during those times.

Xylia et al. (2017) mention that charging infrastructure depends on various factors, and therefore implementation will differ per situation. In a more recent study, Xylia and Silveira (2018) suggest fast charging as a valuable charging system. As electricity demand increases, the likelihood in reaching the maximum electricity level increase as well, certainly as electrification happens often nowadays. Electricity demand should be spread in time. Charging facilities should be spread over various locations and different times in order to make optimal use of all electric buses, since only then all buses can be charged without a shortage of electricity (Xylia & Silveira, 2018). Partly due to the expected energy deficit, batteries with lower capacity are recommended (Xylia & Silveira, 2018). This will contribute to the prevention of energy demand peaks for electric buses. Another important argument for smaller batteries is that emissions and the costs of buses will be lower (Xylia & Silveira, 2018).

The range of fuel cell electric vehicles and battery electric vehicles is lower than the range of fossil fuelled buses. The average range of diesel fuelled public transport buses was 500 kilometres in 2018 (Topal & Nakir, 2018). In 2013, the range for fuel cell electric buses varied between approximately 355 and 525 kilometres (Hua et al., 2014). Battery electric buses do not have enough battery capacity to operate full day without recharging (An, 2020). In city conditions, battery electric buses have a maximum range of 250 kilometres before the battery is empty (An, 2020). However, battery capacity could be increased to enlarge the range. If insufficient range is a threshold to implement zero-emission buses for rural areas, supplementary hydrogen storage reservoirs can be considered (Hua et al., 2014). By realising this strategy, a greater reach can be achieved, at the cost of a part of the transportation capacity (Hua et al., 2014). Nonetheless, fuel cell electric and battery electric buses are mostly introduced to decrease emissions, and if battery capacity will be enlarged, the batteries become heavier (Xylia et al., 2019). This will cause an uprise in emissions by these vehicles with higher battery capacities (Xylia et al., 2019). Xylia et al. (2019) studied the effect of using electric buses on emissions in Stockholm, Sweden. Results of the research by Xylia et al. (2019) show that a volume of 120 kWh is the optimal volume for a battery in Stockholm. Under this condition in Stockholm, the life cycle emissions of zero-emission buses are the lowest. Too low capacity will negatively impact time efficiency and a lower range, causing higher emissions compared to a battery capacity of 120 kWh. As stated before, if battery capacity becomes too high, batteries will be heavier and thus causing an increase in emissions (Xylia et al., 2019).

To cope with the increasing energy demand caused by the increasing number of batteries for zero emission buses, charging needs to be as efficient as possible to avoid a power failure (Xylia and Silveira, 2018). Conductive chargers can charge vehicles faster than inductive chargers as concluded by Xylia and Silveira (2018). In the study by Xylia and Silveira (2018), conductive charging is defined as a charging system where a plug-in is necessary. According to Yilmaz and Krein (2012), in case of conductive charging system there is a direct connection between the adapter and the plug inlet. Inductive charging is a charging method with wireless, indirect, contact via magnetic areas (Xylia &

Silveira, 2018). Prices for charging systems depend on several circumstances, such as the power grid in the specific area. Results from two case studies showed that a conductive charging installation is cheaper than the inductive charging option. Lindgren (2015) observed a difference of fifty thousand euros between the two charging systems, with the inductive charging option having the highest costs of two hundred thousand euros in a case study performed in Sweden. What should be considered, is that the current costs are unreliable, since costs of both systems will probably reduce due to commercialisation in the future (Xylia & Silveira, 2018).

It is high likely that the benefits of zero-emission buses in terms of emission reduction will outweigh the costs of needed infrastructure changes, such as new hydrogen filling stations, within five years (McKenzie & Durango-Cohen, 2012). Bi et al. (2015) concluded that a plug-in charging system is more polluting and less electrical efficient compared to a wireless system for charging the battery electric buses. Thus, a wireless charging system might be a better option (Bi et al., 2015). However, only small differences are observed over their total lifetime: the plug-in system has 0.3% more energy use and emissions that are 0.5% higher (Bi et al. 2015). In addition to the advantages of being more electrical efficient and less pollutant, a wireless charging system is relatively easy to implement compared to the plug-in charging system. That is because no major visible changes must be made in the infrastructure (Xylia & Silveira, 2018). Additionally, a wireless charging system does not contain movements during charging contrary to the conductive charging system (Xylia & Silveira, 2018). Xylia and Silveira (2018) conclude that that will result in relatively lower maintenance costs for an inductive charging system compared to the conductive system.

