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E-mobility for public transport buses – Assessment of considerations towards electrification possibilities

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i. Abstract

In recent years, the conditions for the successful operation of E-buses by public transport operators fundamentally changed from day to day. The main reason for this is the tension between climate protection and economic feasibility. The rapidly increasing international awareness on air quality and the stagnation concerning the development of internal combustion engines resulted in a breakthrough for E-vehicles and E-buses. The success of BEBs and FCBs will be assessed based on environmental and economic criteria. Based on the current state of the art in comparing diesel buses with E-buses, only environmental considerations speak for the operation of E-buses. The total operation costs of E-buses describe the biggest challenge that still needs to be overcome. In the meantime, it is important to first conduct an analysis on the electrification potential as well as to ensure promoting and funding by decision makers before a fleet renewal towards E-buses.

Keywords:
E-bus,
Battery-electric-bus,
Fuel-cell bus
Fleet renewal,
Environmental impact,
Economical feasibility

ii. Table of contents

iii. List of Acronyms and Abbreviations

AC	air conditioner
AQMS	Air quality monitoring station
BEB(s)	Battery electric bus(es)
BEV	battery electric vehicle
Chap.	chapter
CO	Carbon monoxide
CO_2	Carbon dioxide
EAA	Environment Agency Austria
E-bus(es)	Electric bus(es)
EEA	European Environment Agency
E-mobility	Electric mobility
EU	European Union
EV	Electric Vehicle
FCB(s)	Fuel cell bus(es)
GHG(s)	Green-house-gas(es)
HC	Hydrocarbons
ICB	Internal combustion bus
IEA	International Energy Agency
IVB	Innsbrucker Verkehsbetriebe
NO_2	Nitrogen dioxide
NO_X	Nitrogen oxides
O&M	operations and maintenance (costs)
PM	Particulate matter
PHEV	Hybrid Electric Vehicle
µg	microgram

iv. Acknowledgement

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1. Introduction

1.1. Motivation

My personal motivation for elaborating this topic derives from several facts beginning in my childhood. My mother told me that when I was 3 years old I was addicted to sit behind the front window at the second level of a double-decker bus. This connection to buses never left. I could remember that I also looked towards the drivers and tried to understand how they are managing to drive these huge vehicles even through the smallest streets. I know by heard that I have sworn to myself that someday I will be able to drive a bus on my own. The year 2011 was the initial. My ambition led me to achieve the driving licence for buses and I started in the summer holidays as a bus driver in Tyrol for a local bus company operating public transport routes around Innsbruck. Since then for almost 8 years I am doing short-term shifts for the bus company Ledermair whenever it was possible to combine it with my university schedule. In these seven years, I did not only learn how to handle the buses and how to treat the passengers, I also have grown with this big responsibility on a personal level. I have been able to improve my understanding for the technical correlation of component parts. Further, I improved my personality as well. I got more self-confident, more adroit and I achieved skills like being a team player with my colleagues when it comes to situations where you need help from another. Moreover, over the years a personal interest evolved on questions like how the public transport system is organized and how it could be improved. Moreover, the question about the improvement of our public transport system in order to prepare it for the future and the upcoming new tasks and possibilities, is a central concern to me. Especially, the duty to transfer our public transport system and in this case the buses which are based on the heavy use of diesel, into an environmental friendly public transport system with almost zero emissions is calling. However, it is still a long way towards an electrification of the public transport buses. Therefore, this thesis should provide an overview over the status quo and to foster the awareness for this topic.

1.2. Core objectives

The main aim of this thesis is to elaborate this status quo from different perspectives. The main perspectives are based on ecologic and economic values. Convening the technical status quo, it is obvious that the technical opportunities are very fast changing due to their capacities and costs. However, also today decisions have to be met and that’s why this thesis wants to illustrate results and to examine the following hypothesis of interest.

- An E-bus (BEB, FCB) has less negative environmental impacts than a conventional diesel bus
- An E-bus (BEB, FCB) has lower operating costs in the long-run than a diesel bus
- Fuel-cell buses will succeed over BEV buses in the long-run

1.3. Structure of the thesis work

The thesis is divided in 8 chapters. The first chapter provides the personal motivation of the author, the core objectives and the structure of thesis. The following chapters 2 to 6 try according to the subtitle of the thesis to elaborate and to illustrate different aspects which could influence the considerations towards electrification. Chapter 2 starts by giving an overview over the legislation which has an impact on the development of the use of E-buses. Moreover, the chapter provides a list of EU funded test programs and projects on behalf of which BEBs, FCBs and the attributive infrastructure should be supported as well as an estimation of the real numbers of deployed E-buses. In fact that the case study is placed in Tyrol, chapter 3 focuses on the environmental zone Inn-valley and the development of air quality. Due to the complexity of the topic of air quality the chapter deals with policies towards cleaner air, with the most important pollutants inclusive their impact as well as their causes and illustrates and discusses the results of air quality measurements stations in Tyrol. Chapter 4 addresses the status quo of the technical solutions of electrification possibilities as well as their advantages and disadvantages in comparison with properties of a diesel bus. Considerations towards electrification strategies also deal with the assessment of ecological and economical impacts. Therefore, chapter 5 discusses concerning an ecological assessment the impact of fossil fuel and noise, the life-cycle of batteries and the impact of the current existing energy mix. Moreover, the economic assessment tries to answer questions about purchase power loss due to fossil fuel imports and the possibility of domestic value creation through local energy production. Chapter 6 represents the case study based on a purpose-made tracking report. The tracking report is the result of a simulation which included the drive cycle profile of the tracked buses on different routes, the prices and the amounts of the consumed energy resources and the technical specification of the already used diesel buses as well as projected E-buses. In the course of the chapter each route is discussed and the possibility of electrification is elaborated on a multilevel approach for each variant. After extracting the most widely agreed on views regard to electrification, chapter 7 presents the conclusion and findings. Finally, chapter 8 provides a guide list with the main points for the bus company towards a feasible electrification strategy of their fleet.

2. Energy Outlook and rise in use of electric buses

The world and its decision makers have to face big challenges and must meet collective decisions towards the common future of the world's population. The global economy is growing stately each year. The population is expanding to more than 9 billion in 2040 and the process of constant urbanisation changes the demand for energy dramatically. In consequence, this growing energy demand can just be met by a growing energy supply of renewable energy sources and by improvements in efficiency. Without investing in more efficient technologies the projected increase in final energy use would more than double in the future (International Energy Agency 2017) . The IEA (2017) states further that "electricity will be the rising force among world-wide end-uses of energy". Moreover, this applies as well to the stressed mobility sector, which experiences a major growth caused by the growing economy and by high increasing demand of the growing density of the population.

In the last years a lot of conditions changed invariable towards the usage of electric vehicles in the mobility sector. Main drivers are the improvement of the technology, the recognized impact of fossil fuels in traffic and policies with focus on preventing climate change. Two main problems like the energy supply risk of fossil fuels and the essential reduction of GHG emissions must be fixed as soon as possible. Concerning fossil fuels, the European Comission states that the European Union imports oil which is allocated to 94% of transport fuels for 1 billion Euros a day (European Comission 2011). Elaborating those numbers, the amount illustrates the high dependence of oil supply by foreign countries. Furthermore, the whole transport sector is strongly depended on fossil fuels. In addition, the numerous uses of fossil fuels are subsequently responsible for the high emissions of GHG. In order to solve this Gordian knot, it has been obvious that policies and incentive programmes have been introduced for getting closer to the goal of sustainable mobility and transport. Nevertheless, the situation of today is not approximately that one what we would like to have. The progress towards more environmentally solutions is constant but slow and facts like low prices for fuels are obstructive and decelerating.

Hereby urban public bus transport has a major impact to reach those goals. Buses are driving thousands of kilometres yearly and transport millions of people. Especially in urban city areas this transport can be very effective and efficient.
In order to increase energy efficiency and reduce emissions, the use of electric bus systems in the public transport sector play an important role.

2.1. **Policies towards E-buses**

In order of understanding how the E-bus market has evolved and is going to develop, it is important to illustrate the determinant legislation which influences the ongoing process of electrification. In addition, the question of legal support is one of the most central components since E-mobility is a necessary trending topic. The current situation is a following: a few public transport operators are very concerned about the issue of electrification of public transport as well as heavily investing in BEBs and FCBs, others are just testing in pilot projects and others are onlookers who observe the development from a safe distance with interest.[1] Therefore, the first questions about this thesis revolved around this situation, why is not every public transport operator investing in E-mobility and enjoy common benefits through economics of scale and why is not every public transport operator actively testing and checking application-options in their operational network. Austrian Ministry for Transport, Innovation and Technology responded to that questions and stated that there is currently no EU legislation that calls for a dedicated use of E-buses[2]. In addition, the ministry refers to the fact that there are drafts for the amendment of the bill on public procurement. Moreover, the current proposal for public procurement and public service transport after 1370/2007/EU envisages that by 2025 50% of buses of category M3[3] and by 2030 75% of all buses of the same category will meet the definition of the directive according to clean vehicles. The ministry concludes that this will require above all the use of electric buses.

In consequence of a lack of legislation on the dedicated use of BEBs and FCBs a look into to the past illustrates policies and legislations acts which paved the way for the electrification of bus fleets.

Renewable Energy Directive (2009/28/EC)

On major first step forward was established by introducing the EU renewable energy directive in 2009. The focus of directive relies on the production and promotion of clean energy from renewable sources as well as limiting GHG emission and support of cleaner transport within all EU member states. The main aim of the directive in numbers is to ensure that by the year 2020 at least 20% of the total energy need will be covered by renewable sources. Moreover, this directive also includes transport fuels.

[1] cf. Interviews Conrad (2018) and Jug (2018)
[2] cf. E-Mail in Annex C
[3] Buses with more than eight seats excluding the driver's seat and a maximum authorized mass of more than 5,000 kg (Bundeskanzleramt 2018)

All EU countries due to the directive have to ensure that at least 10% of those national used transport fuels come from renewables (European Parliament 2009).

Fuel Quality Directive (2009/30/EC)

To support the formation of clean fuels and vehicles the directive for cleaner fuels for road transport requires the reduction of life cycle GHG emissions for fuels for road transport. This reduction should amount in 6% less GHG emission per unit of fuel in the year 2020. The directive deepens the regulations as well for bio fuels by implementing sustainable criteria. Those criteria focus on the exploitation areas where the material for bio fuel are produced and on the material composition in favour for high carbon stock. Furthermore, the directive also harmonizes rules for fuels and the setting of technical specification on health and the environment (European Parliament 2009)

Clean Vehicles Directive (2009/33/EC)

The directive with focus on clean and energy-efficient road transport vehicles establishes a framework for targets towards energy efficiency and towards reduction of pollutant emissions. The main aim is to stimulate the promotion and development of the market for green and clean vehicles. Especially mentioned is the process of procurement in public transport. Contracting public authorities responsible for public transport services and operators under a public service contract are required to take the energy and environmental impact during their operational lifetime of vehicles into account when vehicles or in this case buses are purchased. Those explicit parameters are energy consumption, CO_2 emissions and pollutant emissions like NOx compounds and PM. In order to fulfil all requirements concerning the environmental impact and energy efficiency of buses, the directive urges on contracting authorities, contracting entities and operators of public transport services to set technical specifications for energy and environmental performance. Furthermore, the directive points out to monetize the production of CO_2, NOx and PM emissions to achieve a holistic environmental lifetime impact overview of a vehicle or bus (European Parliament 2009).

White Paper on Transport (2011)

Concerning policies for the rise of E-buses the white paper on transport of the European Commission provides an outline how the future of transport in the EU will be. Due to the presented facts that urban transport is responsible for a quarter of CO_2

emissions, poor air quality and noise pollution, the paper tries to point out scenarios for phasing out of conventional vehicles and buses in urban areas. In consequence, phasing out would lead to contribution towards reduction of oil dependence, of GHG emissions and of noise pollution. Therefore, the paper illustrates the substantial need for electric and hydrogen vehicles in order to achieve those goals and as well points out the vision of early market deployments and test cycles for new sustainable technologies to gain expertise and information (European Comission 2011, 8). Those early market deployments and test cycles will be mentioned in part 2.2 of the chapter 2 by highlighting EU financed initiatives, projects and programs towards the electrification of bus fleets in public transport.

Regulations on pollutant emissions

Regulations on emissions are part of the whole framework of directives on air quality and clean mobility. Mentioned in the paragraph on the Clean Vehicles Directive (2009/33/EC) the regulations affect parameters on air pollutant emissions like nitrogen oxides, un-burnt hydrocarbons, carbon monoxide and particulate matter. The emission regulations have to be met by the producers of buses for getting the approval for a respective model and type of bus which will be introduced to the market. The regulation for buses, part of the product group heavy-duty vehicles, is declared as EURO standard including roman numbers representing level of tightening up concerning emissions. The standards get tighten up by the authorities since 1991, when the first EURO I was introduced. Since then every four years a new standard has been introduced by the authorities. The results of the improving standards are showing successive drops in emissions of the mentioned pollutants excluding NOx due to the deviations between approval test in laboratories and real-life driving circles. The latest standard is the EURO VI introduced in 2014 (European Comission 2017).

Paris Agreement

Concerning policies for E-buses and upcoming programs the Paris Climate Agreement of 2015 will mark a further milestone on behalf of which policies towards electrification of urban bus fleets will be adopted. Beginning in 2020, the regulations of the Paris Agreement will then apply concerning reduction of GHGs, adaption and financing of climate friendly technologies. Furthermore, in the agreement it is foreseen that also stakeholders beyond being a contracting party to the agreement play an important role in combating climate change. Those additional stakeholders are cities, regional and local authorities, civil society and the private sector (European Comission 2016). The

Global EV Outlook of the IEA contributes towards the goal of the Paris Agreement of limiting the global temperature increase to below 2 degrees Celsius by illustrating models based on numbers. The goal requires a broad approach of electro-mobility ecosystem worldwide based on a low-carbon production of electricity. Furthermore, to achieve this goal IEA modelling predicts that global sales of electric vehicles including BEV, PHEV and FCV have to meet 35 percent of all sales in 2030 (International Energy Agency 2017). Due to this predicted scenario buses and coaches can have here a very strong stake and impact. Especially, buses in urban areas can replace a high number of individual traffic. Furthermore, by electrification of public transport buses a clean irreplaceable transport opportunity will be given, which could have in turn have impact on sales of individual electric cars in order of role-model position (International Energy Agency 2017).

In reflection of the listed policies and regulations towards fulfilling global climate goals we can identify E-mobility as the solution for the questions on how to achieve clean and green mobility on behalf of legislation. The electrification of urban public transport bus fleets will be state of the art instead of dwelling as a niche solution. In consequence, the only interesting thing is the point in time when E-buses will be widely replacing the actual fuel operated buses. Actually, just a small amount of BEBs and FCBs are in operation. In addition, a big part of those E-buses still in operation have been part of EU financed programs and test projects due to the research on feasibility. In the next part 2.2. programmes for E-buses of chapter 2 we will elaborate 3 major project programmes within the European Union.

2.2. **Programmes towards E-buses**

Concerning research on the operations of E-buses you always will be referred to the same major research and innovations programmes funded by EU institutions in addition to private investments. The focus of all projects is alike to manage breakthroughs in applications, to achieve improvements of technology feasibilities and to illustrate beneficial results concerning costs and environmental impacts. Furthermore, all information should result in framework conditions to foster future regularly operations of E-buses in public transport within the EU.

CHIC (2010-2016)

The CHIC (Clean Hydrogen in European Cities) project was introduced in 2006 as successor program of the CUTE and the HyFLEET:CUTE projects and ended in 2016. The main objectives during the timeframe of 6 years were deployment of a large number of FC buses across nine cities, achievements in cost reductions due to higher large-scale productions of FCB with different European bus manufacturers and the demonstration of technological readiness of FC buses on the market of public transport. Furthermore, the aim of the project was to have shown until the year 2016 that FCB are the solution towards decarburization of public transport fleets and to have the same flexibility as a standard diesel bus. After conclusion of the project in 2016 the final project report pointed out the major common findings. First, the FCBs have shown to operate in the same range as conventional diesel buses. Second, due to an average consummation of 8 kg of hydrogen per 100km the FCBs in the magnitude of a 12-meter version are more energy efficient than an identical diesel bus. Third, hydrogen refuelling stations can keep up with the daily requirements of public transport operators and show a low error rate (below 5%). Fourth, by using hydrogen the well-to-wheel[4] energy chain showed high efficiency. Lastly, surveyed bus drivers and passengers were pleased by the experiences with the FCB[5] (Müller, et al. 2017).

ZeEUS (2013- 2018)

The ZEUS (Zero Emission Urban Bus System) was launched in 2013 as well as co-financed by the European Commission. The core objectives of the project are divided up into four main aims. These four aims consist of the extension of fully-electric solutions towards high capacity buses, the evaluation of economic, environmental and social feasibility through operational scenarios, the facilitation the market entry of E-buses by providing tools and services and the support of decision makers with guidelines. The coordinator of the program is UITP[6] which is in cooperation with 40 partners is testing a pool of different BEBs in connection to different charging infrastructure solutions in 10 different core demonstration sites in 9 European countries. The final report of the ZeEUS refers to local conditions and local contexts of operation and that towards an electrification each case has to be analysed on its

[4] "The combination of steps necessary to turn a resource into a fuel and bring that fuel to a vehicle is defined as a Well-to-Tank pathway (WTT)." (Edwards, et al. 2004)
[5] During research for this master thesis the fact was delivered by SASA (public transport operator of Bozen) in a phone call that bus drivers in Bozen (CHIC project city) are in favour for driving with a FCB in order of less noise pollution.
[6] UITP (*Union Internationale des Transports Publics*) - International Association of Public Transport

specific needs due to a technological solution (International Association of Public Transport 2017).

FCHJU (2014 – 2020)

The FCH JU (Fuel Cells and Hydrogen Joint Undertaking) is public private partnership with the aim to support research, technical development and applied use of fuel cell and hydrogen energy technologies. The program consists out of two pillars. The first pillar focuses on road vehicles as buses, on-road machinery, refuelling infrastructure as well as maritime, rail and aviation applications. The second pillar concentrates on energy systems like hydrogen production and distribution. The vision of the FCH JU is being able in the year 2020 to provide portfolio of solutions by the usage of hydrogen. The main objectives and these are the major triggers towards the success of hydrogen are the factors of operating and capital cost (FCHJU 2016). This also applies for the transportation sector, where FCBs can't compete on purchase pricing of conventional diesel buses at first. The report on fuel cell electric buses of the FCH JU programme illustrates the potential as well as those milestones on which still work has to be done. The vision is to broader the deployment of FCBs to decrease prices and cost until the year 2030, because the joint partners of FCHJU consisting out of state authorities, local governments, bus operators and industry stakeholders are convinced of the impact by FCBs towards clean and green public transport (Ammermann, et al. 2015).

2.3. Interpretation of the deployment of E-buses

The aim of this part of the paper has been giving an overview of the deployment of E-buses in Germany and Austria. However, the research has shown that it is complicated to elaborate the concrete numbers of BEBs or FCBs on point. On the one hand, a concrete number fails because of the missing definition in the statistics, which bus types are subsumed under the definition of an electric bus. There is no distinction between pure electric buses, hybrids and trolleybuses. On the other hand, the 2 weight classes[7] M2 and M3 are added together in the sum of E-buses used for the statistic frames. A classic public transport bus belongs to class M3. For example, table 1 published by statista illustrates the growing number of E-buses in Austria. In addition, table 2 shows the number of annual registrations of E-buses per year. However, the majority of those buses are trolleybuses. Approximately 20 trolleybuses are operating

[7] (Bundeskanzleramt 2018)

in Linz (Dirmaier 2017) and 106 trolleybuses are operating in Salzburg (Salzburg AG 2017). In subsequence, the 46 remaining E-buses can be now dedicated to the weight classes M2 or M3 (BMVIT 2018). Thus, despite the information in table 2 no conclusions can be drawn on the size and operation functions of the registered E-buses. Overall, only on the basis of published tenders and public announcements conclusions can be drawn. In Austria, the Wiener Linen GmbH is investing to a greater extent in E-buses for route operation (Wiener Linien 2017).

Moreover, for Germany the same picture is apparent. Currently, there are 530 buses operating with alternative engines in Germany. This figure is composed of E-buses, hybrid buses, trolleybuses and hydrogen buses. According to PWC, 171 of them are pure E-buses. PWC also gives a concrete outlook on the development of E-buses in Germany. Based on orders for 162 E-buses the number of E-buses will double throughout Germany in the next year. Furthermore, a number of public transport operators in Germany announced to order 821 E-buses until the year 2031. If those announcements will be transferred to orders, PWC expects more than 1000 E-buses operating in Germany by 2031 (Arnold 2018).

Table 1: Number of E-buses registered in Austria (statista)

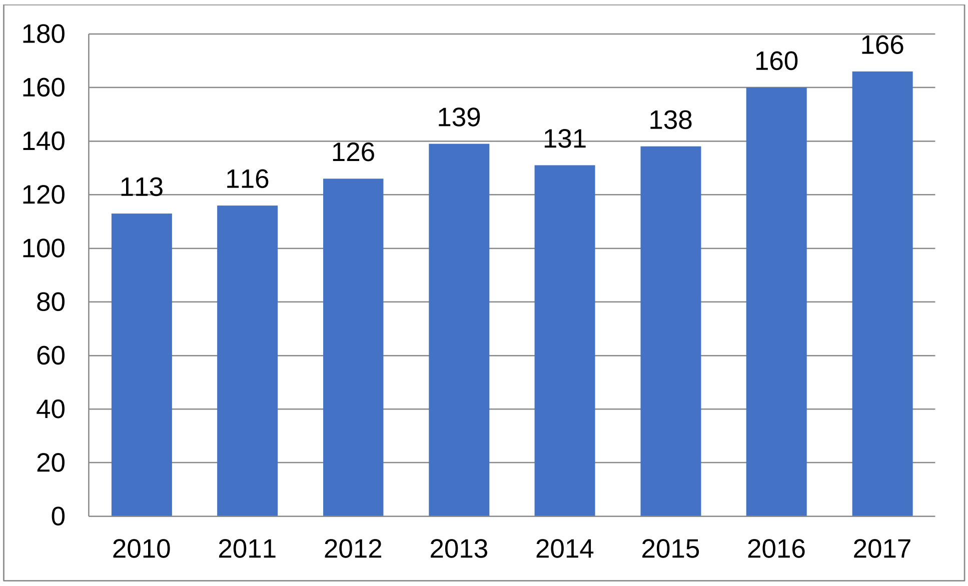
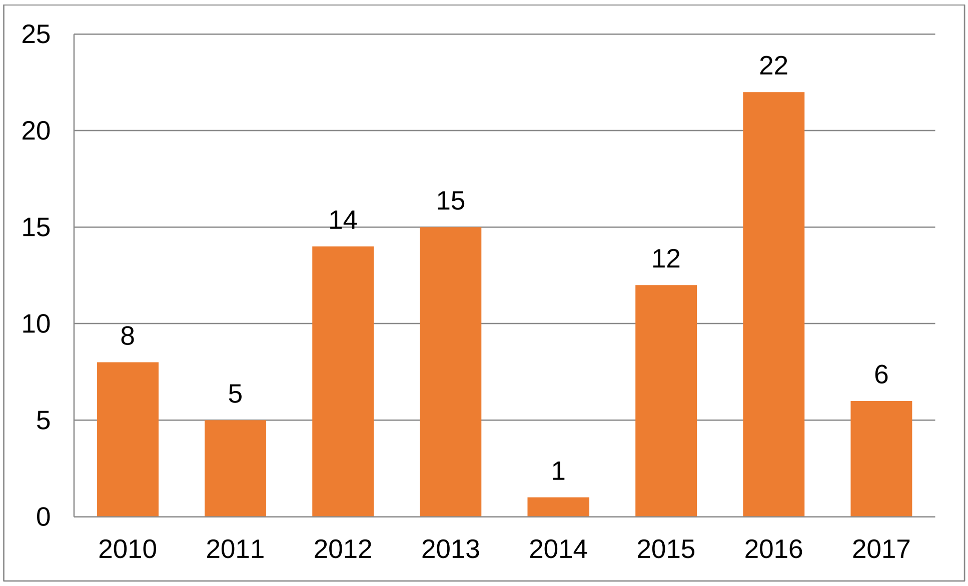


Table 2: Number of registrations of electric buses in Austria from 2010 to 2017 (statista)



3. Environmental Zone Tyrol

For this work, considerations towards of the environmental zone Tyrol are essential. Among other things, the case study in chapter 5 revolves as well around the considerations of the environmental impact of emissions from diesel buses in this already heavily affected zone by transport and traffic. Furthermore, it is important to analyse the current emission load in Tyrol to understand the need for efficient mitigation measures, because the current air pollution negatively affects human health, animals, plants, water areas and the ecosystem as a whole. Moreover, the emitted green-house-gases have the capability to influence the climate, which represents a long-term threat for humans and our environment.

