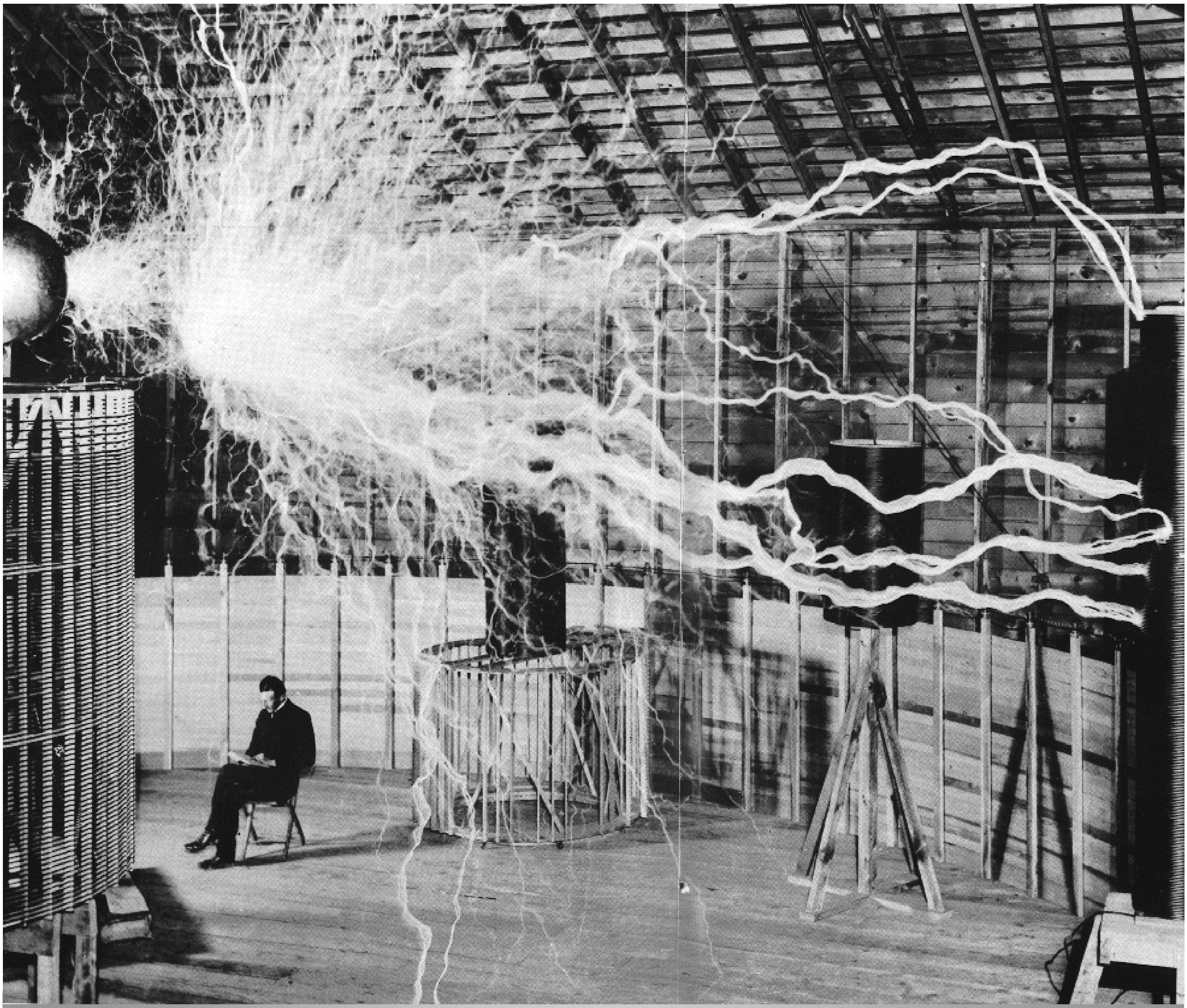

Is the Future Electric? Electric Busses, a Sustainable Alternatives for Alborg's Public Transport System

By introducing a new technology in Aalborg's public transport network this thesis seeks to uncover if autonomous electric busses have a place in the quest for a sustainable public transport system.

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Preface

This thesis is written on the 4th semester of the master in Sustainable Energy Planning and Management under the Board of Study of Planning and Geography, Aalborg University.

Reading Guidelines

The report should provide all necessary information to understand the issues handled in this project. Chicago referencing is used for source references throughout the report. The bibliography is placed at the end of the report where the references are given in alphabetic order. In the text a reference will include (*Surname or Title Year*). All Figures and Tables are sequentially numbered.

Appreciations

The author would like to thank Bernd Möller (Aalborg University), Poul Alberg Østergaard (Aalborg University); M. Mette Olesen (COWI), Christian Trankjær (NT), and Morten Jensen(NT), for their support and patience.

Contents

1 Introduction

An electric vehicle (EV), relies on an electric motor for propulsion using electrical energy stored in an energy storage device rather than being propelled by an combustion motor, in which the combustion of a fuel (normally a fossil fuel) occurs.

Who and when invented the first EV is uncertain as several inventors have been given credit. In the late 1800s, France and Great Britain were the first nations to support the widespread development of electric vehicles. In America, the years 1899 and 1900 were the high point of electric cars, as they outsold all other types of cars. Witnessing increased popularity, electric vehicles enjoyed success until the 1920s with production peaking around 1912.

Most travel of the period used to be local commuting, a perfect situation for electric vehicles. The EV “was the preferred choice of many because it did not require the manual effort to start, as with the hand crank on gasoline vehicles, and there was no wrestling with a gear shifter” (Bellis 2013).

The decline of the electric vehicle began with the discovery of crude oil. This in turn reduced the price of gasoline so it became affordable to the average consumer. Another hard blow to EV was given by Henry Ford. The Ford Motor Company a subsidiary of the Standard Oil Company owned by John D. Rockefeller initiated the mass production of internal combustion engine vehicles. That made these vehicles widely available and affordable. By contrast, the price of electric vehicles continued to rise.

The invention of the electric starter eliminated the need for the hand crank and the development of road systems that now connected cities, brought the need for longer-range vehicles. Needless to say, electric cars had all but disappeared by 1935 and until the 1960s electric vehicle development and their use as personal transportation was abandoned.

As new emphasis on environmental protection emerged in the 60’s and 70’s along with problems with exhaust emissions and dependency on imported crude oil created the proper conditions for resuming EV research and development. Currently the market for electric vehicles is growing rapidly and has reached more than 120000 unit sales worldwide in 2012. Even if the market share of the EV is rising, it is still a far cry from the 62,45 million units sold globally in the same year (Scotiabank Economics 2013).

As with regard to public transport EV took a different route in history.

1.1 A short history of EVs used in public transport systems

The world's first electric tram line was tested in Russia, near Saint Petersburg in 1880 by Fyodor Pirotsky, while the first trolleybus dates back to 1882 and operated in Berlin under the design of Ernst Werner von Siemens (Dunbar 1967). In time, these EVs operated either on or off rails, on the ground or underground, relying on power that came through permanent overhead lines (catenary lines) or electrified third rails.

Going back to their evolution through history, by the end of the 1950s, the rapid ascent of the mass-produced automobile and the improvements in motorized buses leaded to the rapid disappearance of the tram and trolley from most western and Asian countries. These improvements transformed busses into a serious competitor to trams but their biggest advantage came from the fact that they did not require the construction of costly infrastructure. As a result most tram networks were no longer maintained or modernized. Busses gradually replaced trams, a technology that was considered archaic. This state of affairs served to discredit trams into public’s eyes. “However, the demise of the streetcar came when lines were torn out of the major cities by bus manufacturing or oil marketing companies for the specific purpose of replacing rail service with buses” (Tennyson 1989).

Starting with the 70’s, mainly in large cities, smog and sound pollution, traffic congestion and parking became problematic thus the advantages of the tram became once again visible. Since Metro construction was not a universal solution, authorities begun redefining their transport policies. In countries like Germany, France and Spain, tram networks revived, which brought about a series of technological developments. In 2010, catenary free trams were introduced by a company named Bombardier which produces the PRIMOVE LRV tram. The tram is charged by contactless induction plates embedded in the 800 meters track-way, located in Augsburg, Austria (Bombardier Transportation 2010).

Trolleybuses and trams are world wide spread; the majority is located in Eurasia. There are currently around 315 cities or metropolitan areas where trolleybuses are operated (Webb 2010).In Denmark the first catenary electric tram based public transport system was operational in Copenhagen in 1899. Hellerup - Charlottenlund – Klampenborg followed in 1903, Aarhus in 1904, and Odense in 1911. Between 1880s and 1890s, the first unsuccessful attempts to use batteries to power the EV that run on tracks, were made in Australia and in the Netherlands. Also Denmark experimented with a storage battery tram between 1897 -1902, in Copenhagen (Svenska Sparvagssallskapet 2013).

In Denmark, trams had same fate as in the rest of the world as the last Danish tram retired in 1972, in Copenhagen. Almost 20 years later, the urban development of the Ørestad area of Copenhagen crated the conditions for a new planning strategy which would consider similar technologies for use in public transport. The joint venture between the Ministry of Finance and Copenhagen Municipality considered: a tramway, a light rail and a rapid transit. Then years later the M1 Metro was operational (T. O. Jensen 2002).From here it took another ten years for trams to reemerge as a 28 km long, light rail project in Copenhagen when the Transport Ministry, agreed to develop a tram line parallel to the ring 3 highway around the capital city. The project is expected to be completed by 2020 (People's Daily 2011). To avoid confusion, it must be mentioned that Copenhagen has two different train systems, the Metro and the S-train. The latter is in service since 1934 when the first line was opened and it is complementary to the M1 and M2 lines of Metro Copenhagen.

Copenhagen is not the only city in Denmark that looks forward to have a light rail.

The municipality of Odense is currently conducting the EIA for a light rail in the city which is expected to be submitted for public consultation in mid-2013 and finally adopted in Odense City Council at the turn of 2013-2014. The City Council initiated in 2008 a new development plan for urban spaces. The preliminary plans are to connect the main rail station with a shopping mall in the city center, University of Southern Denmark south of the city, and the coming "Super Hospital" at the nearby highway junction. The construction works, are expected to start by 2016 and the line stage of the line should be operational by 2021. There are no plans to establish connections to neighboring cities. (Odense Kommune 2013).

In Aarhus, the planning of a new tram network in Aarhus began in 1999. The network will connect two existing rail lines north and south of the city by building a new rail line from the harbour in central Aarhus and the urban development area in Lisbjerg via Aarhus University Hospital. These are part of a bigger plan to strengthen the public transport system conducted by the Light Rail Transit Secretariat which is working on planning the extensions to the surrounding towns. The first stage of the line should be operational by 2016, while the project should be completed by 2020 (COWI 2009).

In Aalborg the Strategy for Municipal Planning was adopted at the beginning of 2012. Among other issues, particular focus will be applied to light railway and coupling this to the local railway network which reinforced the effort into bringing the tram in the city. The project aims at connecting the airport in the north with the city center the future hospital and the university. The Feasibility Study started in January 2012 and will be followed by an EIA analysis assumed to take approx. two years, will commence in early 2014 and be completed at the beginning of the 2016. This paper work is expected to be completed by mid / end of the 2018 being followed by the construction works. The line is expected to be operational at the end of 2021 (NT 2012).

1.2 Paradigm in Public transport

The purpose of investigating the paradigm in public transport is related to the need of understanding the factors involved in shaping this field and the dynamics of mechanisms present in this arena. In other words a solution has to fit the context. Without a bird eye view over this arena one can fail to grasp the importance of some factors relative to others. As an example it is important to find out if a solution has a social acceptance, or if the business sector is resilient at implementing it, or how the governance can help implement such solutions through the use of sound policies.

Public transport policies and development are influenced by a multitude of factors, including political, technical, environmental, social, economic or even trend. In order to understand the main discourse in public transport planning it is important to investigate the connection between urban development and public transport. In order to get wider views on the discourse among the actors involved in sustainable mobility and urban planning, a review of relevant articles has been carried out.

Several key aspects have been identified by (Naess 2012) in a review of over 30 Nordic studies, carried out between 1982 and 2012 on the **influence of the urban structure on travel** and are presented below.

One of the first aspects is the connection between the urban type and commuting patterns.

Nordic scientific literatures provide clues to the fact that urban structures pose influence on travel behavior. The amount of travel is dependent to a higher extent, to the location of the city's facilities in relation to the residential area's location, rather than the distance to the closest facility within a certain group.

Car ownership in relation to public transport is influenced by residential location, however the situation where car owners use public transport to commute to the city's main concentration of facilities, but compensate by traveling in weekends is also acknowledge thus including car ownership as a control variable can be at least arguable.

Work place location influences commuting patterns. Higher proportions of commuters using public transport, bicycles or walking and lower proportions of car owners are found at inner cities compared to suburban job sites. In other words inner city inhabitants use more public transport to get to their jobs. Therefore job decentralization from inner to outer city areas usually has no significant impact on the average commuting distance.

Also in Nordic and international experience has been found that local area density is weakly related with travel behavior. However high local area density contributes at reducing car traffic and transportation emissions as this situation offers the premises for development of local service facilities, thus increasing the odds that such destinations to be found within walking distance.

Regarding the influences of neighborhood-scale street patterns on travel behavior, Nordic studies fund no relevant connection; however this situation is different for findings in USA studies.

Regarding energy use, the Nordic studies point out that "a centralized pattern of development will require the least amount of energy for transportation" at an intra-metropolitan-scale. However at a wider regional scale "decentralized concentration may be the most energy efficient settlement pattern".

"The conclusions from the Nordic studies add to the quite overwhelming international evidence that urban spatial structures influences travel behavior" (Naess 2012).

1.2.1 Framework for Sustainability

Whit this in mind the next step is identifying the discourse among urban planners and other actors involved in **urban development**. Since sustainable development has become popular in the scientific discourse the key strategy in achieving environmental sustainability is considered to be the decoupling of economic growth from negative environmental impacts.

One of the arguments in favor for the *compact-city* concept, as a sustainable urban form, is the influence of spatial structures over travel behavior. According to (Zegras 2010) sustainable mobility can be more easily attained if the urban area follows a denser more concentrated pattern rather that a low-density spatial development (for the same urban area).

Discourses on sustainable urban development concept, and how this concept is translated into practice and implemented into policies, can be observed by analyzing relevant case studies. Some dominant ideas of the urban planners and urban development, in relation to the challenge of sustainable mobility, were identified by (Næss, et al. 2011) for the metropolitan area of Copenhagen (Denmark) and Oslo (Norway). The study covers 114 Danish articles and 101 Norwegian articles over a 16 years period (1990+2006/7). The study, using qualitative content analyses and semi-structured interviews points that the dominant conceptions among the planners show many common similarities but also differences.

The Danish planners have focused on developing areas close to urban rail stations; nevertheless low-density decentralization was part of a counter-discourse. They have tried to limit the possibilities for spatial urban expansion by increasing the attractiveness on the inner city, an approach called leverage planning.

Another strategy towards sustainable mobility was improving public transport. To increase the use of public transport certain restrictive policies on car use have been considered such as environmental zones, parking policies or even road pricing. So far their implementation has not fully begun. The road building has been part of a transport policy to eliminate exiting or projected congestion."The discourse on sustainable urban development in Denmark has – especially in the present century – had a strong focus on growth stimulation (so-called economic sustainability)" (Næss, et al. 2011).

With respect to the actors within public administration, (Næss, et al. 2011) identified two structures that focused on different directions. The ministry of environment supported vigorously the idea of compact urban development and that development should take place close to urban rail stations. On the other hand, the concept of higher mobility was supported by the national transport authorities, which backed up the investments in public transport and road development.

These two different positions reflect partly the organization cultures they emerged from. While the ministry of environment has a staff that is obviously 'environmental-oriented', the ministries of transport prefer more "the economic methods for project evaluation". Apparently, the economist within the ministries of transport, have more prominent positions and sometimes their recommendations seem to deviate from the adopted political goals. "In spite of wide spread goals of reducing car travel, the municipalities have usually also lobbied toward national transport authorities for the realization of local road projects" (Næss, et al. 2011).

As with respect to environmental organizations, the debate has focused mainly on the focus of urban ecology concept, close circuit of substances, waste and water management, local self-sufficiency and less on land use and development. (Hoftun 2002). Car-dependent development projects are not facing strong opposition from environmental NGOs as they have shown no support for urban densification.

1.2.2 Barriers for Sustainability

A competition between municipalities has been observed. In the race to attract taxpayers and investors sub-urban and outer area municipalities offer large spaces for development as counter measure to inward investments promoted by core municipalities by supporting dense and transit oriented development.In the same time has been observed that investors and land owners can pressure politicians to adopt plans for land use that are not optimal with respect to sustainability.

Another important aspect is the influence of economic stability on policies, as assuring growth is seen as the main task. "In times of crisis growth is the most important goal for the decision makers –

and growth and sustainability seem not to be compatible in the minds of decision makers" (Næss, et al. 2011).

In prosperous time and periods of economic growth, environmental sustainability and reducing the negative impact of growth are more often set as targets in policies and receive higher attention. In the same periods the increasing consumption puts higher pressure on environment than in periods of economic recession. The impact of urban spatial development, in times of low or high growth, tends to be similar with respect to negative environmental impacts, as long as the situation – in which creation or maintaining growth is perceived as more important political goal – will perpetuate. The growth of building stock is regarded as assumed good, by most actors. "Growth in transport and mobility has been taken as unavoidable fact, with *sustainable policies aiming at channeling as much of this growth as possible to public transport*". (Næss, et al. 2011)

1.2.3 Light rail discourse

The support for the light rail projects fits well with the discourse that dominates Danish political and planning arena.

In Copenhagen the light rail transport (LRT) network received much consideration and although bus rapid transit was studied, a more expensive light rail option was chosen for development. In the case of Aalborg, the interviews with key actors within planning arena, pointed out the need for development and the necessity to attract business.

Christian Trankjær, project manager at Nordjyllands Trafikselskab for light rail in Aalborg highlighted some of the key planning concepts that stood behind choosing the LRT solution.

Of relevance is the current discourse where surprisingly, planning policies outweigh the financial consideration. It is acknowledged that thou bus rapid transport system might be cheaper, from an urban planning perspective, LRT solution is preferred.

Businesses can see the metal tracks and thus perceive LRT as a long term commitment of the public transport authority to service the area. In contrast bus lines can be subjected to arbitrary change of routes. The LRT track route matches closely the axes of growth in the city.

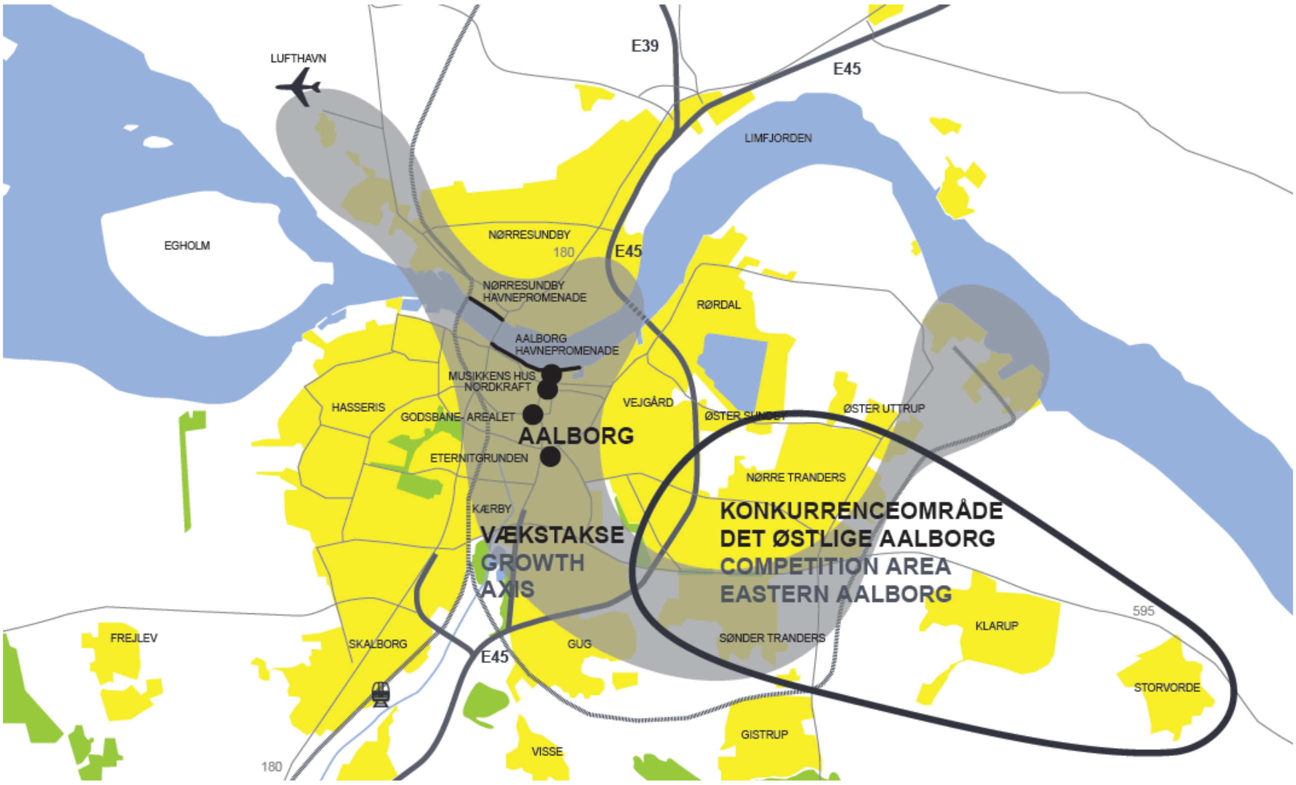


Figure 1 Light rail: central issue in urban development; Source **(Hansen 2011)**

From an urban planning perspective the LRT network attracts and maintains building development, business growth, and increases land value, thus it is used as a backbone to guide city's development in the desired spatial direction (see Figure 1).

From a traffic planning perspective, LRT solution are assumed to reduce congestion, increase the use of public transport and traffic safety , and transfer 5-10% car users to public transport.

From an environmental perspective LRT systems with electric propulsion do not produce same levels of pollution as cars or busses with regard to gas emissions, noise levels, and vibrations (given a quality infrastructure)

From a psychological point of view LRT is the object of desire and city pride as it became the mark of technological advance. Following Aarhus who set a precedent Odense, Copenhagen and Aalborg were soon to follow, afraid of not falling behind. This development unveils the competition between municipalities in attracting business and funds. Psychological rail factor is confirmed also by studies conducted in Germany and Switzerland (Scherer und Dziekan 2012).

It can be noticed that the Aalborg discourse regarding urban planning and sustainable mobility align quite well with the hegemonic discourse and the policies promoted by Danish Authorities.

1.2.4 Transportation Policy Goals

The Danish national target of the growth of traffic in public transport is set at a rate of 2% per year. The objective of achieving a growth in passenger numbers is related to the government desire of curbing CO2 emissions generated by private cars (Trankjær 2013).