For fuel cell electric buses another type of infrastructural change is needed. In order to refuel fuel cell electric buses new refuelling stations are needed which support hydrogen fuel (Hua et al., 2014). This necessary change is expensive to implement. Nonetheless, fuel cell electric vehicles have a lower fuel consumption than diesel or hybrid-diesel vehicles. According to Hua et al. (2014), fuel cell electric buses have on average a 2.1 times lower fuel consumption than diesel fuelled buses. Hua et al. (2014) mention that there should be invested in spacious hydrogen refuelling stations to serve several buses at the same time. An advantage of using hydrogen fuelled buses is the relatively little time needed to refuel: during a hydrogen fuel cell project in London, a refuel time from seven to ten minutes for 30 kilograms of hydrogen was observed (Hua et al., 2014). To compare, the recharging time of battery electric buses can range from approximately 10 minutes to 8 hours, depending on the charging method used and the availability of electricity (An, 2020). However, the fast chargers used to recharge an electric bus in 10 minutes are extremely expensive (An, 2020).

To sum up, fast charging can be used to minimise time waste. Slow charging is advised for dense areas to save space. Additionally, electricity demand peak should be avoided by charging as efficient as possible. Due to the lower range of zero-emission buses compared to diesel fuelled buses, a balance between the range and battery capacity should be found. Conductive charging is faster and cheaper than inductive charging. However, conductive charging is less electricity efficient and inductive charging is easier to implement. Concerning hydrogen fuel cell buses, a hydrogen refuelling station is expensive, but the hydrogen fuel consumption is lower than diesel and refuelling fuel cell buses is faster than recharging electric buses.

2.4 Costs of buses

The purchase price of zero-emission buses is high compared to the price of fossil fuelled vehicles (Hua et al., 2014). The price of a diesel fuelled bus was around €250.000 in 2017 (Potkány et al., 2018). The purchase price for a battery electric bus was around €350.000 in 2018 (Pagliaro & Meneguzzo, 2019). In 2018, average fuel cell bus prices were approximately €650.000 (Pagliaro & Meneguzzo, 2019). The prices of zero-emission buses are expected to decrease. Fuel cell bus prices already decreased for three quarters due to commercialisation since 1990 (Pagliaro & Meneguzzo, 2019). The purchase prices are still higher than the price for diesel fuelled buses. However, these costs are compensated by the relatively low operating and maintenance costs compared to vehicles with other fuel sources (Islam & Lownes, 2019). Xylia and Silveira (2018) mention that due to the early development phase the charging system is in, there is a cost uncertainty. In the United States in 2013, maintenance costs for fuel cell buses ranged between €0.20 and €0.68 per kilometre (Hua et al., 2014). With fuel cell buses there is a high uncertainty regarding the durability of the systems turning hydrogen into electricity (Hua et al., 2014). Also, because the technology of zero emission buses is less developed than the technology of diesel buses, the operational costs for zero emission buses are not yet at an optimal level but are expected to decrease (Hua et al., 2014). Additionally, hydrogen fuel itself is more expensive than diesel. In Canada in 2012, the price of hydrogen was more than three times higher than diesel fuel, causing the usage of hydrogen fuelled buses being expensive (Hua et al., 2014). For hydrogen fuel costs between €4.24 and €5.94 per kilogram were observed in Europe in 2012 (Hua et al., 2014). Contrary, the fuel costs might be higher, the fuel consumption of fuel cell electric buses is much lower than the fuel consumption of diesel buses. Fuel cell buses have an average fuel consumption of 9 kilograms per 100 kilometres, against a fuel consumption between the 11 and 15 kilograms per 100 kilometres for diesel buses (Hua et al., 2014). Over the last couple of years, the benefits of these vehicles are more and more likely to outweigh the costs (Lajunen & Lipman, 2016).