Concerning the observation of air pollutants there are three major processes described by the Environment Agency (EAA) of Austria. Hereby it is obvious that you can differentiate between the emissions, the transmissions and the air quality of pollutants. In regard of this chapter, our emissions come from combustion and our emitters are motorized vehicles like cars, trucks or buses. After the emission, the transmission of air pollutants is causal for dispersion and chemical compilation of the pollutants. In order of atmospheric conditions or characteristics of pollutants it depends if pollutants will stay nearby the area of emission or if the pollutants will be relocated and unfold their impact within a bigger distance to their origin. The last process is the air quality which explains the impact concentration of the pollutants on the environment. And beyond, those concentrations often exceed limits and have a continuous impact on health and the environment (Environment Agency Austria 2016).

In order of traffic being such a major polluter, it is necessary to rethink and transform our mobility habitudes. As well the European Environment Agency (EEA) states that the European Union and its member states can only reach set emission goals by ambitious measures. Those measures do not only focus on the improvement of efficiency levels but also have to deal with the sharp transformation of the mode of drive because

- transport is responsible for more than a quarter of green-house-gas emissions in the EU,
- EU Member States are required to reduce GHGs from transport by 60% until 2050 and
- air quality objectives are exceeding in many areas and traffic numbers are increasing (European Environment Agency 2011).

The congested urban area round about Innsbruck the capital of Tyrol generates an easily interpreted image of pollution caused by traffic. The Inn-valley with its highways A12 and A13 belongs to the most important traffic corridors for transport in Europe. The A12 leading from the German boarder to Zams is passing almost the whole valley and its dense settlement. The A13 diverge from the A12 close to Innsbruck towards Italy. By reason of the dense settlement, the heavy used traffic infrastructure, the increasing amount of traffic and the geographic narrow of the Inn-valley, the environmental zone has been introduced between Zams and Langkampfen (figure 1) in 2016. The introduction of the environmental-zone resulted in the enforcement of bans of driving for vehicles which are not anymore responding to the minimum standard. (Green-Zones GmbH n.d.)

Figure 1: Environmental-zone Tyrol / Inn-valley

A study requested by the Tyrolean State Government investigated the ambient air pollution in the surrounding of transalpine motorways. The Investigation concluded with following three points:

- “Alpine valleys are especially susceptible to air pollution caused by road traffic because of their topographical situation and the meteorological conditions with frequent inversions. Emissions have a larger impact on such regions than on flat areas.
- This impact is worst during the night because of stable atmospheric conditions which suppress the exchange of air masses. Therefore, a limitation of nocturnal haulage makes sense not only because of the noise but also because of air quality reasons.

- The air quality in residential areas a few hundred metres away from the motorway depends particularly on the prevailing exchange conditions.” (Siegrist and Thudium 2002)

The finding out of these three points could be that in those exposed areas (municipal area of Innsbruck and Inn-valley) measures should be undertaken to limit pollution or to reduce pollution.

3.1. Emissions policies

Change and improvement often are related to regulations and policies on behalf of which concrete measures are undertaken. Binding limits by directives or acts are necessary to meet agreements on air pollution. Also for decision makers directives, acts and regulations on air pollution could give an outlook for upcoming management decisions. In order of the importance of legislation on air pollution this paper tries to give an overview of various legislations at different political levels.

European Union

Cleaner Air for Europe (2008/50/EC)

One important act of the European Union is the so-called directive Cleaner Air for Europe. It entered into force in 2008 and should have been transposed in Member State law in 2010. The directive is a merger of already existing legislations on air pollution. The main aim of the directive is to establish air quality objectives as well as to include cost-effective targets for improving the human health and environmental quality until 2020. Further, the directive provides solutions for achieving better air quality and answers how implement correctives if the standards can’t be met. The directive also includes following key elements among others:

- “Thresholds, limit values and target values are set to assess each pollutant covered by the directive: sulphur dioxide, nitrogen dioxide, particulate matter, lead, benzene and carbon monoxide.
- National authorities designate specific bodies to carry out these tasks using data collected at selected sampling points.
- Where pollution levels in any particular area are higher than the thresholds, air quality plans must be introduced to correct the situation. These may include specific measures to protect sensitive groups, such as children.
- If there is a risk that pollution levels may exceed the thresholds, short-term action plans to reduce road traffic, construction works or certain industrial activities, for instance, must be implemented to head off the danger.

- National authorities must ensure that not only the public, but also environmental, consumer and other relevant organisations, including health care bodies and industry federations, are kept informed of the ambient air quality (i.e. the outdoor air) in their area.
- governments of EU countries must publish annual reports on all the pollutants covered by the legislation” (European Parliament 2008)

National Emission Ceilings Directive (2016/2284/EU)

The NEC Directive of 2016 is a revision of a precursor directive. The focus of this directive appoints to National Air Pollution Control Programs which should define the undertaken measures to meet the reduction limits in 2020 as well in 2030. (European Comission 2018)

International Conventions

Gothenburg-Protocol

The Gothenburg-Protocol deals with acidification, eutrophication and ground-level ozone and was ratified by Austria in 2005. The revision in 2012 of the protocol included new reduction levels for major pollutants like SO_2, NH_3, VOC, NO_X, $PM_{2.5}$. Furthermore, those limits form the foundation for the NEC Directive. (Environemnt Agency Austria 2017, 24)

Hereby, the NO_X reduction by -37% on behalf of the emission levels of 2005 will pose the biggest challenge for Austria. Most of the NO_X emissions are connected to road traffic. (UNECE n.d.)

Austria

Implementation of NEC Directive (2016/2284/EU)

The Federal Environment Agency of Austria states in its reports that the measures which are included in the NEC-program have been realized and implemented. However, the Agency points out in its report as well that the reduction goals have not been met in three specific areas. One of them is called mobile sources. Mobile sources include thirteen measures for reducing NO_X like forcing low-consumption driving or the support of environmentally friendly engines. If inner sense of support of environmentally friendly engines means that there will be now a possible change towards E-mobility is left open. Anyhow, the Federal Environment Agency of Austria relegates in its reports as well as on its homepage that the sector of traffic and transport is in high need for immense and rigorous actions. (Environment Agency Austria 2012)

Air quality protection regulation

The air quality protection regulation IG-L is the central law act for air pollution control and air quality control in Austria as well as for the implementation of relevant EU directives. The three aims of the law act have their focus on

- "the permanent protection of human health and the environment from air pollutants,
- the precautionary reduction of air pollutant emissions and
- the preservation of good air quality or the improvement of air quality."

Furthermore, the law act foresees that governor of a federal state of Austria gets active if pollution or emission limits are exceeded. Therefore, the governor is allowed to undertake measures so that IG-L as well as EU air pollution limits can be met. Regarding possible measures the Federal Ministry for Tourism and Sustainability relegates to the opportunity to install driving bans, time and space restrictions, speed limits and environmental zones. (Federal Ministry of Sustainability and Tourism 2018)

Tirol

Tyrolean Mobility Program

In order that NO_2 poses the biggest challenge for achieving better air quality, the Tyrolean Government introduced the Tyrolean Mobility Program for the time period between 2013 – 2020. The program with the focus on reducing NO_2 at the community and state level wants to achieve its goal by increasing public transport, cycling, pedestrian share and decreasing part of personal motor vehicle usage in the mobility share. (Thudium 2016)

Tyrolean NO_2-Program

The Tyrolean NO_2-Program is the implementation of the air quality protection regulation (IG-L) outlined above. Pollution level and trends of NO_X and NO_2 within the environmental zone and the urban area of Innsbruck will be displayed under the headline of emission development. (Environment Agency Austria 2016)

In Conclusion regarding the number of policies and their goals it is obvious that traffic and public traffic service could provide a great deal of enhancement. Unfortunately, no policy touches the topic of E-mobility neither on the sector of private mobility nor on the side of public transportation. Just the NEC Directive mentions measure of supporting environmentally friendly engines, what offers a breadth range of interpretation.

3.2. Classic air pollutants by traffic

By reason of this paper focus on emission of traffic it is obvious that the major pollutants of combustion processes should be described. NO_2 and PM_{10} are concern of every pollution monitoring and focus of pollution management as well as health issues. Furthermore, CO_2 is a further product of combustion process. CO_2 is not a direct threat to health among a certain value but a strong green-house-gas. Furthermore, CO_2 became a worldwide used climate currency regarding reduction and measures on political levels.

NO_X/NO_2

Nitrogen oxides (NO_X) can occur as nitrogen dioxide (NO_2) or nitrogen monoxide (NO). Predominantly, nitric oxide (NO) is emitted. However, NO does not appear on a large scale because this gas is oxidized relatively rapidly by atmospheric oxygen (O_2) and ozone (O_3) to NO_2. NO_2 is produced by the combustion of fossil fuels, such as gas, coal and oil and is therefore part of the exhaust gas of diesel powered vehicles.

PM_{10}

PM_{10} is the term for dust particles with a diameter of less than 10 micrometre. In order of their nature and seize PM_{10} particles can float as well as remain for several days in the air and being transmitted in the air over long distances instead of being deposited. Consequently, the PM_{10} air quality is not only based on local emissions. On the one hand, such particles are directly ejected from the pollutant sources (primary particles) or they are first formed in the atmosphere (secondary particles). One source of primary particles is the combustion process. As a result, soot particles from diesel engines belong in this class.

Primary particles also arise from attrition, industrial or construction activity. Secondary particles, which account for 30-60% of total PM_{10} pollution, are generated from gaseous precursor pollutants such as nitrogen dioxide (NO_2). In conclusion, major emitters remain traffic and transport.

CO_2

Carbon dioxide (CO_2) is produced by burning carbonaceous fuels, including all fossil fuels. For any given energy source, the amount of produced CO_2 is directly depending on the amount of used. Even though modern burning methods and engine systems can make better use of the energy contained in the fuel than in the past, they cannot prevent the formation of CO_2.

Since no effective and economical carbon dioxide removal process is available yet, all CO_2 escapes into the atmosphere. The fact that more and more CO_2 emissions are being discussed in recent years is due to the climate impact of CO_2. It is one of the major greenhouse gases whose increased occurrence in the atmosphere causes climate changes. (Chemie.de n.d.)

Traffic Development

The traffic report 2016 of Tyrol illustrates the development on all Tyrolean roads since 1980, when recording started. For almost now 38 years Tyrol is facing a constant increase of road traffic on all roads. Figure 7 illustrates the developments. The amount of traffic on high- and freeways increased by the factor of 2.5 from the base level of 1980. Besides the traffic federal state roads almost doubled in the last 4 decades. The report states that growth rates on all roads are nearly similar and amount in 2.0% in 2015. (Amt der Tiroler Landesregierung 2017)

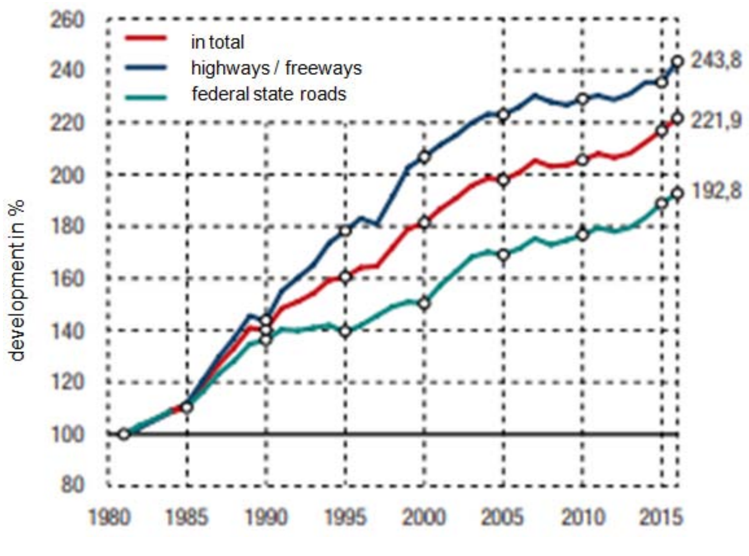


Figure 2: Traffic development in Tyrol (EAA)

Emission development by Traffic in Austria

It is now evident that the motorway and the urban traffic are dominant source of air pollution in all monitored regions. The influence of the motorway A12 is very dominant for the whole Inn valley, the environmental –zone and as well for the capital city Innsbruck. The emission inventory of the Environment Agency Austria notes that the highest emissions share is due to road traffic and the influence of heating activities and industrial plants concerning NO_X is less significant. Figure 8 illustrates the share of NO_X emission of different polluters in Austria. The major origin of NO_X is traffic with a share of almost 40% without fuel export in foreign countries. In relation to that number the second biggest polluter namely industries production processes follow by a considerable distance of almost the half and has a share of 20% of all NO_X pollution.

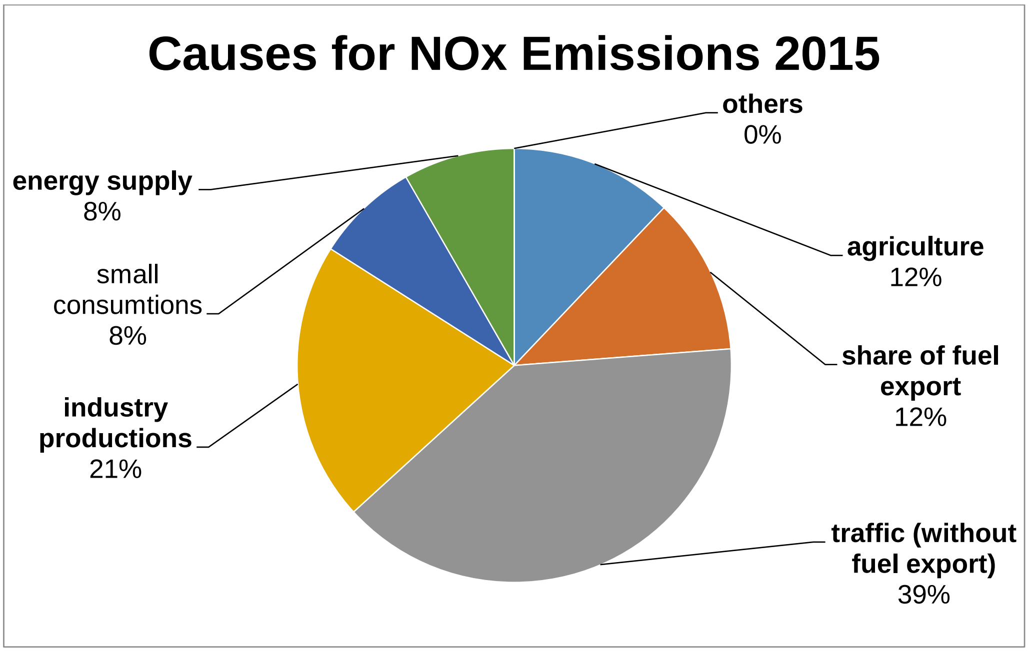


Figure 3: NO_X share of polluters in 2015 (EAA)

Figure 9 shows the development of NO_X Emissions in period of time between 1990 and 2015. In general, a decline of NO_X emissions can be measured. Figure 4 illustrates the development on the one side of inclusive motor fuel (light green) and on the other exclusive export (dark green). The Austria Environmental Agency notes the amount of NO_X emissions in 2015 without fuel export with 131.700 tonnes. Furthermore, the EAA states that the decrease over time of NO_X since 2005 is caused by the development and progress in automotive technology in particular in the sector of heavy vehicles like trucks and buses. (Environemnt Agency Austria 2017, 25)

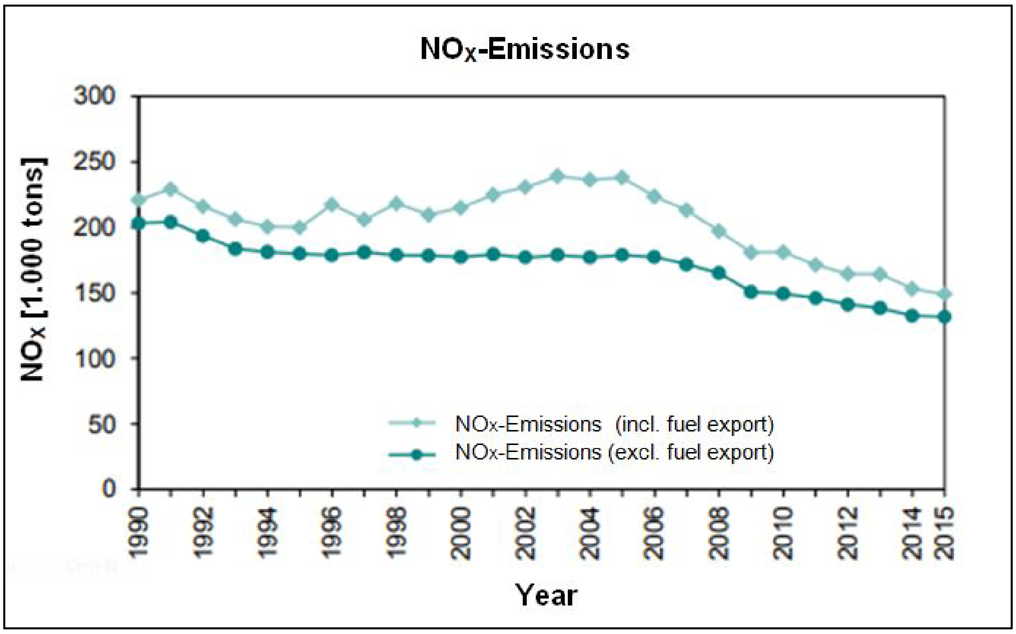


Figure 4: NOx emissions in Austria between 1990 and 2015 (EAA)

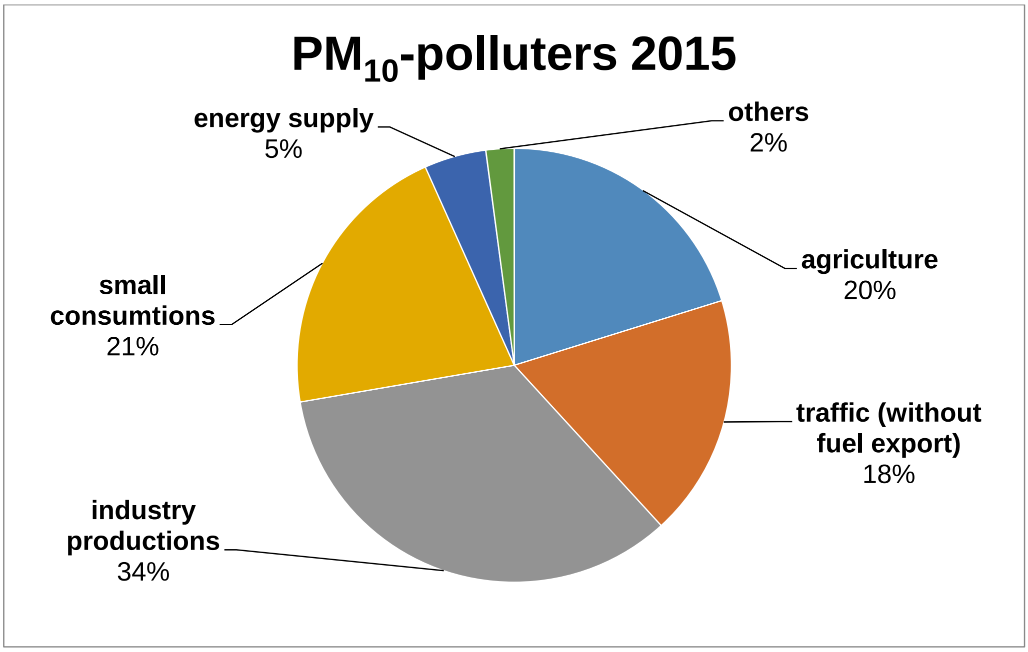


Figure 5: PM_{10} polluters in Austria in 2015 (EAA)

Concerning the list of classical air pollutants by traffic also PM_{10} has a major share in Austria. Figure 10 of the trend report of the EAA shows that 18% of all PM_{10} has been provoked by traffic inclusive fuel export. Although the share of traffic concerning PM_{10} just occupies the fourth place it is worth to mention in order of the impact of diesel engines. We know that PM_{10} is produced by combustion emission and by emissions due to abrasion of tires and by produced eddies. However, also in regard of topic of the master thesis, the key point is that diesel engines produce more PM_{10} by a factor of 5 than gasoline engines. Furthermore, almost all heavy vehicles which produce large amounts of pollution as well as PM_{10} are powered by diesel engines. (Environemnt Agency Austria 2017)

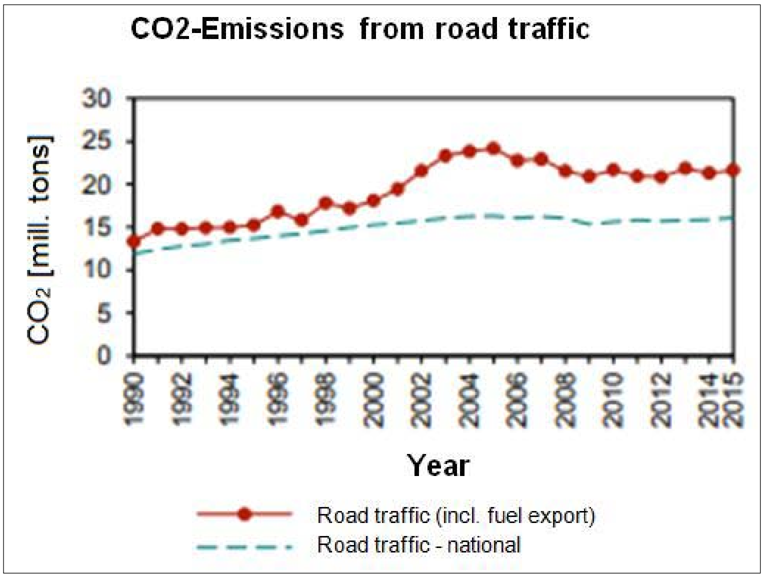


Figure 6: CO_2 emission by road traffic in Austria (EAA)

Figure 11 illustrates the development of CO_2 emissions in captured Austria. The graph from the Federal States air pollutant inventory of the EAA shows a constant increase since the year 1990 until now. The green line represents the CO_2 emissions of the inland road traffic. Furthermore, CO_2 is therefore a reasonable key component of air pollution by road traffic in order of its increase of 35% between 1990 and 2015 in Austria. Seeing that and in order of knowing the impact of CO_2 on climate change, CO_2 remains a hardly deniable objective of importance. (Environemnt Agency Austria 2017, 29)

3.3. **Emission development by Traffic in Tyrol**

In this part of the paper we put now the focus on Tyrol and try to set emission of CO_2, PM_{10} and NO_2 in Tyrol in comparison with the overall emissions of Austria. This comparison should try to work out similarities or possible huge differences on behalf of emissions to get an overview over the unique Tyrolean position. The first figure 7 of the Federal States air pollutant inventory tries gives a first impression. In detail, figure 7 illustrates that the main driver of the general increase in emissions is traffic since 1990.