The long-term goal for Denmark energy policy is to cover the entire energy supply – electricity, heating, industry and transport – with renewable energy by 2050.

The Danish government, through an energy agreement, decided to set a pool of DKK 70 million between the years 2013-2015 for funding the "establishment of more recharging stations for electric cars, infrastructure for hydrogen and for gas in heavy transport". Furthermore, an encompassing strategy will be studied, for the promotion of energy - efficient vehicles, including electric cars or buses. On top of that, DKK 15 million has been allocated to continue to 2015, the electric vehicle pilot scheme. The Danish government has also decided to give priority to "joint efforts in the EU to promote electric cars with focus on harmonization and roll - out of a car recharging infrastructure". (Danish Ministry of Climate, Energy and Building 2012)

The Danish government is going to present a proposal for a "kilometer - based tax on lorries". This tax aims on one side to be part of the revenues which are to be used in public transport investments and on the other side to make public transportation more affordable. Furthermore, the Ministry of Transport has set aside another pool for initiatives aiming at reducing the energy consumption and carbon emissions generated by the transport sector. (Danish Ministry of Climate, Energy and Building 2012)

The EU target of 10% renewables in the transport sector by 2020 is included in the Renewable Energy Directive. In December 2010 the 10% Directive was implemented into Danish legislation. "The EU Fuel Quality Directive requires that cradle to grave emissions of CO2 per energy unit must be reduced by 6% in 2020 compared with 2010". (Danish Ministry of Climate, Energy and Building 2012)

Another decision included in the energy agreement is to "amend the current Biofuels Act to ensure a mix including 10% biofuels by 2020". This is however pending analysis of. An analysis must be finished by 2015 is currently pending to be carried out with the purpose of identifying alternatives which can support Denmark in reaching and meeting it's EU commitment . (Danish Ministry of Climate, Energy and Building 2012)

1.3 Research Questions

For start, it is important to mention that EU sustainable mobility policies have emphasized the importance of reducing the growth in urban motoring, and made it an important policy goal (OECD/ECMT 1994). This idea has grown strong roots in today's planers. As a result new ideas emerge as how to limit the growth in urban motoring: implementing high prices to vehicles, limiting the building of additional road lines or road extensions for the fear of releasing latent demand for space on the roads and even limiting the access for private car owners to certain city areas. These restrictionist ideas aim more at containing a problem and are more goal reaching oriented rather than problem solving. Beside raising moral questions related to civil rights of the current car owners the above policies also lack vision. Their base concept is to make it too difficult for the current car owners to commute using their cars thus they will switch to public transport.

However EU's policy is relevant for situations where the vehicle's main source of propulsion is based on fossil fuel, which is dominant case today. In the case of a non-polluting vehicle these policy would be just wrong. So the question arises: why not facilitate and support the evolution and implementation of proven cleaner propulsion technologies?

At least some studies point towards this possibility. The findings of (Driscoll, et al. 2012) point that electric vehicles integrate well "into the existing transport planning and engineering approach" and shifting to this more sustainable form of mobility, "does not…require a path breaking policy turn".

However, regardless of the policies in place, they are not the only ones at fault for the current situation. Some studies advocate for a technological fix and also suggest that mass transportation alone is insufficient at solving the challenges of sustainable transport.

At a European level, in 2010 the Spanish Presidency came up with a proposal for an action plan for electric vehicles. This plan was opposed by UK, and Czech government, while Denmark and Sweden were critical of it. (Driscoll, et al. 2012)

"If a non-environmentally harmful growth were to be possible anywhere, it is likely that this must be in countries with a high degree of economic freedom of action, a high level of prosperity, as well as a high level of knowledge in the population" (Næss, et al. 2011).

From this point of view the metropolitan area on Aalborg can be the right candidate for the task.

Furthermore the city of Aalborg has already started a journey towards a sustainable future thorough various projects including the LRT project mentioned in chapter 1.1. If all goes according to plan the LRT network will be operational by the end of 2025.

But what happens until then? Should the city wait 12 years for the arrival of a tram? Or are there are alternatives that have to be discovered? This is exactly where this thesis comes into play. By introducing a 'technological fix' in Aalborg's public transport network and the current policy in public transport, this thesis seeks to uncover if autonomous electric busses have a place in the quest for a sustainable public transport system. And its objective is reflected in the research question:

Can Electric Busses be a sustainable alternative to Aalborg's current diesel based Public Transport System?

In order to answer this question the existing situation is compared with an alternative scenario, taking into consideration sustainability from an economic and environmental perspective, thus four sub questions arise.

From an economic perspective the first sub question is:

1. *Is the EB solution cheaper than the existing situation?*

From an environmental perspective the sub question are:

2. *What is the electric consumption of the EB fleet?*
3. *Can the needed electricity be generated locally?*
4. *What are the environmental implications for the EB alternative compared with the existing situation?*

The path followed to answer the questions is described in Chapter 2: Methodology.

1.4 Limitations

One on the first limitation is related to social aspect of the EB solution, which is not addressed in this thesis. In order to fully understand the dynamics of how the EB solution will work in a real setting this aspect should be also investigated in future works.

With respect to available driving technologies another limitation is that this thesis only focuses on super capacitor buses and no other vehicles that use alternative fuels are considered, like hydrogen, or biofuels nor hybrid solutions.

With respect to electricity generation solutions another limitation is that in this thesis it is only investigated the solar potential of the local region.

1.4 Thesis Structure

The project flow is linear and three main parts can be seen at glance: an introductory and methodological part, the scenario part and the results part. The thesis is structured according to Figure 2.

In Chapter 1 the report discusses the issues outside and within the focus area and leads to the research question. Chapter 2 contains the overall methodology and the methods and tools applied for each chapter. Also describes what are the considerations and assumptions, are considered when creating scenarios in which is assessed the performance of the bus fleets.

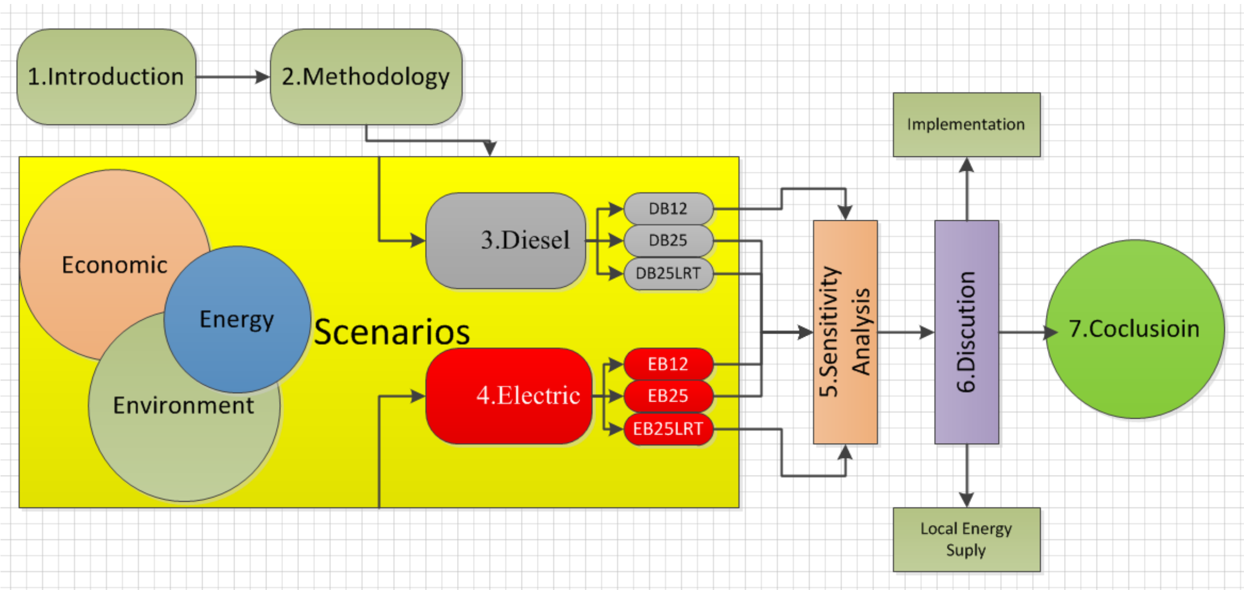


Figure 2 Report Structure

Chapter 3 contains three different scenarios with respect to the diesel bus: Diesel Bus Network in 2012 (DB12); Diesel Bus Network 2025 (DB25); Diesel Bus Network with Light Rail 2025 (DB25). They cover the situation before the implementation of the Electric Buses. They are considered the business as usual scenarios and will be also referred to as Diesel Scenarios.

Chapter 4 contains three different scenarios with respect to the electric bus: Electric Bus Network in 2012 (EB12); Electric Bus Network 2025 (EB25); Electric Bus Network with Light Rail 2025 (EB25). They cover the situation after the implementation of the Electric Buses and will be also referred to as Electric Scenarios.

Both chapter 3 and 4 hold information regarding the technical behavior of the bus fleet, economic parameters, impact on environment and externalities expressed as the social cost of carbon.

Chapter 5 contains the sensitivity analysis. In Chapter 6 the results are discussed along with possible implementation solutions, and a possible local electricity sources.

Chapter 7 presents the conclusions, and future works.

2. Methodology

2.1. Introduction

The values uses in the thesis are coded using Central and East European encoding: a decimal point is a comma and a thousand mark, is a full stop.

The discount rate set for economic calculations is set for 3% in the thesis.

The currency exchange rates considered are: 1 US Dollar ($) for 5,68 Danish Krone (DDK); 1 Euro for 7,46 (DDK).

The diesel price in 2012 is considered to be 9,18 DDK / l of fuel, price that already includes the 7% bio diesel in the mix and taxes.

2.2 Research design

The general approach of this thesis in answering the research question is the one of feasibility study. A feasibility study is a way of finding solutions for a specific problem or problems under some given circumstances. This can include more than just the business economic perspective, since the parties involved may have priorities that do not involve economic perspectives. The main criteria to decide feasibility is the cost of the options that are to be compared. In order to include the impact on environment the cost are calculated with considering externalities quantified as the social cost of carbon (SCC) (see Chapter 2.3).

There are several limitation determined by factors like, time availability, length of report, data availability, language barriers, access to sensitive information's considered trade secrets and so on.

The approach to answer the research questions is to create from known data, several scenarios that would model the current and future situation, before and after the implementation of electric buses. An overview of the mechanisms that stay behind the scenarios can be seen in Figure 3. Starting with given data, a set of relations between parameters that describe the operation of the current bus fleet is constructed. This set of relations is applied to 2012 data and will generate values for the new scenarios.

This is a deterministic model, since results are the same each time the model performs computation given the same input parameters.

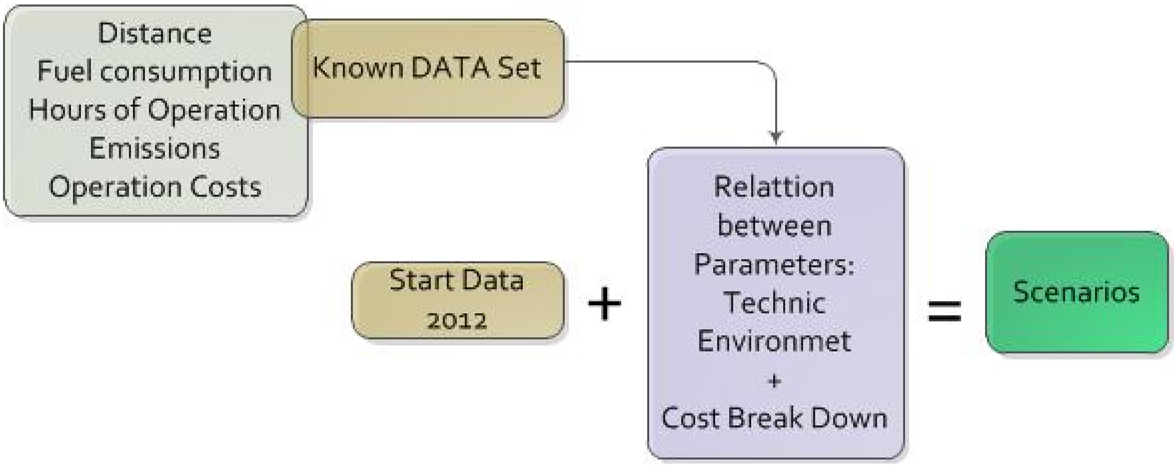


Figure 3 Data management diagram

Table 1 presents the reference data – known data set – for building the scenarios that will be presented in the following chapters. The data corresponds to the traveling undertaken by buses that are part of Aalborg bus network, and include: city-, service-, basis- night buses and the ones in Metro bus network during 2011.

Rute	Actual Km	Liters of diesel	*Total Driving Hours*	*Passengers*	*Expenses*	*Revenues*	*Coverage*	*Ton CO2 0% BD*	*Ton O2 7% BD*
Aalborg city-, service-, basis- night bus	4.455.978	2.026.625	167.865	8.785.000	114.176.172	64.180.690	56%	5431	5051
Aalborg metrobus	4.510.046	1.880.284	150.179	5.382.000	99.410.123	52.601.763	53%	5039	4686

Table 1 Reference data for building the scenarios **(M. Jensen 2013)** and **(Trankjær 2013)**

Starting from the data in Table 1 a set of technic and economic parameters was calculated and is presented in Table 2. The set is used to generate the values for the upcoming scenarios. The known values for creating the scenarios – Start Data 2012 (see Figure 3) – are the total driving hours, on daily bases for each bus line and will be further presented starting with Chapter 3.

	Ecnomic	Technic				Emissions	
Rute	**cost per hour [DDK]**	**L/km**	**h/km**	**km/h**	**L/h**	**g CO2/km using 0% biodisel**	**g CO2/km using 7% biodisel**
Aalborg city-, service-, basis- night bus	680	0,45	0,04	26,54	12,07	1218,8	1133,56
Aalborg metrobus	662	0,42	0,03	30,03	12,52	1117,31	1039,10

Table 2. Specific parameters for the bus network services

Costs for Diesel Buses

The cost breakdown per hour of operation is calculated starting from (M. Jensen 2013) values: total cost per hour, driver expenditures and Fixed Costs, presented in Table 3. It is noticed that the cost per hour of operation has a larger threshold than the one form Table 2, thus further calculations use it as starting point.

	cost per hour	Driver	Fixed	Fuel	P+M*	Other
NT	740,00	363,00	188,00	110,83	42,44	35,73
NT	648,00	361,00	132,00	114,94	48,01	-7,95
Average	694,00	362,00	160,00	112,88	45,23	13,89
%	100	52,16	23,05	16,27	6,52	2,00

Table 3: Cost breakdown per hour of operation; **(M. Jensen 2013)*** P + M: Parts + -Maintenance

The fuel costs are calculated multiplying the diesel price of 9,18 DDK /l with the fuel consumption, all divided with the total driving time. The parts and maintenance price for diesel buses, is calculated using data from the US National Center for Transit Research (CUTR 2011) seen in Table 4.

Input (CUTR 2011)					Output			
Buses	Average Vehicle Age (years)	Average Acquisition Cost ($)	Parts Cost per Mile ($)	Maintenance Cost per Mile ($)	Parts Cost per km (DDK)	Maintenance Cost per Km (DDK)	Parts Cost per hour (DDK)	Maintenance Cost per hour (DDK)
1253	6,4	299.179	0,218	0,235	0,769	0,829	21,77	23,46

Table 4 Parts and Maintenance Cost

There are other costs associated with operating the bus fleet that amount to about 14 DDK per hour or 2% from the total hour cost. The expenditures associated with the driver have the biggest share 52 % followed by fixed cost with 23,05%, Fuel costs with 16,2 % and Parts & Maintenance Cost with 6,52%.

The costs subsidized by the government cover 47-44 % of all expenditures. The revenues cover the rest, about 53-56% of the expenses for Metro-Bus Line and City-Bus lines, and are considered to increase or decrease proportionally with the expenditures, since generated from ticket sales. It is also considered that travel habits and preferences will suffer no change at remain at the same level as now, regardless if there is a fleet of Electric or Diesel Buses. Also it is considered that legislation will remain the same and will not limit private care use, or access to specific areas of the city. So in this case there will be no increase or decrease in public transport ridership to influence the revenues, and thus the economic indicators. Therefore revenues are not taken into consideration when calculating the economics values of the scenarios; however they are discussed in chapter 6.4.

Costs for electric buses

The cost breakdown per hour of operation is calculated maintaining the same structure as for Diesel buses (see Table 5), however the fuel is no longer Diesel but electricity, and cost of the parts and maintenance is specific to Electric Buses. The Driver costs, the fixed cost and other costs were kept unchanged.

	cost per hour	Driver	Fixed	MWh**	P+M*	Other
BYD	-	363,00	188,00		0,85	-
BYD	-	361,00	132,00		0,92	-
Average	-	362,00	160,00	280,54	0,89	13,89

Table 5 Cost breakdown per hour of operation for electric buses *P+M: parts and maintenance; ** cost of electricity DDK/MWh;

According to BYD's[1] overseas marketing department, the cost for parts and maintenances is $150.000 (846.000 DDK) for 12 years of operation for one electric bus (CALSTRAT 2012). Also the same source estimates the annual travel distance between 77.000 – 83.000 km. This places the expenditures on parts and maintenance in the rage of 0,15-0,16 $ / km (0,85 -0,92 DDK/km). The average between the two (0,89 DDK/km) is considered.

[1] BYD – company that manufatures electric buses

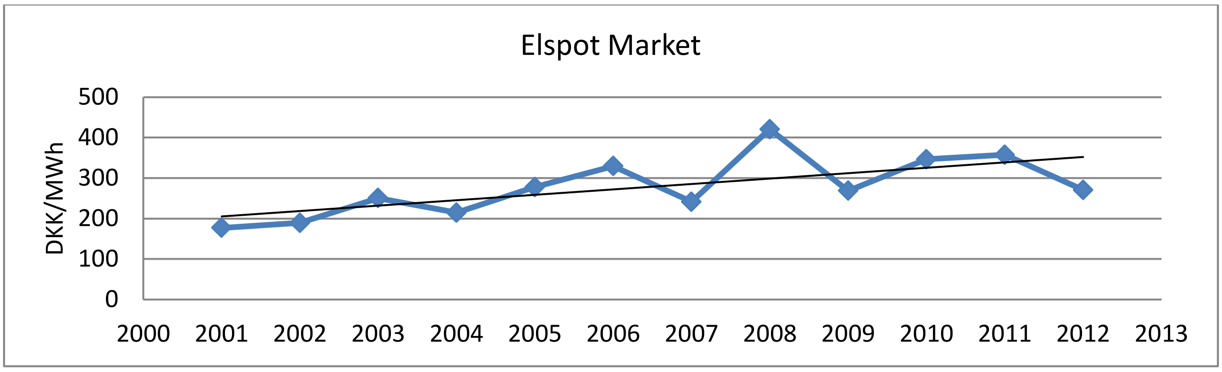


Figure 4 Elspot market 2000-2013

The electricity cost is an average of the last 13 years on (Nord Pool Spot 2013) (see Figure 4) with 280,54 DDK / MWh.

2.3 Data acquisition and management

Throughout the thesis different software, tools and methods were used for data acquisition, and processing and management. They are presented in Table 6.

Chapter	Methods used	Software
1. **Introduction**	Literature review Field study Interviews	MS Word
2. **Methodology**	Literature review	MS Word
3. **Scenarios for Diesel Buses**	Literature review Interviews	Excel MS Word
4. **Scenarios for Electric Buses**	Literature review Interviews	Excel MS Word
5. **Sesistivity Analysis**		Excel MS Word
6. **Discution**	Literature review Interviews	Excel MS Word GIS
7. **Conclusions**		MS Word

Table 6 Methods and Tools used in the project

Interviews

The interviews are one of the most important methods used for this project. They lead to gathering valuable data regarding the operation mode of the bus fleet, consumption, travel distance, cost. Also the interviews provide data towards discourses in public transport urban planning.

There persons have been interviewed: Mette Olesen, Christian Trankjær, and Morten Jensen.

Mette Olesen is a business Ph.D. conducting a qualitative analysis of Light Rails based upon European experiences at COWI, a company working on the Aarhus light rail and also conducting the pre-feasibility study for Aalborg LRT system. She is working within the area of traffic planning and public transport. This was an orientation interview, and it was mostly aimed toward the discourse in traffic planning, governance, and policies, traffic growth and acquiring new contacts.

Christian Trankjær is the Project Manager for Aalborg Light Rail at Nordjyllands Trafikselskab (NT). He participates in the work of integrating the state rail (DSB) and the local private railways (Nordjyske Railways) which also are coordinated with NT's bus service. This work follows the daily responsibility of contact and cooperation with Nordjyske Railways, DSB, Arriva and Rail Net Denmark. Furthermore, he is in charge to lead the development of the NT's collective traffic plan every four years.

Christian Trankjær was metaphorically speaking the cornerstone in this thesis, since he provided most of the data necessary for the study. However sensitive data could not be provide yet, since currently there is an undergoing feasibility study which will be available to public later this year. The interview was not only aimed at collecting numerical data but atlso at understanding the discourse around LRT implementation in Aalborg. Mr. Trankjær strengthens touches the gathered during the previous interview with Mette Olesen presented in Chapter 1.2. The audio recording of the interview can be accessed on the CD which is located on the last page of the thesis.

Morten Jensen works with public transport in Aalborg Municipality. The interview was oriented towards checking the assumptions for the future bus network layout and time tables.

Literature review

As seen in Table 6, literature review is another information gathering method used throughout the thesis. It consists in finding relevant information from deferent sources: articles in scientific journals, reports and documents, news articles, presentations found either online or in promotional information.

Selection of the electric bus was based also on finding relevant information over the specification of commercially available technologist.

Software

This section is an overview of the software programs used in the project. They are presented in Table 8.

Writing the report	MS Word, Open Office
Creating Diagrams and Graphics, Acquire images, map generation	GIMP, MS Excel GIS-Arc Map 10
Calculations	EXCEL

Table 7: Software tools used in the report

Emissions

In Table 9 are presented the emissions of carbon dioxide (CO2), particle matter (PM), nitrogen oxides (NOx), hydrocarbons (HC), carbon monoxide (CO) associated with driving as averages per km. These is the average of 20 cities, 930 buses, during 2009-2010 in Denmark, and do not include emissions from biodiesels. (Midttrafik 2011)

Particles	Average per km (grams)
PM	0,15
Nox	9,15

CO	1,68
HC	0,43
CO2	1.026,29

Table 8 Emissions table; **(Midttrafik 2011)**

However for Aalborg the situations is a bit different and values are a bit higher, when comparing the measured data: actual driven km and CO2 emissions (see Table 1). As it can be seen in Table 9, there is an increase of almost 8% for Metro Bus lines, and 18,8% for City Bus lines.