The run-in period can take very long for fuel cell buses, causing these buses not being that beneficial at the beginning of usage. This is mainly due to malfunctioning of communication between the different system components within the vehicle (Hua et al., 2014). After the laboratory testing period, the fuel cell buses go into the run-in period in which the bus developers fix the errors found in that period (Hua et al., 2014). Often, many complications make their first appearance in the run-in period (Hua et al., 2014). In a case study in London, an availability of almost at 70 percent for hydrogen fuelled buses has been observed. Hua et al. (2014) mention that this value is significantly lower than the observed availability percentage of diesel buses. Hua et al. (2014) appoint that this difference is mainly due to the not fully developed logistics network and various obstacles with specific elements. The most common reasons for downtime are related to manufacturing problems and malfunctioning related specifically to the hydrogen system (Hua et al., 2014). However, Hua et al. (2014) mention that once these main problems are solved, it is high likely for fuel cell buses to reach an availability of or even more than 90 percent. Next to this, it might be advantageous for hydrogen fuelled buses to decrease the fuel capacity (Hua et al., 2014). This strategy has been applied to the project in London which ensured that the fuel cell buses could transport more people and that less time was needed to refuel the vehicle (Hua et al., 2014).

Additionally, there is uncertainty regarding financing the vehicles. Institutions form an important body in innovation systems (Negro et al., 2012). Different parties are included in institutions: firms, legal bodies, and government agencies (Negro et al., 2012). In the Netherlands, there are many unstable institutions. The former in combination with institutions which are not enough aligned with practices cause many troubles. One of these problems include that such institutions obstruct and complicate innovation (Negro et al., 2012). Additionally, many made policies regarding subsidies for public transport operating companies are delayed or eventually not introduced at all (Negro et al, 2012). Negro et al. (2012) mention that often if they are introduced, the subsidy will come to an end earlier than expected. This can work demotivating towards bus operators, since they need the money to finance the more expensive zero-emission buses.

The first city that became fully electric in public transport is the city of Shenzhen, China. The most important cause of this successful change in the public transport was the well-matched cooperation between different organizations (Zhang, 2019). The model used, helped ensuring that the problem regarding the high costs of the zero-emission buses could be allayed (Zhang, 2019). First off, the vehicle itself and the power units were bought separately. The financial setup for the vehicles consisted of a financial leasing company, which paid for only the buses directly to the bus production companies. Consequently, the leasing company lends the buses to the public transport company

(Zhang, 2019). The purchase of the battery is done in a different way. A special body is responsible for the charging facilities in Shenzhen (Zhang, 2019). This body receives subsidies from governmental and non-governmental financial institutes and a service fee from the bus company. With this money, it purchases the batteries and oversees all charging facilities, including infrastructure and maintenance (Zhang, 2019). Hereby, the local government cuts costs in the charging framework. Because many parties are involved, the risks in investing in such an operation are shared, which causes the barriers to participate in such an investment being lower (Zhang, 2019).

In short, fuel cell buses are the most expensive followed by electric buses. Diesel fuelled buses are the cheapest. Regarding zero-emission buses, there is uncertainty in maintenance costs, durability and the financing. Hydrogen buses have high fuel costs, but their fuel consumption is lower compared to diesel fuelled buses. By letting multiple parties work together, risks of being involved in the implementation of zero-emission buses are shared, and barriers become lower.

3. Methodology

In this paper, a qualitative research is conducted to determine what the opportunities and challenges are of implementing zero-emission buses in public transport in The Netherlands. Data is collected by combining both a desk and field research. First, a desk research is done by using secondary data obtained via literature found in Google Scholar. The literature is used to review what is already known about the implementation of zero-emission buses, for both battery electric buses and hydrogen fuelled buses. The literature review is divided into four different sections: emissions, electricity, infrastructure changes, and costs. Secondly, a field study in the form of interviews is performed to obtain primary data on how the implementation of zero-emission buses turns out in real-life in The Netherlands. The interviews are semi structured to leave room for additional information provided by the interviewees. The standard questions asked during the interviews can be found in appendix A, sometimes additional questions were asked to get more in-depth answers. The interviews are held separately per company online via Microsoft Teams and had a duration of approximately 45 to 60 minutes per interview. The interviews took place on the 21st and 22nd of July 2021 and only with employees which have experience with projects concerning zero-emission buses. The interviews are recorded to analyse them in as much detail as possible afterwards, with permission of the interviewees. Three interviews are held with three different Dutch public transport companies to see how they experience the implementation. GVB, RET and Arriva are interviewed. The first company interviewed was GVB, operational in Amsterdam. Two employees of GVB were interviewed, namely a program manager responsible for the implementation of electric buses and an employee who is a program manager responsible for projects regarding new vehicles. The next interviewee works as program manager for zero-emission buses at RET. RET is the public transport company in Rotterdam. The last participant of the interviews was a program manager sustainability working at Arriva. Arriva operates in 10 of the 12 Dutch provinces in the north, east, and southeast of The Netherlands. Each of these companies has a different operating area in The Netherlands, and together cover a big part of The Netherlands. Therefore, the interviews together are likely to sketch a representative image of the implementation of zero-emission buses overall in The Netherlands. To analyse the answers given by the interviewees, the questions have been prior subdivided into four sections, the same sections as in the literature review: emissions, electricity, infrastructure changes, and costs. By doing so, the findings of the literature review and the interviews can be easily combined to find an answer to the research question what the opportunities and challenges are of implementing zero-emission buses in public transport in The Netherlands.