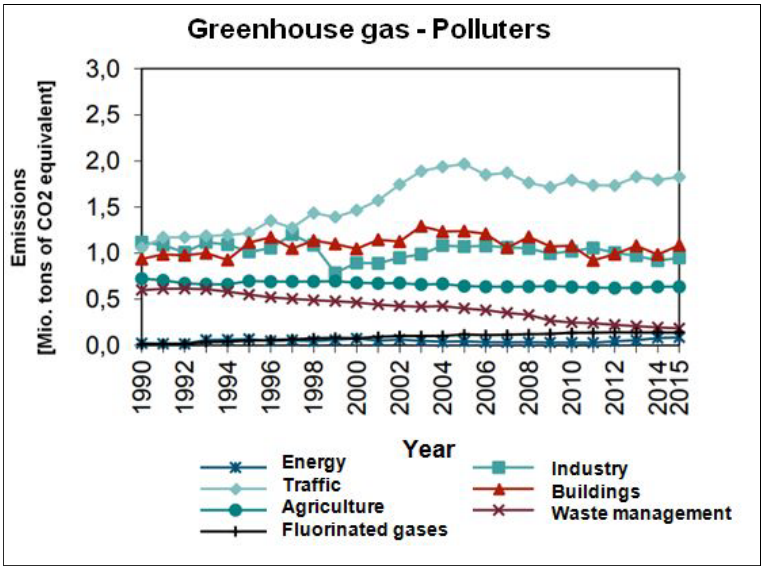


Figure 7: Green-house-gas development and emitters in Tyrol (EAA)

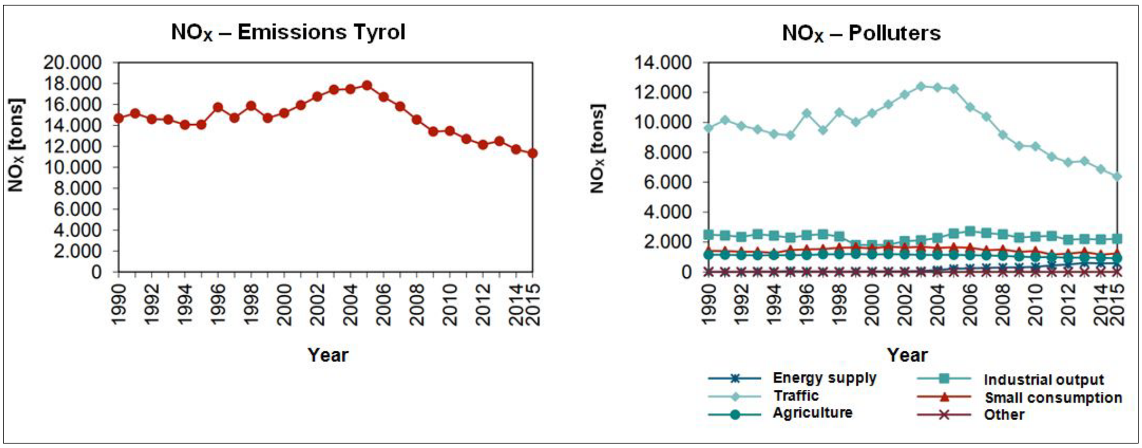


Figure 8: NO_X emissions in Tyrol (EAA)

Concerning NO_X emissions, figure 8 shows on the one side the development of the emissions and on the other side the share by different polluters. Since the year 1990 the emission of NO_X in Tyrol decreased by 23% and in 2015 11.300 tonnes have been emitted. However, also due to the emission of NO_X the sector of traffic and transport caused by far the largest amount of nitrogen oxides in 2015 with a share of 56%. Those 56% represent 6328 tonnes of NO_X only produced by traffic and account 4% for the overall Austrian NO^X emissions.

Figure 9 take focus on the PM_{10} emissions. The level of emission stayed quite constant between 2000 and 2015. Concerning the quota of traffic caused PM_{10} the graph shows that share decreased drastically over time and amounts in 2015 by 21% among the Federal States air pollutant inventory of 2017. The inventory report further states that the decrease is mainly caused by the improvements in propulsion and exhaust after treatment technologies especially the use of Particle filters. (Environemnt Agency Austria 2017, 180ff)

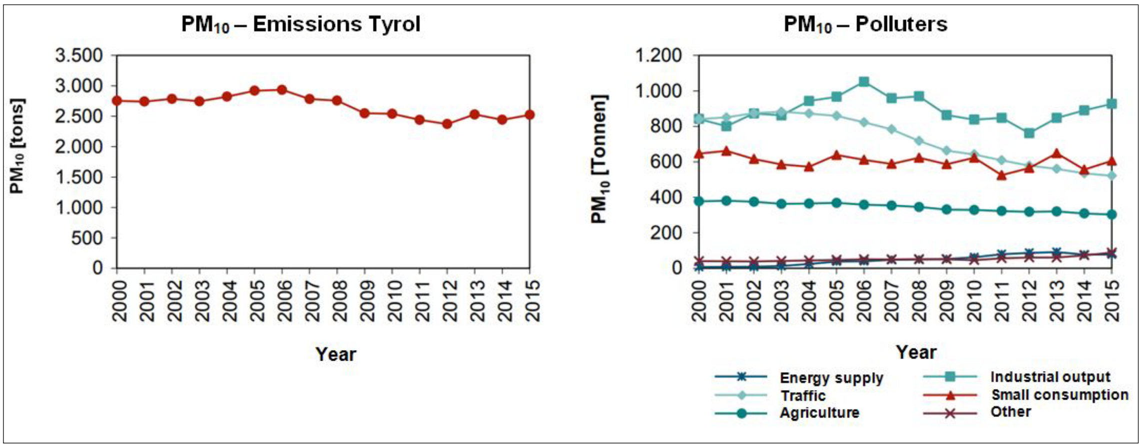


Figure 9: PM_{10} emissions in Tyrol (EAA)

Environmental-Zone Inntal, threshold values and air quality monitoring stations

In order of the significance of pollution by traffic there are a number of air quality monitoring stations collecting data along the Inn-valley and in the urban area of Innsbruck both parts of the environmental. Overall, figure 10 illustrates all 11 aqms. The EAA provides all collected data online in an interactive map and gives information about the aqms itself and the pollution values. The aqms have been installed between 1997 and 2007 and collect data about NO_2, SO_2, PM_{10}, $PM_{2.5}$ and CO among others. For a better close-up the focus in this part of the paper relies on NO_2 monitoring and its threshold values.

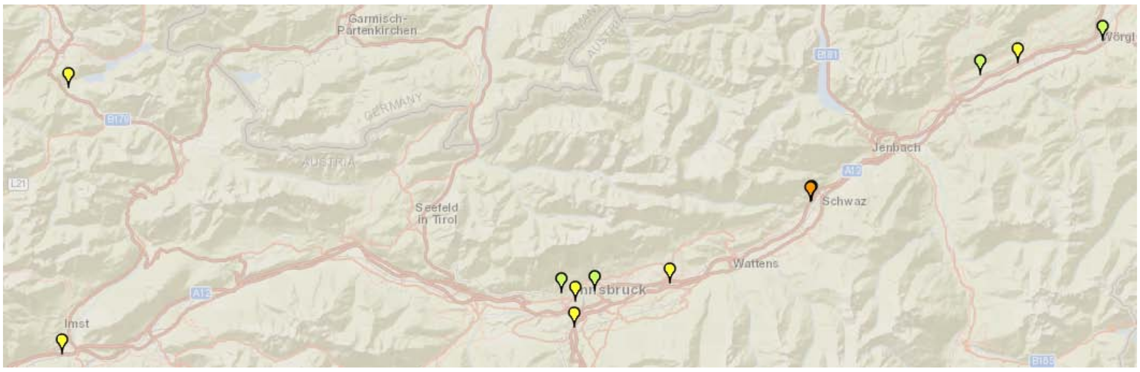


Figure 10: Air quality monitoring stations of NOx and PM_{10} pollutants in Tyrol

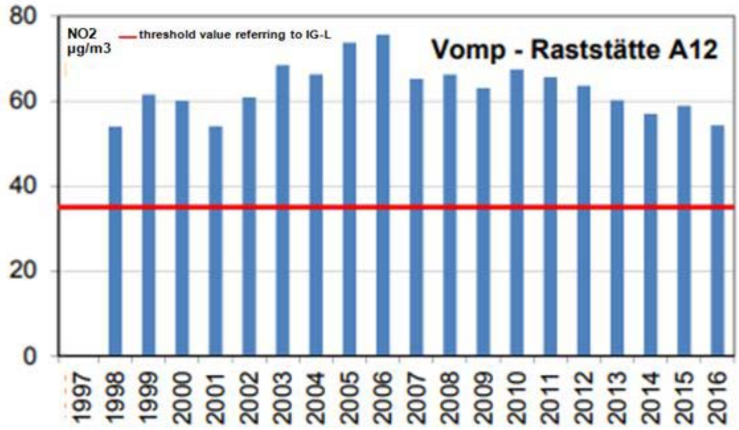
In order of EU regulations and national implantations there exist several NO_2 threshold values depending on the time period base for calculation. The EAA provides for the interpretation of NO_2 value graph following thresholds noted in table 3. On a yearly average base, the threshold value of NO_2 should not exceed 30 µg / m³. This threshold is valid since 2012. In addition, this value can be exceeding in order of a granted tolerance margin in order of 35 µg / m³. By knowing the threshold of NO_2 emissions we will have next a look on the long-term trends at different aqms visualised in figure 10. (Environment Agency Autria n.d.)

Table 3: Thresholds for NO_2 in Austria (EAA)

NO_2	annual average value	30 µg / m³ (35 µg / m³ incl. tolerance margin)
	daily average value	80 µg / m³

Air quality monitoring stations along A12/A13

We will start with three aqms along the highway. The first measurement point is marked in orange and represents two separate sites. Figure 11 of the aqms in Vomp illustrates remarkable results. At both sites since starting the monitoring the threshold inclusive tolerance level has never been met. The first aqms is situated on area of the rest stop on the highway and the second aqms is located nearby in the village of Vomp.



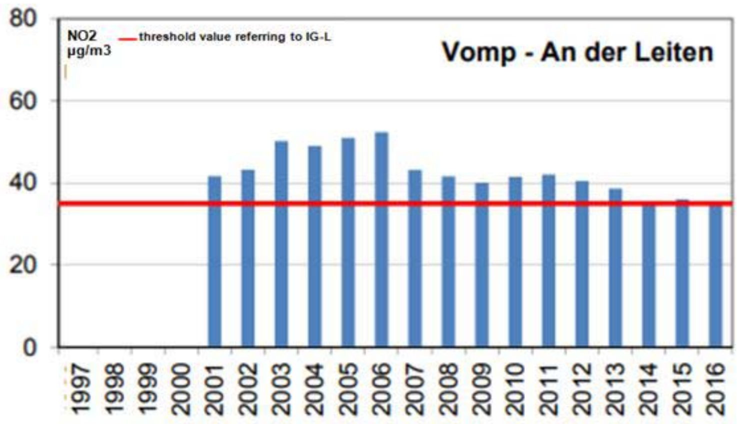


Figure 11: NO_2 values of air quality monitoring station Vomp (EAA)

Another air quality monitoring station nearby the highway A13 is located in Gärtenbach and not far away from the capital city Innsbruck. As well as in Vomp this aqms has never recorded an annual value lower than the given threshold value, illustrated by figure 12.

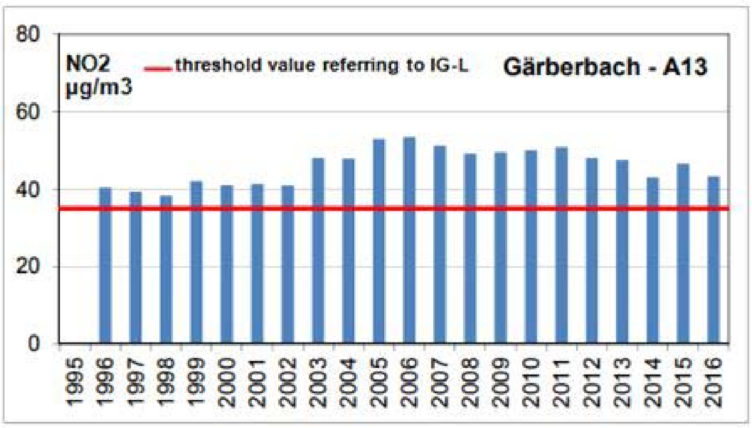


Figure 12: NO_2 values of air quality monitoring station Gärtenbach (EAA)

However, the aqms in Vomp and the aqms in Gärtenbach are situated along the Brenner transport axes. This shows again the high impact of traffic concerning NO_2 pollution. That the Brenner transport axis has high share concerning NO_2 pollution shows the comparison with the aqms in Imst, which is situated at western end of the environment zone Inntal and not part of the Brenner transport axis. The reported values in figure 13 show that they have been almost always underneath the values of Gärtenbach and Vomp. (Amt der Tiroler Landesregierung n.d.)

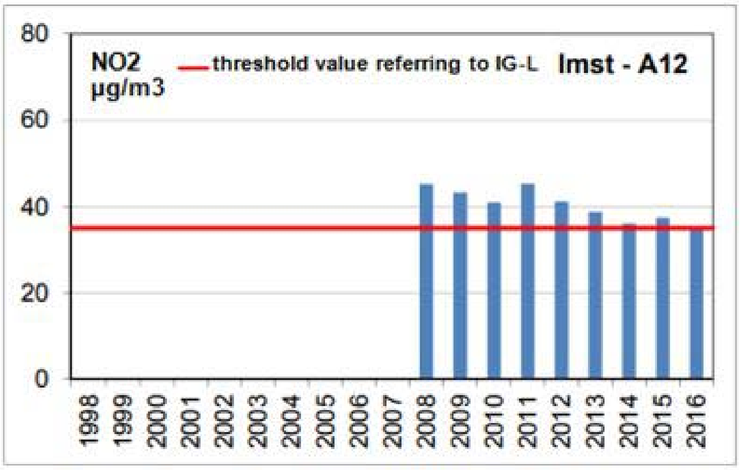


Figure 13: NO_2 values of air quality monitoring station Imst (EAA)

Measurement points in the city centre of Innsbruck

Innsbruck is really situated in the middle of the environment zone and faces itself a high amount of traffic in its city road network. Figure 14 illustrates the development of NO_2 since 1988. At both aqms the monitored value almost always touched or exceeded the annual threshold value. Besides this, the red line marks the threshold value inclusive tolerance. Overall, the threshold of NO_2 was always above the ambient air quality limit concerning the health of the settled population around. The questions which arise now is on the one side, do the high pollution values come from inner city traffic or is transmission from highway pollution responsible for those figures and on the other side can E-mobility improve the situation in the city of Innsbruck as well as in the environmental zone. E-mobility and its technical implementation emit except for pollution of PM_{10} in order of abrasion of tires no further pollution on the site of operation. (Amt der Tiroler Landesregierung n.d.)

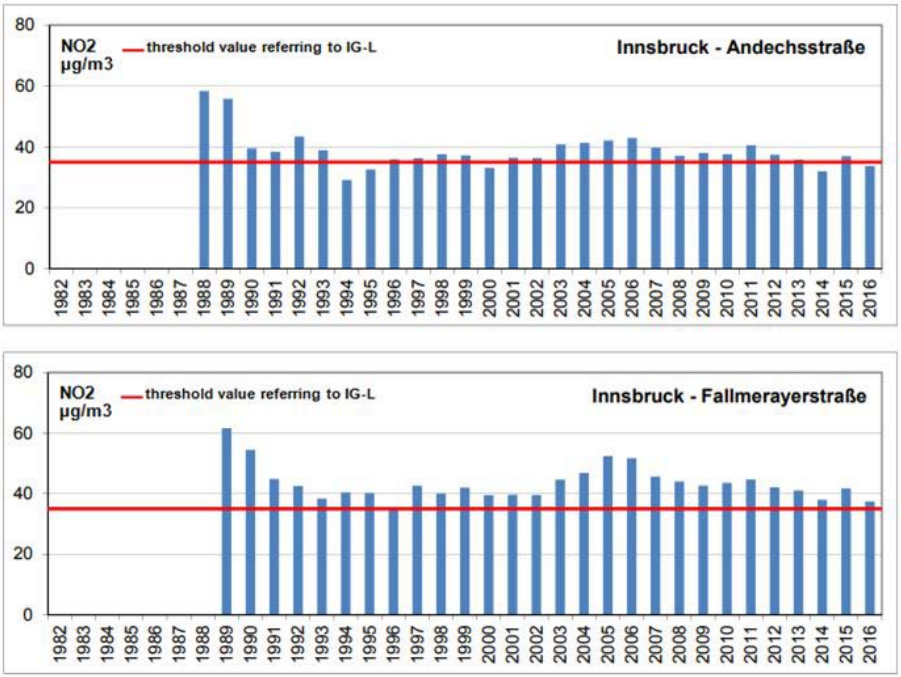


Figure 14: NO_2 values in the city centre of Innsbruck (EAA)

Chapter 3 illustrates the complexity of air quality in Tyrol. On the one hand, there is the basic load burden by the heavy traffic going through the Inn-valley, but on the other hand, the locally produced emissions should not be forgotten. Anyway, measures such as IG-L are trying to reduce emissions. However, the reduction is not enough to compensate all emissions caused by the growing volume of traffic. Therefore, it needs pilot projects and measures that do not only reduce the production of emissions but also generally terminate them effectively. E-mobility can be a solution for local traffic in Tyrol. Here, politics in Tyrol could play a central pioneering role through the electrification of public transport buses. Instead of just expressing the interest and showing the need (Energie Tirol 2017), massive investments should be made in the development of electric buses (BEBs or FCBs). In consequence, Chapter 4 deals with available technologies and their advantages and disadvantages.

4. Technical Overview of status quo in 2018

In 2018, there are a high number of available technologies for operating public transport buses. The diesel bus represents the internal combustion process and is the most improved technology on the market. Anyhow, the numbers of alternative fuel and engine technologies are rising. Beside the diesel bus, there are other technologies as buses powered by gas, hybrid buses, battery-electric-buses and fuel cell buses powered by hydrogen. For this section of the master thesis we concentrate on three technologies (Patil, et al. 2017). In chapter 4 we compare the diesel bus, BEB and FCB by illustrating differences and by elaborating pros and cons of the technologies as well as of the charging opportunities of the electric technologies.

Table 4 offers a first impression and data about the current competitive situation between the technologies in 6 different categories. The first parameter is the purchasing price of a bus. From the table we can derive that the diesel bus in status quo has the big advantage of a very low entry-price. The second parameter which is important to elaborate is the availability of the fuel which is being consumed by the different engine technologies. Unlike hydrogen, diesel and electricity are easily accessible. However, high-capacity charging stations require investments in infrastructure in order to be able to charge buses on demand, while diesel can be refuelled without any additional investment costs over a wide area without access barriers. The third category deals with emissions and pollution on behalf of which distinctions can be made. The focus relies here on the tailpipe emissions and local impact. In that context, BEBs and FCBs have here the biggest advantage like no local emissions. The fourth parameter on behalf of which distinctions can be made is the progress of development. The technical maturities of BEBs and FCBs are still improving while the diesel bus is matured. Safety of fuel in operation is further critical binding criterion. While diesel is the easiest manageable medium here, the high-voltage electronic components of BEBS need equitable safety measures for maintenance as well during operations and FCB has increased attention to high-pressure components due to possible leaks. The last indicator is performance of the buses. A high and reliable mileage is definitive a purchase criterion, as possible uncertainties in the operation represent a risk and thus rather avoided. The status quo points out that BEBs still suffer from short range mileage and FCBs are analysed due to the longevity of the fuel cell.

Table 4: Overview comparison of technology parameters (Patil, et al. 2017)

Criteria	Diesel bus	BEB	FCB
Purchase Prise (EUR)[8]	~250.000 EUR (Can increase due to more complex flue gas cleaning methods)	~500.000 EUR (will decrease due to development and economics of scale)	~650.000 EUR (will decrease due to development and economics of scale)
Fuel	Fuel is easily available	Charging (overnight, opportunity) requires investments in infrastructure	Lack of fuel and fuelling infrastructure, which can be a bottleneck
Emissions and pollution	High local GHG emissions and high noise pollution	No tailpipe emissions and very low noise pollution, if no additional diesel generator is installed for delivering electricity for heating or AC	No tailpipe emissions and almost zero noise pollution
Technology	Mature technology	Technological barriers still to be overcome – large and fast development leaps	Technological barriers still to be overcome
Safety	Most stable fuel	Power battery system is a key component of an electric vehicle which affects the safety of the vehicle concerning maintenance handling	Hydrogen is stored in high pressure cylinders, potential for leaks and explosions
Performance	Proven service record	Limited durability of batteries	Proved technology but unknown durability of the fuel cell
Summary	Stable fuel, proven technology, but higher emissions	Low emissions, improving range and still expensive	Lowest on road emissions, almost proved technology and very expensive

4.1. Bus engine systems

4.1.1. Internal Combustion Bus

The conventional diesel bus is the most used bus worldwide in order of its mature technology and the constant supply of fuel. In addition, the diesel engine technology is still advancing in order of new improvements and innovations as well as requirements concerning efficiency and emission treatment management due to air quality guidelines. Concerning emission treatment management, the usage of catalysts and particle filters reduce emissions of NO_X and HC as well as fix PM. Engine measures

[8] Basis prices – the end prices are strongly depending on the manufacturer and the chosen equipment

which increase the engine efficiency and thereby reduce emissions based on the usage of diesel are turbo-charging, after-cooling, high pressure fuel injection, retarding injection timing and optimizing combustion chamber design. In order that the improvements of the diesel engine are reaching limits new flue gas after treatments opportunities, like the AdBlue additive, have to be further explored and developed to meet rising and more compelling emission standards about NO_x and PM pollution.