Average CO2 emissions per km **1.026,29** (grams)	**0% biodiesel [g CO2/km]**	**Difference from average [g CO2/km]**	**Difference from average [%]**	**7% biodiesel [g CO2/km]**
Aalborg city-, service-, basis- night bus	1.218,89	192,89	18,8	1.133,56
Aalborg metrobus	1.117,31	91,31	8,89	1.039,10

Table 9 CO2 emissions for Metro bus City bus lines in Aalborg; Difference form average: difference between measured data and calculated values for CO2 emissions

The CO2 emissions associated with the productions and transport of Biodiesel fuels to the gas station can vary largely, depending on the source and type of end product. Biofuels produced out of soya beans can dump as much as 661 g CO2/l (HaraBara GFC 2007) while emission for producing bioethanol from sugar cane from "well to wheel" can be as low as 200 – 300 g CO2/l. (IEA 2007). Giving the fact that these numbers are 6 years old and the Bio diesel mix that is being used by the current bus fleet is unknown, for calculating the annual emission generated by producing the Bio Diesel is considered that 300 grams of CO2/l of fuel is a satisfactory value. The total CO2 emissions per year are considered to be the sum between the CO2 emission corresponding to total driving distance and the CO2 emissions corresponding to the production and transport of the biodiesel used during the same year.

Assumptions for the Social Cost of Carbon (SCC)

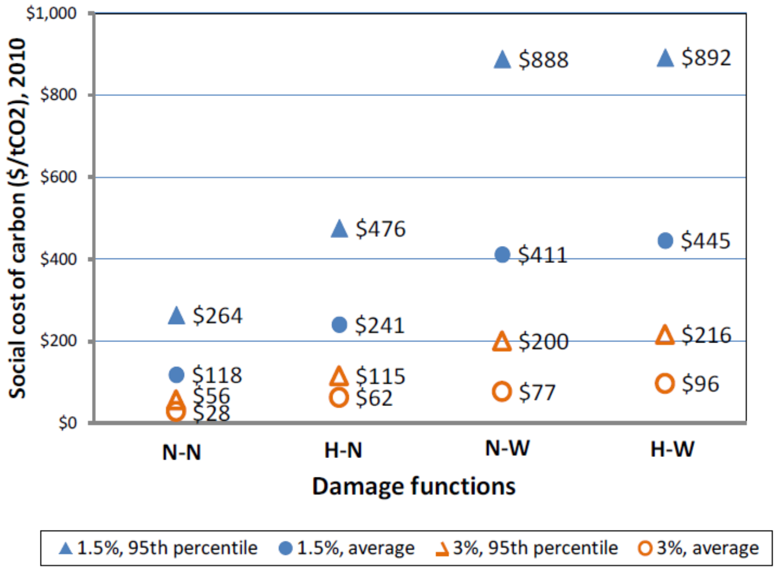


Figure 5 Social cost of carbon, in 2007 USD; **(Ackerman und Stanton 2011)**

The social cost of carbon, for year 2010 – a measure of the damage done by an adding a ton of CO2 emissions into the environment – can range between 21 and 893 $/t CO2 (199 to 5072 DDK), as seen in Figure 5. The damage has been estimated using four different functions, given the uncertainty of the relations between economic damage and temperature increases.

The values depend on several factors: "the sensitivity of the value of the climate sensitivity parameter; the level of climate damages expected at low temperatures; the level of damages at high temperatures; and the discount rate" (Ackerman und Stanton 2011)."The scientific evidence on likely values of climate sensitivity adopt a probability distribution which assumes a two-thirds probability that climate sensitivity is between 2.0 °C and 4.5 °C. The minimum is zero and the maximum is 10 °C; the distribution has a median of 3.0 °C and a 95th percentile of 7.14 °C" (Ackerman und Stanton 2011).

The social cost of carbon could take values between 28 and 216 $/t CO^2 if considering a 3% discount rate. The average between the values corresponding to 3% discount rate from Figure 5 is 106 $/t CO2. According to (USIC 2013), the value of 106 $ in 2012 is 117,38 $.

The SSC is considered 666,72 DDK /t CO2 (117,78 $ x 5,68 exchange rate).

Other Assumptions

It is assumed that passengers will manifest same preference for Electric Busses as for Diesel buses.

The capacity and the fleet size is considered the same for both types of vehicles.

In designing the Electric Scenarios is considered that the electricity purchased for powering the electric busses has the same mix of sources as the national residual mix. "The residual mix is the electricity mix delivered to these consumers that don't have a contract to get a particular form of electricity" (RES-E 2013).

The residual mix is calculated using statistical data, for electricity production at a national level, correlated with, imports and exports for electricity and Guarantee of Origin certificates (proves a given amount of electricity has been produced by a specific electricity production site), that are all together correlated at a European level. According to (RE-DIS II 2013) Denmark's residue mix is presented in Table 10. In Chapter 5 it is discussed what happens if this mix is changed for a preferential contract for using renewable electricity.

	RES	NUC	FOS	% CONS	g CO_2/ kWh	mg RW/ kWh
AT	40.7 %	0.5 %	58.9 %	55.1 %	220.6	0.01
BE	7.2 %	53.1 %	39.8 %	56.7 %	147.1	1.59
BG	10.1 %	35.8 %	54.0 %	99.9 %	551.2	1.07
HR	28.0 %	19.8 %	52.2 %	100.0 %	388.3	0.59
CZ	5.9 %	35.6 %	58.5 %	100.0 %	401.0	1.07
DK	20.8 %	12.2 %	67.0 %	94.1 %	487.1	0.37
EE	13.0 %	0.0 %	87.0 %	99.9 %	1071.1	0.00

Table 10 European Residual mixes for 2012; RES: renewable energy sources; NUC: nuclear energy sources, FOS: fossil and other energy sources % CONS: share of Residual Mix in total consumption; RW: radioactive waste; EAM: European Attribute Mix **(RE-DIS II 2013)**

Since CO2 and radioactive waste figures reported are not destined for other uses as another source is used in this thesis.

According to Covenant of Mayors's documentation for preparing a Sustainable Energy Action Plan, in order to create a Baseline Emission Inventory the following emission factors for local renewable electricity production or green electricity purchases can be used (Covenant of Mayors 2013) (see Table 11).

Electricity source	Standard emission factor ($t\ CO_2/MWh_e$)	LCA emission factor ($t\ CO_2$-eq/MWh_e)
Solar PV	0	0,020-0,050
Windpower	0	0,007
Hydropower	0	0,024

Table 11 Emission factors for consumed electricity **(Covenant of Mayors 2013)**

At a national level, for Denmark the CO2 emission according to the same source, are 0,461 t CO2/ MWh for consumed electricity. Other sources have mentioned the national averages emissions intensities of electricity providers in Denmark is 0,41 t CO2/ MWh (co2benchmark 2013) and 0,455 (ATEA 2012) for consumed electricity. The values of 0,461 t CO2/ MWh is considered for further use in relation with the price of 280,54 DDK/ MWh.

In the economic calculations the price of electricity is correlated with the type of electricity source considered for powering the bus fleet, and the CO2 emissions associated with the electricity production.

2.4 Selection of Technologies

In this sections are presented the reason for which certain technologies were selected. The first part is with respect to electric vehicles and the second one focuses on local electricity production possibilities.

Electric Bus

Figure 6 From top to bottom: Aggie Bus, Eco-Ride, Emil.

In selecting the technologies for electric vehicle, several aspects have been considered: commercial availability, certification with EU market, manufacturing capabilities of the producer, t and drive test data availability. Thou several products exist on the market only one has been found to fit all requirements presented above. Some of these products are briefly mentioned in this section.

On the American continent there are several contenders in this field. At Utah State University, researchers have designed the Aggie Bus: a bus capable of recharging itself at each stop using inductive charging. The prototype has a smaller battery setup that reduces downtime, lowers battery costs and free up interior space. The down side is that induction plates have to be installed at each stop. The bus's charging system tolerates up to 15 cm of misalignment from the charge plate and still receives 25 kW at 90% efficiency. One prototype bus is already being tested on the road; however there is no commercial vehicle available on the market. (Barry 2012)

Protera is another company that produced a fast charge battery electric bus called: EcoRide™ BE35. The batteries use lithium-titanate chemistry and can be charged in less than 10 minutes every several hours, with a life time expectancy of 8 years. The bus has a permanent magnet motor rated at 100 kW continuous (150 kW peak) power and generates 650 Nm of torque and makes use of regenerative braking (Bullins 2011).

Bombardier has also developed a new bus that charges using induction, called Bombardier (TSX:BBD.B). The bus will undergo testing in Montreal, Canada in 2014. In Europe the bus is currently being tested in Manheim, Germany (CBC News 2013). The bus called EMIL (Electro mobility means of inductive charging) has started test operations in May 2013, being the first purely electrically powered and charged by induction bus on the M19 test bus line, that operates in Brunswick, Germany (BS Energy 2012).

However none of these products meet the requirements presented at the beginning of this section. The only one that does meet all criteria for selection is Chinese Byd bus.

The BYD bus called K9 in China, is produced by a manufacturer located in the Guangdong Province, Shenzhen city. The company is specialized in producing electric vehicles and batteries. The bus is powered by a Iron-phosphate battery. According to the manufacturer the bus has the longest drive range (250 km) on one single charge under normal urban road condition.

The producer has manufactured for the Chinese Hunan province, 1000 units (China Daily 2012), and has received orders totaling more than 1200 units, from other countries. The buses are running or tested in different countries. In Shenzen China 200 buses serving public transport need have covered more that 7 million km by the end of 2012 (Eergy Trend 2012).

Figure 7 BYD bus; Source: **(Eergy Trend 2012)**

More important for the current investigation is the fact that the busses are certified for European market and has passed all 25 W.V.T.A. (Whole Vehicle Type Approval) test for vehicle safety and performance. (Eco Seed 2013). Also in May 2013 the BYD entered the Dutch market in island of Schiermonnikoog with 6 units making it "the first area in Europe where public transport has been completely electrified" (InsideEVs 2013).

In Demark two BYD busses have been introduced by Movia. The busses are operating in Copenhagen on test routes. The two yearlong project is being carried out in a joint effort by the Municipality of Copenhagen, City-Trafik, DONG Energy and Arriv a (Eergy Trend 2012).

BYD Technical specifications

The technical specifications for the BYD electric bus are presented in Table 12 (BYD 2013).

Acceleration	0–50 km/h in 20s
Top speed	96 km/h
Normal charge	6h for full charge
Fast charge	3h for full charge
Half charge	30 min
Or overnight charging	60 kW Max.power to fully charge the bus within 5h
Range	250 km
Length*Width*Height	12,000mm*2,550mm*3,200mm
Standard seats	31+1 (31 for passengers and 1 for driver)
Weight	18,000Kg

Table 12 Technical specification for BYD electric Bus

The most important feature is the electric consumption which unfortunately varies depending on source, even if the source is the manufacturer. (BYD - Mexico 2012) estimates the fuel efficiency at 0,832 km/ kWh, thus setting the consumption at **1,201 kWh/km**. The same source states the same parameter to be 320 kWh/250 km, thus setting the consumption at **1,28 kWh/km** and in onther part of the document emphasize an average consumption of 112 kWh/100 km, with le lowest value so far: 1,12 kWh/ km. Another source (BYD-NA 2013) sets the consumption for 2,02 kWh for one mile (1,609 km), thus setting the consumption at **1,255 kWh/km**. For further calculations the highest consumption is considered (1,28 kWh/km).

From the same sources it has been estimated that the battery capacity is 320 kWh and the exterior noise is 60 dBA.

The prices for BYD busses vary according to contract size and country.

Price	Price (DDK)	Units	Country	Source
€ 400.000	2.984.000	-	Hungary	(MAK 2012)
€ 331.601	2.473.743	700	Israel	(Wautom 2012)
$ 550.000 – $ 650.000	3.124.000 - 3.692.000	-	USA	(China Daily 2012)
€ 249.302 – € 373.953	1.859.793 - 2.789.689	500	Singapore	(AsiaOne 2010)

Table 13 Price of BYD electric buses

The average price is **2.820.583 DDK**, a value that will be used for economic calculations.

Charging Stations

The batteries are charged by connecting the bus to an electric power source which is typically located inside charging stations.

There are two options for choosing the electric vehicle supply equipment for a charging station depending on several factors.

For a fast charge it is required a charging equipment called by the manufacturer C100D, a three phase 480 V and a 100 kW line. This setup is generically being called a Level 3 charging station. The charge time is approximately 3 hours (BYD - Mexico 2012).

For an overnight charge it is required a charging equipment called by the manufacturer C60, a three phase 208 V and a 60 kW line. This setup is generically being called a Level 2 charging station. The charge time is approximately 5 hours (BYD - Mexico 2012).

The cost of the electric vehicle supply equipment for a charging station depends on the level of sophistication. The most basic charging equipment has only status lights and standard safety features. Advanced Level 2 products offer larger range of features like: keypads, communications capabilities, charging timers, and enhanced displays. The next class is the “Intelligent” or networked products mainly because the have smart-grid compatibility. They have enhanced ergonomics and durability. Moreover these products are equipped with features like internal metering, computer controlled power flow, automated diagnostics, advanced displays, wireless communication and billing software.

In terms of cost a Level 2 charging station with one charging unit (equipment) plus installation can vary between 15.000-18.000 USD (85.200-102.240 DDK). The cost per one additional unit is between 4000-8000 USD (22.720 – 45.440 DDK)

For Level 3 charging stations the prices vary from 45.000-100.000 USD (255.600-568.00 DDK). The cost per one additional unit is between 20.000-50.000 USD (113.600 – 45.440 DDK).

In this thesis it has been considered a Level 3 charging station, with 90 Level 2 charging units and 4 Level 3 units. The total cost for installation and equipment is about 5,8 million DDK (see Table 14) (U.S. Deparment of Energy 2012).

Infrastructure type	Cost	Cost
Charge station Level 3	**$100.000**	**568.000,00 DKK**
4- Level 3 charging units	$200.000	1.136.000,00 DKK
90 –Level 2 charging units	$720.000	4.089.600,00 DKK
Cost : installation and equipment	$1.020.000	5.793.600,00 DKK

Table 14 Installation and equipment cost. **(U.S. Deparment of Energy 2012)**

Local electricity supply selection

There is a wide range of technologies that produce electricity, of greater interest being the ones that involve as little as possible or no fossil fuel technologies. Another requirement is locating the plant within Aalborg municipality.

Electricity generation from wind power has an impressive social acceptance in Denmark, being supported by all major political parties as well as by the general public. However when it comes to locating the wind turbines the NIMBY (Not In My Back Yard) case is a common problem. Additionally "… ownership in the Danish wind power sector has become increasingly concentrated and remote, and local opposition to new wind developments has stiffened". (Kernan 2013)

In turn looking at the electricity generation using solar power the NIMBY is no longer an issue. Another aspect for looking at the Aalborg municipality PV potential is strongly related with the access to data from "a solar atlas based on a high-resolution digital elevation model (DEM) of all 2.9 million buildings in the country, combined with a building register" (Möller, Nielsen und Sperling 2012) developed by Bernd Möller from Department of Development and Planning, Aalborg University, Denmark.

Chapter 6 discusses the cumulative electricity generation potential variation by the marginal costs of production. To obtain this curve to sets of data are needed. The cumulative electricity generation potential and the levelized production costs, which are both extracted from the solar atlas. In calculating the levelized production costs, the considered useful life time is 25 years, and the discount factor is 5% (Möller, Nielsen und Sperling 2012). Marginal costs are defined in general terms as the variation in total costs as a result of changing the output with one unit (producing one additional unit).

3. Scenarios for Diesel Buses

3.1 Introduction

There are there scenarios presented in this chapter also referred to as Diesel Scenarios: Diesel Bus Network in 2012 (DB12); Diesel Bus Network 2025 (DB25); Diesel Bus Network with Light Rail 2025 (DB25). They cover the situation before the implementation of the Electric Buses.

The start point for all scenarios is the bus network of Aalborg. A graphic representation of the bus routes in Aalborg can be seen in Figure 8. Aalborg's bus network is based on the principles of a collective traffic plan from 2004, which included creating high-frequency bus lines, called Metro buses, which was an attempt to gather more bus lines in some corridors with more direct route and fewer stops.

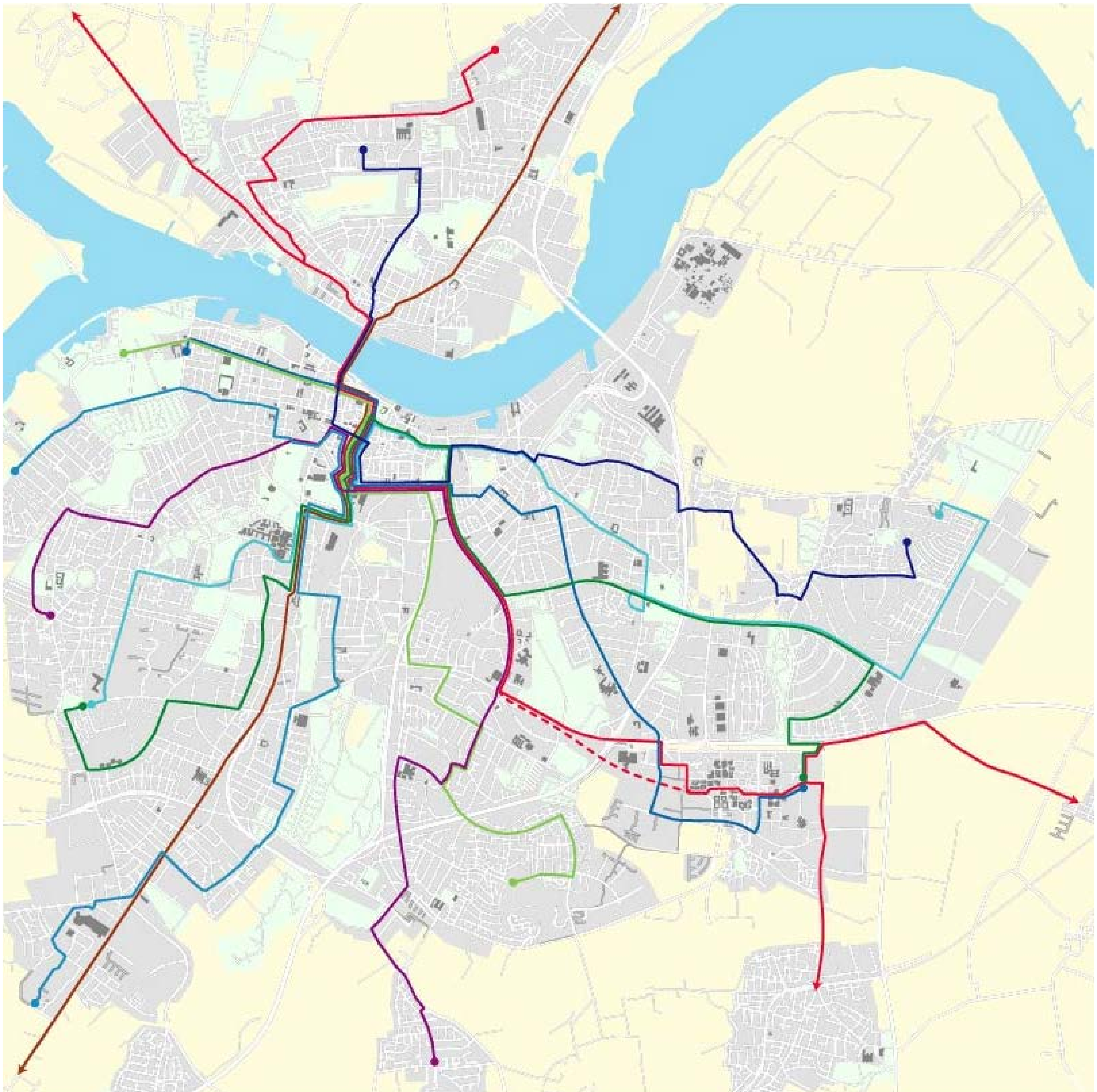


Figure 8 Bus network layout for specific routes; source: NT 2013

In the development of thesis's scenarios several bus routes in Aalborg are covered. These are presented in Table 15. The total number of busses that cover these routes is estimated to be 70 units in 2012. (Trankjær 2013) Lines 1 and 2 are grouped in the so called Metrobus lines and the others – 11 to 18 – form the Aalborg city bus lines.

Line 1	1A 1B 1C 1D 1E 1H 1J 1K 1L 1M 1P	metro bus
Line 2	2A 2B 2C 2D 2E 2F 2H 2J 2K 2L 2M	
Line 11		by bus
Line 12		
Line 13		
Line 14		
Line 15		
Line 16		
Line 17		
Line 18		

Table 15 Investigated bus lines

3.2 Diesel Bus 2012 Scenario (DB12) - (start case scenario)

For this scenario the amount of hours driven on weekly bases, by busses that cover the routes present above was provided by NT (see Table 16). The days were divided in blocks named hours of operation. The week day has three blocks: rush hour block (6,5 hours); day time block (5 hours); evening block (5 hours); all amounting 16,5 hours per weeks day. There are three additional blocks: Saturday morning (4 hours); Saturday afternoon and night (10 hours); Sunday all day (12 hours). Rush hours block is from 7.00 to 8.30 and 13.30 to 18.30; Daytime block from 8:30 to 13:30; Evening block is from (18.30 to 23.30).

Line	Weekdays, rush hours	Weekdays, daytime	Weekdays, evening	Saturday morning	Saturday afternoon/night	Sunday	Sum
1	111,4	60,0	60,0	48,0	120,0	144,0	1348,8
2	99,7	54,5	36,7	31,9	73,3	88,0	1074,0
11	32,1	15,0	13,3	10,7	26,7	32,0	344,7
12	31,2	23,3	11,7	9,3	23,3	28,0	368,3
13	30,3	16,7	23,3	9,1	22,7	27,2	387,9
14	39,9	23,3	13,3	10,7	26,7	32,0	425,3
15	20,4	15,7	13,3	10,7	26,7	32,0	289,5
16	18,2	14,0	13,0	10,4	22,7	27,2	263,6
17	45,5	17,5	11,0	8,8	22,0	26,4	405,2
18	4,8	3,7	0,0	2,9	0,0	0,0	45,1
Sum	433,3	243,7	195,7	152,4	364,0	436,8	**4952,5**

Table 16 Total hours of driving per week in 2012, Source NT:2013

The total amount of driving hours during 2012 was 277.769. Naturally most of the driving is done during rush time, with 433,3 hours For this a fleet of 70 busses is needed. The buses travel almost 7.850.000 km a year consuming a bit more than 3.400.000 liters of fuel (see Table 17).

2012	Route	total Driving Hours	Km	Liters of diesel
	by bus	141.073	3.744.770	1.703.160
	metro bus	136.697	4.105.155	1.711.481
	Sum:	277.769	7.849.924	3.414.641

Table 17 Driving time, distance and fuel consumption, 2012

Economic perspective

The expenditure was divided in driver's costs, fixed cost, operation and maintenance cost. The last is divided in fuel cost (diesel) parts cost plus maintenance costs and other costs. Two subcontractors that provide services for NT have been considered but will not be mentioned by name.

With this in mind, the total cost per hour of driving can vary from 648 to 740 DDK. There is a difference in the breakdown of expenditure on fixed and variable costs, but for the driver the price is almost the same. The driver of the bus is paid an amount which varies slightly, from 361 to 363 DDK per hour.