4. Results

4.1 The current position of Dutch public transport companies concerning zero-emission buses

GVB, the public transport provider in Amsterdam, currently has 75 battery electric buses, and will deploy more in the future. GVB plans to have zero-emission buses only by 2025. This is five years earlier than nationally agreed upon, because all diesel fuelled buses will have reached the end of their lifespan by 2025. It would be unsustainable to replace them with new diesel fuelled buses that would need to be replaced with battery electric buses only a few years later. Therefore, GVB chooses to replace the diesel fuelled buses immediately with battery electric buses once they reach the end of their lifespan (program manager implementation electric buses GVB, personal communication, July 21, 2021). GVB does not own any hydrogen fuelled buses, since hydrogen buses are more expensive.

RET currently has 55 battery electric buses deployed (program manager RET, personal communication, July 21, 2021). 42 battery electric buses will be introduced to the fleet in 2021, with an additional 45 electric buses expected by the end of 2024. RET is planning to have a fully zero-emission bus fleet at the beginning of 2030, in line with the Dutch governmental measures. RET additionally has two hydrogen fuelled buses, however no further information about these buses is available.

The public transport company Arriva is also making a change to become more environmentally friendly. A strategy for 90 percent reduction and 10 percent compensation of Arriva's emissions has been implemented in 2019 (program manager sustainability Arriva, personal communication, July 22, 2021). Arriva wants to fully operate zero emission by 2025. 217 of the 1500 buses in the total fleet are currently zero emission. These zero-emission buses are battery electric buses. Arriva has no hydrogen fuelled buses, due to the more developed battery electric buses. Arriva intends to do a hydrogen fuelled bus trial in the future.

4.2 Emissions

The program manager of zero-emission buses working at RET (personal communication, July 21, 2021) mentioned that diesel fuelled public transport buses, emit on average 3.473 kilograms CO_2-equivalent per litre from the production of the energy source to the usage of the energy source. On average, a bus uses 24.000 litre per year, resulting in total emissions of 83.352 kilograms of CO_2-equivalent per bus per year (program manager RET, personal communication, July 21, 2021). Therefore, if transformed to a fully battery electric bus fleet, many tons of CO_2-equivalent can be spared since battery electric buses do not have any emissions once in use. Battery electric buses need electricity to function. If the electricity source of these vehicles is not renewable, there will still be emissions during the production of the electricity source itself. Currently, the electricity source of RET is not hundred percent renewable. However, RET is planning on using only renewable energy by 2030, which means the total emissions will significantly further decrease.

The program manager for new vehicles from GVB (personal communication, July 21, 2021) remarked that some public transport companies still use fossil fuel during operation for their battery electric buses. Because the range of battery electric buses is lower than the range of fossil fuelled buses, the electricity should be used optimally. If during colder times electricity is also used to heat the vehicle itself, the range of battery electric vehicles will be even lower (program manager new vehicles GVB, personal communication, July 21, 2021). GVB however opted to be fully emission-free in operation and thus chose to not use fossil fuelled heaters to be as sustainable as possible. GVB does not have any hydrogen fuel cell buses in service. GVB did consider hydrogen fuelled buses as an option and have had a couple hydrogen fuelled buses in the past, since it is technically a good alternative. Due to higher total prices of hydrogen fuelled buses compared to battery electric buses, GVB chose to not have any hydrogen fuelled buses in service. Therefore, no emission information about hydrogen buses was available.