Table 5 illustrates the pros and cons of a diesel bus. Overall it can be stated that the diesel bus convinces through its existing technology with a very high reliability. Furthermore, a common diesel bus can be purchased for prices which cannot compete in 2019 with the purchase prices from BEBs or FCBs, which are often double or triple as expensive as the diesel bus. Moreover, a very confirmed advantaged of using and operating diesel buses is that no additional infrastructure or new infrastructure investments are needed. In contrast to the pros, there are as well significant disadvantages of the diesel bus. First of all the large emissions of greenhouse gases can be seen as the major con, followed by the high noise pollution. A further notable detriment is the dependence on the diesel fuel price. The diesel price can be seen as a strong trigger. If the price will go up other technologies will enter the bus market easier and faster. In consequence, if the prices stay low and are unrivalled there will be hardly a change towards another even more expensive technology.

Table 5: Pros and cons of a conventional diesel buses

	+ Pros	- Cons
Conventional[9] Diesel Bus	• Existing technology (high reliability) • Lowest bus purchase cost • No new infrastructure needed	• Large GHG emissions • High noise pollution • Bound by diesel fuel price

4.1.2. BEB

Battery electric busses are pure electric vehicles that are equipped with an electric motor that is only powered by a battery. BEBs are currently still struggling with the problem of too short mileages with one battery load and very high and no-competing purchase costs. Increasing the battery capacity can increase the range, but it also increases the costs, the weight and size of the battery as well as from the bus in total. Therefore, one possible method of reducing fuel consumption is recuperation of

[9] (Consumer Reports 2014)

braking energy. This is done by the electric motor which is used as a generator during braking with the result that braking energy charges the battery bus. In addition, main big advantages of the BEB including an electric motor are first of all the quiet running in order of no strong vibrations and engine noises and secondly the high efficiency of the electric engine paired with the low market prices for electricity. Furthermore, the low prices for operation and maintenance and the significant reduction of GHG emission during operation make an operation attractive and less arguable. GHG emission will be reduced in order of the possible fact that the consumed electricity derives from renewables energy sources. This issue is discussed in chapter 5.

However, some bus models are not fully 100% electrified. In order of the disadvantage of a limited range bus manufactures equip buses with diesel generators to provide energy for heating or cooling. Anemüller (2018) marks this as big weak point and as wrong turn, because the emissions of those generators are released worse after treated or even infiltrated in the environment. This con is in tight contrast to the pro in table 3 of a strong GHG emissions reduce.

Table 6: Pros and cons of BEBs

	+ Pros	- Cons
BEB[10]	• Quiet while running • High vehicle efficiency, low electricity cost and low O&M[11] cost • Reduce GHG emissions significantly (cf. chap. 5)	• Very high bus purchase cost • Very poor driving range • Major infrastructure upgrades • Can have diesel generators for heating and AC • Growing reliability (evolving technology) • High voltage handling

Today's electric buses are equipped with lithium-ion batteries, which are considered to be promising battery technology for electric vehicles of the future. The advantage of this technology is a five times higher energy density than lead batteries, due to a higher number of charging cycles. This battery type is characterized by a low self-discharge. Self-discharge refers to the loss of energy when energy in a charged-state battery is lost without targeted consumption. Noteworthy are the extremely fast charging times of the lithium-ion battery. Within 10 minutes 90% of the charging capacity can be achieved by high charging power. In addition, quick charging at high voltage reduces

[10] (Consumer Reports 2014)

[11] Operation & Maintenance

the lifetime of a battery significantly, which can be show by the usage of the Rampini Midibusse in Vienna. In order of quick opportunity charging at every end-station the batteries have to be changed after 4 years already. Disadvantages of the technology are currently still high investment costs in materials, safety electronics and additional trainings for service personnel working in the high-voltage range surrounding as well as the high costs of infrastructure upgrades in the bus depot and depending on the charging strategy on the route (cf. Section 3.2). However, a trend of falling market prices can be observed. Battery configuration and charging system of the bus models are highly dependent on the equipment and use of the bus (Seelinger et al., 2016).

4.1.3. FCB

The fuel cell represents the heart of a FCB, which is bundled with other fuel cells in a stack. A fuel cell reverses the process of electrolysis in the bus, which splits water into its components to produce hydrogen. In the fuel cell there are two electrodes which are separated by a separating layer, the so-called electrolyte. Hydrogen flows in on one side and oxygen on the other side. The hydrogen is now divided into its components of two electrons and two protons. The protons pass through the electrolyte to the oxygen side. The electrons must take a detour via an electric circuit to get to the oxygen side, where an electron deficiency exists. Protons, electrons and oxygen form water after the process and are released as water vapour. The voltage that arises in the circuit is about 1.2 volts of one fuel-cell. To generate greater voltages, several fuel cells are stacked together and connected in series (Rosenberg, Gent and Ziegler 2017).

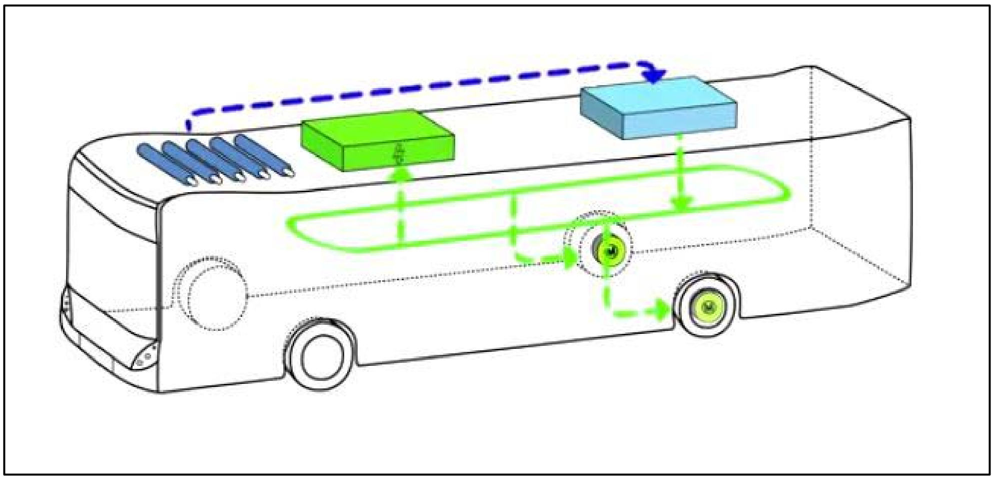


Figure 15: Mode of operation of a FCB (Hamburger Hochbahn)

Figure 15 illustrates all main components of a FCB. The hydrogen is stored in high pressure tanks on the roof of the bus. The Fuel cell at the rear of the bus turns the hydrogen into electricity and operates wheel hub motors at the rear axle of the bus. Leftover electricity which was not consumed by the motors or auxiliary consumers as well as produced recuperation energy will be stored in a high volt power bank.

Table 7: Pros and cons of FCBs

	+ Pros	- Cons
Fuel Cell [12]	• Extreme quiet while running • Operational range • No other emissions than water vapour • high power efficiency • no wear parts except mechanical components • Hydrogen is abundant and can be made from renewable energy • Continuing of heating or cooling at end stations	• Technology is very expensive • requires extremely-high-pressure, on-board hydrogen storage • Few places to refuel. Hydrogen is very expensive to transport and there is less infrastructure in place yet • Currently the majority hydrogen fuel is made from non-renewable natural gas in a process that creates enormous CO_2 emissions • Higher O&M costs due to intensive maintenance

There are a number of important differences concerning the operation of a FCB. In table 7 pros and cons are listed, which are based on the literature and the Interview with Conrad (2018). A major current disadvantage is that the fuel cell technology is still very expensive in order of the fact that constructed buses are mostly custom-built vehicles and the components behind the fuel-cell are highly complex. Furthermore, in order of this complexity the components and the full-cell have to be maintained more often due to real maintenance but also in order of constant security checks. These checks are mandatory due to the high-pressure components in which the hydrogen is stored. Additional disadvantages which occur due to the usage of FCB are the lack of refuelling infrastructure, what causes a costly construction of an own hydrogen fuelling station and the fact that the major volume of hydrogen is produced by electricity from non-sustainable energy sources, which are responsible for additional CO_2 or NO_X emissions. On the other side, the FCB provides a number of advantages concerning operation. First of all, the FCB can compete with the diesel bus concerning the range and the bus is extreme quiet and even more than a BEB where you have a whir in the cabin of the bus. Second, the fuel-cell technology offers the highest power efficiency and the fuel-cell has no wear parts. Third, a FCB has no other emissions than water

[12] (Seki, Hendrickson and Stine 2017)

vapour and can even have a low CO_2 footprint when the electricity for the electrolyses comes from renewables energies. A further advantage of the FCB is the fact that during daily operation the bus is able to cool and heat during standstill at end stations, where a conventional diesel bus is turned off due to flue gas emissions as well as a BEB to save electricity.

4.2. Charging systems for Battery-Electric-Buses

Today, different approaches exist to charge the energy storage of battery-electric-buses. Basically, two main types of charging strategies are distinguished: the overnight charging in the bus depot and the opportunity charging. Further strategies like the inductive charging, exchange of the battery pack or the exchange of the electrolyte of a battery are under supervision and still under development. The most common technology methods for overnight charging and opportunity charging are via cable connection or pantograph. In end, the final decision on one charging method falls with the decision concerning the operation of the buses.

4.2.1. Overnight Charger

The overnight charging method is used to load the buses during parking overnight in the bus depot. Thereby, the buses will be connected by wire to a fix installed charging station at the bus depot. Figure 16 shows the additional possibility of a mobile charging station offered by the bus manufacturer Sileo, which allows higher flexibility.

Figure 16: Mobile overnight charger of Sileo (Sileo GmbH)

Table 8 mentions pros and cons of overnight charging. However, overnight charging is used when the battery of the bus is designed for a full day operation of the bus in its limit of the installed battery. In consequence, a further advantage is that expensive investments in on route charging stations can be omitted. An additional positive argument is that having more flexibility by not being dependent on the use of outside the bus depot installed charging facilities. Anemüller[13] (2018) refers to the fact that transport operators tend to use buses on different use during one day of operation, for example enhancement in the morning or during rush hours. However, a big disadvantage of the wired loading of a BEB is the fact that it is very time-consuming. In general, it can be determined that a time frame of 6 to 8 hours is needed to fully recharge the bus. Furthermore, by loading more buses over night the bus depot must be technically updated to have enough charging stations as well as to provide the required electric power to charge in foreseen time with a foreseen power. Moreover, Anemüller (2018) refers as well to the danger that buses are not full charged in the morning what could result in operational outfall of buses and delays. In addition, these risks could induce the bus operator to keep diesel buses as back up at the bus depot. A final con of the overnight charging strategy is that the installed battery packs are more expensive in order of higher capacity.

Table 8: Pros and cons of overnight charger

	+ Pros	**- Cons**
Overnight Charger	• Battery capacity designed for a full day's use • No expensive investments in on loading infrastructure outside the bus depot • Buses are more flexible • Low infrastructure investment	• In case of simultaneous charging of several buses, provision of the appropriate number of charging points and grid power • Long charging periods (approximately 6 to 8 hours) • High battery bank costs

4.2.2. Opportunity Charger

The opportunity charger illustrated on figure 17 allows the charging or reloading of BEBs during operation at selected stops or at the end station. A pre-condition is an investment in several opportunity charging stations. One station amounts in 2018 in approximately 1.000.000 Euro[14] including all steps of installation. The opportunity charger allows recharging the bus in-between of minutes. The procedure is the following. The bus rolls towards the stopping position. The driver of the bus recognizes on behalf of a signal, could be lamps or lettering on the bottom, that the bus is standing

[13] cf. Interview with Stephan Anemüller (Annex B)
[14] cf. Interviews of (Thimm 2018), (Anemüller 2018)

on the right position. Now there are two technical solutions. We can distinguish between an

- opportunity charging station including the pantograph illustrated in figure 17 where the pantograph comes down and starts the recharging process and an
- opportunity charging station where the pantograph is installed on the roof of the bus and which moves up and connects then with the platform of the station illustrated in figure 18.

This operating recharging system allows having smaller battery pack in the buses, which lowers the purchasing price of the buses but in addition refers to high investments costs concerning the installation of a number of opportunity charging stations. A savings effect would then come into play when the saved amount of money due to smaller battery packs is higher than the costs for a number of charging stations. This effect would occur in a larger used bus fleet. As well as in Hamburg (figure 17) and in Cologne (figure 18) each bus line was equipped by 3 stations to avoid problems like that a station isn't working or that a station is parked by another bus. In consequence, the system is not designed for long mileage of the bus routes, what reduces the number of routes where BEBs could be used. Table 9 includes all disadvantages and advantages and mentions also the fact that also BEBs which are operating with opportunity charging have also to be recharge at the bus depots. This results from the fact mentioned in section 4.1.2. that the batteries unload themselves but also that in that way the battery packs can be full charged with low power overnight what prolongs the lifecycle of a battery.

Figure 17: Opportunity charger of innovation line in Hamburg

Figure 18: Opportunity charger in Cologne

Table 9: Pros and cons of opportunity charger

	+ Pros	**- Cons**
Opportunity Charger	• Allows to have smaller battery packs on buses (smaller battery costs less) • Recharge on the depot with low charging power	• Battery capacity not designed for long mileage • Reload during line use on the track with high charging power (at turning points and / or selected stops) • High investment costs • Needs as well as a recharge overnight possibility • Operating failures at the opportunity charging stations

4.3. Charging system for Fuel-Cell Bus

The filling stations for hydrogen can be slightly compared with normal fossil fuel station, but a hydrogen station is technically more complex and significantly more expensive than the conventional filling station. The most in common is the fact that fuelling a bus at the pump takes about 10 minutes and refuelling happens as well through a tap. In this type of gas station, you have a large reservoir with gaseous at a relatively low pressure of about 30 bars. In addition, there is also the possibility that hydrogen is stored in liquid form, when it is already delivered in liquid form with tanker trucks. However, hydrogen is being refuelled in gaseous form. After the large reservoir, the gas is compressed by an ionic compressor and stored under elevated pressure in a high-pressure bank consisting of several high-pressure vessels and cooled. The pressure in the high-pressure bank is approximately 700 bars and the hydrogen gets cooled down to between minus 30 and minus 40 degrees Celsius.

Conrad (2018) states that the big bottleneck is the capacity of how many buses can be refuelled in a row. The technical components of a hydrogen station which are responsible therefore are the compressor and the high pressure storing components. Furthermore, to have classification between costs of a hydrogen station and its service capability we can assume that to refill four FCBs in a row the costs amount in 800.000 up to 1 million Euros. Further, Conrad points out that if a bus operator wants to refuel now more than four buses in a row also the construction costs of a hydrogen station rise in-line. So, if a bus transport operator can assure refuelling of its buses uniformly distributes over the day a hydrogen station with a smaller capacity is adequate. In reality, a bus operator refuels its fleet mostly in a short period of time in the evening when the buses get back to the bus depot, what requires then a bigger refuelling capacity by the hydrogen station.

Table 10: Pros and cons of hydrogen fuelling stations

	+ Pros	**- Cons**
Hydrogen Fuelling Stations	• Fast refuelling • possible on-site production by electrolysis	• High investment costs • Complex technology (pressure, temperature and storing) • Limitation through limited use of fuelling stations

5. Impact Assessment of Electrification Strategies

5.1. Ecological impacts

5.1.1. Emission impact of Euro6 Diesel-buses

5.1.1.1. Air pollution

Air pollution is a key issue in regard to an evaluation of the ecological impact of diesel buses. The emissions are the end products of the combustion process which are released by the exhaust gas system. Table 8 lists the several types of compounds after having burned one kilogram of diesel and their impact and contribution to the environment. Table 9 and 10 illustrate dimension of the different emissions products which can be adopted as example for the exhaust emissions of a diesel bus operating in the field of public transportation. The biggest components after having burned one kilogram of diesel are 1.1 kg of water in the gaseous state and 3.2 kg of $CO_{2.}$ Water vapour and even more CO_2 can be classified as GHGs. In consequence, that the combustion process never occurs as a total clean combustion several substances of incomplete combustion are released. The main substances are particulate matter (PM) which is responsible for soot formation, hydrocarbons (HC) which are forming smog and in a very small amount carbon monoxide (CO) which acts as a poisonous gas. Furthermore, in order of the high temperatures during the combustion process NO_X is formed as a reaction between nitrogen and oxygen. NO_2 causes lung irritation in order of inhalation as well as smog formation. Moreover, the NO_2 transforms in the catalyst to NO2 which is a further major monitored GHG (Kaustubh, et al. 2014, 32 ff).

Table 11: Exhaust from diesel buses for 1kg burned diesel (Patil, et al. 2017)

Emissions	Classification of pollutant	KG	%
Water (Vapour/Steam)	Greenhouse gas	1,1	25,49%
CO_2	Greenhouse gas	3,2	74,14%
NOx	Lung irritant and smog	0,008	0,19%
PM	soot	0,0017	0,04%
HC	smog	0,0035	0,08%
CO	poisonous gas	0,003	0,07%

Table 12: Classification of main pollutants by 1 kg of diesel (Patil, et al. 2017)

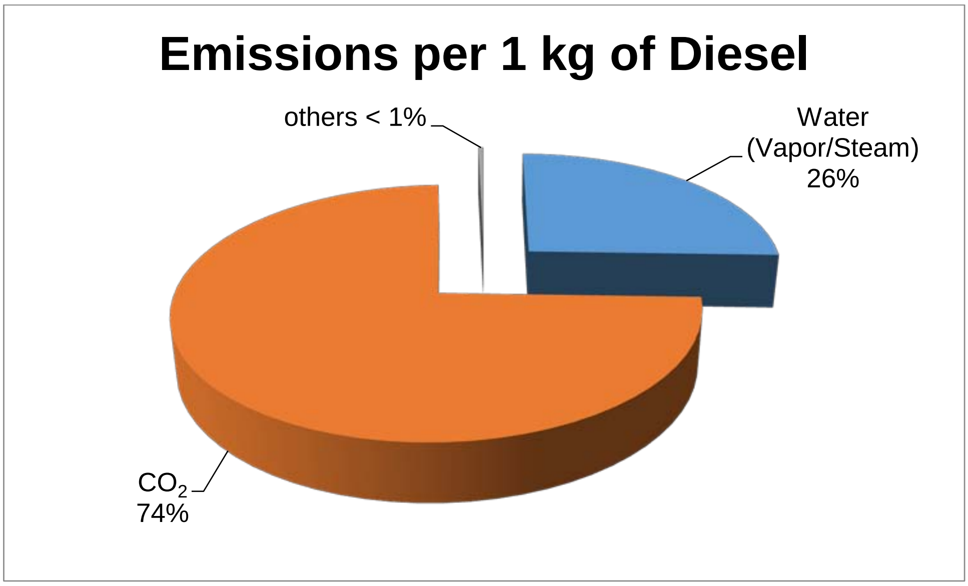
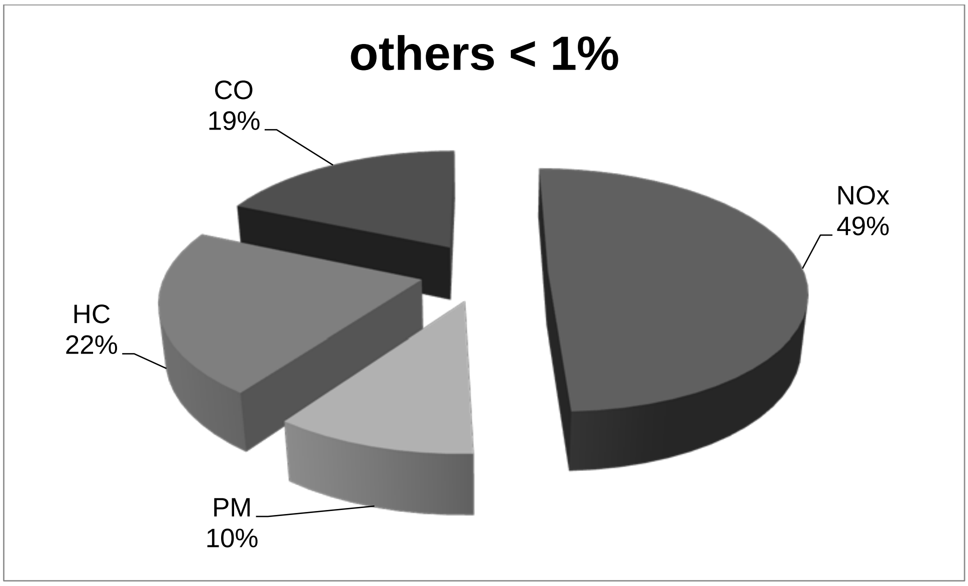


Table 13: Classification of other pollutants by 1 kg of diesel (Patil, et al. 2017)



In Europe, cars are covered by the EURO emission standard classes mentioned in chapter 2, which define the permissible emissions for air pollutants like NO_x, CO, HC, PM. Thereby and this is stunning, CO_2, illustrated in table 12, represents more than 74% of the emissions of burned diesel. However, CO_2 emissions are not regulated so far in the environment of transport and traffic. Due to the knowledge about all emissions, thresholds have been introduced for the protection of ecosystems and vegetation and primarily for the health of the population. The EAA states and this is very interesting, that those threshold values apply in the first instance for healthy adults and not for expectant mothers, children, elderly or sick people. Concerning health and environmental impact of NO_2 which is a monitored pollutant the Federal Environment Agency of Austria (Umweltbundesamt 2018) states the following. NO_2 is a strong irritant gas and damages the lung function, in addition, cardiovascular diseases are promoted and the mortality rate is increased. In addition, the nitrogen oxides are partly responsible for the acidification and eutrophication (over-fertilization) of soils and water. In the cold season in winter, particulate ammonium nitrate is formed from gaseous nitrogen oxides and ammonia. This contributes to a large-scale load of particulate matter (PM_{10}). In summer, nitrogen oxides together with hydrocarbons lead to the formation of ozone.

Furthermore, table 13 in comparison with table 12 shows that the NO_x, CO, HC, PM_{10} occur just in small mass per burning 1 kg of diesel. Nevertheless, the number of ultrafine particles is more important concerning their impact than their mass. Transport and deposition of the particles in the respiratory tract are decisively influenced by their diameter. The smaller the particles, the deeper they penetrate the lungs. Children, especially in cities, are much more exposed to traffic emissions than adults because they inhale and exhale much more often in proportion to their body size. In addition, the organs of children are not yet fully grown and therefore more sensitive. The fact that the carcinogenic particles are most concentrated at the level of children at the level of children is also a major cause of serious effects on children (Umweltbundesamt 2018).

5.1.1.2. Noise pollution

Noise pollution is not a trending topic due to the discussion of electrification of public transport buses and is not really perceived as pollution of the environment. More or less, the reduction of exterior and interior noise by the implantation of BEBs in comparison with conventional diesel buses is more seen as a beneficial side effect. The main focus still relies on the reduction of emissions. However, Münzel et al. (2014) states that noise pollution is more and more going to be recognized as a health problem in city and more densely populated areas but also that it is far more complicated to decrease noise pollution than air pollution in cities. In general, noise can be identified as a stress indicator resulting in physical stress reactions like annoyance. Furthermore, constant noise exposure could cause in increasing incidences of arterial hypertension, myocardial infarction and strokes.