Costs 2012:	Driver	Fixed	Diesel	P+M	Other	Total min.	Total max.
[DDK/year]	*362 [DDK/h]*	*160 [DDK/h]*	*9,18 [DDK/l]*	*45,2 [DDK/h]*	*13,9 [DDK/h]*	*648 [DDK/h]*	*740 [DDK/h]*
by bus	51.068.281	22.571.616	15.635.010	6.380.351	1.959.454	91.415.045	104.393.724
metro bus	49.484.169	21.871.456	15.711.393	6.182.436	1.898.673	88.579.397	101.155.484
Sum:	100.552.450	44.443.072	31.346.403	12.562.787	3.858.127	179.994.442	205.549.208

Table 18 Minimum and maximum annual expenditures for City bus and Metro bus lines; Source: NT 2013

In Table 18 the annual expenditures are presented. They are in the range of 180 million DDK to 205 million DDK per year. These values do not include environmental cost like carbon cost or mitigation of CO2 effects. An increase in the fuel price of 200%, will increase the annual expenditures with 19,5%. The cost per bus per month ranges from 37.875 to 43.689 DDK. (Trankjær 2013)

Emissions and cost impact

In Table 19 are presented the main emission generated during a year of operation: carbon dioxide (CO2), particle matter (PM), nitrogen oxides (NOx), hydrocarbons (HC), carbon monoxide (CO). The CO2 emissions are calculated also with respect to the fact that 7% of the fuel that comes from the gas stations must be Bio diesel.

Emissions 2012								
	PM [kg]	Nox [kg]	CO [kg]	HC [kg]	CO2 [t] 7% BD	CO2 [t]		total CO2
g/km	0,15	9,15	1,68	0,43	300 g/l	0% BD	7% BD	[t/year]
by bus	562	34.265	6.291	1.610	35,8	4.564	4.245	4.281
metro bus	616	37.562	6.897	1.765	35,9	4.587	4.266	4.302

1.177	71.827	13.188	3.375	72	9.151	8.511	8.582

Table 19 Emission 2012; DB12- scenario; * the emissions for generation and transport of the Bio Diesel (BD); ** emissions generated by using 7% Bio-Diesel in the fuel mix

The combustion of biodiesel also produces CO2 however this amount is considered neutral since there is no net increase in CO2 in the carbon cycle. However the production and transportation of the biodiesel used by the bus fleet, will add 72 tons of CO2 per year into environment. In this scenario 8.582 tons of CO2 are annual released into the atmosphere. If taken into account a SCC of 666,72 DDK/t CO2, almost 5.700.000 DDK as additional cost, should be considered.

3.3 Diesel Bus 2025 Scenario (DB25)

For this scenario the amount of hours driven on weekly bases is presented in Table 20 according to information provided by NT. There is considered an yearly growth of 1,9% for the Metro Bus lines and 2,75% for the City Bus lines (By-Bus) for public transport in the period 2013 to 2025. This means that there is an expected growth of 42% for City Bus lines and 27,84 % for the Metro bus lines, by 2025.

This growth is based on the Danish national target of the growth of traffic in public transport at rate of 2% per year NT's traffic plan for 2013-2016 has set the objective of achieving a growth in passenger numbers, which correspond to the state's goals. This means that there is an expected growth of 35,23% by 2025.

It is assumed that passenger growth is evenly distributed throughout the day and throughout the network and the permeability of the buses is the same as today.

Line	Weekdays, rush hours	Weekdays, daytime	Weekdays, evening	Saturday morning	Saturday afternoon/night	Sunday	Sum
1	149,9	73,0	60,0	48,0	120,0	144,0	1726,7
2	158,2	91,2	36,7	31,9	73,3	88,0	1623,2
11	45,9	30,0	13,3	10,7	26,7	32,0	515,7
12	46,8	35,0	11,7	18,7	23,3	28,0	537,3
13	45,5	35,0	11,7	18,1	22,7	27,2	528,8
14	79,7	29,3	13,3	21,3	26,7	32,0	692,0
15	37,3	14,3	13,3	10,7	26,7	32,0	394,0
16	36,4	14,0	13,0	10,4	22,7	27,2	377,3
17	91,0	35,0	11,0	26,4	22,0	26,4	759,8
18	4,8	3,7	0,0	2,9	0,0	0,0	45,1
Sum	**695,5**	**360,5**	**184,0**	**199,1**	**364,0**	**436,8**	**7199,9**

Table 20 Total hours of driving per week in 2025, Source NT:2013

The total amount of driving hours during 2025 is expected to be 375.633. Most of the driving is done during rush time, with 695,5 hours. The number of driving hours during a week has increased with 1.883 hours and since 2012 while the driving hours a year has increased with 97.873 hours. To cover the transportation demand it is estimated that a fleet of 98 busses is needed. The buses travel almost 10 million km a year consuming a bit less than 4,6 million liters of fuel (see Table 21).

	Rute	*total Driving Hours*	Km	Liters of diesel
2025	by bus	200.871	5.332.119	2.425.103
	metro bus	174.762	5.248.302	2.188.070
	Sum:	375.633	10.580.421	4.613.173

Table 21: Driving time, distance and fuel consumption, 2025

3.3.1 Economic perspective

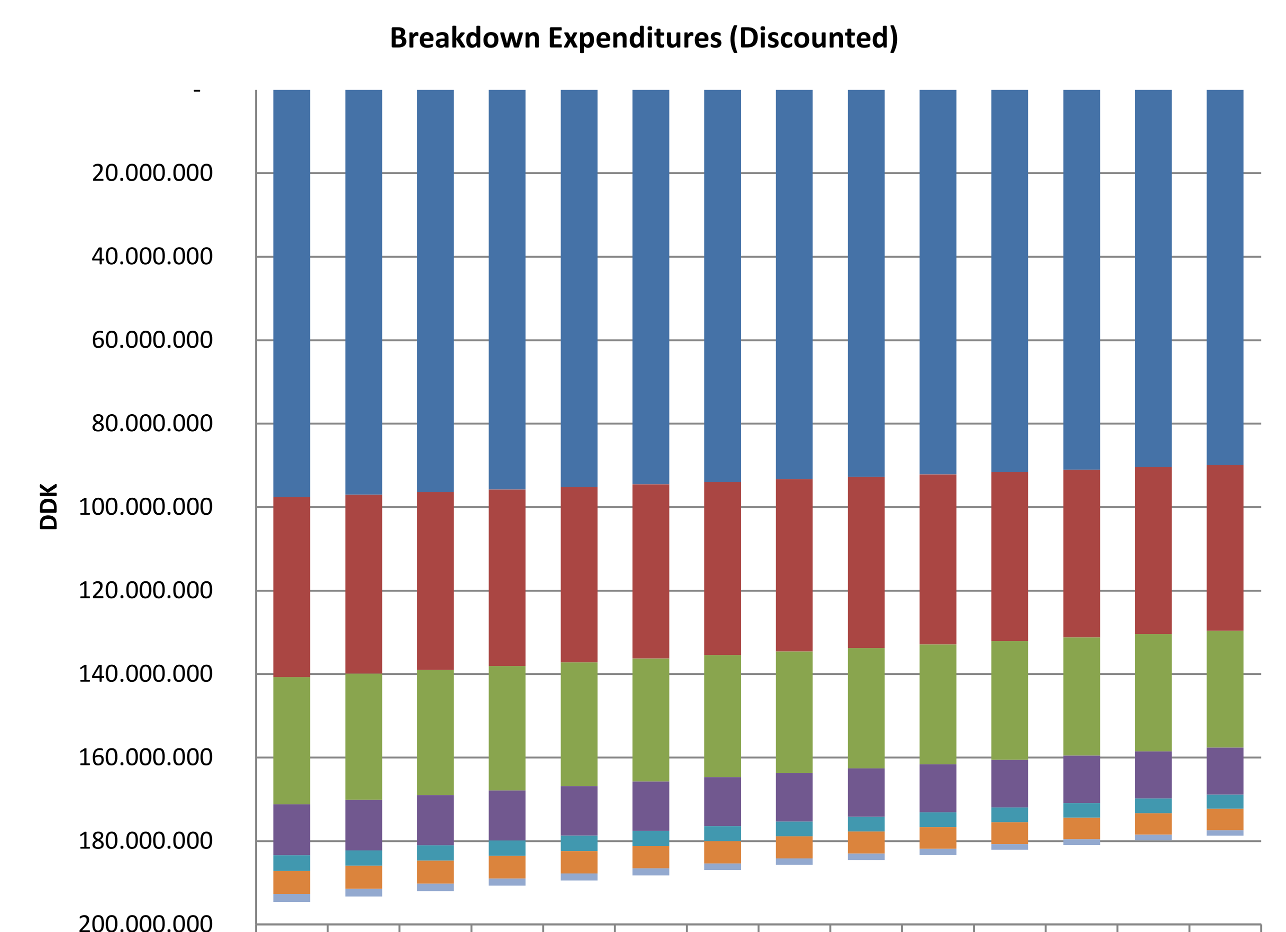
If a fleet like that would operate in 2012, the annual expenditures are in the range of 243 million DDK to 277 million DDK per year. These values do not include environmental cost like carbon cost or mitigation of CO2 effects. The values also do not include investment cost for new busses or additional infrastructure (e.g.: depot enlargement).

Costs 2012:	Driver	Fixed	Diesel	P+M	Other	Total min.	Total max.
[DDK/year]	*362 [DDK/h]*	*160 [DDK/h]*	*9,18 [DDK/l]*	*45,2 [DDK/h]*	*13,9 [DDK/h]*	*648 [DDK/h]*	*740 [DDK/h]*
by bus	32.139.371	22.262.445	9.084.882	2.790.036	32.139.371	130.164.451	148.644.589
metro bus	27.961.920	20.086.487	7.904.036	2.427.389	27.961.920	113.245.776	129.323.880
Sum:	60.101.291	42.348.932	16.988.918	5.217.425	60.101.291	243.410.227	277.968.469

Table 22 Non discounted expenditures corresponding to the 2025 bus network

Given the growth in traffic an expansion of the bus fleet is required to satisfy additional demand. It was assumed that the bus fleet will increase with two busses per year reaching in 2025, 98 units. The price for a diesel bus according to (DEA 2010) is 966.871 DDK. Therefore and additional annual expenditure of about 1,9 million DDK, is considered.

In Table 23 are presented the discounted expenditures for the period 2012-2025. For the year 2012 the expenditures consists of following costs: Investment in new buses (1,87 milion DDK/year), Social Cost of Carbon (5,55 million DDK/year); Parts and Maintenance Cost (12,19 million DDK/year); Fuel Cost (30,4 million DDK/year), Fixed Cost, averaged (43,1 million DDK/year), Driver costs (97,6 million DDK/year) and other cost(3,74 million DDK/year).



	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Investment	1.87	1.82	1.76	1.71	1.66	1.61	1.57	1.52	1.48	1.43	1.39	1.35	1.31	1.27
SCC	5.55	5.51	5.48	5.44	5.41	5.37	5.34	5.30	5.27	5.24	5.20	5.17	5.14	5.11
Other	3.74	3.72	3.69	3.67	3.65	3.62	3.60	3.58	3.55	3.53	3.51	3.49	3.46	3.44
P+M	12.1	12.1	12.0	11.9	11.8	11.8	11.7	11.6	11.5	11.5	11.4	11.3	11.2	11.2
Diesel	30.4	30.2	30.0	29.8	29.6	29.4	29.2	29.0	28.8	28.7	28.5	28.3	28.1	27.9
Fixed Cost(av.)	43.1	42.8	42.5	42.3	42.0	41.7	41.5	41.2	40.9	40.7	40.4	40.2	39.9	39.7
Driver	97.6	96.9	96.3	95.7	95.1	94.5	93.9	93.3	92.7	92.1	91.5	90.9	90.4	89.8

Table 23 Discounted Yearly Expenditures; (SCC: Social Carbon Cost; P+M :Parts & Maintenance Cost; Fixed Costs(av.): Fixed Costs, average between 132-188 DDK/hour of driving)

The total net present value (NPV) of this scenario in the time interval 2012-2025 is 2.610.276.829 DDK while the specific NPV for each expenditure category is as follows: Investment in new buses: 21,8 million DDK; Social Cost of Carbon: 74,5 million DDK; Parts and Maintenance Cost: 163,8 million DDK; Fuel Cost: 408,6 million DDK; Fixed Cost, averaged: 579,6 million DDK; Driver costs: 1.311 million DDK and other cost: 50 million DDK (see Figure 9). Considering a 14 year time frame for the project, the annualized cost is 186.448.345 DDK.

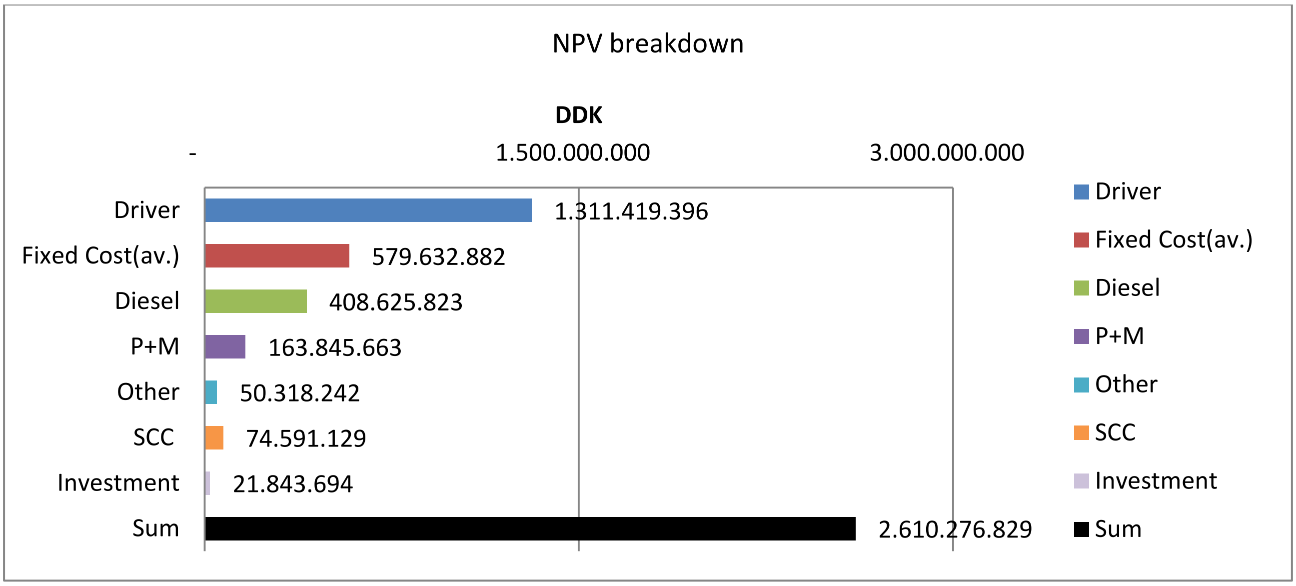


Figure 9 NPV breakdown; DB25 Scenario

3.3.2 Emissions and cost impact

In Table 24 are presented the main emission generated between 2012-2025: carbon dioxide (CO2) 140.205 tones, particle matter (PM) 19 tones, nitrogen oxides (NOx) 1.171 tones, hydrocarbons (HC) 55 tones, carbon monoxide (CO) 215 tones. The CO2 emissions are calculated also with respect to the fact that 7% of the fuel that comes from the gas stations must be Bio diesel. The emissions increase at the same rate with the growth in traffic.

Emissions 2012								
g/km	PM [kg] 0,15	Nox [kg] 9,15	CO [kg] 1,68	HC [kg] 0,43	CO2 [t] 7% BD 300 g/l	CO2 [t] 0% BD	 7% BD	total CO2 [t]
by bus metro bus	19.212	1.171.926	215.173	55.074	1.171	149.498	139.033	140.205

Table 24 Emission 2025; DB25- scenario; * the emissions for generation and transport of the Bio Diesel (BD); ** emissions generated by using 7% Bio-Diesel in the fuel mix

In this scenario an average of 10.015 tons of CO2 are annually released into the environment. If taken into account a SCC of 666,72 DDK/t CO2, almost 74 million DDK is considered as additional cost.

3.4 Diesel Bus 2025 after implementation of LRT Scenario (DB25 LRT)

This scenario shows how the Diesel Bus 2025 scenario will look like after the implementation of the phase one of the Light Rail Transport system into Aalborg public transport network. This scenario does not include any expenditures or technical parameters related to the LRT system. The layout of the future tram line is presented in Figure 10.

The establishment of the tramway line will mean that some bus lines become redundant, because they will run parallel to the light rail. It is likely that there will be an expansion in housing, work and study places near university, which is part of Aalborg's growth axis. In turn this means that there will be a greater potential for passenger growth for Metro Bus 2 and the bus lines serving Aalborg East than in the other bus lines. Bus operation will be discontinued on lines where there is a parallel operation with the LRT. (M. Jensen 2012)

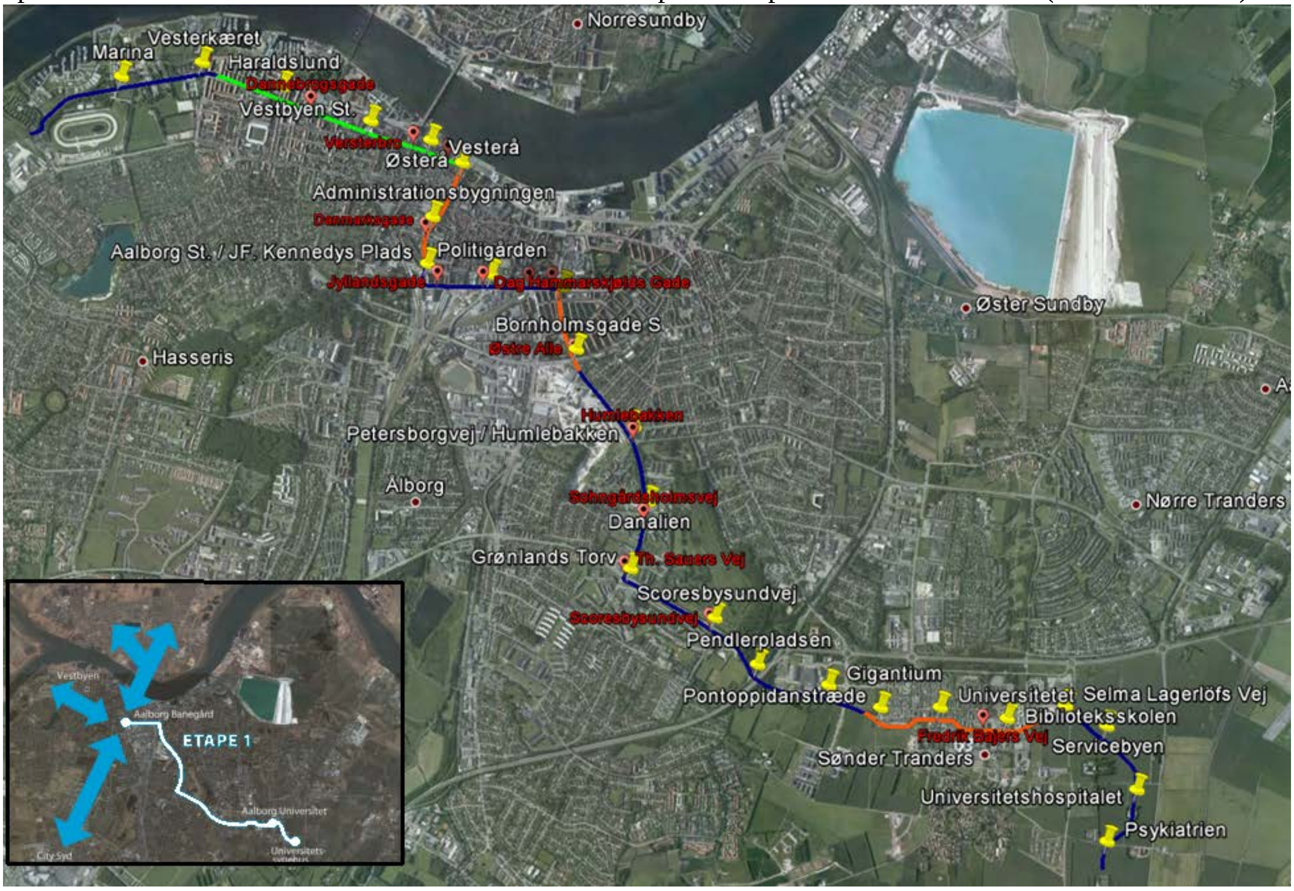


Figure 10 LRT network: Stage 1. **(Trankjær 2013)**

The main impact of introducing the LRT for the DB25 scenario is related to the total driving hours. The change in bus line configurations, timetables, frequencies is going to reduce the amount of driving hours, which in turn affect the travel distance, and fuel demand. The amount of driving hours per week is presented in Table 25.

Line	Weekdays, rush hours	Weekdays, daytime	Weekdays, evening	Saturday morning	Saturday afternoon/night	Sunday	Sum
1	136,9	73,0	60,0	48,0	120,0	144,0	1661,7
2	15,2	13,3	8,3	6,7	16,7	20,0	227,5
11	45,9	30,0	13,3	10,7	26,7	32,0	515,7
12	31,2	23,3	11,7	9,3	23,3	28,0	391,7
13	30,3	23,3	23,3	9,1	22,7	27,2	443,9
14	79,7	29,3	13,3	21,3	26,7	14,4	674,4
15	26,0	10,0	13,3	10,7	26,7	32,0	316,0
16	20,8	8,0	7,0	5,6	10,7	27,2	222,5
17	91,0	35,0	11,0	26,4	22,0	26,4	759,8
18	4,8	3,7	0,0	2,9	0,0	0,0	45,1
Sum	481,9	249,0	161,3	150,7	295,3	351,2	5258,2

Table 25 Total hours of driving per week in 2025, Source NT:2013

The total amount of driving hours during 2025 after the implementation of LRT, is expected to drop from 375.633 to 274.318 a value that is below the one of 2012. Most of the driving is done during rush time, with 482 hours. The number of driving hours during a week has decreased with 1941 hours compared to DB25 scenario, while the number of driving hours a year has decreased with 101.314 hours.

To cover the transportation demand it is estimated that the buses will travel almost 7 million km a year consuming a bit more than 3,3 million liters of fuel (see Table 26).

	Rute	*total Driving Hours*	Km	Liters of diesel
2025	by bus	175.775	4.665.949	2.122.122
	metro bus	98.543	2.615.834	1.233.792
	Sum:	274.319	7.281.782	3.355.914

Table 26: Driving time, distance and fuel consumption, 2025

3.4.1 Economic perspective

If a fleet like that would operate in 2012, the annual expenditures are in the range of 177 million DDK to 202 million DDK per year (see Table 27). That means an average decrease of 70,3 million DDK from the DB25 scenario. These values do not include environmental cost like carbon cost or mitigation of CO2 effects. The values also do not include investment cost for new busses or additional infrastructure (e.g.: depot enlargement). Also the salvage value of the buses that were replaced by trams is not included.