According to the program manager sustainability from Arriva (personal communication, July 22, 2021) the technology of battery electric vehicles is the most developed, compared to hydrogen fuel cell buses. Therefore, Arriva mostly uses battery electric buses. Arriva has a hydrogen fuel cell bus trial at the end of 2021, therefore not much information is available about emissions of hydrogen fuelled buses yet. If Arriva wants to use hydrogen, it prefers to only use hydrogen from renewable sources to minimize the emissions. However, the availability of hydrogen is scarce. Regarding emissions, Arriva not only pays attention to sustainable driving mechanisms, but also examines the circularity of buses before purchasing them (program manager sustainability Arriva, personal communication, July 22, 2021).

4.3 Electricity sources and electricity efficiency

Currently, RET already makes use of some renewable energy sources. To emit as less as possible, RET is making the transition to operate with fully renewable energy sources (programme manager RET, personal communication, July 21, 2021). At RET, when a battery electric bus needs to be charged, approximately five percent of electricity is lost. GVB, the public transport company in Amsterdam, also uses renewable energy sources for charging the battery electric buses. The program manager for new vehicles from GVB (personal communication, July 21, 2021) stated that the electricity efficiency is never a hundred percent. At GVB, around two to three percent of electricity is lost during the charging of electric buses. Several charging factors, like cable length, influence how efficient the electricity is (program manager new vehicles GVB, personal communication, July 21, 2021). The program manager sustainability working at Arriva (personal communication, July 22, 2021) noted that Arriva's buses are already powered entirely by renewable energy. Dutch wind energy and solar energy are the electricity sources for Arriva's buses. A few percent of electricity are lost during charging at Arriva. Additionally, a program manager sustainability at Arriva (personal communication, July 22, 2021) stated that the charger consumes power as well, leaving less power available for charging the bus itself.

As the demand for electricity is rising, the availability of electricity is affected. The program manager for the implementation of electric buses at GVB (personal communication, July 21, 2021) appointed that the electricity demand by public transport companies is much lower than for instance by residential areas or data centres. However, the availability of electricity becomes critical for example in the north of Amsterdam (program manager new vehicles GVB, personal communication, July 21, 2021). The program manager implementation electric buses from GVB (personal communication, July 21, 2021) mentioned that GVB tries to prevent a shortage of electricity by indicating its preferred demand for electricity early to its network operator Liander. GVB tries to keep a good relationship with Liander: for instance, the electricity demand is lower during night, thus GVB agrees to only use the charging stations for slow charging during night (program manager implementation electric buses GVB, personal communication, July 21, 2021). At Amsterdam Central Station, the availability of electricity is critical, whereby GVB might need to purchase a system to limit the demanded power since the charging points are able to demand more power than at hand. RET has not experienced a deficit of electricity (program manager RET, personal communication, July 21, 2021). RET's network operator Stedin can supply the demanded electricity. Additionally, RET uses the substation of the metros and trams for charging buses during the night, since the metro and tram do not use electricity during the night.

If an electricity shortage would happen, RET and GVB have enough reserve fleets since only a small portion of all their buses are currently battery electric. However, as more battery electric buses are put into use, it should be investigated how to deal with power failure (program manager implementation electric buses GVB, personal communication, July 21, 2021). The program manager for new vehicles at GVB (personal communication, July 21, 2021) appointed that the energy grid is available for 99.99% of the time, implying that electricity is only unavailable for a small portion short of each year. As a result, the program manager for new vehicles working at GVB (personal communication, July 21, 2021) questioned whether GVB should invest in a backup plan or just accept a power outage because the buses will not be inoperable immediately due to batteries on board.

Additionally, keeping diesel fuelled buses behind brings costs (program manager new vehicles GVB, personal communication, July 21, 2021).