A study by Ross & Staiano in 2007 has already shown that noise pollution can be tremendously reduced by the implementation of BEBs. Especially in a speed range below 40mph[15] BEBs have a constant lower noise profile. In consequence, “at speeds 40 mph and above, maximum noise levels for all bus technologies begin to converge as noise from the tire/pavement-interaction begins to dominate” (Ross and Staiano 2007, 7). In this study, components of the diesel bus like the exhaust system, engine block, cooling system and the tire street noise have been monitored. On the side of the BEB electric motors, auxiliary components like cooling or AC equipment and the tire street interaction have been observed.

The arguments mentioned above compared with the consideration that buses in inner cities areas operate in low speeds shows the advantage of BEBs. Furthermore, concerning operation noises during standstill the difference between a diesel bus and a BEB or FCB is significant. During a diesel engine operates with 600 rpm[16] a BEB as well as FCB have no mechanical parts which are working concerning the drive train (Ross and Staiano 2007). Thimm (2018), Conrad (2018) and Anemüller (2018) point out that in order of growing experience in operation passengers and drivers recognize the advantages of less noise in the bus cabin of BEB and FCB. Especially the bus drivers really enjoy after some scepticism at the beginning the quieter running of the BEBs or FCBs.

5.1.2. Life-cycle-analyses of Batteries

The electrification of the public transport as well as the electrification of vehicles in general does not only offer new opportunities. Concerning the electrification of buses, the focus relies on batteries due to their major environmental impact. Studies show the environmental burden from the first exploitation of raw materials over production until the final end-use or recycling.

A significant value in the review has lithium. Lithium is considered to be a geochemically scarce metal. However, lithium is currently very little recycled. Recycling is neither efficient nor of great interest because of the low lithium content in batteries in contrast to cheap lithium resources, reported in 2013 (Ellingsen, et al. 2013). Romare and Dahllöf (2017) add in their research report that LFP[17] batteries have still no material value and that are not recycled but sent to waste incineration plants for energy recovery by being burned. Elingsen, et al. (2014) point out that it is more important to

[15] Approximately 65 km/h
[16] revolutions per minute
[17] Lithium-Iron-Phosphate ($LiFePo_4$)

ask how the copper, aluminium components and the electrode pastes and electrolytes of a battery are recycled due to their bigger ecological footprint impact than lithium.

In order to these facts above, both studies relegate to focus on the CO_2 emissions during manufacturing and production of battery cells and its components like the positive electro paste and the negative current collector. In addition, mining and refining tent in studies to contribute relatively small towards a holistic life cycle of batteries. Romare and Dahlhöf (2017) poured the environmental impact of batteries in numbers and based on their review 1 kWh[18] of a battery corresponds to 150 up to 200 kg CO_2 and 180 kWhs are used to produce 1 kWh of battery. In addition, if the battery industry which is majorly based on carbon-intensive electricity would change to manufacture batteries with hydrologic power the environmental CO_2 footprint could be reduced by more than 60% (Ellingsen, et al. 2013).

To achieve progress on sustainable battery production, Romare and Dahlhöf (2017) analyse the situation as follows that *"since production location currently is based on labour cost it can be important to promote a choice based on environmental factors as well. Legislation can be one way to ensure this by giving incentive to choose production location or electricity type based on environmental factors"*.

In regard of this evidence above and in anticipation of a potential upcoming large-scale electrification, it would need now clear transparency and regulated terms towards legislation on the sustainable production of batteries by political decision makers. Because, if the decision of purchasing a bus would be based on the carbon food print and either the total life cycle carbon emissions or grey energy emissions would represent a major cost criteria in future then a diesel bus would be superior to BEBs or FCBs.

In consequence, the authors of both studies came to the result that the lifetime of batteries must be extended to increase on the one side the attractiveness and to broaden the high short-term allocation of CO_2 caused by batteries on the other side. However, the approaches are different. Elingsen, et al. (2013) argues that concerning electric vehicles the situation could already be improved if batteries have the same lifespan as the vehicles themselves. In addition, this would eliminate the need of a number of replacements of batteries and thus make it more sustainable overall and could trigger an environmentally friendlier effect for the environment. On the contrary, Romare and Dahlhöf (2017) focus on the second life of batteries. The second life of

[18] Kilowatt-hour

batteries starts when batteries are replaced due to loss of power and reuse becomes an issue of interest. Moreover, it is described that batteries which reached 80% of the initial capacity no longer meet the requirements for electric vehicles and thus be exchanged. Further, these batteries would, according to the authors, be suitable for less demanding applications. Examples of such a second life usage could be renwable energy grid storages, backup systems and small-scale electricity.

In this context, batteries of BEBs could open up a new market and find buyers for after reuse because, according to Thimm (2018), Anemüller (2018) no transport company knows to what extent there will be a second-hand BEB market and in the case someone who will buy a 10-year-old second-hand BEB will further purchase a new battery pack for the bus. Using the example of the Wiener Linien and its Rampini Midi-BEB, where the batteries must be changed every four years as they have lost 50% of their power, it becomes clear that it must be possible to reuse batteries even if they only have 50% of their power left (Peretti 2018) .

In this context of second life use for replaced batteries of BEB, the example of MAN shows that this consideration is not only mature but also going to be implemented. The bus manufacturer MAN expects that batteries of their urban BEBs last about six years in comparison to a bus average life of 12 years. However, MAN wants to apply waste batteries of BEBs arising during the change to meaningfully after uses behalf of their remaining capacities instead of being disposed. The batteries could prevent current spikes in the grid when the exchanged batteries of BEBS will be used as an energy storage. Furthermore, at low load times the memory would be filled so that subsequently buses can be loaded at peak times then. This would not only save costs and stabilize the power grid, but could also provide insights into the aging behaviour of batteries (MAN Truck & Bus 2018).

5.1.3. Environmental Impact of used energy resource

The enormous consumption of oil by transport and traffic causes environmental damage and the origin of imported crude oil or fossil fuel has as well an impact on the climate balance of transport and traffic. Therefore, it is necessary to pay attention to the energy sources from which electricity and moreover from which electricity hydrogen is produced. These considerations play a major role in the question of whether electric mobility can make a contribution to the reduction of greenhouse gases. Furthermore, by knowing the origin of the primary energy consumed by BEBs or FCBs it can be stated if the environmental footprint is a better or even worse one than one of a conventional diesel bus.

5.1.3.1. Electricity

Concerning electricity, it is extremely important to be aware of its origin. Due to an example of Austria, table 11 illustrates the electricity mix of 2016 and the primary energy sources (E-Control 2017). We can identify that almost 87 percent of the Austrian electricity comes from renewable energy sources. In comparison to that, table 12 illustrates the electricity mix of Germany in 2017. In Germany only, 38.5 percent of the available electricity comes from renewable sources. In reference to the fact that BEBs and FCBs are brought to the public under the opinion that they are truly 100 percent emission free can't be validated with inclusion of these aspects. Including this line of argumentation, a BEB in Austria would be more climate friendly than a BEB in Germany.

Table 14: Electricity mix of Austria 2016 in% (E-control)

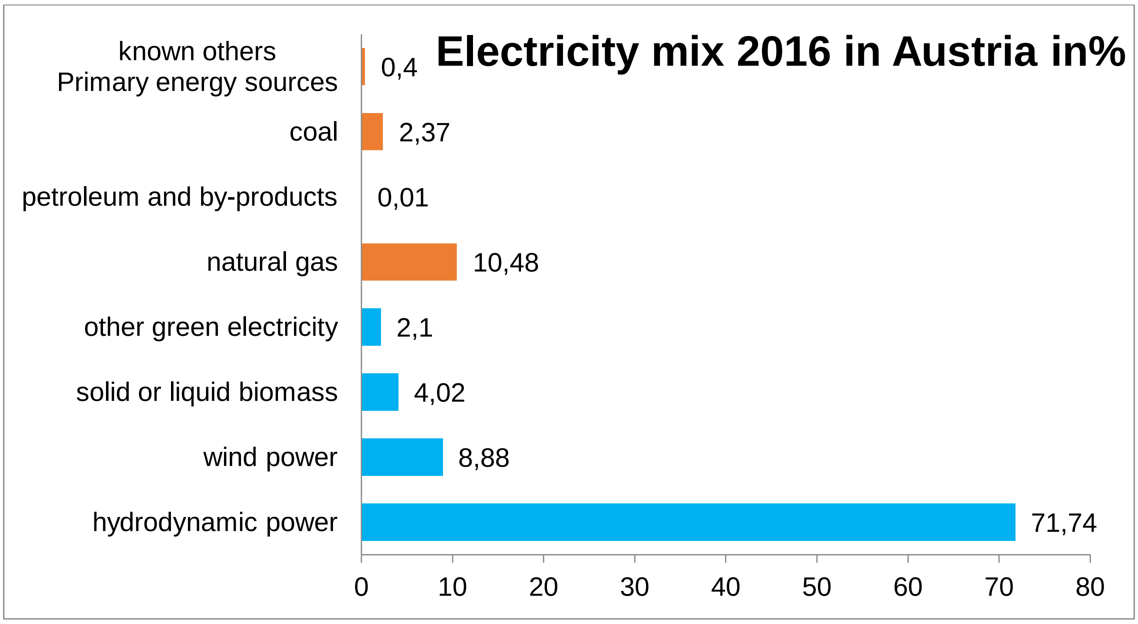
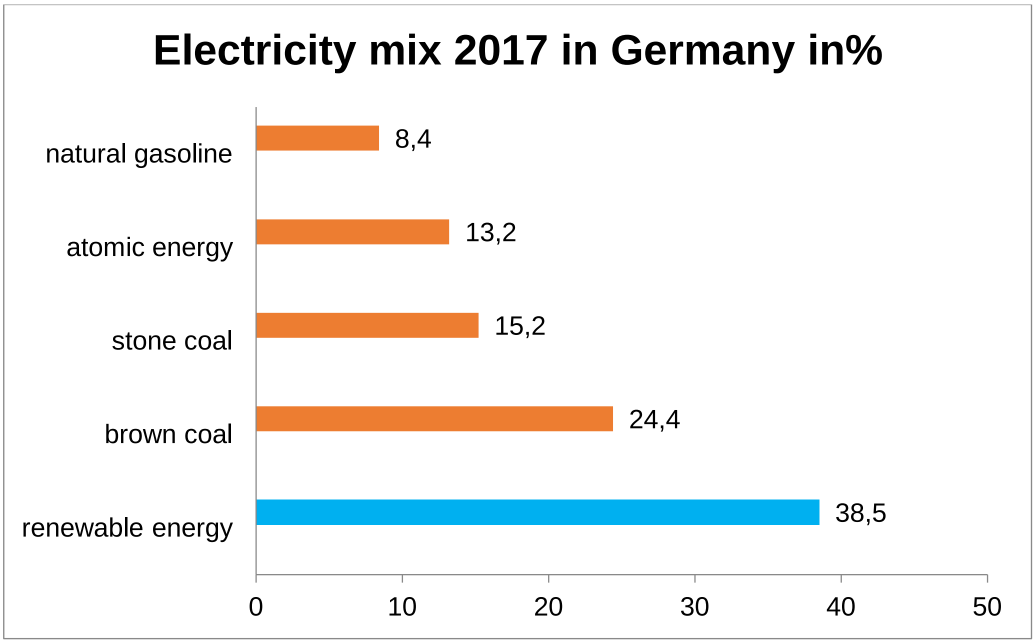


Table 15: Electricity mix Germany 2017 in% (Fraunhofer ISE)



5.1.3.2. Hydrogen

Hydrogen does not occur in nature and therefore it must be extracted from water, biomass or fossil hydrocarbons such as coal and natural gas. All processes are very energy intensive. In addition, only a certain part of the released hydrogen can be stored. However, by using fossil fuels for the production of hydrogen as much as of the greenhouse gas carbon dioxide CO_2 will be released same as the fossil fuel is burned itself. By using biomass like wood for the production of hydrogen the climate balance can be improved due to the fact that burning biomass releases only the amount of carbon dioxide that was previously absorbed by the growth of the plants from the atmosphere. One method of obtaining hydrogen is electrolysis. With the help of electric current, hydrogen and oxygen are generated from the water in an electrolyser. Unlike the use of fossil fuels, no CO_2 is released during electrolysis. In electrolysis, water (H_2O) is split into H_2 and O_2 using electrical energy. However, to be fully climate-neutral only applies if the electricity used was not generated from fossil fuels. (Randelhoff 2014)

Figure 5 illustrates exactly now the connections and processes mentioned above. We can identify in the figure brown as well as green hydrogen. The difference is the origin of the electricity. Brown hydrogen is produced by fossil energy sources in contrast to green hydrogen which is produces by renewable energy sources coupled to solar or wind power. Furthermore, brown H_2 is produced through the process of steam reforming. Randelhoff (2014) mentions that steam reforming is currently the most economical and widely used form for the production of hydrogen by chemical plants or in pharmaceutical industries. However, for the process of steam reforming natural gas is used in large amounts and represents the most important raw material for it, what points out the reverse site of brown hydrogen concerning its the climate balance.

Cornering green hydrogen, Randelhoff (2014) refers to the fact that electrolyses could become significant in the context when very cheap electricity by renewable energy sources is available. If this could be achieved, the next step would be that hydrogen is produced on site and on purpose.

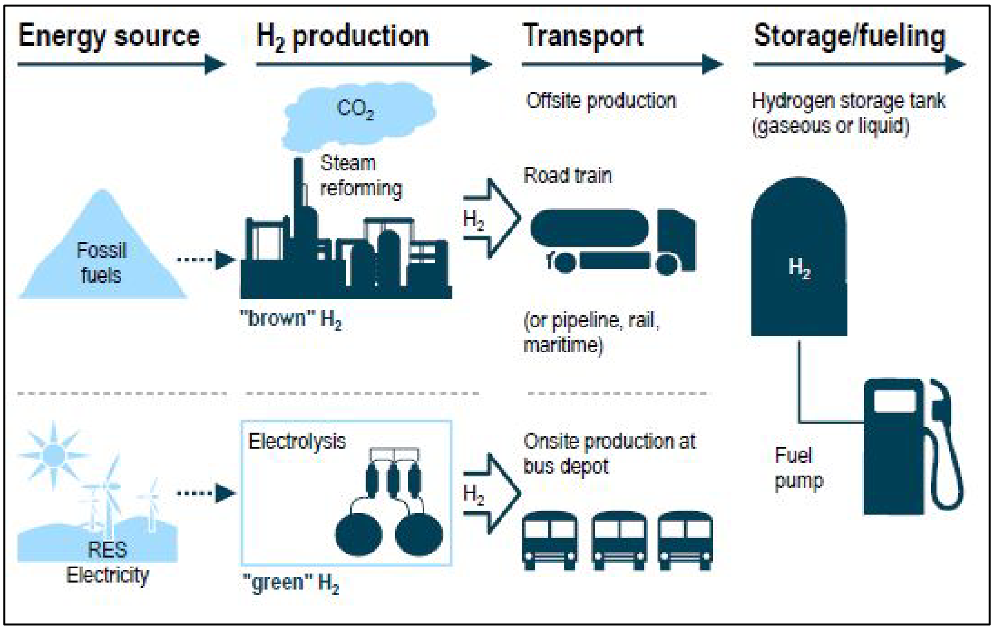


Figure 19: Hydrogen chain (FCH JU)

5.2. **Economic impacts**

Towards considerations about electrification of the public transport buses it is not done by highlighting the environmental aspects or the technical feasibilities. Furthermore, it is important to analyse as well to describe the impact of diesel which is majorly used for the operation of buses. Therefore, this chapter is foreseen to provide some considerations compared with facts about the purchasing power loss through diesel or oil imports and in consequence the chance of domestic value creation if the energy or hydrogen which is used for a BEB or a FCB derives from local production.

5.2.1. Purchasing power loss through the import of fossil fuels

Austria is heavily dependent on crude oil imports and transport and traffic are responsible for 80 percent of domestic oil consumption. In the years 2011 to 2015, Austria imported oil for almost 22 billion Euros, which means that almost 17.5 billion are attributable to transport and traffic alone. Table 12 illustrates the amount of money for crude oil imports per year. With regard to energy security, it should be noted that on the one hand, 80 percent of crude oil imports come from just ten oil companies worldwide and on the other hand that Austrian oil imports derive from politically unstable crisis states that are not even listed in the Top 100 in the Democracy Index. The enormous oil consumption of traffic causes in major environmental damage as well as health problems and makes Austria dependent in a certain range on politically unstable states and a fluctuating oil price. (Cambridge Econometrics 2016)

Table 16: Crude oil imports in Euros from Austria between 2015 -2011 (VCÖ)

2015	3.2 billion Euro
2014	4.5 billion Euro
2013	4.9 billion Euro
2012	4.9 billion Euro
2011	4.4 billion Euro

If now climate-friendly forms of mobility would be more expanded and conventional public transport diesel buses would faster be switched to BEB and FCB, the loss of purchasing power through oil imports could be reduced. Furthermore, political will as well as financial incentives could foster the local production of electricity and especially the local production and storing of hydrogen and thus local value creation and creation of jobs.

5.2.2. Domestic value creation through local energy production

Following up on the idea of the preceding section that domestic value and jobs are created by reducing the loss of purchasing power and that focusing on local added value creation in the energy sector and employment effects occur is confirmed by a study on behalf of the Austrian Energy Agency. This study describes the effects of regional value creation and increasing employment through solid biomass energy in the region of Hartberg. Höher, et al (2015) describes regional structures and value-added flows in the study. Concerning fossil fuels in the study, they have only a small share of the local adding value. Using the example of heating oil, it becomes apparent that there is no value creation on site in the region due to the supra-regional import of fuel oil. Only 2% of the gross sales price of one litre of heating oil remains in the region without secondary effects.

A secondary or a fiscal multiplier effect in economics is a factor that indicates to what extent an initial economic impulse has an effect on further economic effects and monetary values. In the case mentioned above, secondary effects would be that the local suppliers of oil heating systems profit from maintaining the oil boilers which are operated with the imported heating oil (Investopedia 2018).
As a result, regional energy supply and consumption would strengthen the local income as well as increase the purchasing power and would result in a local domestic value creation of a region. Furthermore, multiplier effects like the demand for other goods and services of the population would create an employment effect (Höher, et al. 2015).

In this context, the increasing implementation and operation of BEBs and FCBs could create then regional domestic value. Therefore, the best example is hydrogen. The illustrated hydrogen chain in figure 5 shows the opportunity of hydrogen contributing towards local value creation if

- the energy comes from local renewable resources,
- the production is happening close to place of consumption,
- the transport is achieved by local companies and
- the storage and fuelling stations are maintained by regional skilled workers.

Further, it is possible to use hydrogen when it occurs as a by-product in regional industries like chemical plants or as well in pharmaceutical industries. In Cologne the RVK uses local hydrogen and keeps distances and additional emissions low (Conrad 2018).

6. Case Study: Towards electrification of bus network lines in Tyrol

Due to the idea of replacing convenient propulsion technology with electric engines in buses, it is also important to look on incentives and arguments in the environment for this change. Moreover, this change will have a major impact on the emission side as well as on the air quality side. The cessation of using diesel or fossil fuel by buses will have measurable impacts, especially in areas like the Inntal (Inn-valley) which are highly affected by local and trans-boundary traffic. Furthermore, the Inn-valley has to deal with its geographic characteristics.

6.1. Bus Company Ledermair

The bus company Ledermair is situated in Tyrol and represents the largest private own bus company in Tirol. The headquarter of the company is located in Schwaz and XX bus sites are in operation in different parts of Tyrol due to different regional transport missions. Nevertheless, the company was founded in 1924 with focus on transport of goods with a horse-drawn vehicle. In 1946, the purchase of 4 small buses and the launch of shuttle traffic between Schwaz and Innsbruck lay the foundation for the bus company of today. Since then, the company driven by a constant growth caused by acquisitions of new line concessions and the takeover and incorporation of other bus companies. Overall, the Ledermair bus group consists today out of XX companies with focus on public transport, factory workers shuttle transport and bus travels. Furthermore, the Ledermair group employees 200 people and operates in total 100 buses.

6.1.1. Bus fleet

The entire bus fleet of the company amounts in 100 buses. XX of them are urban buses for public transport and XX are overland coaches used for travelling and touring. The average age of the bus fleet is 3 years in April 2018 and the oldest bus is 5 years old. All new buses used for public transportation are leased for 5 years in generally and will be returned to the general contractor or importer and replaced by new bus models of the same or a different bus producer. The mileage of the whole bus fleet amounts in 5.5 million kilometres in average per year. All buses are powered by internal combustion diesel engines and the total consumption of the entire bus fleet can be represented by the sum of the total fuel costs which amounts in 1.6 million Euros for the last year 2017.

The focus of this paper lays on buses which are operated from the Ledermair site in Innsbruck. The bus depot is located in the industry area of Innsbruck with good and fast connection to the Highway A12 as well as the city streets of Innsbruck and the federal road network. The bus depot includes XX buses which are used for 4 route networks in Innsbruck and its surrounding area, for the city buses of Hall in Tirol and overland buses used for bus tours and factory workers shuttle transport.

6.1.2. Route network

Mentioned in the paragraph above, the route network of the site in Innsbruck operated by Ledermair includes 4 different lines. The concessions of those 4 lines have been taken over in the year 2003. In the official usage for the company Ledermair as well as for passengers the lines are nominated as W, LK, TS, 501. The difference in labelling between letters and numbers causes in the facts that W, LK, TS are operated within the city borders of Innsbruck and in consequence that the major part of the route of the line 501 is allocated outside the city borders of Innsbruck. Figure 20, part of the Tracking Report in Annex A, illustrates 3 of the lines mentioned above and part of the analysis. The bus route W is coloured red, the TS (Tourist Sightseer) is defined by the orange colour and the green colour traces the route of the bus route 501.