Costs DB25 LRT:	Driver	Fixed	Diesel	P+M	Other	Total min.	Total max.
[DDK/year]	*362 [DDK/h]*	*160 [DDK/h]*	*9,18 [DDK/l]*	*45,2 [DDK/h]*	*13,9 [DDK/h]*	*648 [DDK/h]*	*740 [DDK/h]*
by bus	63.630.610	28.124.027	19.481.079	7.949.859	2.441.462	113.902.308	130.073.623
metro bus	35.672.723	15.766.949	11.326.212	4.456.866	1.368.737	63.856.145	72.922.141
Sum:	99.303.333	43.890.976	30.807.290	12.406.725	3.810.199	177.758.453	202.995.764

Table 27 Non discounted expenditures corresponding to the 2025 bus network and the LRT system

3.4.2 Emissions and cost impact

In Table 28 are presented the main emission generated by the Diesel Bus fleet, in 2025 after the LRT system has been introduced: particle matter (PM) 1 tone, nitrogen oxides (NOx) 66 tones, hydrocarbons (HC) 3 tones, carbon monoxide (CO) 12 tones. The CO2 emissions are calculated also with respect to the fact that 7% of the fuel that comes from the gas stations must be Bio diesel.

The overall emissions levels have decreased as a result of the introductions of the LRT system, below the 2012 levels. The CO2 emissions released into the environment have decreased with 3.517 tons, from the 11.595 tons in the DB25 scenario.

Emissions 2025+LRT								
	PM [kg]	Nox [kg]	CO [kg]	HC [kg]	CO2 [t] 7% BD	CO2 [t]		total CO2
g/km	0,15	9,15	1,68	0,43	300 g/l	0% BD	7% BD	[t/year]
by bus	700	42.693	7.839	2.006	44,6	5.687	5.289	5.334
metro bus	392	23.935	4.395	1.125	25,9	2.923	2.718	2.744

	1.092	66.628	12.233	3.131	70	8.610	8.007	8.078

Table 28 Emission 2025; DB25- scenario; * the emissions for generation and transport of the Bio Diesel (BD); ** emissions generated by using 7% Bio-Diesel in the fuel mix

In this scenario 8.078 tons of CO2 are annually released into the environment. If taken into account a SCC of 666,72 DDK/t CO2, almost 5,4 million DDK is considered as additional cost.

3.5 Diesel Scenarios at a glance

This section offers an overview on diesel scenarios DB12, BD25, DB25 LRT.

As it can be seen in Figure 11 (left), the main parameters in the scenario follow the same ascending curve until 2025 when they decreases below 20012 values as a result of the implementation of LRT system. The annual costs, the social cost of carbon (see Figure 11, right), and emissions follow the same pattern. This pattern is linked directly with the transportation demand which increases between the years 2012-2025. From 2025, part of this demand is covered by the LRT system.

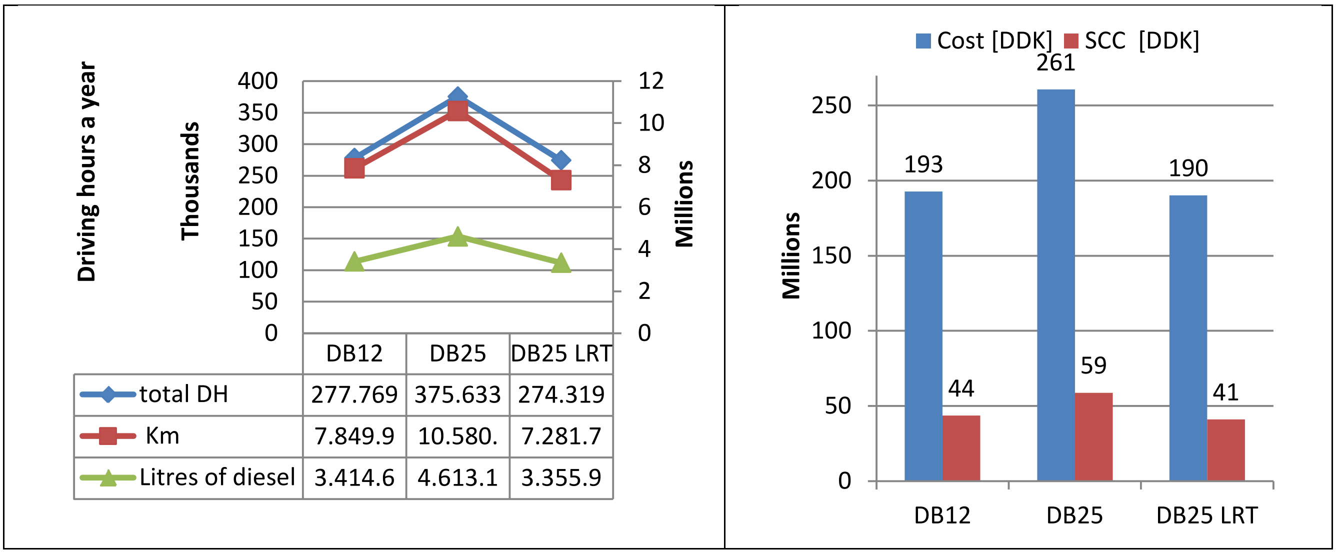


Figure 11 Comparisons for Diesel Scenarios

4. Scenarios for Electric Buses

4.1 Introduction

There are there scenarios presented in this chapter also referred to as Electric Scenarios: Electric Bus Network in 2012 (EB12); Diesel Bus Network 2025 (EB25); Diesel Bus Network with Light Rail 2025 (EB25+LRT). They cover the situation after the implementation of the Electric Buses.

The start point for the Electric Scenarios is the Diesel Scenarios presented in Chapter 3. The Electric Scenarios are structured in a similar fashion: an economic perspective, and another perspective that combines energy, emission and costs.

4.1.1 Initial investment

The initial investment is considered to occur during 2012, at the beginning of the year, therefor it is not discounted in the economic calculations. This investment consists of expenditures on acquiring new buses, building the charging station and the charging units.

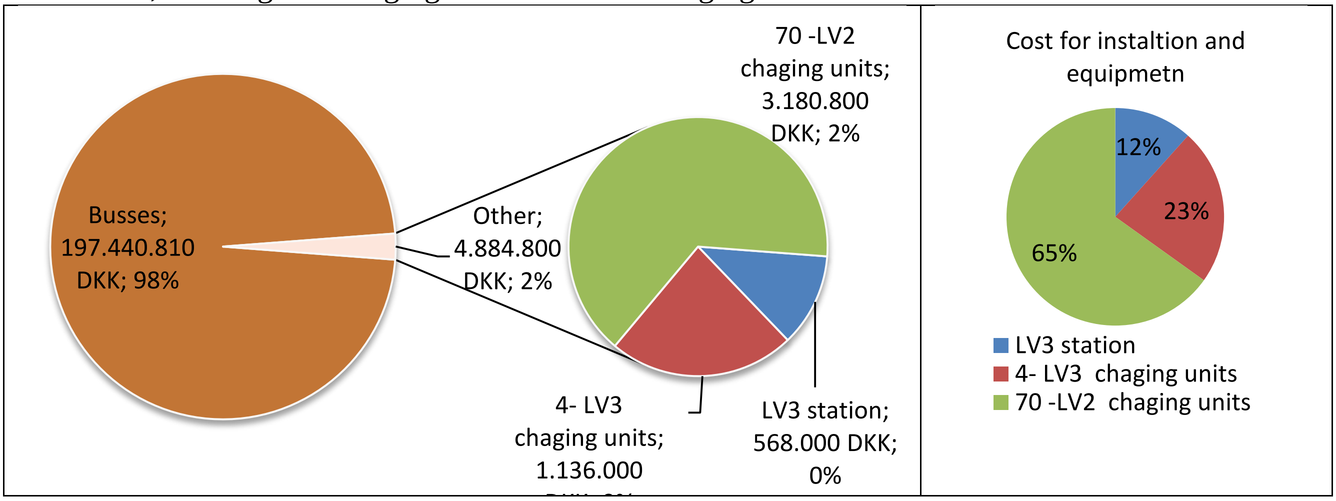


Figure 12: Initial investment

As it can be seen in Figure 12(left), the cost for 70 new electric BYD busses is 197.440.810 DKK and represents 98% of the total investment cost which is 202.352.610 DDK. The cost for installation and equipment is 2% of the total initial investment cost.

The expenditure on the Level 3 charging station is 568.000 DDK,. In addition to that, the cost for 70 Level 2 (night charge) charging units is 3.180.800 DKK and another 4 Level 3 (fast charge) charging units 1.136.000 DKK. The cost for these units is almost 200% larger that the costs for the charging station (see Figure 12, right).

There is no reinvestment considered since there is no need to buy new BYD buses. The maintenance costs are calculated based on a 15 years maintenance contract that comes with the BYD bus (Li 2012).

4.2 Electric Bus 2012 Scenario

With the introduction of electric busses the diesel fuel has been removed from the previous DB12 scenario. From en environmental perspective this means that emissions related to this type of fuel are no longer present. Following the same pattern as in Chapter 3.2 the same number of hours and same values for the travel distance are considered. The electricity consumption for the bus fleet is 10.048 MWh per year (see Table 29).

2012	Route	total Driving Hours	Km	MWh
	by bus	141.073	3.744.770	4.793
	metro bus	136.697	4.105.155	5.255
	Sum:	**277.769**	**7.849.924**	10.048

Table 29 Driving time, distance and electricity consumption, 2012 EB12 Scenario

4.2.1 Economic perspective

The expenditure was divided in the same way as in Chapter 3.2: driver's costs, fixed cost, operation and maintenance cost. The last is divided in fuel cost (electricity), parts cost plus maintenance costs and other costs. With this in mind, the total cost per hour of driving an electric bus has been determined. It could vary from 496 DDK to 597 DDK.

Costs 2012:	Driver	Fixed	MWh	P+M	Other	Total min.	Total max.
[DDK/year]	*362[DDK/h]*	*160 [DDK/h]*	*280,54 [DDK/h]*	*0,885 [DDK/h]*	*13,9 [DDK/h]*	*496 [DDK/h]*	*597 [DDK/h]*
by bus	51.068.281	22.571.616	1.344.736	124.849	1.959.454	69.983.686	84.328.010
metro bus	49.484.169	21.871.456	1.474.149	120.976	1.898.673	67.812.827	81.712.198
Sum:	100.552.450	44.443.072	2.818.885	245.826	3.858.127	137.796.513	166.040.207

Table 30 Minimum and maximum annual expenditures for City bus and Metro bus lines in EB12 sceanrio

In Table 30 the annual expenditures are presented. They are in the range of 137 million DDK to 166 million DDK per year. These values do not include environmental cost like carbon cost or mitigation of CO2 effects.

4.2.2 Emissions and cost impact

In Table 31 are presented the main emission considered during a year of operation: carbon dioxide (CO2), particle matter (PM), nitrogen oxides (NOx), hydrocarbons (HC), carbon monoxide (CO). The CO2 emissions are calculated as described in the Chapter 2, taking into account the fact that the electricity needed to power the bus fleet comes from different generation sources, specific for Denmark.

Emissions 2012						
	PM [kg]	Nox [kg]	CO [kg]	HC [kg]	CO2 [t/year]	SCC [DDK/ t CO2]
g/km	-	-	-	-		666,72
by bus	-	-	-	-	2.210	1.473.257
metro bus	-	-	-	-	2.422	1.615.038
	-	-	-	-	4.632	3.088.295

Table 31 Emission 2012; EB12- scenario; the emissions factor for electricity generation is considered 0,461 t CO2/ MWh.

The electricity generation also produces CO2. In this scenario 4.632 tons of CO2 are annual released into the atmosphere. If taken into account a SCC of 666,72 DDK/t CO2, almost 3.088.295 DDK as additional cost, should be considered.

4.3 Electric Bus 2025 Scenario

The premises for this scenario are the same as the ones in Chapter 3.3. The amount of hours driven on weekly bases is presented in Table 20, according to information provided by NT. This means that there is an expected growth of 42% for City Bus lines and 27,84 % for the Metro bus lines, by 2025.

With the introduction of electric busses the diesel fuel has been removed from the previous DB25 scenario. From en environmental perspective this means that emissions related to this type of fuel are no longer present. Following the same pattern as in Chapter 3.3 the same number of hours and same values for the travel distance are considered. The electricity consumption for the bus fleet is 13.543 MWh per year (see Table 32).

	Route	total Driving Hours	Km	MWh
2025	by bus	200.871	5.332.119	6.825
	metro bus	174.762	5.248.302	6.718
	Sum:	375.633	10.580.421	13.543

Table 32 Driving time, distance and electricity consumption, 2025 EB25 Scenario

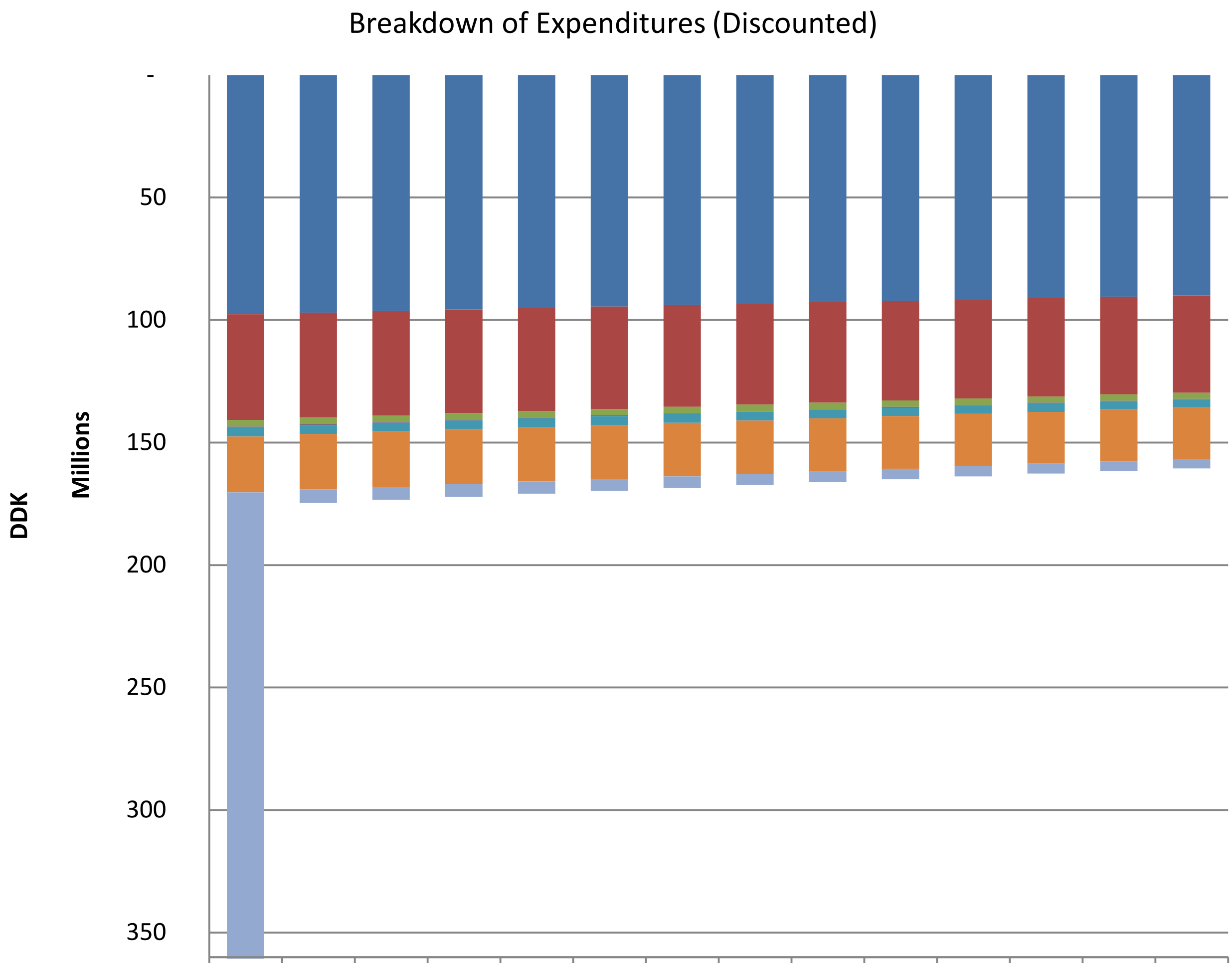
4.3.1 Economic perspective

With the increase of transportation demand it is natural to have an increase in expenditures. They are divided into: driver's costs, fixed cost, operation and maintenance cost. The last is divided in fuel cost (electricity), parts cost plus maintenance costs and other costs.

Costs 2025:	Driver	Fixed	MWh	P+M	Other	Total min.	Total max.
[DDK/year]	*362[DDK/h]*	*160 [DDK/h]*	*280,54 [DDK/h]*	*0,885 [DDK/h]*	*13,9 [DDK/h]*	*496 [DDK/h]*	*597 [DDK/h]*
by bus	72.715.326	32.139.371	1.914.748	177.771	2.790.036	99.648.674	120.073.333
metro bus	63.263.844	27.961.920	1.884.650	154.664	2.427.389	86.696.416	104.466.293
Sum:	135.979.170	60.101.291	3.799.399	332.435	5.217.425	186.345.091	224.539.626

Table 33 Minimum and maximum annual expenditures for City bus and Metro bus lines in EB25 sceanrio

In Table 33 the annual expenditures are presented. They are in the range of 186 million DDK to 224 million DDK per year. These values do not include environmental cost like carbon cost or mitigation of CO_2 effects.



	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Investment	207.	5.40	5.24	5.09	4.94	4.80	4.66	4.52	4.39	4.26	4.14	4.02	3.90	3.78
SCC	22.8	22.6	22.5	22.3	22.2	22.0	21.9	21.7	21.6	21.4	21.3	21.2	21.0	20.9
Other	3.74	3.72	3.69	3.67	3.65	3.62	3.60	3.58	3.55	3.53	3.51	3.49	3.46	3.44
P+M	238.	237.	235.	234.	232.	231.	229.	228.	226.	225.	223.	222.	221.	219.
Electric	2.73	2.71	2.70	2.68	2.66	2.64	2.62	2.61	2.59	2.57	2.56	2.54	2.52	2.51
Fixed Cost(av.)	43.1	42.8	42.5	42.3	42.0	41.7	41.5	41.2	40.9	40.7	40.4	40.2	39.9	39.7
Driver	97.6	96.9	96.3	95.7	95.1	94.5	93.9	93.3	92.7	92.1	91.5	90.9	90.4	89.8

Figure 13: Discounted Yearly Expenditures; (SCC: Social Carbon Cost; P+M :Parts & Maintenance Cost (Thousands DDK); Fixed Costs(av.): Fixed Costs, average between 132-188 DDK/hour of driving)

Given the growth in traffic an expansion of the bus fleet is required to satisfy additional demand. It was assumed that the bus fleet will increase with two busses per year reaching in 2025, 98 units. The price for an electric bus is 2,820,583 DDK (see Chapter 2.4). Therefore and additional annual expenditure of about 5,6 million DDK, is considered every year. Also two additional charging stations are considered to be built every year for about 90.000 DDK.

In Figure 13 are presented the discounted expenditures for the period 2012-2025. For the year 2012 the expenditures consists of following costs: Initial investment (202 milion DDK), New buses (5,6 million DDK/year); New Charging Units (90.000 DDK/year) Social Cost of Carbon (2,9 million DDK/year); Parts and Maintenance Cost (0,24 million DDK/year); Fuel Cost (2,7 million DDK/year), Fixed Cost, averaged (43,1 million DDK/year), Driver costs (97,6 million DDK/year) and other cost(3,74 million DDK/year).

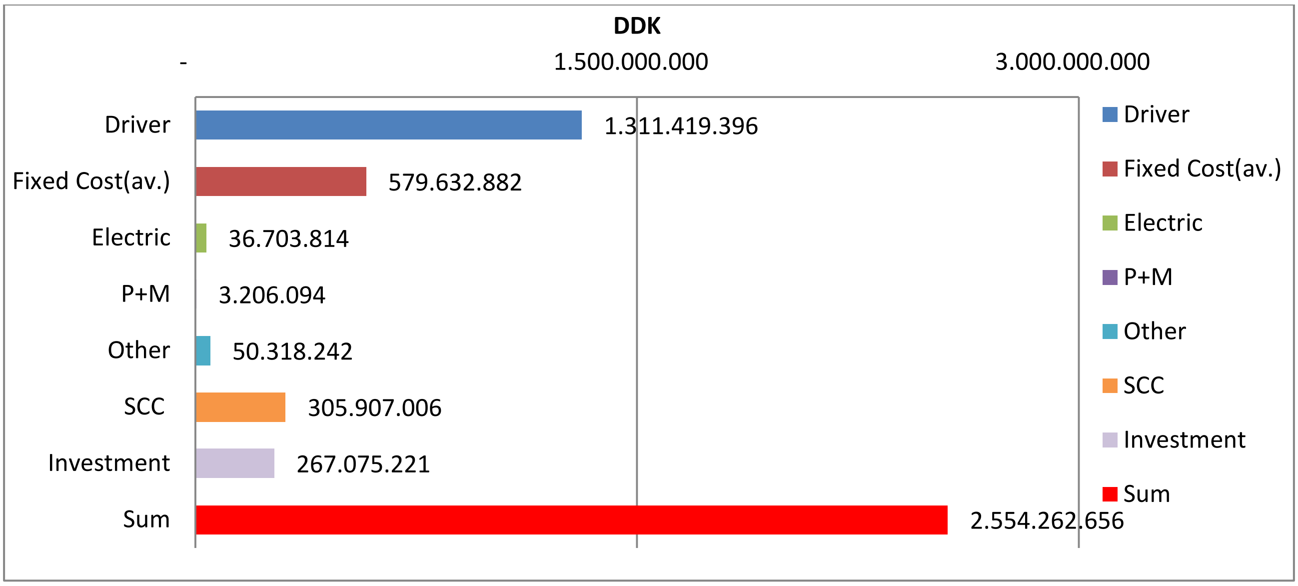


Figure 14 NPV breakdown; DB25 Scenario

The total net present value (NPV) of this scenario in the time interval 2012-2025 is 2.288.567.367 DDK while the specific NPV for each expenditure category is as follows: Investment in new buses and infrastructure: 267 million DDK; Social Cost of Carbon: 40,2 million DDK; Parts and Maintenance Cost: 3,2 million DDK; Electricity Cost: 36,7 million DDK; Fixed Cost, averaged: 579,6 million DDK; Driver costs: 1.311 million DDK and other cost: 50,3 million DDK (see Figure 14Figure 9). Considering a 14 year time frame for the project, the annualized cost is 163.469.098 DDK.

4.3.2 Emissions and cost impact

In Table 31 are presented the main emission considered during the year of operation 2025: carbon dioxide (CO2), particle matter (PM), nitrogen oxides (NOx), hydrocarbons (HC), carbon monoxide (CO). The CO2 emissions are calculated as described in the Chapter 2, taking into account the emissions factor for electricity generation – 0,461 t CO2/ MWh – specific for Denmark.