4.4 Necessary infrastructure changes for charging and refuelling zero-emission buses

For battery electric buses, charging facilities need to be placed, such as charging stations. Multiple charging points need to be installed, to be of service for as many buses as possible. Which charging facilities these exactly are, depend on which charging method the public transport company chooses (program manager new vehicles GVB, personal communication, 21 July, 2021). RET utilizes pantographs on top of the bus which move upwards to connect with the charging point for recharging the battery electric buses (program manager RET, personal communication, 21 July, 2021). An image to show what these pantographs look like can be found in appendix B. These moving pantographs from the bus upwards to the charging point is a technique that GVB and Arriva implemented as well. According to the program manager for new vehicles at GVB (personal communication, 21 July, 2021) this is the most common charging method used in The Netherlands. There is less risk with pantographs on top of the bus compared to pantographs that move from the charging station to the bus (program manager new vehicles GVB, personal communication, 21 July, 2021). If the pantograph moves from the charging station to the bus and the pantograph has a malfunction, there will not be enough capacity left to charge other buses, because that whole charging facility cannot be used any longer. If there is a malfunction with a pantograph that is on top of the bus which moves upwards to the charging point, then that will only affect that bus. Other buses will still be able to charge, since each bus has its own pantograph (program manager new vehicles GVB, personal communication, 21 July, 2021). Furthermore, pantographs on top of buses are more reliable. If the pantograph moves from the charging point to the bus, it is required to communicate with the bus over some sort of Wi-Fi network to determine when to move the pantograph (program manager new vehicles GVB, personal communication, 21 July, 2021). If the pantograph is on top of the bus, the bus driver can easily push a button which enables the pantograph to move upwards and connect with the charging point (program manager new vehicles GVB, personal communication, 21 July, 2021). GVB did not implement the plug-in or magnetic field charging option. Arriva has done a trial with induction charging. However, this was no success and therefore implemented the pantograph charging method (program manager sustainability Arriva, personal communication, 21 July, 2021).

For the installation of charging facilities is space required. A program manager at RET (personal communication, July 21, 2021) stated that getting locations for charging infrastructure is challenging in Rotterdam. RET underestimated the effort needed to come to an agreement with the municipality about the charging facilities' locations. For example, Zuidplein in the south of Rotterdam is going to be renewed, but the municipality did not take the necessary infrastructure for electric buses into account with the new layout of Zuidplein. Therefore, it is not possible to place electric charging facilities at Zuidplein. Furthermore, the bus station is covered at Zuidplein. This is not safe in terms of fire safety. The program manager implementation electric buses from GVB (personal communication, July 21, 2021) appointed that location is also an issue in Amsterdam. GVB wants charging facilities to be located where the majority of buses pass to be of use to as many buses as possible. With the help of computer programs, it is decided which locations are optimal. According to a program manager sustainability working at Arriva (personal communication, July 22, 2021), if there is a shortage of space, it is generally resolved through consultation with stakeholders.

Another feature of electric buses that should be considered is the lower range of battery electric buses compared to diesel fuelled buses. The base rule for RET, GVB and Arriva is that the bus timetable must stay the same as the bus timetable with diesel fuelled buses as far as possible due to their concessions. However, due to the lower range, sometimes extra buses are needed to fulfil the original bus timetable which brings extra costs (program manager sustainability Arriva, personal communication, July 22, 2021). Additionally, battery electric buses must be charged multiple times a day. The program manager for the implementation electric buses at GVB (personal communication, July 21, 2021) appointed that the electric buses from GVB are mostly slow charged during the night to save power. At daytime, GVB fast charges the electric buses between rides, also called opportunity charging. Charging at stopovers is ineffective: only charging at end stations is effective, because the bus will be there for a longer period. Additionally, if charged at the end station, the charging often occurs at the same time as the bus driver's break, thus almost no time is lost (program manager new vehicles GVB, personal communication, 21 July, 2021). The program manager for new vehicles from GVB (personal communication, July 21, 2021) mentioned that GVB does not want bigger battery capacity, because this will come at the cost of passenger capacity. There is more to gain in faster charging than is happening now (program manager new vehicles GVB, personal communication, July 21, 2021). The program manager sustainability from Arriva (personal communication, 22 July, 2021) mentioned that the range of electric buses is increasing due to developments in the battery.

4.5 Costs of buses

The purchase prices of zero-emission buses are significantly higher than the prices of diesel fuelled buses. Currently, battery electric buses are twice as expensive as diesel fuelled buses and the price of a hydrogen fuel cell bus is twice as high as the price of a battery electric bus (program manager sustainability Arriva, personal communication, July 22, 2021). GVB uses 12 metre length electric buses, which are 1.5 times cheaper than 18 metre buses. The expected lifespan of battery electric buses is 15 years, compared to a lifespan of 10 to 21 years for diesel fuelled buses. Thus, the purchase price might be higher, but due to the higher lifespan, public transport companies do not need to buy new buses as often as with diesel fuelled buses. Actual prices paid for the buses are confidential at GVB, RET and Arriva.