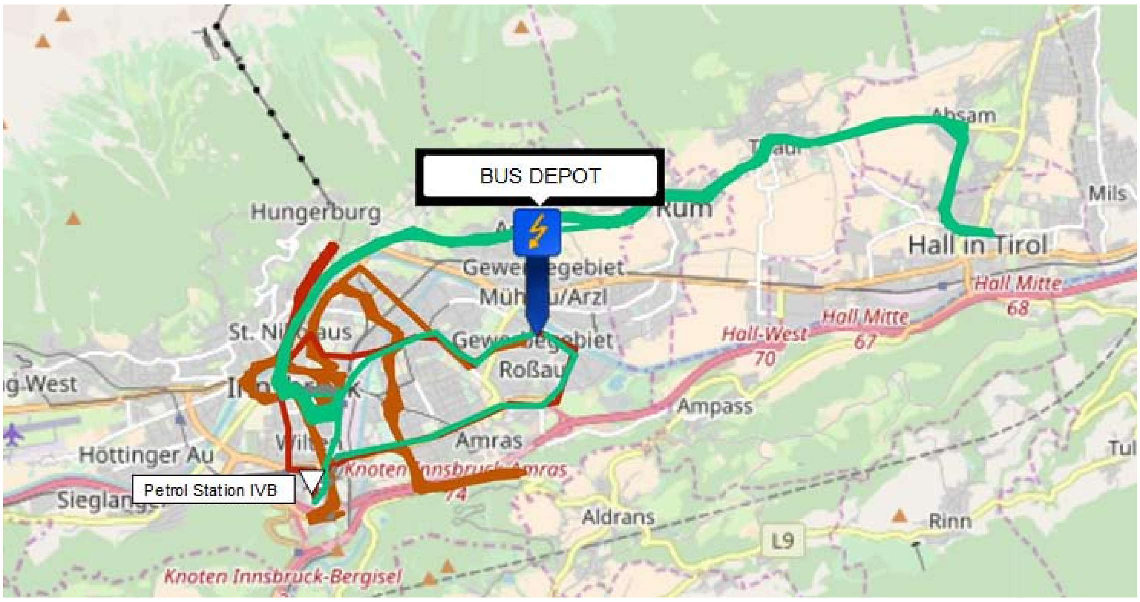


Figure 20: Illustration of route network of W, TS, 501

6.2. Description of the Analysis-Tracking-Simulation Report

6.2.1. Methodology

The primary sense was to identify the power demand of the bus network route to have a common unit one which it would be feasible to make assumptions and to calculate on different possibilities. In the first step GPS-trackers were installed in 3 different bus types which operate on 3 different routes with the focus to record one average day of operation. The trackers were installed in the front behind the front window to achieve constant signal strength. Important was that all loggers have been connected the whole day of tracking to an energy source. The installation happened in the morning were the buses where still parked at the bus depot. In consequence, the trackers were removed in the evening when the buses have been parked again at their depot building. In Annex C can the logging data can be observed. Figure 21 shows the installation of the loggers in the Mercedes Citaro bus which was tracked running on line 501 this day.

Figure 21: Installation of logger in the Mercedes Citaro on line 501

The second step towards the final report was to import the single-data files of the tracker into the software of the LEEFF[19] research project, for which the author got the permission to use it for this master thesis. Information on the purpose LEEFF project is mentioned in the last passage of the methodology chapter. The goal by using the software was to simulate one year of operation on behalf of the power demand profile and reference data and to simulate if the network routes can be operated by BEV- or FC-buses. In order that the software is designed for trucks and transporters, drive cycle profile data of buses were programmed into the software for the master thesis. Furthermore, the software calculated behalf of the feasibility which alternative vehicle

[19] Low Emission Electric Freight Fleets

can be used instead of the diesel buses the difference in fuel costs and the prevented CO_2 emission. The following parameters have been used:

- Drive cycle profile (speed, topography, route)
- Energy costs (diesel €/litre, electricity €/kWh, €/kg H_2)
- Technical data of buses (fuel/energy demand, CW-value[20], data-sheet)

The LEEFF project:

LEEFF is a public financed projected of universities and private partners with the aim for a holistic approach improvement towards electrification of transport businesses and logistic enterprises. The software was created and is still under development and focuses on the perfect match between charger station management and the size and features of the battery-pack inside the vehicles.

6.2.2. Results[21]

Concerning the results, the expectation was to achieve data which illustrates an economic and ecologic difference between the variant 0 which is represented by the status quo and the variants with electric vehicles. In consequence, the results have been reviewed by comparison between the provided data of the bus company Ledermair. The average company data nearly matches the results of the report. Due to the given deviations, it can be stated that those are within a tolerance range. In addition, the deviations concerning kilometres by year and costs can result in the fact that the buses are maintained or are used for additional transport missions.

[20] Drag coefficient by automobiles to quantify the resistance during driving.
[21] Cf. Analyse of Tracking Report in Annex A

6.3. **Variant 0: status quo and assumptions**

Variant 0 illustrates the current status and provides an overview over the actual used bus models, annual mileages, fuel costs and CO_2 emissions. On behalf of the current variant 0 the case study wants to elaborate results by comparing the actual used buses with matching E-buses. The current bus fleet of the bus company Ledermair consists of bus models from three different bus manufacturers like Solaris, Setra and Mercedes, which consume diesel and fulfil all the EURO6 emission standards. For the analyses and the tracking report the focus relied on three buses, which are operating on three different lines with different network properties. The three different bus models are

- a Solaris Urbino 8.9 in operation on the line W,
- a Setra S415 LE Business in operation on the line TS and
- a Mercedes Citaro in operation the line 501.[22]

Furthermore, to derive with an adequate status quo for comparison with electrified solutions it was important to have primary validated data from the bus company Ledermair about every single bus mentioned above, before doing the analysis. In an interview with Christian Haas, he is responsible for infrastructure and tendering of the bus company, data and information about costs and pricing were elaborated.[23] The three following tables 17/18/19 illustrate general basic operation data like average kilometres per year, average kilometres per day and fuel consumption per day as well as cost factors like diesel net costs per litre and maintenance costs per km. The collected data from the bus company Ledermair was used as input for the analyses. Further, the data were used as comparative values after the software has calculated on behalf of one day tracking an annual average drive cycle.

Table 17: W (Solaris Urbino 8.9)

W (Solaris Urbino 8.9)	
average driven kilometres per year	54.000km (planed)
average kilometre per day	160 km
average fuel consumption per day	70-80 litres/day (34-40l/100km)
average fuel costs per day	60-70€ / day
diesel costs per litre	0.85 Euro per litre
maintenance costs	0.075 Euro / km

[22] Pictures of all three buses in Annex D
[23] Cf. Interview with Christian Haas in Annex A

Table 18: TS (Setra S415 LE)

TS (Setra S415 LE)	
average driven kilometres per year	47.000km
average kilometre per day	120 km
average fuel consumption per day	40-45l litres/ day
average fuel costs per day	34€/day
diesel costs per litre	0.85 Euro per litre
maintenance costs	0.07 Euro / km

Table 19: 501 (Mercedes Citaro)

501 (Mercedes Citaro)	
average driven kilometres per year	100.000km
average kilometre per day	250 km
average fuel consumption per day	120 litres/day (40-50l/100km)
average fuel costs per day	100-110 € / day
diesel costs per litre	0.85 Euro per litre
maintenance costs	0.07 Euro / km

Table 20 illustrates the simulated status quo of the 3 buses concerning fuel consumption and CO_2 emissions projected to an annual base. The Setra bus on the line TS with the tracker number E002 drives on average 34.621 kilometres a year. For this distance the bus needs fuel in an amount of 12.503 Euro per year. The calculated emission on CO_2 amounts in 38.979 kg a year. Only the projected number of annual mileages of the Setra bus differs between analyses and the provided data by Ledermair. This gap in kilometres derives from the fact that the bus is used for other transportation issues or on other lines before or after it is in operation on the TS line.

The Solaris bus on the line W with the tracker number E122 drives on average 53.666 kilometres a year and this value meets almost the exact planned annual mileage of 54.000 kilometres by the bus company. In addition, in 2017 the bus just drove only 47.196 kilometres in order of higher maintenance. This higher requirement of maintenance reflects in slightly higher maintenance costs per kilometre, e.g. table 17. So, by fulfilling the total annual mileage the bus consumes diesel in an amount of 19.733 kilometres and is responsible for CO_2 emissions of 61.520 kg a year.

The Mercedes Citaro on line 501 with the tracker number E139 has an annual mileage of 107.080 kilometres a year. The fuel costs per year derive in 45.027 Euros and the annual emissions of CO_2 are 140.379 kg per year in this constellation.

In total, all three buses cover a total distance of 195.367 kilometres per year. In consequence, the total amount of consumed fuel amounts in 77.262 Euros and the total emission of CO_2 is 240.877 kg.

Table 20: Variant 0 - overview of status quo (Tracking Report)

Current vehicle	Annual mileage	Fuel costs per year	CO_2-emissions per year
E002 Setra TS	34.621 km	12.503 €	38.979 kg
E122 Solaris W	53.666 km	19.733 €	61.520 kg
E139 Citaro 501	107.080 km	45.027 €	140.379 kg
total fleet	**Total 195.367 km**	**Total 77.262 €**	**Total 240.877 kg**

Concerning Variant 0, table 20 represents the three single tracked buses. For further considerations towards an electrification of a single total line like TS or 501 it is important to know that on TS two buses and on 501 three buses of the same type are in operation. That means the line TS is operated by two Setra buses and the line 501 by 3 Mercedes Citaro.

For further considerations in the following parts of the thesis due to variants of electrification we assume for additional calculations that each bus which operating on line has the same annual mileage and operating parameters. In consequence, the CO_2 footprint of the line TS amounts approximately in 77.958 kg CO_2 and the total fuel cost per year will be around 25.000 Euro. Concerning the line 501, in average the three buses in operation emit 421.379 kg CO2 and consume fuel for 135.081 Euros.

Assumptions, determinations and definitions for the case study

For being able to compare variant 0 with variant 1, 2 and 3 on an economic level we have to meet fixed values as well as to assume and predict specifications. The aim of the investment calculation is to explore the potential of different bus technologies to make the financial gap visible. Behalf of a simple cost comparison procedure, the case study wants to illustrate the profitability of the BEB or FCB technologies. Therefore, following determinations and assumptions have been set:

- **Purchase prices of buses:**

All purchase prices are based on interviews contacted, because there are no uniform list prices for BEBs and FCBs.

- **Finance Delta:**

The financial delta is that amount of that must ultimately be funded by the company. Moreover, the financial delta is that amount which remains if the repurchase price is subtracted from the purchase prise. Afterwards, the finance delta will be referred to as leasing in the calculations.

- **Repurchase value and alternative cost calculation:**

Ledermair has a contract with Evobus[24], which guarantees that after 5 years all buses are repurchased at a fixed percentage of the purchase price. For all cost calculation the repurchase percentage value is 40%. Moreover, in order that (Anemüller 2018), (Conrad 2018) and (Thimm 2018) stated that new BEBs or FCBs are purchased completely and there is no leasing and no repurchase price for these new technologies by the bus manufacturers. In consequence, when it comes to the comparison of total and operating costs for each variant of BEB or FCB there will be a first column which is calculated after financial terms of Ledermair and literature based costs. The second column tries to reconstruct the cost calculation based on the reference values from the interviews.

- **Cost calculation:**

The cost calculation of all variants illustrates the major items such as leasing costs, fuel costs and maintenance costs and derives the costs for years or kilometres driven from the simulated annual mileage from the tracking report. Moreover, the relative fuel costs are based on the given numbers in table 21.

[24] European subsidiary of Daimler AG - full-line provider in the European bus market

Table 21: Overview fuel prices for Case-study

Diesel	0,85 € / L
Electricity[25]	0,15 € / kWh
Hydrogen[26]	7.50 € / kg

- **Maintenance cost:**

Since the electric drive of the E-bus requires almost no lubricants and involves much fewer moving parts, eliminates a large part of the costs incurred in the diesel vehicle maintenance. The literature says that the maintenance costs for an E-bus are on average 30-40% lower than the maintenance costs charged for a conventional diesel bus (Seelinger, et al. 2016). Ledermair 7.4 we charge for BEB in first column 4 cent and the maintenance cost 4 2 column derive from interviews.

[25] Selection of the highest possible tariff by IKB; assumed electricity costs in the case study illustrate therefore the maximum costs.
[26] Current price at the reference gas station OMV in Innsbruck Andechsstraße 83, which could be used as filling station for FCBs of Ledermair to avoid investments in an own hydrogen tank facility at the bus depot.

6.4. **Variant 1: Bus line W**

6.4.1. Route description[27]

Figure 22 illustrates the route of the bus line W. In the morning, before taking up the timed service operation the bus takes the direct route to the starting station called Marktplatz.

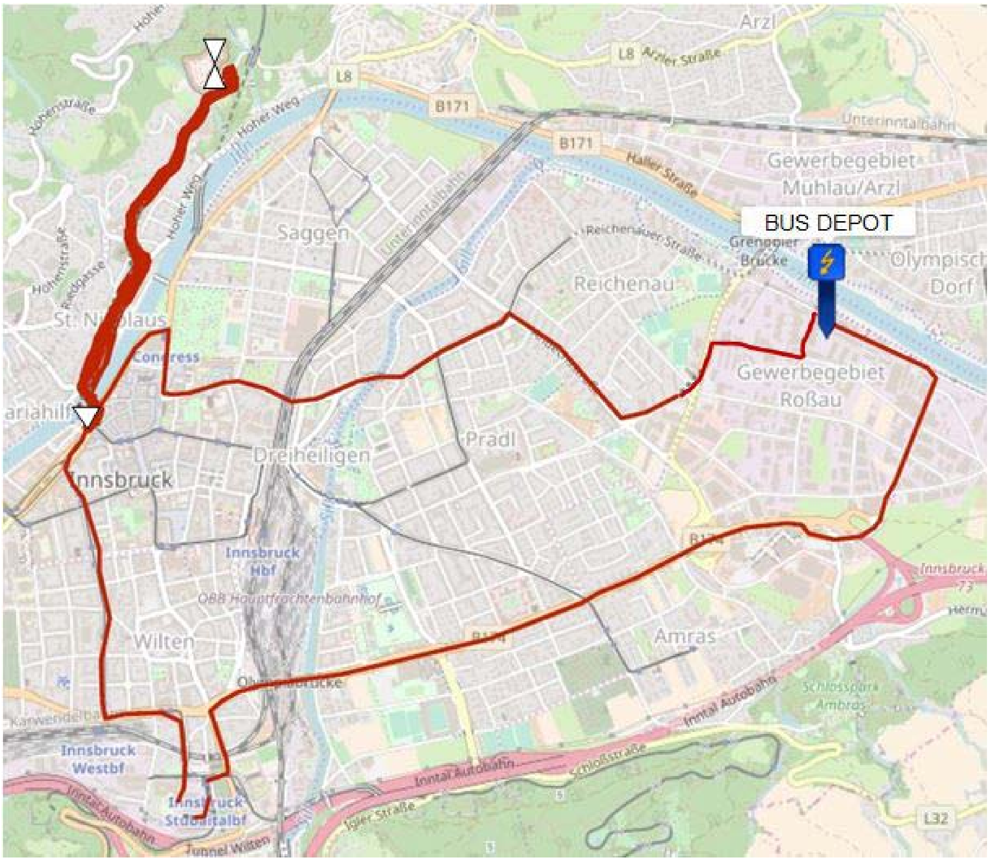


Figure 22: Route of W

The station Marktplatz is marked by a triangle in the figure 22. From this position the bus takes up his operation towards the end station called Alpenzoo. The end station is marked in the figure 22 by a double triangle in form of an hourglass. Until his last drive in the evening the bus is commuting between both stations. In-between the bus has 4 request stops in each direction. In direction of operation towards Alpenzoo the stations are *Innstrasse, Schmelzerstrasse, Schloss Büchsenhausen and Villa Blanka* (vice versa towards Marktplatz). At the end station Alpenzoo the bus has a dwell time of 15 minutes. One single direction has a length of operation of 2 kilometres. Behalf of the topography of Innsbruck, the second kilometre towards Alpenzoo is a constant ascending slope or vice versa has a strong declining slope. The total length of one turnaround is almost exact 4 kilometres. Over the whole day of operation, the one bus

[27] Cf. (IVB 2018)

which is used drives around 147 kilometres a day. These 147 kilometres are composed by an approach drive of around 5 kilometres, a departure drive of approximately 7 kilometres. The lasting 135 kilometres are representing the total distance in operation, which are 31 turnarounds. After the last drive the bus takes a detour to the gas station of the municipal bus operator IVB before the bus is parked at the bus depot.

6.4.2. Operating time

The bus line W is daily operating. The schedule is between 6:15 am and 23:01 pm. In order that the whole day the same bus is used derives in a total operation time of 16 hours and 46 minutes. Concerning approach and departure drive additional 30 minutes can at least be added. This time period cannot be exactly determined because it belongs to the driver in charge, how long or how much time he spends therefore. From around 23:30 pm until 06:00 am in the morning the bus is parked in the bus depot. This time frame in the bus depot could be used for charging.

6.4.3. Dwell time

In order of analysing possible charging opportunities during the operation it is important to measure dwell times. Furthermore, the dwell time can influence the used charging technology described in chapter 3.2.. The analyses of the bus line W has shown that the dwell times at the request bus stops are in average under one minute, which is too short for opportunity charging. The average dwell time at the station Marktplatz depends on the traffic situation and can be determined with a time frame of 1 to 3 minutes. The longest dwell time is given at the stopover station Alpenzoo where the bus stops for 15 minutes. This time frame would allow charging the bus by an opportunity charging technology.

6.4.4. Bus model change[28]

Since the route W is accredited to operate only a short bus, the Rampini Midibus provides an optimal fit. Table 22 shows the range of costs. If an electric bus from Ledermair can be purchased under the same conditions as the current Solaris (5 years use and fixed purchase price) then there are additional costs of 114.000 Euros (finance delta between Solaris and Rampini), but as well savings in energy and maintenance costs at the same time. The literature points to 1/3 lower maintenance costs, which were set at 4 cents per kilometre in this case study. However, the common practice is that the BEB is not leased, since there is no information about repurchase prices from

[28] Pictures of Solaris Urbino 8.9 and Rampini Midibus in Annex D

the manufacturer, but purchased for a planned operation time frame of 10 years[29]. The last column tries to illustrate this aspect and therefore additional costs of 190,000 Euros derive compared to Solaris Urbino. Moreover, the Wiener Linien point out higher maintenance costs of 33 cents per kilometre which results in a difference in the maintenance costs with the Solaris bus in the amount of 25.5 cents per kilometre.

Table 22: Route W - comparison of bus model exchange costs

General information	Solaris Urbino 8,9	Rampini	Rampini[30]
acquisition costs	210 000 EUR	400 000 EUR	400 000 EUR
-40% repurchasing price	-84 000,00 EUR	-160 000,00 EUR	- EUR
finance delta (leasing)	126 000,00 EUR	240 000,00 EUR	400.000 EUR
Average consumption	43 litre/100km	1,5 kW/km	1,2 kW/km
fuel costs	0,85€/litre	0,15€/kWh	0,0894€/kWh
maintenance cost	0,075€/km	0,04€/km	0,33€/km

* assumed for 5 years under the purchase terms of Ledermair

6.4.5. Fuel consumption

As part of the tracking report, fuel consumption was also calculated based on the route and driving profile, which coincides with the data provided by Ledermair. The simulation with a Hyundai Elec City BEB resulted in the following fuel cost deviations from the diesel bus illustrated by table 20. The diesel bus consumes fuel in an amount of around 19.733 Euros while the BEB consumes electricity amounting in 10.666 Euros. If the line would be operated with a BEB annual fuel saving of 9.067 Euro would occur. Due to the fact, that Ledermair operates a bus around 5 years it can be assumed that in this time period a BEB would save around 45.000 Euros.

Table 23: Route W - comparison of annual fuel costs

Current vehicle	Annual mileage	Fuel costs per year	Suitable alternative vehicle	Fuel costs per year	cost savings fuel per year
E122 Solaris W	53.666 km	19.733 €	E-Bus Rampini Midibus	10.666 €	9.067 €

6.4.6. Environmental impact

[29] Thimm (2018), Anemüller (2018), Conrad (2018)
[30] costs assumed behalf of numbers from Wiener Linien for 10 years of operation without infrastructure investments and costs for battery replacements

The simulation concerning CO_2 emissions, illustrated in table 21, has revealed that the actual Solaris diesel bus is responsible for 61.5 tons of annual CO_2 emissions. In consequence, operating the route W with a BEB would have no local tailpipe emissions and the noise pollution would be very low, which are both benefits for the residents in the city of Innsbruck. Furthermore, in fact that Ledermair operates a bus around 5 years it can be assumed that in this period a diesel bus on the route W would emit more than 307 tons of CO_2 which could be saved.

Table 24: Route W - comparison of annual CO_2 emissions

Current vehicle	Annual mileage	CO2-emissions per year	Suitable alternative vehicle	CO2-emissions per year	CO2-savings per year
E122 Solaris W	53.666 km	61.520 kg	E-Bus Rampini Midibus	0 kg	61.520 kg

6.4.7. Infrastructure requirements and changeover

The simulation based on the BEB Elec City of Hyundai has shown that no opportunity charging stations has to be built, as theoretically the BEB would have enough battery capacity for one day of operation without charging. However, as the Rampini Midibus will be used in the case study, a charging station at the final stop Alpenzoo should be built, where the bus has the opportunity to charge during a scheduled brake of 15 minutes every single round or every 30 minutes. Peretti (2018) refers to the construction costs of 19,000 Euros of a loading point. In the bus depot a mobile charger (cf. Figure YY) would be purchased and the necessary electrical connections for overnight charging installed. Thus, the largest construction works would occur at the stop Alpenzoo.

6.4.8. Comparison of total and operating costs

Table 25 illustrates the economic feasibility and cash flow values due to a bus exchange from diesel bus to a BEB on the route W. On the base of a Solaris Urbino and a Rampini bought under the purchasing standard conditions of Ledermair as well as Rampini purchased with the conditions of the Wiener Linien, we can see in table 25 that the costs of one driven kilometre amount in a range of 91 cents and 1.16 Euros. With regard to fuel costs, we can clearly see that diesel cannot compete with electricity costs here. Depending on the tariff, the electricity costs can amount to 1/3 of the original diesel costs. In terms of costs after years, the competitiveness of the BEB depends on the 2 conditions. If it is possible getting guaranteed a fixed redemption price and the operation lifetime of the BEB is extended from 5 to 10 years and no battery pack is added, the figures show that the BEB will be superior to the diesel bus not only in ecological aspects but also in economic issues.

Since the bus on the W line has a mileage of over 250,000 kilometres in 5 years, the costs can be derived from the table 25 as well. The financial difference between the Solaris and the Rampini bus amounts in 7.500 Euros in 5 years including the purchase and return conditions of Ledermair. In addition, this calculation does not include costs for replacement parts, replacement fluids or checks and repairing as well as no charging infrastructure investments.

The analysis of the bus route W shows that an electrification of the bus in use would already be possible. In addition, the bus is branded with images of animals of the Alpine Zoo of Innsbruck and accordingly very noticeable in the city traffic. Here, the bus also gets the role of an image medium in addition to a possible BEB role model for public transport in the region. Furthermore, the Alpine Zoo in Innsbruck stands for the important sustainable handling with the alpine flora and fauna, which can only be supplemented with a green bus. This aspect can trigger a huge marketing and campaigning potential on the one side for tourists and on the other side for the success of BEBs and FCBs in Tyrol.