Emissions 2025						
g/km	PM [kg] -	Nox [kg] -	CO [kg] -	HC [kg] -	CO2 [t/year]	SCC [DDK/ t CO2] 666,72
by bus	-	-	-	-	3.146	2.097.747
metro bus	-	-	-	-	3.097	2.064.772
	-	-	-	-	6.243	4.162.520

Table 34 Emission 2012; EB12- scenario; the emissions factor for electricity generation is considered 0,461 t CO2/ MWh.

The electricity generation also produces CO2. In this scenario 6.243tons of CO2 are annual released into the atmosphere. If taken into account a SCC of 666,72 DDK/t CO2, almost 4,2 million DDK as additional cost, should be considered.

4.4 Electric Bus 2025 Scenario after implementation of LRT Scenario (EB25 LRT)

This is a pure electric scenario, in which no fossil fuels are used to satisfy public transportation demand in Aalborg. This scenario shows how the Electric Bus 2025 scenario will look like after the implementation of the phase one of the Light Rail Transport system into Aalborg public transport network. This scenario does not include any expenditures or technical parameters related to the LRT system. The main impact of introducing the LRT for the EB25 scenario is related to the total driving hours.

The total amount of driving hours during 2025 after the implementation of LRT, is expected to drop from 375.633 to 274.318 a value that is below the one of 2012 (M. Jensen 2013). The number of driving hours during a week has decreased with 1941 hours compared to DB25 scenario, while the number of driving hours a year has decreased with 101.314 hours.

To cover the transportation demand it is estimated that the buses will travel almost 7,3 million km a year consuming a bit more than 9300 MWh per year (see Table 35).

2025 LRT	*Route*	*total Driving Hours*	Km	MWh
	by bus	175.775	4.665.949	5.972
	metro bus	98.543	2.615.834	3.348
	Sum:	274.319	7.281.782	9.321

Table 35 Driving time, distance and electricity consumption, 2025 EB25 LRT Scenario

4.4.1 Economic perspective

If a fleet of electric buses assisted by an LRT system, would operate in 2012, the annual expenditures are in the range of 136 million DDK to 163 million DDK per year (see Table 36). That means an average decrease of about 55,4 million DDK from the DB25 scenario. These values do not include environmental cost like carbon cost or mitigation of CO2 effects. The values also do not include investment cost for new busses or additional infrastructure (e.g.: depot enlargement). Also the salvage value of the buses that were replaced by trams is not included.

With the decrease of transportation demand it is natural to have a decrease in expenditures. They are divided into: driver's costs, fixed cost, operation and maintenance cost. The last is divided in fuel cost (electricity), parts cost plus maintenance costs and other costs.

Costs 2025 LRT:	Driver	Fixed	MWh	P+M	Other	Total min.	Total max.
[DDK/year]	*362[DDK/h]*	*160 [DDK/h]*	*280,54 [DDK/h]*	*0,885 [DDK/h]*	*13,9 [DDK/h]*	*496 [DDK/h]*	*597 [DDK/h]*
by bus	63.630.610	28.124.027	1.675.529	155.561	2.441.462	87.199.031	105.071.927
metro bus	35.672.723	15.766.949	939.338	87.211	1.368.737	48.885.699	58.905.639
Sum:	99.303.333	43.890.976	2.614.867	242.772	3.810.199	136.084.730	163.977.566

Table 36 Minimum and maximum annual expenditures for City bus and Metro bus lines in EB25 LRT sceanrio

4.4.2 Emissions and cost impact

In Table 37 are presented the main emission considered during the year of operation 2025: carbon dioxide (CO2), particle matter (PM), nitrogen oxides (NOx), hydrocarbons (HC), carbon monoxide (CO). The CO2 emissions are calculated as described in the Chapter 2, taking into account the emissions factor for electricity generation – 0,461 t CO2/ MWh – specific for Denmark.

Emissions 2025 LRT						
	PM [kg]	Nox [kg]	CO [kg]	HC [kg]	CO2	SCC [DDK/ t CO2]
g/km	-	-	-	-	[t/year]	666,72

by bus	-	-	-	-	2.753	1.835.664
metro bus	-	-	-	-	1.544	1.029.114
	-	-	-	-	4.297	2.864.778

Table 37 Emission 2012; EB12- scenario; the emissions factor for electricity generation is considered 0,461 t CO2/ MWh.

The electricity generation also produces CO2. In this scenario 4.297 tons of CO2 are annual released into the atmosphere. If taken into account a SCC of 666,72 DDK/t CO2, almost 2,9 million DDK as additional cost, should be considered.

5. Sensitivity Analysis

This section presents the "what-if analysis" most commonly kwon as the Sensitivity Analysis. This analysis has several benefits: helps the decision makers to understand how a system will behave when changing the initial assumptions. Also the sensitivity analysis also helps to find errors in the model and reduces uncertainty by increasing the knowledge about the relationships between input and output parameters in the scenarios.

The reference values for comparisons are the NPV and Annualized Costs for DB12 and EB12 scenarios expanded over a period of 14 years reaching the values of DB25 and EB25 scenarios, considering investments costs and environmental costs.

Time Frame 2012-2025		NPV		Annualized Cost	
Variables	**Values**	**Diesel**	**Electric**	**Diesel**	**Electric**
Byd Bus	2.820.583 DKK				
Diesel bus	966.871 DKK				
Electricity	281 DKK				
Diesel	9 DKK	2.610.276.829	2.288.567.367	186.448.345	163.469.098
Discount factor	0,03%				
SCC	667 DKK				
CO2 [t]/MWh	0,416				

Table 38 Reference values and variables for the sensitivity analysis.

The sensitivity analysis is performed by OAT/OFAT method. This involves changing one variable/factor-at-a-time, while leaving the others unchanged. The sensitivity can then be measured by observing the magnitude of changes in the new results/output.

This is a logical approach and any modification observed in the results is a direct consequence of changes applied to that one single variable, which is tested. Furthermore, by modifying only one variable at a time, the researcher can have all other variables "locked" to their base-line values. This enhances the comparability between results since all 'effects' are calculated using same central point as reference. (Saltelli und Annoni 2012)

Another advantage is the possibility of using the method an error tester. In case the model fails to deliver a reasonable output or fail to deliver an output at all, under OFAT analysis the researcher can immediately determine which input variable caused the failure or which computation tree needs to be redesigned or adjusted. However, this method does not fully cover the input space, since it does not considers the "simultaneous variation of input variables". (Czitrom 1999)

The sensitivity analysis focuses on comparing the economic performance of the DB scenarios and the EB scenarios with input parameters changes.

With respect to annual operation costs, the fixed costs and driver costs have the biggest share in the expenditures. However it is considered that these costs are the same in both electric and diesel scenarios therefore will have the same influence in both of them.

5.1 BYD Price

In discussing the initial investment cost (see Figure 12) it is clearly that the BYD bus price is a highly significant factor for the economic performance of EB scenarios, representing 98% of the total initial cost.

The cost variation implications are presented in Figure 15. Since the acquisitions cost for BYD busses affects only the EB scenario, the NPV of DB scenario is constant. The BYD bus price was increased and decreased by 10% increments up to 250% of the initial price, and also decreased down to 50% of the initial price.

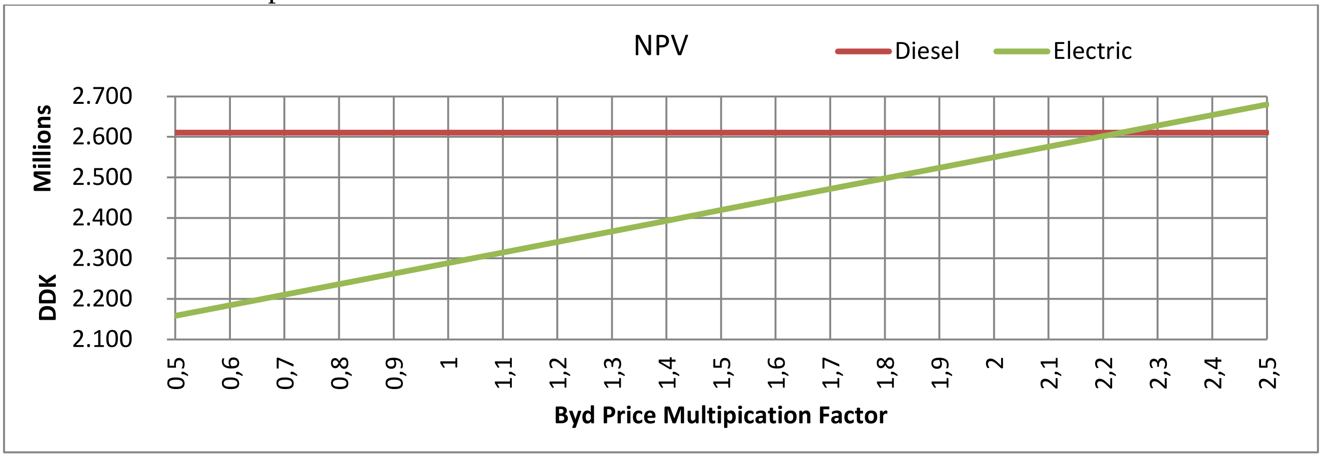


Figure 15 Net Present Value (NPV) for DB and EB scenarios, for BYD price variation; 2012-2025 interval.

As it can be seen from Figure 15, an increase beyond 220% in the acquisition cost for BYD bus, will result in a biger NPV value for the EB scenario. However the prices for electric busses are expected to drop in the future rendering the EB scenario even more favorable in contrast to the DB scenario. The same applies for the Annualized Cost.

As we can see in Figure 16, the NPV and Annualized Cost increase or decrease at the same rate.

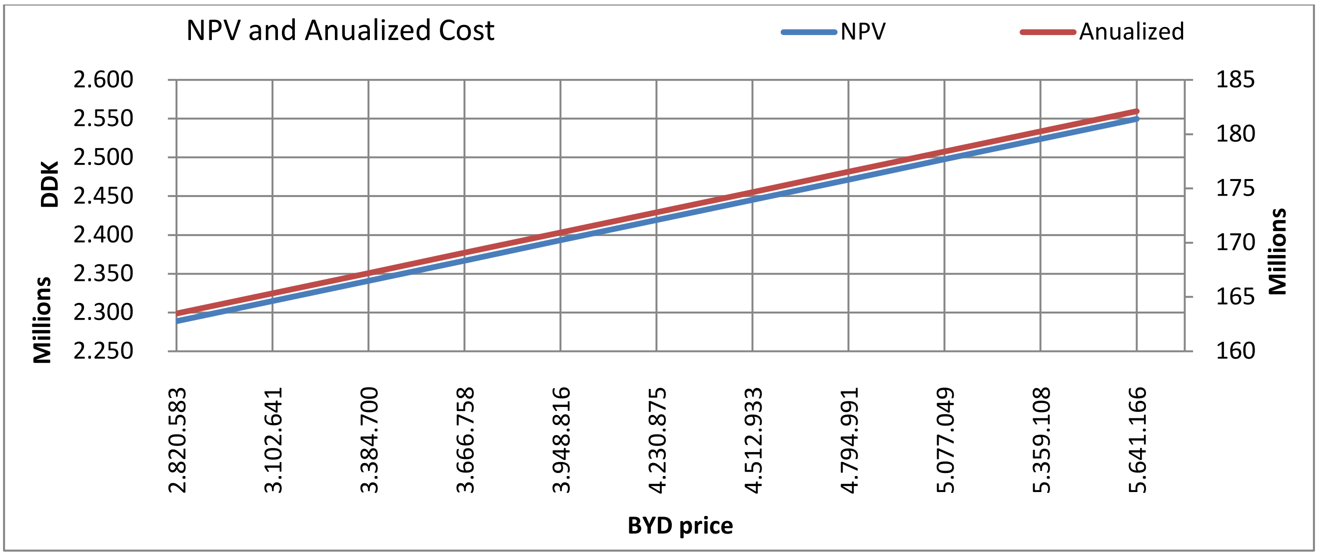


Figure 16 Net Present Value and Annualized Cost for DB and EB scenarios, for 2012-2025 interval

In Figure 17 it can be seen growth in the BYD price, and how that affects the NPV value and difference between the NPV values of the DB scenario compared to the EB scenario.

While the BYD cost per unit has increased by 200% the effect over the NPV is an increase of 117,1%. The difference between DB and EB scenarios (NPV values), grows at faster rate that the price.

As the BYD price increases, the difference between the NPV value of the DB scenario and EB scenario decreases until it takes negative values. When the green line (Diesel – Electric) descends below the “1” value on y axes, the EB scenario gets closer to DB scenario.

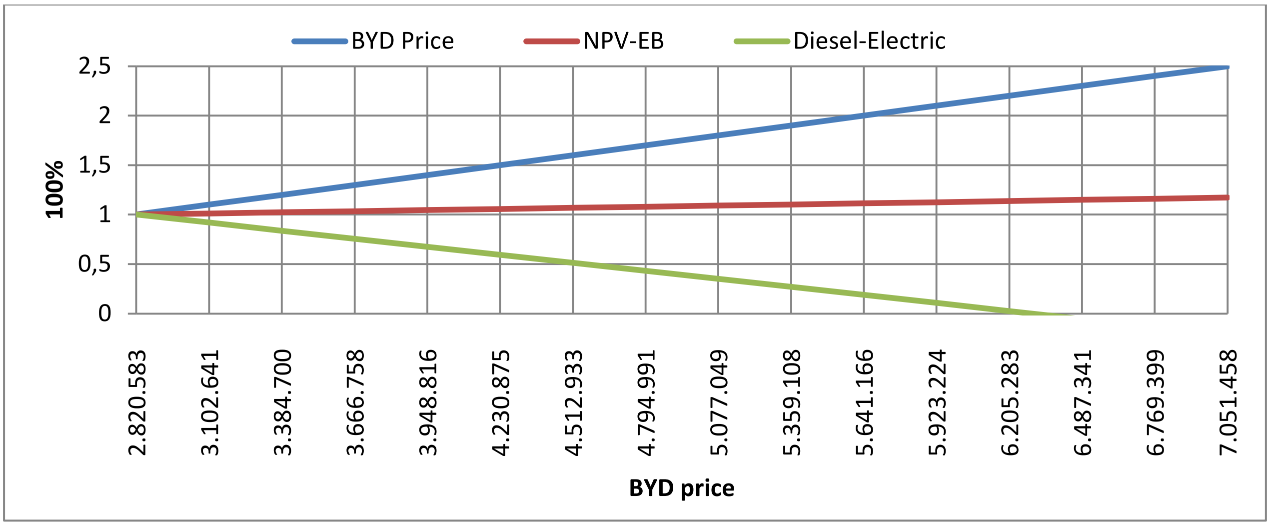


Figure 17 Influence of BYD bus price over NPV; When the green line (Diesel – Electric) descends below the "1" value on y axes, the EB scenario gets closer to the more expensive DB scenario; when the green line ascends above the "1" value on y axes, the DB scenario gets even more expensive and is further away from EB scenario; the greater the slope, the faster growths the difference between them.

In concussion the BYD price is a parameter to which the scenarios are sensitive and can influence significantly the economic performance of EB scenarios in comparison to DB scenarios.

5.2 Diesel Bus Price

In this section the impact of Diesel Bus prices on the economic performance of DB scenarios is investigated. The cost variation implications over the NPV value are presented in Figure 18. The Diesel Bus price was increased and decreased by 10% increments up to 250% of the initial price, and also decreased down to 50% of the initial price. Since the acquisitions cost for Diesel Busses affects only the DB scenario, the NPV of EB scenario is constant.

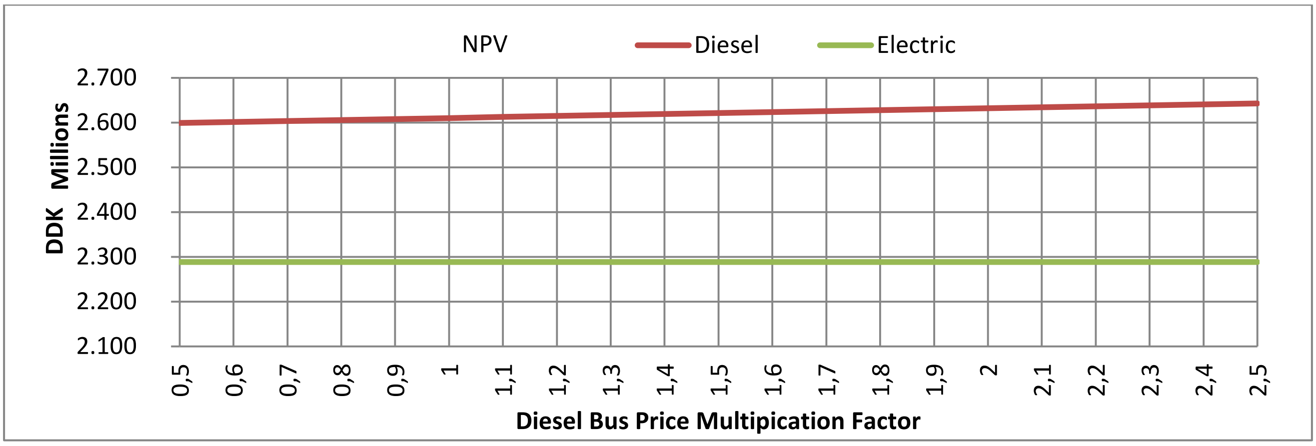


Figure 18 : Net Present Value (NPV) for DB and EB scenarios, for Diesel bus price variation; 2012-2025 interval

As it can be seen in Figure 18 the increase in the acquisition cost for Diesel buses, will result in a bigger NPV value for the DB scenario. However the prices for Diesel busses are expected to drop in the future decreasing the gap between the DB scenario and EB scenario. The same applies for the Annualized Cost.

As we can see in Figure 19Figure 16, the NPV and Annualized Cost increase or decrease at the same rate

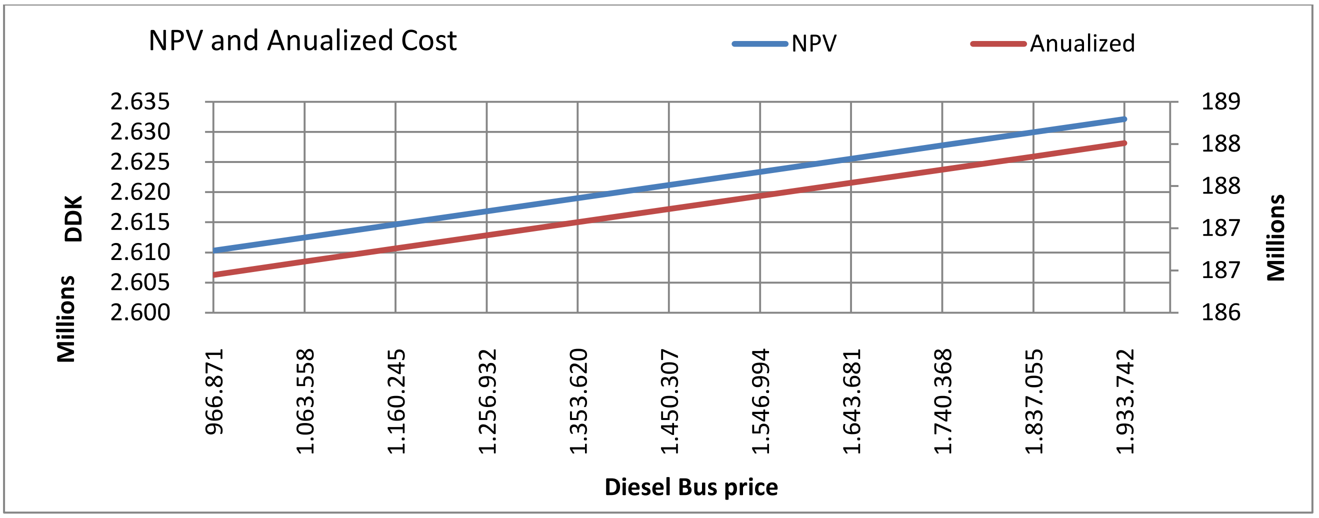


Figure 19: Net Present Value and Annualized Cost for DB and EB scenarios; sensitivity to Diesel Bus Prices; 2012-2025 interval

In Figure 20 it can be seen the growth in the Diesel Bus price in 10% increments on the X axes, and how that affects the NPV value and difference between the NPV values of the DB scenario compared to the EB scenario.

While the Diesel Bus cost per unit has increased by 200% the effect over the NPV is an increase of only 101,17%. The difference between DB and EB scenarios (NPV values), grows at much lower rate that the price.

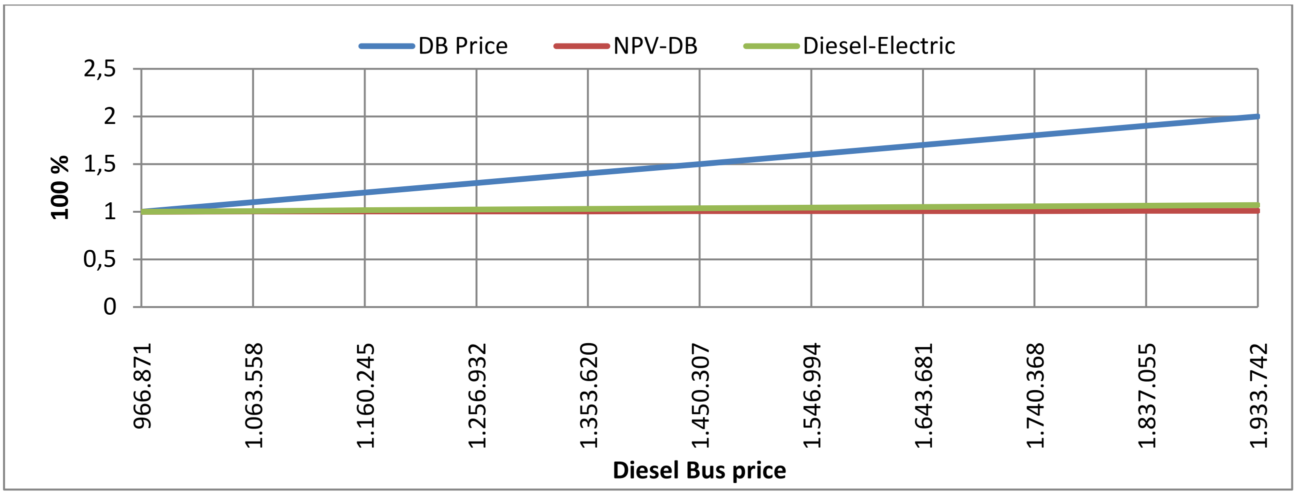


Figure 20: Influence of Diesel Bus price over NPV; When the green line (Diesel – Electric) descends below the “1” value on y axes, the EB scenario gets closer to the more expensive DB scenario; when the green line ascends above the “1” value on y axes, the DB scenario gets even more expensive and is further away from EB scenario; the greater the slope, the faster growths the difference between them.