In addition to the purchase price, maintenance costs are involved. RET experiences mostly teething problems, but most of these maintenance expenditures are still covered by the manufacturer's warranty because the buses are relatively new (program manager RET, personal communication, July 21, 2021). Therefore, the maintenance costs are not substantial high. A program manager sustainability at Arriva (personal communication, July 22, 2021) also remarked that the maintenance costs are reasonable at Arriva. The program manager for new vehicles working at GVB (personal communication, July 21, 2021) appointed that the expected maintenance costs of electric buses are twenty percent lower than the maintenance costs of diesel fuelled buses, battery costs not included. Electric buses tremble less, resulting in less wear. However, the less tremble is due to the 300 kilograms of battery on top of the electric buses. As a result, while the chassis may be fortunate, the vehicle's body is more heavily loaded, potentially creating operational problems (program manager implementation electric buses GVB, personal communication, July 21, 2021). The maintenance costs will increase as the buses get older. Furthermore, the battery does not last as long as the battery electric bus itself. Approximately two times during the lifespan of these buses the battery needs to be replaced which results in extra costs (program manager new vehicles GVB, personal communication, July 21, 2021). However, according to the program manager for the implementation electric buses from GVB (personal communication, July 21, 2021) it is uncertain what the actual maintenance costs will be, since electric buses have only been in operation for a short time and because of the difference in components of electric buses compared to diesel fuelled buses no comparison can be made between the two.

Additional to the purchase price and maintenance costs, other costs are involved. The impact of introducing zero-emission buses on the organisation is much higher than expected by all three public transport companies. Presumably more bus drivers are necessary. This is because the range of battery electric buses is lower than the range of diesel buses (program manager sustainability Arriva, personal communication, July 22, 2021). Additionally, time is lost since battery electric buses need to be recharged during daytime, contrary to diesel fuelled buses. Because the three public transport companies are required to maintain the current bus timetable due to their concessions, more buses are necessary to maintain the original timetable (program manager new vehicles GVB, personal communication, July 21, 2021). Furthermore, the drivers need to learn about the new vehicles, since they must perform new actions, such as pushing the button the move the pantograph to charge the bus (program manager new vehicles GVB, personal communication, July 21, 2021). Additionally, new specialised mechanics are needed for battery electric buses.

As mentioned earlier, electric buses are expensive. Therefore, the financing should be carefully considered. GVB has a concession for diesel fuelled buses with the municipality since 2015. This concession does not include subsidies for battery electric buses and therefore must finance the electric vehicles by itself. Unfortunately, GVB gets a new concession once the transition to zero-emission buses is already completed. Therefore, GVB tries to be creative in order to get subsidies for the implementation of new electric buses. For example, GVB discovered that subsidies were accessible if argued from the perspective of improving air quality. By doing so, GVB received a subsidy (program manager implementation electric buses GVB, personal communication, July 21, 2021). Third parties are interested in investing, but GVB is not interested in this. GVB can borrow money for a low interest rate at the government due to GVB's trustworthiness. RET and Arriva both have a concession with the municipality that includes money for battery electric vehicles, wherefore RET and Arriva experience less difficulty with financing the zero-emission buses. The concession Arriva has, includes enough money to implement all zero-emission public transport buses (program manager sustainability Arriva, personal communication, July 22, 2021). All three public transport companies receive support from the European Union. The European Union awarded RET a couple of million euros for the installation of battery electric buses (program manager RET, personal communication, July 21, 2021). GVB is working on a subsidy application for electric bus charging points (program manager implementation electric buses GVB, personal communication, July 21, 2021).

5. Conclusion and recommendations

In this paper, I investigated what the opportunities and challenges are of implementing zero-emission buses in public transport in The Netherlands. By combining a literature review and interviews with Dutch public transport companies, data was collected to find an answer to the research question.