Table 25: Route W - comparison of total and operating costs

Total costs for 5 years	Solaris Urbino 8,9	Rampini*	*Rampini/10ys*[31]
leasing/5ys	126 000 EUR	240 000 EUR	400 000 EUR
fuel costs/5ys	98 665 EUR	60 374,25 EUR	35 983,05 EUR
maintenance costs/5ys	20 124,75 EUR	10 733,20 EUR	88 548,90 EUR
costs for 10 years	- EUR	- EUR	560 517,01 EUR
costs for 5 years	244 789,75 EUR	311 107,45 EUR	280 258,50 EUR
costs for 1 year	48 957,95 EUR	62 221,49 EUR	56 051,70 EUR
cost per km (53666 km/y)	0,91 EUR	1,16 EUR	1,04 EUR
costs per 100,000 km	91 000,00 EUR	94 000,00 EUR	104 445,46 EUR
costs per 250,000 km	227 500,00 EUR	235 000,00 EUR	261 113,65 EUR
costs per 500,000 km	455 000,00 EUR	470 000,00 EUR	522 227,30 EUR

* assumed for 5 years under the purchase terms of Ledermair

[31] costs assumed behalf of numbers from Wiener Linien for 10 years of operation without infrastructure investments and costs for battery replacements – cf. Annex C

6.5. **Variant 2: Bus line TS**

6.5.1. Route description[32]

Figure 23 illustrates the route of the tourist bus line TS. In the morning, before taking up the timed service operation the bus takes the direct route from the bus depot to the starting station called Marktplatz, which also marks the end station of one turnaround. The station Marktplatz is marked by a triangle in the figure 24, which represents the tracked route of the analyses. From this position the bus takes up his operation towards a stopover station called Tirol Panorama Bergisel, where the bus stops for 15 minutes if it is on schedule. This stopover station is marked in the figure by a double triangle in form of an hourglass. The final stop after a whole day of operation in the evening is at the main station of Innsbruck, which is marked by a square in figure 18. The route of the bus is special because the bus is just predicted for being used by tourists of the purpose of sightseeing. In consequence, the bus just runs in one direction clockwise so that the tourists have the possibility to cross all sights and historic places in one go. In one turnaround from Marktplatz to Marktplatz the bus crosses 17 request stops inclusive the start- and end station as well as the stopover station at Tirol Panorama Bergisel. The stops can be derived from figure 23. Over the whole day of operation, the one bus which is used drives around 102 kilometres a day. These 102 kilometres are composed by an approach drive of around 5 kilometres, a departure drive of approximately 7 kilometres. The lasting 90 kilometres are representing the total distance in operation, which are 5 total turnarounds and a lasting drive from the station Marktplatz to the main station. The total length of one turnaround is almost exact 17.7 kilometres. After the last drive the bus takes a detour to the gas station of the municipal bus operator IVB before the bus is parked at the bus depot.

[32] (IVB 2018)

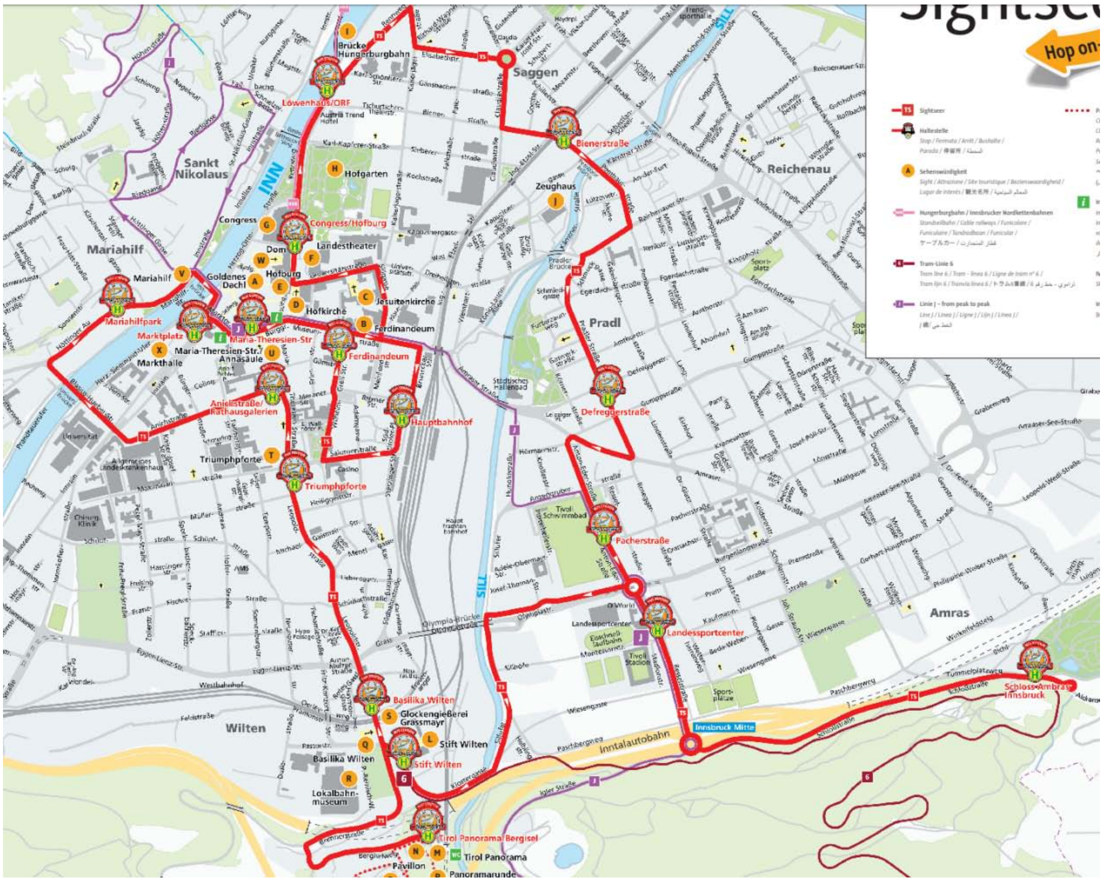


Figure 23: Route of TS with stations (IVB)

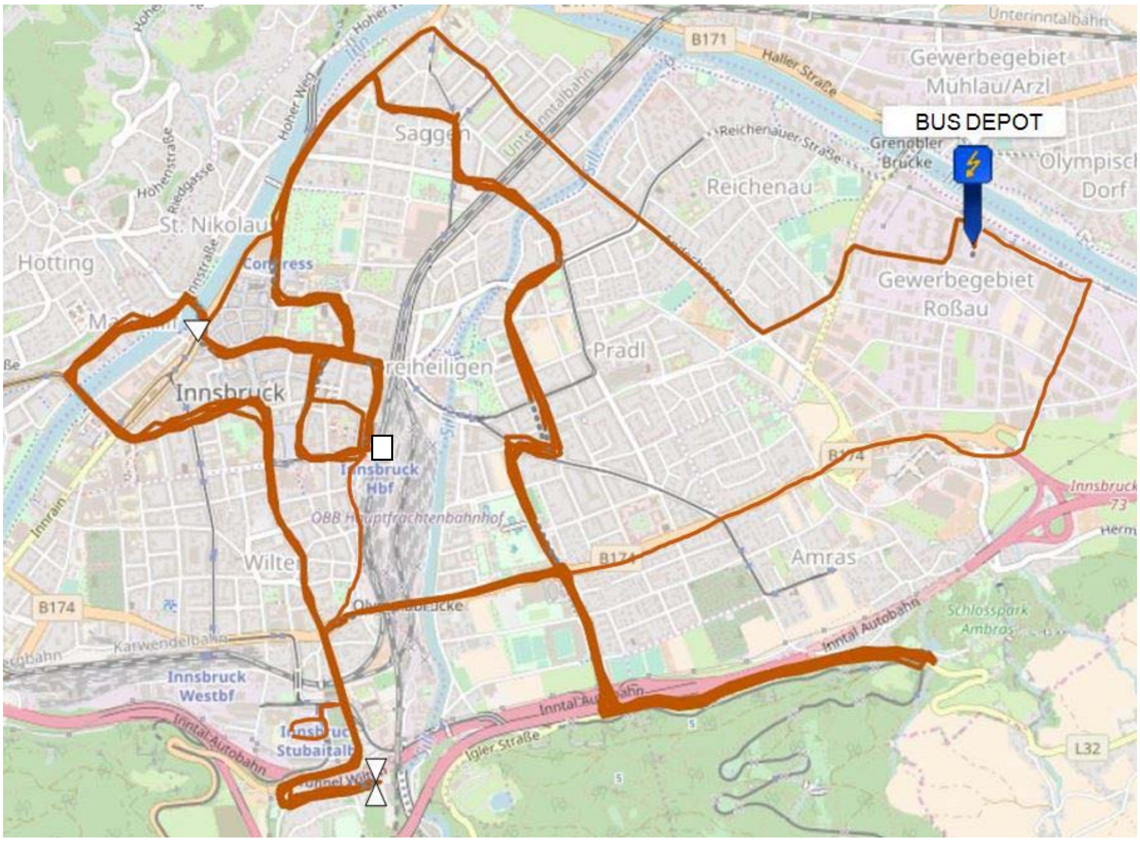


Figure 24: Route of TS

6.5.2. Operating time

The sightseer bus line TS is daily operating. The schedule is timed between 10:15 am and 18:01 pm. In addition, during the main tourist season May until October the operation time is extended for an hour. Furthermore, concerning approach and departure drive approximately additional 30 minutes can be added. This time period cannot be exactly determined because it belongs to the driver in charge, how long or how much time he spends therefore. Overall, the longest possible mission time on the route TS is 9 hours and 48 minutes. For the remaining 60 percent of the 24 day the bus is parked in the bus depot or is used for other transport missions. Anyway, the remaining time could be used for overnight charging at the bus depot.

6.5.3. Dwell time

In order of analysing possible charging opportunities during the operation the schedule of the TS route offers two main dwell times. The analyses of the bus line TS has shown that the dwell times at the request bus stops with one exception the Bergisel Panorma Tyrol stop are in average under five minutes, which is too short for opportunity charging. The longest dwell time is given at the stopover station Bergisel Panorama (marked by a double triangle) where the bus stops for 15 minutes (cf. figure 24). This time frame would allow charging the bus by an opportunity charging technology. Furthermore, the parking time frame of 14 hours at longest in the bus depot could be used as well for overnight charging with a low power.

6.5.4. Bus model change[33]

The route TS is actually operated by the bus model Setra S415 LE. For the case study the bus model S12 from Sileo provides an optimal fit. Table 26 shows the range of costs. If the BEB Sileo S12 can be purchased from Ledermair under the same conditions as the current Setra (5 years use and fixed repurchase price) then there are additional costs of 150.000 Euros (finance delta between Setra and Sileo), but as well savings in energy and maintenance costs at the same time. However, the common practice is that the BEB is not leased, since there is no information about repurchase prices from the manufacturer, but purchased for a planned operation time frame of 10 years[34]. The last column tries to illustrate this aspect and therefore additional costs of 350,000 Euros derive compared to Setra S415 LE.

[33] Pictures of Setra S415 LE and Sileo S12 in Annex D
[34] Thimm (2018), Anemüller (2018), Conrad (2018)

Table 26: Route TS - comparison of bus model exchange costs

General information	SETRA S415 LE Business	SILEO S12*	SILEO S12**
acquisition costs	250.000 EUR	500.000 EUR	500.000 EUR
-40% repurchasing price	-100.000 EUR	-200.000 EUR	- EUR
finance delta (leasing)	150.000 EUR	300.000 EUR	500.000 EUR
Average consumption	45litre/100km	1,5kW/km	1,5kW/km
fuel costs	0,85€/litre	0,15€/kWh	0,15€/kWh
maintenance cost	0,07€/km	0,04€/km	0,04€/km

* assumed for 5 years under the purchase terms of Ledermair
**assumed for 10 years of operation without replacement of the fuel cell

6.5.5. Fuel consumption

As part of the tracking report, fuel consumption was also calculated based on the route and driving profile, which coincides with the data provided by Ledermair. The simulation with a Hyundai Elec City BEB resulted in the following fuel cost deviations from the diesel bus listed in table 27. The Setra S415 diesel bus consumes fuel in an amount of around 12.503 Euros while the BEB Sileo S12 consumes electricity amounting in 6.974 Euros. If the route would be operated with a BEB annual fuel saving of 5.529 Euro would occur. Due to the fact, that Ledermair operates a bus around 5 years it can be assumed that in this time period a BEB would save around 27.000 Euros.

Table 27: Route TS - comparison of annual fuel costs

Current vehicle	Annual mileage	Fuel costs per year	Suitable alternative vehicle	Fuel costs per year	cost savings fuel per year
E002 Setra TS	34.621 km	12.503 €	E-Bus Hyundai Elec City	6.974 €	5.529 €

6.5.6. Environmental impact

The simulation concerning CO_2 emissions, illustrated in table 28, has revealed that one actual used Setra diesel bus is responsible for almost 39 tons of CO_2 emission per year. In consequence, operating the route TS with a BEB would have the advantage of no tailpipe emissions and the noise pollution would be very low, which are both benefits for the inner city of Innsbruck, where the major route of the TS is situated. Furthermore, in fact that Ledermair operates the route TS with two Setra buses for a period of around 5 years it can be assumed that in this period both Setra diesel buses on the route TS would emit around 400 tons of CO_2 which could be saved.

Table 28: Route TS - comparison of annual CO_2 emissions

Current vehicle	Annual mileage	CO_2-emissions per year	Suitable alternative vehicle	CO_2-emissions per year	CO_2-savings per year
E002 Setra TS	34.621 km	38.979 kg	E-Bus Sileo S12	0 kg	38.979 kg

6.5.7. Infrastructure requirements and changeover

The simulation of the route TS based on the BEB Elec City of Hyundai has shown that no opportunity charging stations has to be built. On the one side, the BEB would have enough battery capacity for one day of operation without charging and on the other side, one day of operation on the route TS comes to a maximum mileage of 102 kilometres.

However, as the Sileo S12 will be used in the case study, an opportunity charging station has not to be built, because the Sileo BEB has the capacity to drive 300 kilometres in one go. This range will vary especially in the winter months when heating is mandatory. In the bus depot a mobile charger which is included by purchasing a Sileo S12 (cf. Figure 16) would be needed for overnight charging (Baianov 2018).

6.5.8. Comparison of total and operating costs

Table 29 illustrates the economic feasibility and cash flow comparison due to a bus exchange from diesel bus to a BEB on the route TS. On the base of a Setra S415LE and a Sileo S12 under the purchasing standard conditions of Ledermair as well as Sileo S12 purchased under the condition of 10 years of operation, we can see in table 29 that the costs of one driven kilometre amount in a range of 1.30 and almost 2.00 Euros. With regard to fuel costs, we can clearly see that diesel cannot compete with electricity costs here. In a 5-year period we can determine a savings of fuel expenses of more than 23.500 Euros.

Concerning the competitiveness of the BEB, by comparing the costs per driven distance we can derive from table 29 that by growing mileage and useful-life that the costs between the diesel bus and the BEB are assimilating. From the row focusing on the cost per kilometre the big difference is clear. The Setra costs actually 1.30 Euro and by changing to a BEB it comes to a price surcharge in a range of 30 to 76 percent which in terms of money will be a surcharge between 41 to 70 cents per kilometre.

The financial difference between the Setra and the Sileo bus amounts in more 121.000 Euros in 5 years including the purchase and return conditions of Ledermair. Moreover, even if the Sileo bus would be used 10 years without costs for battery pack replacement, it would be in comparison more favourable purchasing 2 Setra buses in the same time period than a FCB. In addition, without including a rate of price increases the savings between two purchased diesel buses and one FCB would be about 142.000 Euros.

The analysis of the bus route TS shows that an electrification of the bus route would on technological base already be possible. However, the funding gap between the diesel bus and the BEB is the main issue depending on the chosen financial and useful-life frame conditions.

In view of the fact, that the bus is frequented by a huge number of international tourists per year, the bus itself can be used an image medium for Innsbruck and Tyrol. The bus must not only be a vehicle for transporting the tourists from one sight to another sightseeing attraction. Furthermore, the bus could also reflect the right sustainable interaction between society and nature on behalf of transport and traffic. This aspect can trigger a huge marketing and campaigning potential on the one side for tourists and on the other side for the success of BEBs in Tyrol.

Table 29: Route TS - comparison of total and operating costs

Total costs for 5 years	SETRA S415 LE Business	SILEO S12*	SILEO S12**
leasing	150.000 EUR	300.000 EUR	500.000EUR
fuel costs	62.515 EUR	38.948,63 EUR	38.948,63 EUR
maintenance costs	12.117,35 EUR	6.924,20 EUR	6.924,20 EUR
costs for 10 years	- EUR	- EUR	591.745,65 EUR
costs for 5 years	224.632,35 EUR	345.872,83 EUR	295.871,83 EUR
costs for 1 year	44.926,47 EUR	69.174,57 EUR	59.174,57 EUR
cost per km (34621 km/y)	1,30 EUR	2,00 EUR	1,71 EUR
costs per 100,000 km	129.766,53 EUR	199.805,22 EUR	170.921,02 EUR
costs per 250,000 km	324.416,32 EUR	499.513,05 EUR	427.302,54 EUR
costs per 500,000 km	648.832,64 EUR	999.026,10 EUR	854.605,08 EUR

* assumed for 5 years under the purchase terms of Ledermair
**assumed for 10 years of operation without replacement of the fuel cell

6.5.9. Illustration of total and operating costs of FCB on the route TS

This additional section of part 6.5 deals with the question if it would possible to operate the route TS as well with a FCB and which parameters would change and which advantages or disadvantages would occur. As already known from Chapter 4, it is technically possible and feasible. However, you have to pay attention in this case to the additional occurring costs. Table 30 is dealing with this purpose. From Table 30 we can derive that operating a FCB is uneconomical on this route compared to ordinary diesel as well compared to a BEB. In the best case, a driven kilometre with a FCB is 1.40 Euro more expensive than one driven kilometre of the Setra diesel bus. However, if it is possible to operate a hydrogen bus on the same terms as a diesel bus from Ledermair, then the costs increase by 2.60 Euros. The comparison between table 30 and table 29 clearly shows the financial advantages of a BEB. With regard to environmental sustainability both bus types have the advantage of having no local emission and the final impact will derive from the energy mix used for the several fuel productions, which is described in chapter 5.

Table 30: Theoretical comparison of total and operating costs due to FCB usage on route TS

Total costs for 5 years	SETRA S415 LE Business	VanHool A330 FCB*	VanHool A330 FCB**
leasing	150.000,00 EUR	390.000,00 EUR	650.000,00 EUR
fuel costs	62.515,00 EUR	129.828,75 EUR	129.828,75 EUR
maintenance costs	12.117,35 EUR	155.794,50 EUR[35]	155.794,50 EUR
costs for 10 years	-EUR	-EUR	935.623,25 EUR
costs for 5 years	224.632,35 EUR	537.139,25 EUR	467.811.63 EUR
costs for 1 year	44.926,47 EUR	107.427,85 EUR	93.562,33 EUR
cost per km (34621 km/y)	1,30 EUR	3.90 EUR	2,70 EUR
costs per 100,000 km	129.766,53 EUR	390.296,79 EUR	270.247,32 EUR
costs per 250,000 km	324.416,32 EUR	975.741,96 EUR	675.618,30 EUR
costs per 500,000 km	648.832,64 EUR	1.951.483,93 EUR	1.351.236,60 EUR

* assumed for 5 years under the purchase terms of Ledermair
**assumed for 10 years of operation without replacement of the fuel cell

Overall, for financial reasons the BEB must clearly be given priority here. In the end, it depends on the chosen strategy or the politically desired and promoted traffic planning which technology is accelerated or whether both BEBs and FCBs are parallel supported and purchased.

[35] cf. chapter 6.6.4

6.6. **Variant 3: Bus line 501**

6.6.1. Route description[36]

Figure 25 illustrates the route of the bus line 501. In the morning, before taking up the timed service operation the bus takes the direct route to the respective starting station. During the normal operation modus, three buses are in charge on the route of 501 and start from three different starting bus stops in the morning. The observed bus in the analysis left the bus depot and drove to its starting station the main station of Innsbruck, which is marked in the figure 25 by a double triangle in form of an hourglass. From the starting point the bus drives through the city towards the end station Kurhaus in Hall in Tirol and back again. The total length of one turnaround is almost exact 32.3 kilometres. Over the whole day of operation, the observed bus drives around 293 kilometres a day. This number of kilometres differs with the other two used buses on the line in order of the mentioned starting points in the morning and also on different end points in the evening. In addition, the end point of operation is always either the main station or the end station Kurhaus in Hall. In-between the bus has 26 request stops in each direction. Figure 25 illustrates the route which leads the bus from Innsbruck through the villages Arzl, Rum, Thaur, Absam before it reaches Hall in Tirol. After the last drive the bus takes a detour to the gas station of the municipal bus operator IVB before the bus is parked at the bus depot.

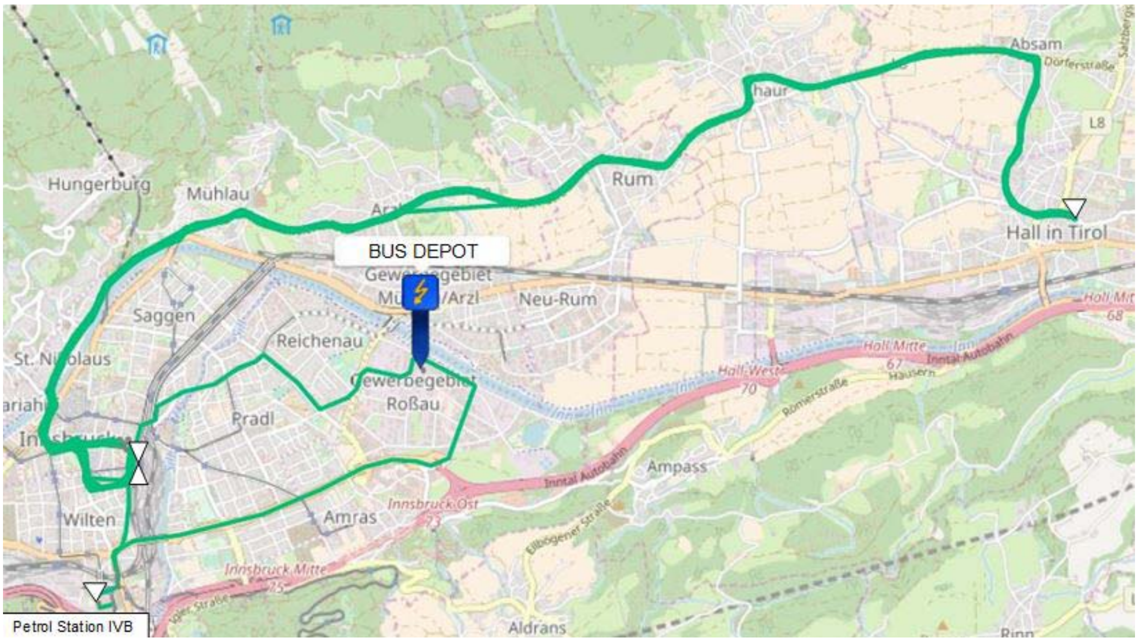


Figure 25: Route of 501

6.6.2. Operating time

36 (IVB 2018)

The tracked Mercedes Citaro diesel bus is daily operating. The schedule time frame is timed between 05:00 am and 23:00 pm. In addition, no exact time can be given because on the one hand the bus has different operating times on weekdays, Saturdays, Sundays and during holidays. Furthermore, the three buses running together on the line 501 are in a rotating alternation. Furthermore, concerning approach and departure drive approximately additional 30 minutes can be added. This time period cannot be exactly determined because it belongs to the driver in charge, how long or how much time he spends therefore. Overall, the longest possible mission time of the tracked Mercedes Citaro diesel bus can be approximately 19 hours per day. For the remaining approximately 5 hours the bus is parked in the bus depot.

Anyway, the remaining time would be too short for overnight charging as well as the high number of driven kilometres including the additional energy load for heating and cooling not correlates with the capacity of a BEB. The simulation of the tracking report came to the same conclusion that only a FCB could match the performance profile of the route 501.