As the Diesel Bus price increases, the difference between the NPV value of the DB scenario and EB scenario increases. When the green line (Diesel – Electric) ascends above the “1” value on y axes, the DB scenario gets further away from EB scenario.

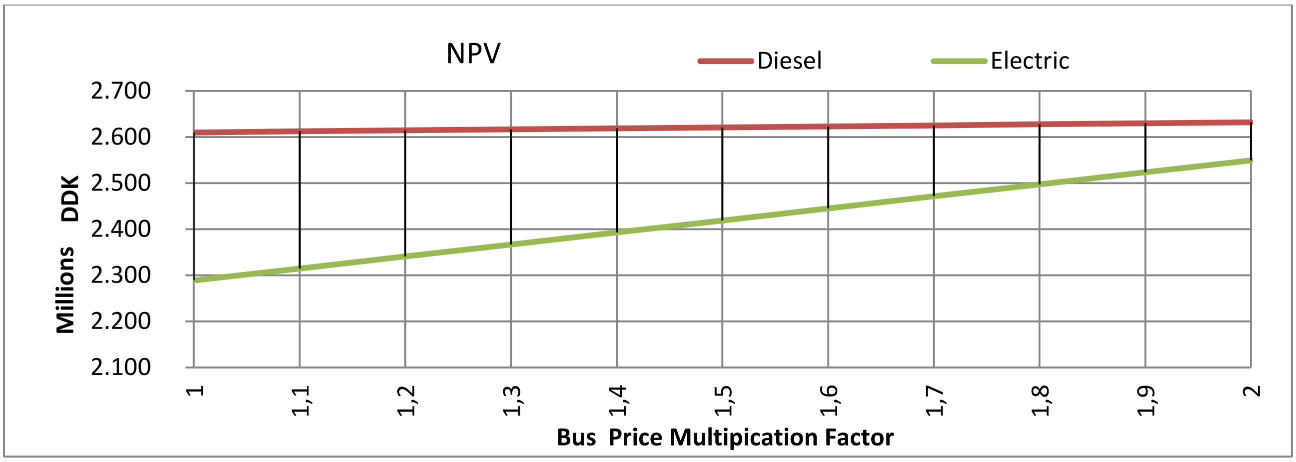


Figure 21: NPV growth rate depending on Diesel buses acquisition costs increases.

Also in Figure 21, it can be seen that the same growth factor applied to both BYD price and Diesel Bus price has different impact over their NPV values. While the EB scenario's NPV grows by 117,1% the DB scenario's NPV grows by 101,2%. The same is valid for the Annualized cost. It is concluded that the Diesel Bus price has low impact over the economic performance on DB scenario.

5.3 Electricity Price

In this section the impact of electricity price variation on the economic performance of the EB scenarios is investigated. The cost variation implications over the NPV value of the EB scenario are presented in Figure 22. The electricity price was increased by 10% increments up to 200% of the initial price. The price was not decreased since the electricity price follows an ascendant trend line (see Figure 4). Since the electricity price affects only the EB scenario, the NPV of DB scenario is constant.

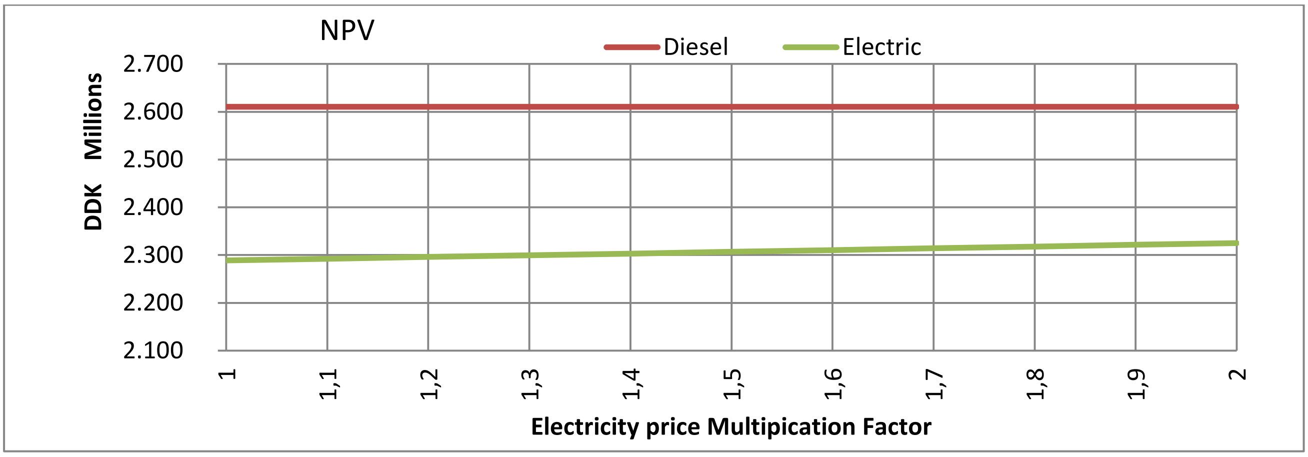


Figure 22 : Net Present Value (NPV) for DB and EB scenarios, for electricity price variation; 2012-2025 interval

As it can be seen from Figure 22, an increase beyond 200% in the electricity prices will result in a slight increase of the NPV value for the EB scenario. The same applies for the Annualized Cost

As we can see in Figure 23, the NPV and Annualized Cost increase or decrease at the same rate.

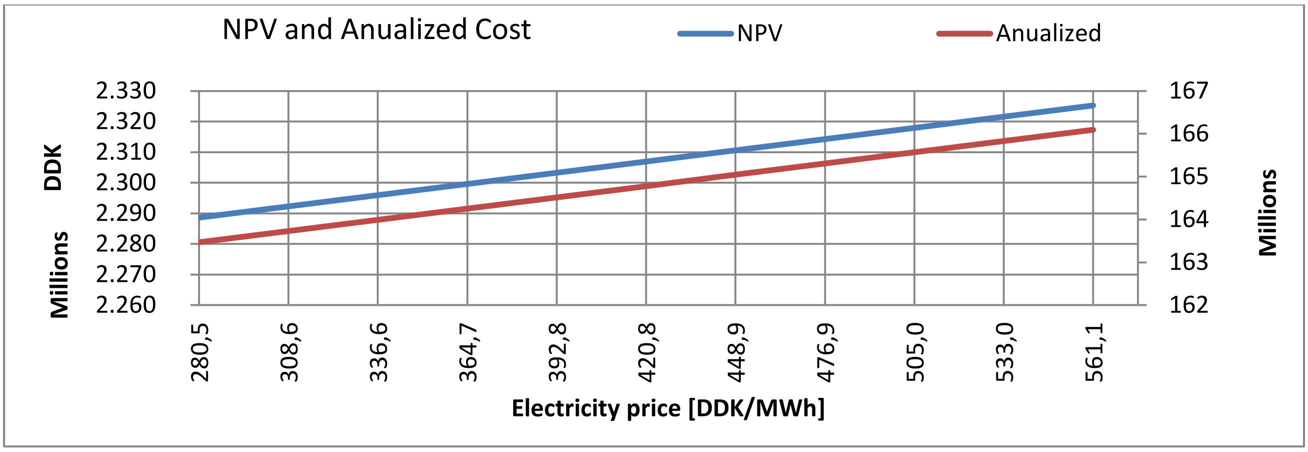


Figure 23 Net Present Value and Annualized Cost for DB and EB scenarios; sensitivity to Electricity Prices; 2012-2025 interval

In Figure 24 Figure 20 it can be seen the growth in the electricity price in 10% increments on the X axes, and how that affects the NPV value and difference between the NPV values of the DB scenario compared to the EB scenario.

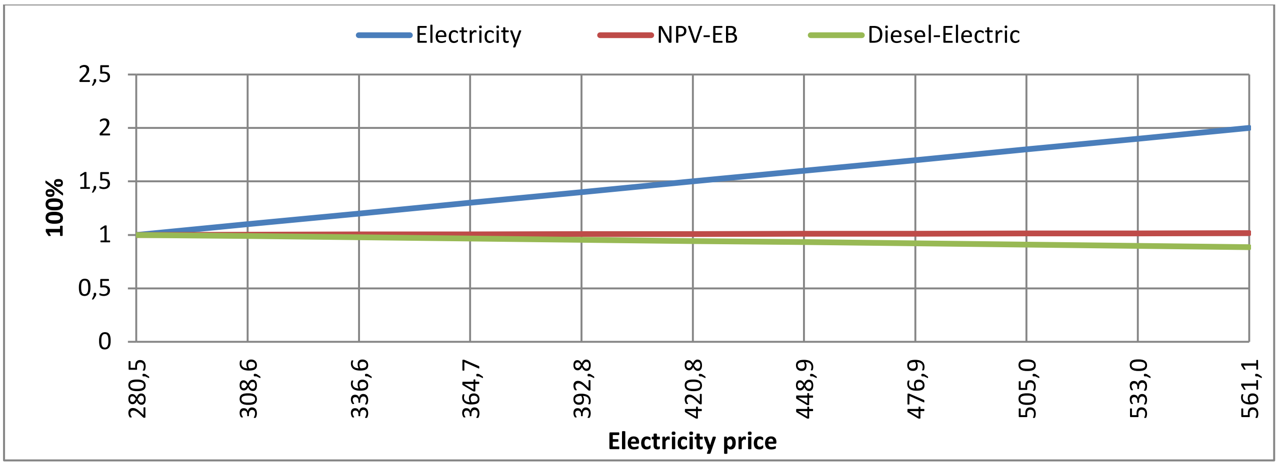


Figure 24 Influence of Electricity price over NPV; When the green line (Diesel – Electric) descends below the “1” value on y axes, the EB scenario gets closer to the more expensive DB scenario; when the green line ascends above the “1” value on y axes, the DB scenario gets even more expensive and is further away from EB scenario; the greater the slope, the faster grows the difference between them

While the electricity price has increased by 200% the effect over the NPV is an increase of only 101,6%. The difference between DB and EB scenario (NPV values), grows at much lower rate that the price.

As the Electricity price increases, the difference between the NPV value of the DB scenario and EB scenario decreases. When the green line (Diesel – Electric) descends below the “1” value on y axes, the EB scenario gets closer to DB scenario.

In concussion the Electricity price is a parameter to which the scenarios are less sensitive and can have only a reduced influence over the economic performance of EB scenarios in comparison to DB scenarios.

5.4 Fuel Price (Diesel)

In this section, in order to avoid confusion between Diesel Bus price and Diesel price, the Diesel price is referred to, as Fuel price. The impact of Fuel prices on the economic performance of DB scenarios is investigated in this section. The cost variation implications over the NPV value are presented in Figure 25Figure 18. The Fuel price was increased by 10% increments up to 200% of the initial price. The price was not decreased since the Fuel prices follow an ascendant trend line. Since the Fuel price variation affects only the DB scenario, the NPV of the EB scenario is constant.

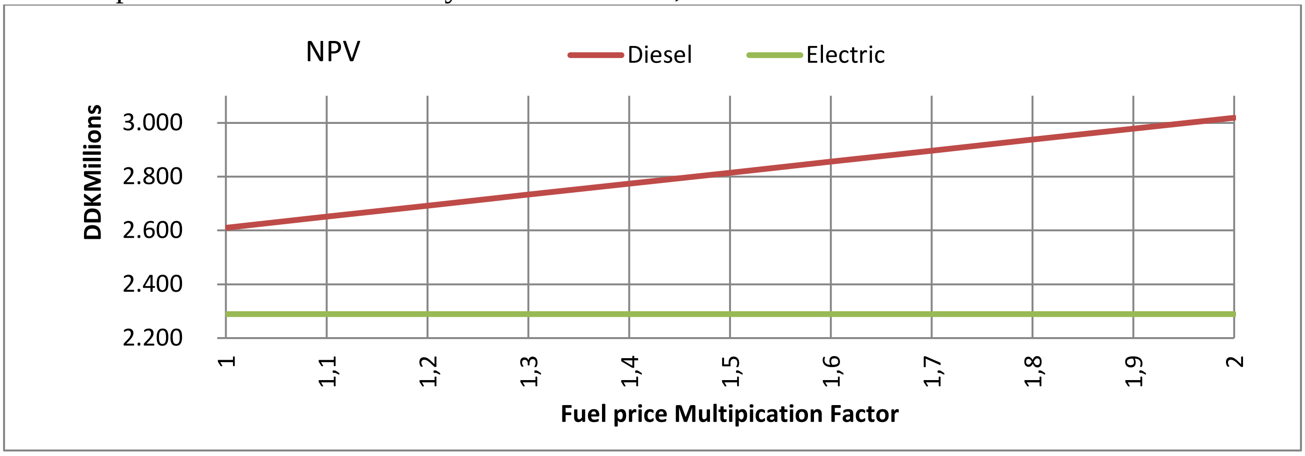


Figure 25: Net Present Value (NPV) for DB and EB scenarios, for Fuel price variation; 2012-2025 interval

As it can be seen in Figure 25 the increase in the Diesel price, will result in a bigger NPV value for the DB scenario. However the prices for Diesel fuels are expected to grow in the future further increasing the gap between the DB scenario and EB scenario. The same applies for the Annualized Cost as seen in Figure 26.

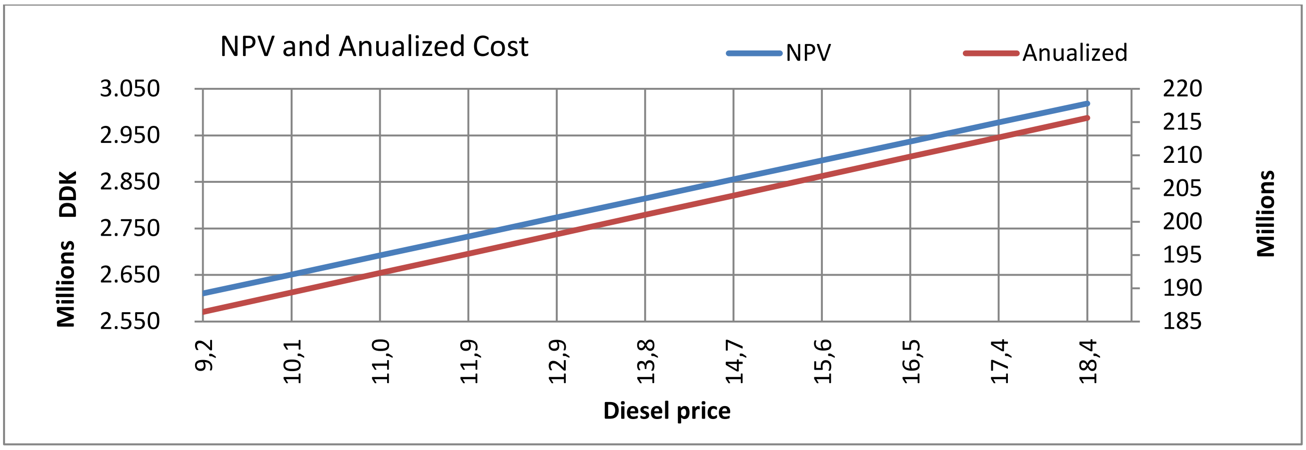


Figure 26 Net Present Value and Annualized Cost for DB and EB scenarios; sensitivity to Fuel Prices; 2012-2025 interval

In Figure 27 it can be seen the growth in the Fuel price in 10% increments on the X axes, and how that affects the NPV value and difference between the NPV values of the DB scenario compared to the EB scenario.

While the Diesel Bus cost per unit has increased by 200% the effect over the NPV is an increase of 115,7%. The difference between DB and EB scenarios (NPV values), grows at faster rate that the price.

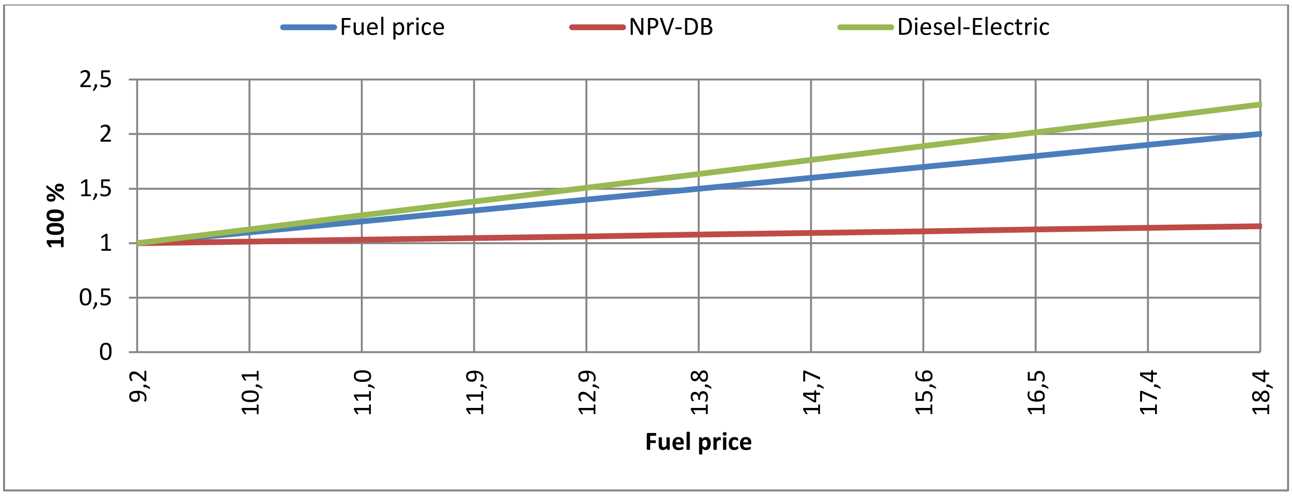


Figure 27: Influence of Fuel price over NPV; When the green line (Diesel – Electric) descends below the "1" value on y axes, the EB scenario gets closer to the more expensive DB scenario; when the green line ascends above the "1" value on y axes, the DB scenario gets even more expensive and is further away from EB scenario; the greater the slope, the faster grows the difference between them

As the Fuel price increases, the difference between the NPV value of the DB scenario and EB scenario increases. When the green line (Diesel – Electric) ascends above the "1" value on y axes, the DB scenario gets further away from EB scenario.

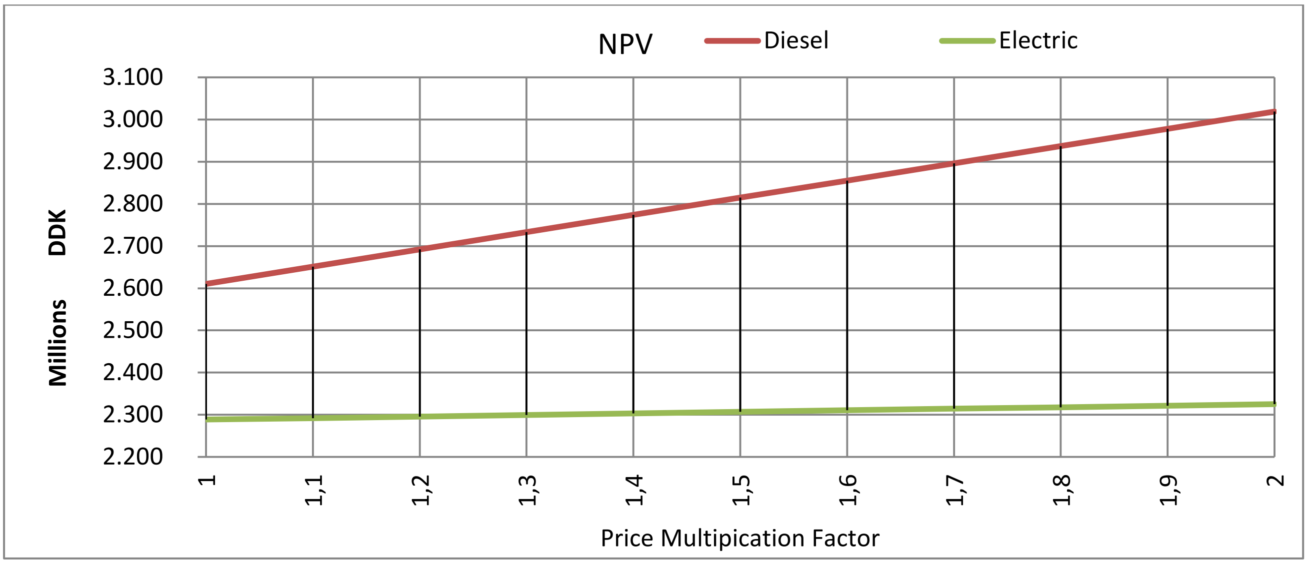


Figure 28: NPV growth rate depending on electricity and fuel price increases

Also in Figure 28, it can be seen that the same growth factor applied to both electricity price and Fuel price has different impact over their NPV values. While the EB scenario's NPV grows by only 101,6 % the DB scenario's NPV grows by 115,7%. The same is valid for the Annualized cost.

It is concluded that the Fuel price has a high impact over the economic performance on DB scenario.

5.5 Discount Rate

In this section the impact of the Discount rate is investigated. This variable affects the economic performance of both the EB scenarios and DB scenarios. These are presented in Figure 29.

The increase of the discount rate reduces that NPV of the Diesel Buses Scenarios faster that the NPV of the Electric Buses Scenario. If a highly unconventional discount rate is considered, (over

20%) the DB scenarios performs better from an economic point of view that the EB scenario. The same implications are true with respect to the Annualized Cost (see Figure 29).

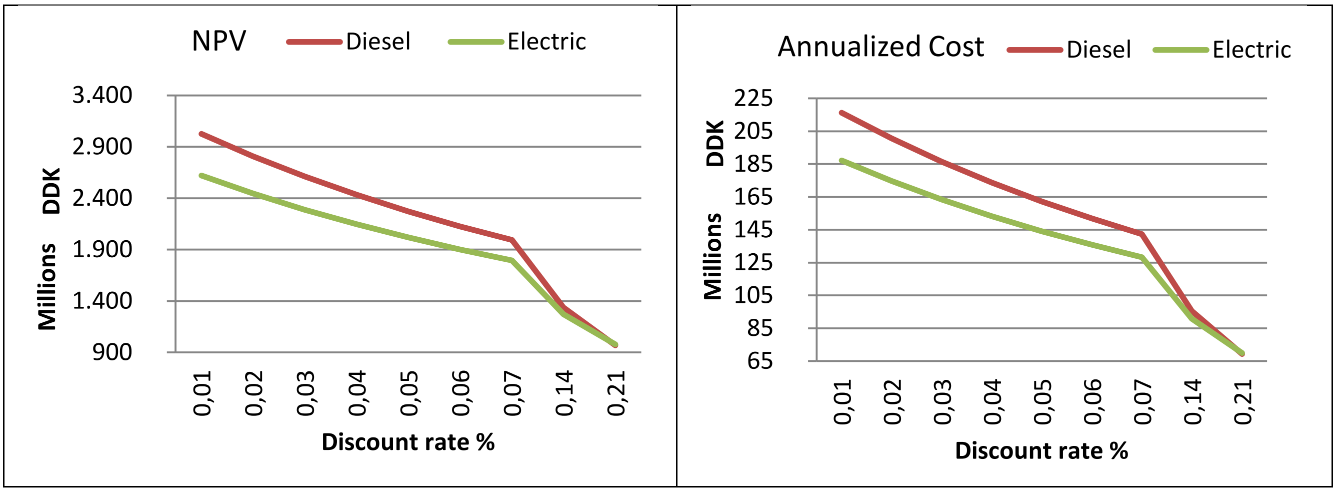


Figure 29 : Discount rate variation impact on the economic performance of EB and DB scenarios

However such large discount rates are highly uncommon, and therefore the discount rate is considered to have moderate to low effect over the economic performance of the scenarios.