To conclude, Dutch public companies are experiencing the transition to fully operate with zero-emission buses generally doable. Dutch public transport companies mostly use battery electric buses. Hydrogen fuelled buses are almost not in service, due to the relative high costs compared to battery electric buses. By implementing zero-emission buses, the operational emissions will become zero. However, the electricity sources should also become more sustainable to further decrease emissions. As a result, the three interviewed companies are transitioning to using more renewable energy and intend to use exclusively renewable energy. To make this important transition easier for Dutch public transport companies, the Dutch government should support these companies by for example subsidies for using renewable energy, since a decrease in emissions is also in the government's interest. Experienced electricity losses vary between two to five percent during charging of the electric buses. Dutch public transport companies are facing an increasing electricity scarcity. This increase could be a problem for the implementation of zero-emission buses. It should be questioned whether electricity outage should be seen as a problem for the implementation, because it almost never occurs. For now, there are diesel fuelled bus reserve fleets if an electricity shortage will occur. It is recommended for Dutch public transport companies to make agreements with their electricity suppliers to prevent outages, as this strategy has worked out well in the past. Regarding charging, Dutch public transport companies should use pantographs which move from the top of the bus upwards to charge the battery electric buses, because this technique is reliable. By doing so, charging is not dependent on whether the network for communication with the charging point is available, and a challenge is avoided. A challenge that most Dutch public transport companies face is location scarcity for charging facilities in cities. However, Dutch public transport companies should make agreements with the municipality. By doing so a solution can often be found, which also happened in the past. Additionally, public transport companies should make more use of computer programs to find the optimal location for the charging facilities. Another challenge is the low range of battery electric buses. Buses need to be charged multiple times during the day. Buses should be charged slowly at night to save power. During daytime, fast charging at end stops provides an opportunity. Public transport companies should apply this latter in addition to the charging during the night, so that the bus can operate longer during daytime. In the future, range might not be a problem anymore due to developments in the battery and the fast charging becoming faster whereby buses need to be charged less frequently. Lastly, Dutch public transport companies do not experience major problems with costs of zero-emission buses. Zero-emission buses are more expensive than fossil fuelled buses, but zero-emission buses are expected to last longer. Additionally, there is a cost uncertainty because these buses are not in service for that long, but most is still covered by the manufacturer's warranty. The battery brings extra costs compared to fossil fuelled buses. Also, the operational costs are higher, since more drivers are needed. However, the financing of these zero-emission buses is not a major problem. The European Union helps most companies with the implementation of zero-emission buses in the form of subsidies. Some companies receive money via their concessions and others do not. Some need to be creative to find an eligible subsidy for zero-emission buses, which makes the financing more challenging. However, they all manage to collect money to finance the implementation of zero-emission buses. To stimulate Dutch public transport companies more for making the transition to operate with zero-emission buses only, the financing of these buses should be made easier. The government and European Union can stimulate this zero-emission bus transition by providing easier access to subsidies for Dutch public transport companies.

For further research, it is recommended to interview more than three Dutch public transport companies to get more reliable results. Additionally, it could be advantageous to interview not only public transport companies, but also other stakeholders, such as governmental bodies, municipalities or an employee of the European Union. Governmental bodies might be able to provide information about the overall transition to zero-emission buses in The Netherlands. Municipalities might know more about the shortage of location availability. Lastly, an employee of the European Union might have knowledge about the subsidies provided by the European Union and gives insights from another point of view.

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8. Appendices

Appendix A: Interview questions

General questions:

1. What are the sustainability goals of your company?
2. How far developed in the field of sustainability is your company?
3. How many zero-emission buses are currently in service?
4. How many of these are hydrogen fuelled and how many are battery electric?

Questions regarding emissions:

5. Which steps have already been taken for the transition to zero-emission buses?
6. What does your company consider when becoming more sustainable?

Questions regarding electricity sources and electricity efficiency:

7. To which extend is your company already using renewable electricity sources?
8. How efficient is the recharging and refuelling of zero-emission buses?
9. To which extend does your company experience electricity deficit or scarcity?
10. If experiencing electricity scarcity, how is your company dealing with that?

Questions regarding necessary infrastructure changes for charging and refuelling zero-emission buses:

11. What charging option does your company use?
12. To what extent is your company content with the range of buses?
13. Would your company change the battery capacity for a higher range and why?
14. Does your company experience difficult accessibility for charging and refuelling facilities?
15. How accessible is hydrogen?

Questions regarding costs of buses:

16. What does your company pay for battery electric buses and fuel cell buses?
17. By what means is your company having other operational costs for the zero-emission buses compared to diesel fuelled buses?
18. To what extend is your company experiencing maintenance costs for the zero-emission buses?
19. To what extend is your company facing zero-emission bus malfunctions?
20. How is the durability of the buses progressing, is the certainty regarding durability increasing?
21. How is your company handling the uncertainty for these buses: is there a back-up plan?

22. How does your company finance the zero-emission buses?

<u>Appendix B: Pantographs on top of buses from RET</u>

Source: Verweij, 2019.