6.6.3. Dwell time

In addition to the route description in part 6.6.1 a bus on the route 501 has two dwell times. At the end station Kurhaus the bus has a three minutes dwell time when it is in schedule before it takes the same route back. At the starting station (main station) the bus has a scheduled dwell time frame of 10 to 15 minutes. This length of dwell time occurs only under an optimal traffic situation. Traffic jams in Innsbruck, longer waiting times at traffic lights or longer stays at stops due to ticket sales cannot guarantee a constant dwell time at the main station. In consequence, a BEB on this route would need guaranteed dwell times for opportunity charging, because without a trouble-free operation would not be possible.

6.6.4. Bus model change[37]

The route 501 is actually operated by the bus model Mercedes Citaro. For the case study the bus model A330 Fuel Cell from VanHool provides an optimal fit. On the on hand because VanHool is able to deliver a functional FCB which is already being built in large numbers (Conrad 2018) and on the other hand it is difficult to find other manufacturers which are able to deliver (Thimm 2018). Table 31 shows the range of costs. The maintenance cost represent the biggest challenge since the technology is

[37] Pictures of Mercedes Citaro and VanHool in Annex D

still partially in a testing and development phase. Moreover, statements about repair, maintenance and service costs are scarce (Seelinger, et al. 2016). For the case study the maintenance cost from the report on fuel cells in public transport of the Hessian Ministry of Economy, Energy, Transport and Regional Development were used. In the report the development of maintenance costs based on the VanHool FCBs are illustrated as well as and the cost per kilometre which derive in 0.90 Euros on an average base since 2016. (Huss and Corneille 2015). In addition, Conrad (2018) adds that the maintenance cost would be already matching with those of diesel buses, but the big cost drivers are the regular and accurate inspections of the high-pressure tanks, valves and seals of skilled workers. Concerning the purchase costs, if the FCB from VanHool can be purchased from Ledermair under the same conditions as the current Mercedes Citaro (5 years use and fixed repurchase price) then additional costs of 240.000 Euros arrive. In regard to the comparison of the bus model exchange from diesel to BEB in variant 1 and 2, at a change from a diesel bus to a FCB there derive no energy savings. However, the common practice is that a FCB is not leased, since there is no information about repurchase prices from the manufacturer, but purchased for a planned operation time frame of 10 years[38]. The last column tries to illustrate this aspect and therefore additional costs of 500,000 Euros derive compared to Mercedes Citaro. The last column points out a higher consumption of hydrogen, because with an average consumption of 8.5kg of hydrogen in column 3, which represents the best case in table 31, an overly optimistic literature based hydrogen consumption could have been chosen in regard to the topography of route 501.

Table 31: Route 501 - comparison of bus model exchange costs

General information	Mercedes Citaro Diesel	VanHool A330 FCB*	VanHool A330 FCB**
acquisition costs	250.000 EUR	650.000 EUR	650.000 EUR
-40% repurchasing price	-100.000 EUR	-260.000 EUR	- EUR
finance delta (leasing)	150.000 EUR	390.000EUR	- EUR
Average consumption	50litre/100km	8,5kg/km	12kg/100km
fuel costs	0,85€/litre	7.5€/kg	7.5€/kg
maintenance cost[39]	0,07€/km	0,90€/km	0,90€/km

* assumed for 5 years under the purchase terms of Ledermair
**assumed for 10 years of operation without replacement of the fuel cell

[38] Thimm (2018), Anemüller (2018), Conrad (2018)
[39] (Huss and Corneille 2015)

6.6.5. Fuel consumption

As part of the tracking report, the hydrogen consumption was simulated based on the route and driving profile. The simulation with an artificial created driving profile of a FCB resulted in the following fuel cost deviations from the diesel bus listed in table 32. The Mercedes Citaro diesel bus consumes fuel in an amount of around 45.027 Euros while the FCB consumes hydrogen amounting in 71.271 Euros. By operating a FCB on the route 501 an annual loss of 26.244 Euros would occur in regard of fuel costs.

Table 32: Route 501 - comparison of fuel costs

Current vehicle	Annual mileage	Fuel costs per year	Suitable alternative vehicle	Fuel costs per year	cost savings fuel per year
E139 Citaro 501	107.080 km	45.027 €	H2 Bus	71.271 €	-26.244 €

6.6.6. Environmental impact

The simulation concerning CO_2 emissions, illustrated in table 33, has revealed that the tracked Mercedes Citaro is responsible for approximately 140 tons of CO_2 emission per year. In consequence, operating the route 501 with a FCB would have the advantage of no tailpipe emissions and the noise pollution would be very low. Furthermore, in fact that Ledermair operates the route 501 with three Mercedes Citaro buses it can be assumed that three FCB in 10 years of operation will save around 4200 tons of CO_2 emissions.

Table 33: Route 501 - comparison of CO_2 emissions

Current vehicle	Annual mileage	CO_2-emissions per year	Suitable alternative vehicle	CO_2-emissions per year	CO_2-savings per year
E139 Citaro 501	107.080 km	140.379 kg	H2 Bus	0 kg	140.379 kg

6.6.7. Infrastructure requirements and changeover

With regard to the required tank facility for hydrogen, no infrastructure constructions and investment costs would occur due to the fact of an existing hydrogen fuel station of the OMV nearby the bus depot.[40] At this OMV gas station 1 kg of hydrogen can be fuelled for 7.5 Euros/kg net. This gas station is on the way back to the bus depot and the former detour to the diesel filling facility of the IVB would be omitted.

[40] OMV gas station, Andechsstraße 83, 6020 Innsbruck

6.6.8. Comparison of total and operating costs

Table 34 illustrates the economic feasibility and cash flow comparison due to a bus exchange from diesel bus to a FCB on the route 501. On the base of a VanHool FCB under the purchasing standard conditions of Ledermair as well as VanHool FCB costs of one driven kilometre amount in a range of 2.09 and approximately 2.29 Euros. The relatively low mileage price compared to BEB by variant 2 results from the high annual mileage of the buses on the 501 line. With regard to fuel costs, we can clearly see that hydrogen cannot compete with diesel costs in variant 3. In a 5-year period we can determine a loss of fuel expenses of more than 131.200 Euros. In addition, if the FCB is 10 years in operation the loss due to higher hydrogen consumption in column three amounts in 511.888 Euros in comparison by using the double fuel costs of the diesel bus as a basis.

Concerning the competitiveness of the FCB, by comparing all costs of a Mercedes Citaro compared to the two variants of the FCB we can derive from table 34 that without financial support from public funding or without being required to operate with a FCB the technology is too expensive and uneconomic.

Table 34: Route 501 - comparison of operating total cost line 501

total costs for 5 years	Mercedes Citaro Diesel	VanHool A330 FCB*	VanHool A330 FCB**
leasing	150.000 EUR	390.000 EUR	650.000 EUR
fuel costs	225.135 EUR	356.355,00 EUR	962.158,00 EUR
maintenance costs	37.478EUR	481.860.00 EUR	600.000,00 EUR[41]
costs for 10 years	- EUR	- EUR	2.212.158,00 EUR
costs for 5 years	412.613,EUR	1.228.215,,00 EUR	1.106.079,00 EUR
costs for 1 year	82.522,60 EUR	245.643,00 EUR	221.215,80 EUR
cost per km (107080 km/y)	0,77 EUR	2,29 EUR	2,07 EUR
costs per 100,000 km	77.066,31 EUR	229.401,38 EUR	206.589,28 EUR
costs per 250,000 km	192.665,76 EUR	573.503,46 EUR	516.473,20 EUR
costs per 500,000 km	385.331,53 EUR	1.147.006,91 EUR	1.032.946,40 EUR

* assumed for 5 years under the purchase terms of Ledermair
**assumed for 10 years of operation without replacement of the fuel cell

[41] FCB is purchased including a service package flat charge which provides an all-round service for 10 years at a fixed price (Conrad 2018)

6.7. Overview of the Tracking Report results of the entire fleet

The overview should provide a clear structured overall view into findings from the tracking report and the case study. Table 35 represents a comparison of fuel costs CO_2 emissions and savings of both based on the one-year simulation of the tracking report per one single bus. In addition, table 36 tries to give an impression in which high payment flows can be expected if the entire fleet operating on all 3 routes will be replaced by the suitable buses described in the case study. As the author of this thesis, it seems to me particularly important to differentiate between on the one side fuel savings and CO_2 emissions and on the other side purchase prices in order to be able to look at the values individually. The future will show which reference value or which combination of values will be crucial for the procurement process of E-buses.

Table 35: Tracking Report results - fuel costs savings/ CO_2 emissions per year

Current vehicle	Annual mileage	Fuel costs per year	CO2-emissions per year	Suitable alternative vehicle	Electrical driving profile coverage	Fuel costs per year	CO2-emissions per year	Cost savings fuel per year	CO2-savings per year
E122 Solaris W	53.666 km	19.733 €	61.520 kg	E-Bus Rampini Midibus	100%	10.666 €	0 kg	9.067 €	61.520 kg
E002 Setra TS	34.621 km	12.503 €	38.979 kg	E-Bus Sileo S12	100%	6.974 €	0 kg	5.529 €	38.979 kg
E139 Citaro 501	107.080 km	45.027 €	140.379 kg	VanHool A330	100%	71.271 €	0 kg	-26.244 €	140.379 kg
total fleet	**Total 195.367 km**	**Total 77.262 €**	**Total 240.877 kg**	**total fleet**	**100%**	**Total 88.911 €**	**Total 0 kg**	**Total -11.648 €**	**Total 240.877 kg**

Table 35 illustrates that in total more than 240 tons of CO_2 could be saved when all three conventional diesel buses would be replaced by an E-bus. In addition, only the replacement by a FCB shifts the fuel saving budget into a loss. Considerations regarding electrification can therefore start with the routes W and TS where positive results in regard to fuel and CO_2 savings can be shown.

On the contrary to table 35, table 26 does not reflect an approximate truth but tries to illustrate the sums that need to be funded and accounted due to a possible electrification of the routes W, TS and 501. If the bus company Ledermair maintains to purchase diesel buses for a period of 5 years a payment of 876.000 Euros has to be made due to a total fleet renewal. Nevertheless, if Ledermair decides to substitute the actual diesel fleet by BEBs and FCBs like stated in table 36 the purchase sum would amount in 5.650.000 Euro which represents more than 6 times total purchase sum of the diesel buses. Considerations regarding electrification can therefore start with the routes W where the smallest loss can be recorded. Ultimately, the defined perspective determines whether higher purchase prices or low emissions are more important in future.

Table 36: Outlook of costs in case of electrification

Current vehicle	Number of vehicles	Purchase price*	Suitable alternative vehicle	Electrical driving profile coverage	Number of vehicles	Purchase price**	CO2-savings per year
Solaris W	1	126.000€	E-Bus Rampini Midibus	100%	1	400.000€	-274.000€
Setra TS	2	300.000€	E-Bus Sileo S12	100%	2	1.500.000€	-1.200.000€
Citaro 501	3	450.000€	VanHool A330	100%	3	3.750.000€[42]	-3.300.000€
total fleet		**Total 876.000€**	**total fleet**	**100%**		**Total 5.650.000€**	**Total -4.774.000€**

* assumed for 5 years under the purchase terms of Ledermair
**assumed for 10 years of operation

[42] Unit purchase price (650.000€) plus service package flat charge (600.000€)

7. Conclusions and Findings

The main aim of this master thesis has been to elaborate on considerations towards electrification strategies and illustrate the topic from 4 different perspectives. Those perspectives are based on legal, environmental, economic and technical considerations. Furthermore, based on those elaborated perspectives the thesis has proven to what extent electrification is possible. The argumentation and demonstration of the feasibility has been done by conducting a case study. Moreover, the case study focused on 3 routes as well on the current used bus models of the bus company Ledermair. The first step towards the case study has been the tracking of one operating bus on each route. In addition, on the tracked route W is just one bus operating, on the tracked route TS two buses and on the route 501 three buses. The tracking has been realized on the 28. of march 2018. In subsequence, the recorded data has been input into a new developed software. Thus the software simulated behalf of programmed virtual operational profiles of BEBs and FCBs which E-bus technology could replace the used diesel buses on the three different routes. The output is a tracking report which illustrates that it would be technically feasible to replace the diesel buses on the routes W and TS with BEBs and as well that the diesel buses on the rout 501 could be replaced by a FCB. In addition, the tracking report illustrates as well the environmental and economical consequences of the replacement in regard to fossil fuel savings and reduction of CO_2 emissions.

Anyhow, the second step has been investigating the legal base on behalf of which electrification is possible or which is beneficial for electrification projects. A first finding has been that there is no decided directive that postulates the usage of BEBs or FCBs. In consequence, the chapter 2 provided an overview of directives which influenced indirectly the development of E-buses. Those directives have their focus mainly on air quality issues in order that traffic is a major pollutant and engages on reducing the main pollutants like CO_2, NO_X and PM. Furthermore, the second chapter lists EU funded projects which are forerunners for BEB and FCB technology testing and development. The chapter two is concluded by an interpretation of the deployment of E-buses. The knowledge is that the bill wears. A close-up of very sparingly existing statistics shows that the majority of used E-buses are trolleybuses behalf of examples Germany and Austria.

In the following, the chapter 3 elaborated on a very crucial component of the environmental perspective. The whole chapter turns around the environmental zone Inn-valley in Tirol. The main aim of chapter 3 from the beginning on is to give any reader of this thesis such broad overview concerning all stakeholder issues of ambient air pollution that even the last hindmost person recognizes an acute need for action. Elaborating on the impacts of traffic combustion based emissions in Tyrol the chapter further lists emission regulations on international and national levels to illustrate the development towards cleaner air in the first attempt. The second attempt mentions and describes all classic air pollutants which are monitored in Tyrol and their development. The last part of chapter 3 focus on the measurements of air quality monitoring stations. To this end, an anxious finding is that the inner-city air quality monitoring station located in the southern beginning of the in Fallmerayer-street is since ever exceeding the current fixed limit for NO_2 year by year since records began in 1989. Moreover, alarming is the circumstance that those threshold values apply in the first instance for healthy adults and not for expectant mothers, children, elderly or sick people like the Environment Agency of Austria publishes on their webpage (Placeholder1).

With aim to elaborate the technical perspective, the fourth chapter of the master thesis provides an overview of the technical status quo and describes the potential technologies which are considered for replacing the diesel buses in the case study by means of their advantages and disadvantages. The biggest challenge for BEBs and FCBs is to compete against the existing pros of the diesel bus which become manifest in a higher reliability, lower purchase cost and the inexistent necessity for new infrastructure. In consequence, the need for new charging opportunities for BEBs and FCBs beyond the conventional known gas stations is illustrated. The subchapter 4.2. discusses the two existing charging of the a BEB. Concerning the two different charging possibilities, opportunity charging and overnight charging have both stringent impacts on the operation of BEBs due to their pros and cons. On the one side, opportunity charging allows smaller battery packs in the BEB which affects the purchase price, but has as well the disadvantage of expensive infrastructure investments in on route charging points. In addition, a BEB powered by opportunity charging has to be charged as well over night in the bus depot. On the other side, overnight charging requires long charging periods in the bus depot, which limits the time frame where the bus could be used for transport missions, but requires no expensive investments in charging infrastructure. Furthermore, the subchapter 4.3. describes the pros and cons of a hydrogen fuelling station. First of all, it seemed that beyond the high construction costs of the complex technology and the limited spread of fuelling station no further disadvantages are existing. However, Conrad (2018) emphasised in an interview on a real further bottleneck which could have an impact on the management of FCB fleets. The bottleneck is the capacity concerning the number of buses which can be refilled in a row. The limiting components are the compressor and the high pressure tanks which increase tremendously in price by escalating the capacity.

Chapter 5 has elaborated on different considerations concerning direct ambient ecological impacts and economic effects due to the operation of diesel buses or E-buses. In conjunction with the diesel bus, the pollutants which are deriving after the combustion-process are classified and illustrated according to their amount. From this point of view, it can be seen that after the combustion of one kilogram of diesel in total, just one percent of the total sum of exhaust gas is composed of the pollutants NO_X, HC, CO and PM. In connection, it is referred again to the negative health effects of ultrafine particles, which can have cancerous effects especially on children in the regard that children disproportionately often inhale and exhale in comparison to their body size. This alarming fact in connection with the pollutant measurements of the aqms at Fallmerayer-street does not make the inner city of Innsbruck seem ideal for children for growing up. Another direct but still less noticed ecological impact of bus traffic is noise pollution. This short subchapter refers to the constant lower noise profile of E-buses especially during stand still and the process of driveaway. In return, the adjacent subchapter 5.1.2. deals with the ecological analyses of the life-cycle of a battery of a BEB. Anyone who is interested in the degree of lithium battery recycling will be disappointed by the fact that instead of recycling batteries according to their lithium content, they will be burned to recover energy. Therefore; there are 3 solutions to make batteries more environmentally friendly. On the one hand, battery production based on hydropower would reduce the carbon footprint by 60 percent and on the other hand, batteries would have a more environmentally impact if they had the same lifespan as the bus or if they were used as power storage media after being replaced due to capacity degradation. In addition, Chapter 5 also analyzes the electricity mix, which can be used to charge BEBs or to produce hydrogen through electrolysis. The example of Germany and Austria shows that the Austrian electricity mix relies more on renewable energy sources than the electricity mix of Germany and is thus more suitable for the operation of E-buses and the production of hydrogen due to the environmental impact.

The second part of chapter five elaborates on questions concerning purchasing power loss through the import of fossil fuels and domestic value creation through local energy production. The statistics show that Austria imports crude oil for several billion Euros per year from politically unstable crisis states. The review of the domestic value chain shows as well that only a marginal share of one litre fuel oil remains in the region as added value.

Hereby hydrogen could contribute significantly towards a reduction of purchase power loss and a local value creation. Therefore, hydrogen could be produced by electrolyses using electricity from local renewable energy sources. This process could be integrated in the hydrogen fuelling station or located close to the place of consumption and transported by local companies. Secondary economic effects would occur by the possibility that hydrogen fuelling stations are maintained by local skilled workers. What is more, if then an expansion of hydrogen refuelling stations would take place, private households could be in favour to switch to hydrogen cars and companies to FCBs or hydrogen trucks. This would entail an increased demand for hydrogen and trigger an expansion of renewable energy sources such as photovoltaic, wind or hydropower plants.

Finally, chapter 6 represents the main part of the thesis. In variant 0 the initial current situation is discussed. Further, the results from the tracking report are picked up again and incorporated in the individual detailed assessment of the routes W, TS and 501. Each bus route is evaluated as a standalone variant due to its electrification potential with regard to route description, operation time, dwell time, possible bus model change, fuel consumption, environmental impact, infrastructure requirements and total and operating costs. In addition, the variant is crosschecked with a suitable E-bus model to illustrate differences. In the model description and the cost calculation of the chosen a suitable bus model, the E-bus is compared to the diesel bus in two different billing variants. Since it is customary to lease a diesel bus in the case of Ledermair for 5 years and return it with a fixed buy-back price to the seller, the second variant was calculated with the same E-bus but under the conditions full purchase and a useful-life of 10 years. The analysis of the individual variants has shown that all E-buses save CO_2 emissions. Furthermore, it can be stated for the lines W and TS that as well fuel savings can be achieved by using BEBs. In contrast, the operation of FCBs on the route 501 achieves no financial benefits due to the fact the expenditures for hydrogen almost 60 percent higher than the amount of expenditures for fossil fuel for a diesel bus. The most important findings deriving from the case study are that the route W would be a perfect candidate for being electrified and that it is obvious to electrify the route TS due to environmental as well as image reasons.

In view of all the elaborated considerations, the 3 hypotheses set up at the beginning of the thesis can now be answered. Yes, an E-bus (BEB, FCB) has less negative environmental impacts than a conventional diesel bus because first of all an E-bus has no direct tailpipe emissions and no noise pollution. Furthermore, if the E-bus operator charges his BEB with electricity or refuels his FCB with hydrogen produced by electricity from renewable energy sources then the energy used for the production of all components becomes important. From the thesis we know that the biggest energy consumer is the production of battery components and there can easily improvement be achieved. Anyhow, for critics the E-mobility is in general worse than the conventional traffic, but none of those ever questions the environmental impact and the amount of consumed energy for the production of 1 litre diesel.

The second hypothesis due lower operating costs of E-buses (BEB, FCB) than diesel buses in the long-run cannot be answered clearly. Concerning the BEB, this hypothesis can be confirmed, as a BEB has lower fuel costs and maintenance costs. With regard to the FCB, this cannot yet be confirmed, as the technology is still in a test phase and the maintenance costs in 10 years are similar to the purchase price of the bus. In the distant future, every E-bus will certainly be cheaper to operate than a diesel bus, since it can be speculated that eventually a CO_2 tax will be introduced according to a polluter pays principle.

The third and last hypothesis questions if FCB will succeed over BEV buses in the long-run. In view of the circumstances it can be assumed that in the next decade primarily BEBs will be purchased. Moreover, only from the time on when fuel cells are cheaper, hydrogen is available in sufficient quantities at a lower price and technical challenges have been solved the FCB will be increasing in demand. However, we must remember that the use of FCBs can make more sense than the use of BEBs, since the main components of BEBs are the battery packs which are produced in China and thus there is a loss of purchasing power to Asia. The opposite would be the approach that the increasing operation of FCBs could create local value creation through a growing hydrogen branch of the economy.

To sum up, the future will belong to E-mobility and that will be undisputed, but it is still a long way to the full-scale deployment. Until then, years will pass and many discussions will have to be conducted. These discussions will revolve around dismantling of tax concessions for diesel, prohibition of non-emission-free buses in inner cities, about subsidies of E-buses and the reuse of batteries.

8. Suggestions for Bus Company / Guidance

The master thesis shows the complex relationship of all considerations towards an electrification of public transport buses. Caused by the acquired knowledge and the elaborated topic areas recommended courses of action can be derived for the bus company Ledermair towards an electrification strategy.

The **first** step would be that Ledermair should investigate all routes due to their electrification potential. Each bus should be tracked for a period of one month for receiving a broad overview over the operation mission. Afterwards, the recorded data should be used to generate a requirements specification for the feasible application of E-buses

The **second** move should be that Ledermair deduce from the results which route could be operate with BEBs or has to be operated by FCBs as well as which technology needs which additional infrastructure requirements and thus additional investments. An additional **third** step should be that Ledermair screens the E-bus market on behalf of the required technology specifications to determine which bus manufacturers can supply suitable buses at what prices.

In the **fourth** run, Ledermair should carry out a cost calculation on the basis of which it can be decided which route is the most feasible due to economic reference values for being electrified and at what price this electrified route can be operated in case of tender. Steps 3 and 4 should be repeated by Ledermair in an annual interval as the E-bus market changes rapidly in terms of supply, technical possibilities and decreasing purchase prices of BEBs and FCBs due to economies of scale.

Beyond the first four steps, Ledermair would have to develop a common concrete electrification strategy with fixed milestones in conjunction with VVT, the government of Tyrol and other bus operators. The bottom line is that E-buses need a joint subsidy platform where for example, the government of Tyrol takes over the higher costs or subsidizes with a certain percentage the additional costs of BEBs and FCBs in comparison to diesel buses.

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