5.6 Cost per hour assessment

In Chapter 2.2, Table 2 and Table 3 are presented the cost per hour of operation and the reasons behind selection the particular values. In this section is discussed the impact of choosing different method of assessing the cost. While the values 648 DDK/h and 740 DDK/h (method 2) were chosen based on the larger threshold, the values 661 DDK/h and 680 DDK/h (method 1) were discarded.

In Figure 30 the breakdown of cost per hour of operation for both methods is presented. In method 1 the average cost per hour of operation is 671,06 DDK/h while in method 2 is 694 DDK/h.

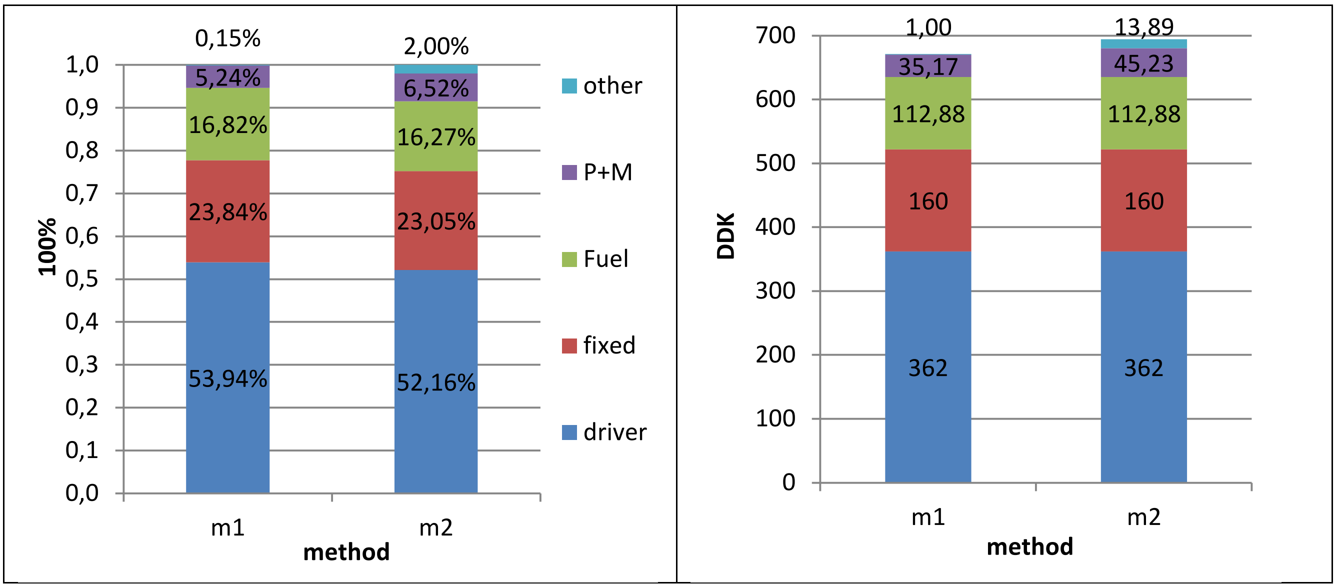


Figure 30 Cost of operation per hour –Components in % left and DDK right – for method 1 and method 2

In Figure 31 are presented the differences between the methods related to economic performance. The average value for the cost per hour of operation using the first method is 671,06 DDK/h for the

Diesel Buses and 534,0, DDK/h for the Electric Buses. The cost per hour of operation for the electric bus is 20,41 % lower than the diesel bus.

	Cost per Hour		
	Diesel	Electric	Dif %
method 1	680,17	537,93	-
	661,94	510,03	-
	671,06	534,03	20,42
			0,77
method 2	740,00	597,76	-
	648,00	496,08	-
	694,00	546,92	21,19

Figure 31 Differences between Cost per hour of operation Diesel Bus vs Electric Bus fleet

The average value for the cost per hour of operation using the second method is 694 DDK/h for the Diesel Buses and 546,92, DDK/h for the Electric Buses. The cost per hour of operation for the electric bus is 21,41 % lower than the diesel bus.

There is less than 0,8% difference between the two methods. This means that using the second method the electric busses will have a slight advantage: they are a bit cheaper to operate when compared with the diesel buses (more expensive to operate if compared to the first method: 671 to 694 DDK/h).

It is considered that this aspect has a low impact in overall economic performance.

5.7 Social Cost of Carbon (SCC)

The SCC values are discussed in Chapter 2.3. In this section it is investigated the impact of increasing the value up to 7,6 times corresponding to 5072 DDK /t CO2 and its impact on the NPV and annualized cost.

The SCC influences both the DB scenarios and EB scenarios as it can be seen in Figure 32. The SCC price is increased in 10% increments up to 200% from its initial value.

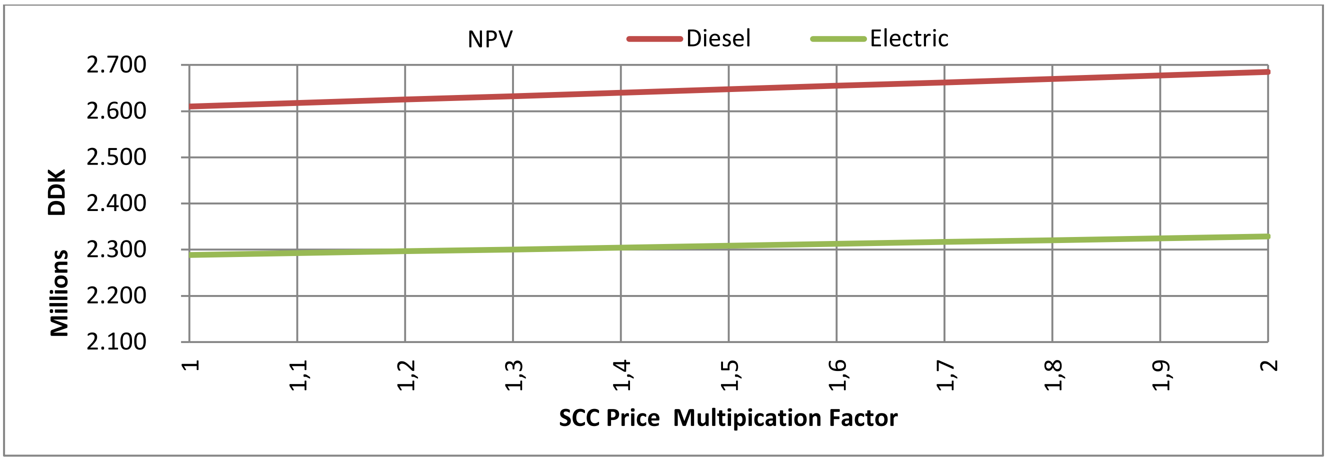


Figure 32 Impact of SCC increase over NPV values for DB and EB scenarios.

An increase by 200% in the SCC price will result in an increase the NPV for DB scenarios by 102,9% and 101,8% for the EB scenario. Clearly, SCC price affects more the DB scenarios that the EB scenarios. The same is true for the Annualized Cos ass seen in Figure 33.

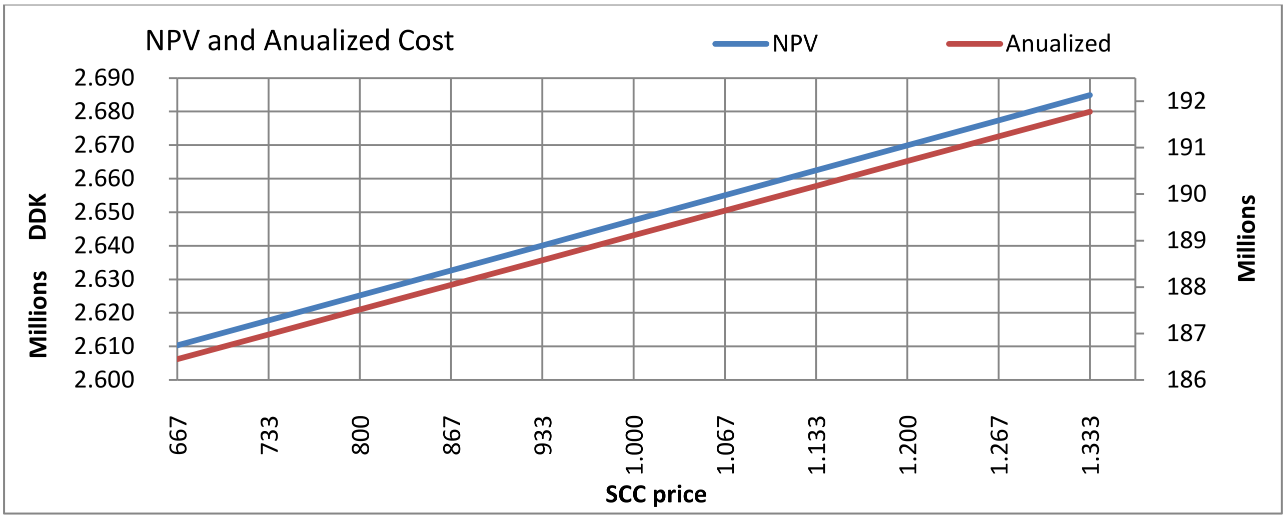


Figure 33 Net Present Value and Annualized Cost for DB and EB scenarios; sensitivity to SCC Prices; 2012-2025 interval

As it can be seen in Figure 34, the NPV for EB scenarios grows at the slowest rate, flowed by the BD scenario. The difference between them grows at a slight higher rate, but still much lover the price of SCC.

Figure 34 Influence of SCC price over NPV; When the green line (Diesel – Electric) descends below the "1" value on y axes, the EB scenario gets closer to the more expensive DB scenario; when the green line ascends above the "1" value on y axes, the DB scenario gets even more expensive and is further away from EB scenario; the greater the slope, the faster grows the difference between them

If considering the worst case scenario from Chapter 2.3 Figure 5 the SCC will have a significant impact over the economic performance of both DB scenarios and EB scenarios, ass seen in Figure 35. In this case the NPV for DB scenario can grow by 119% while the NPV for EB scenarios can grow by 112%.

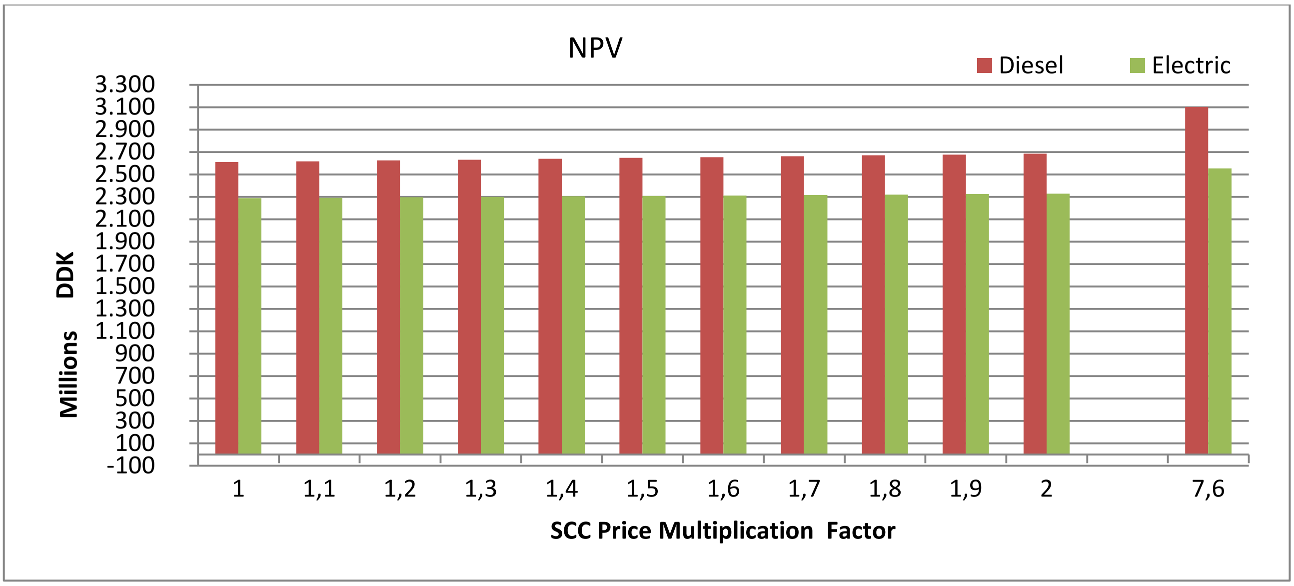


Figure 35 NPV for DB and EB scenarios considering

5.8 Factors with environmental impact

In this section the impact of other variables with environmental impact are discuses. In Sections 5.3 and 5.7 concluded that the electricity price and SCC price have love influence in the economic performance it is interesting to investigate what is the impact on the environment if the source of electricity is changed. These changes affect only the EB scenarios and their economic performance.

As mentioned in Chapter 2.3 the price of the electricity must be correlated with the generation mix.

Energy Nord is company that offers green electricity generated by hydropower in Norway at 0,3424 DDK/ kWh including the additional price for the green certificate of 0,016 DDK/kWh (excluding tax). (Energi Nord 2013)

Dong Energy is company that offers green electricity generated by wind power at 0,4046 DDK/kWh including taxes. (Dong Energy 2013)

For the electricity generated by solar power it has been assumed a price of 0,5 DDK/kWh.

There is a wide polemic over how these green certificates are handled and if in truth the green electricity arrives at the consumers, however this topic is not engaged.

Source	CO2 [t]/MWh	Demand [MWh]	CO2 emission [t]	Electricity price [DDK/MWh]	Electricity Cost [DDK]	SCC [DDK]	Electricity + SCC Cost [DDK]
General Mix	0,416	27.777	11.555	280	7.777.560	7.704.086	15.481.646
Hidro	0,024		667	342,4	9.510.845	444.466	9.955.311
Wind	0,007		194	404,6	11.238.574	129.636	11.368.210
PV	0,035		972	500	13.888.500	648.180	14.536.680

Table 39 Variation of Annual costs associated with Electricity use in EB scenarios with respect to source of electricity

As it can be seen in Table 39 using more expensive electricity increases the annual costs almost doubling them in the case of solar sources. As it can be seen in Figure 36 the general trend line for total cost (electricity costs and externalities) is almost horizontal given away the fact that the source of electricity is less relevant on a general look, as higher electricity prices compensate the decrease of externalities costs.

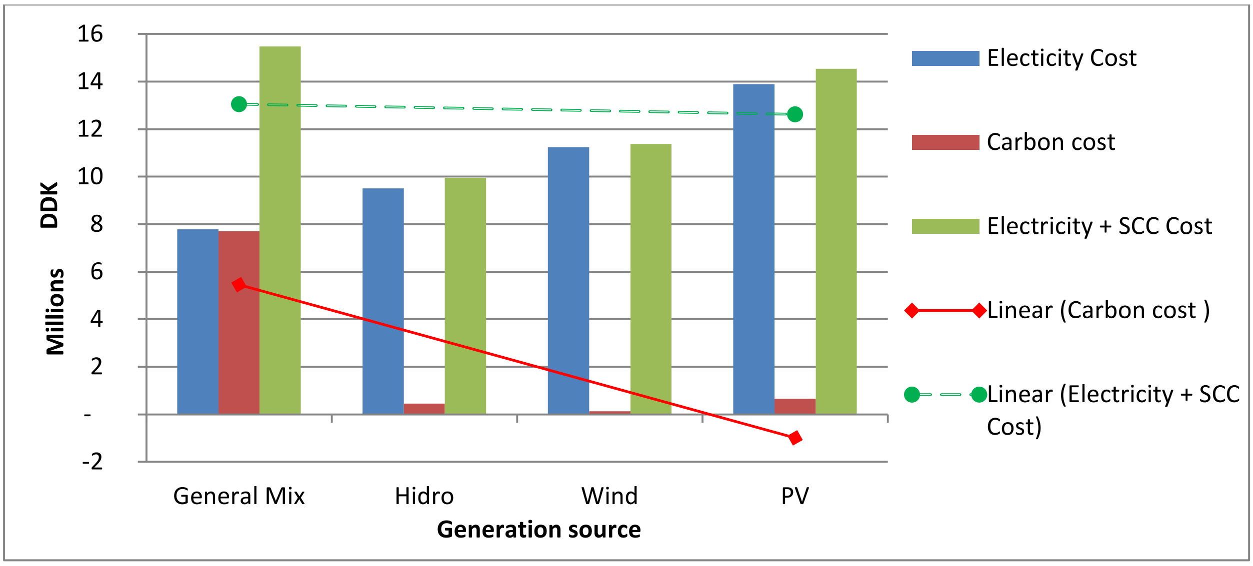


Figure 36 Variation of Annual costs associated with Electricity use in EB scenarios with respect to source of electricity

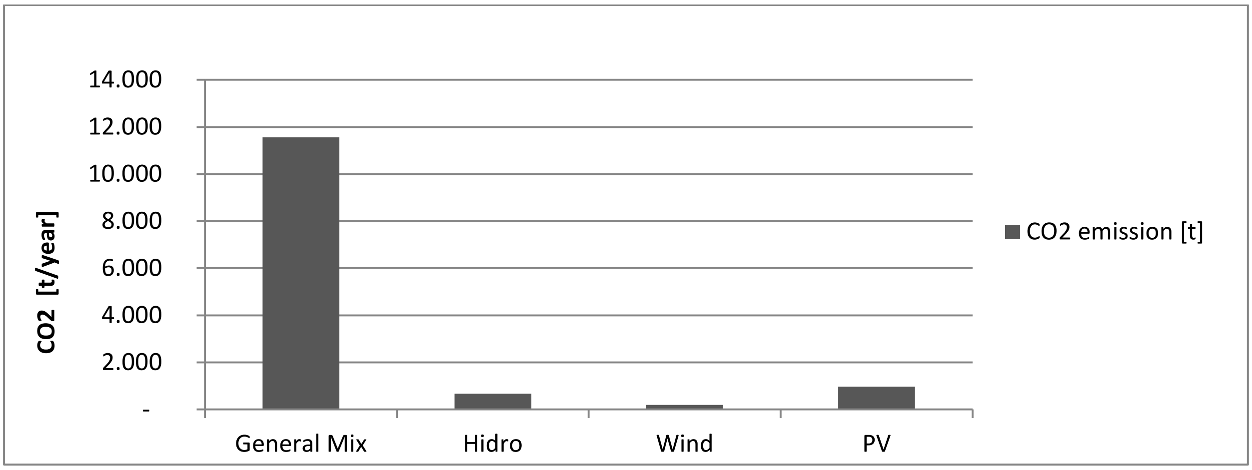


Figure 37 CO2 Emissions released into the environment according to electricity source of generation

However, the source of electricity used by the Electric Buses fleet is plays a major role when considering the effects on environment. As it can be seen in Figure 37, the amount of CO2 released annually in the environment drops from 11.555 t/year to less than 1.000 t/year depending on the origin of the electricity. The most environmentally friendly source is the wind (194 t/year), followed by hydro power (667 t/year) and PV (972 t/year), when it comes to the amount of CO2 emitted during generation.

5.9 Reinvestment

The DB and EB operation assumptions are that that they will run for the entire time frame of the project (14 years) without a complete reinvestment. According to U.S. Department of Transportation (FTA 2007) the minimum lifetime of a heavy duty large bus used in pubic transportation is 12 years. After 12 years operators are eligible to receive replacement funds. However these buses continue to run being purchased by private operators (MacKechnie 2012).

This section investigates the performance of these scenarios considering a complete reinvestment in the rolling stock after 8, 10 and 12 years of operation, for both DB and EB scenarios considering the scrap value at 3% of the original price. The results are presented in Figure 38.

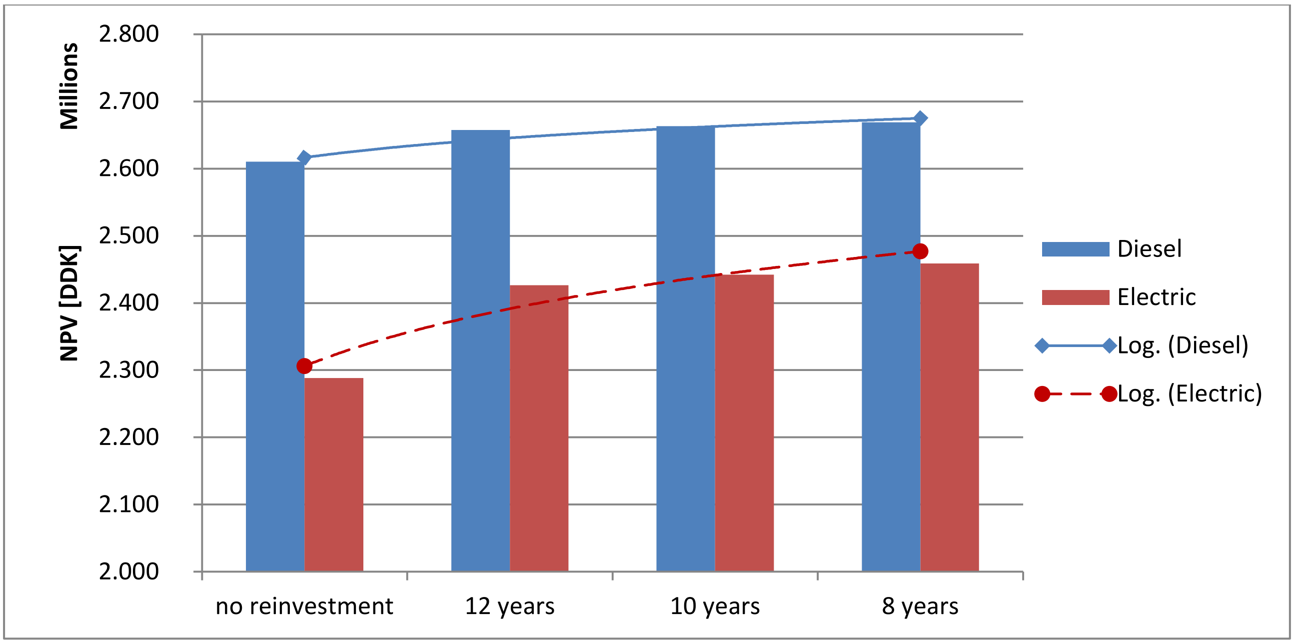


Figure 38: Comparison between the NPV of DB and EV scenarios considering reinvestment and scrap value;

As it can be seen in Figure 38, the NPV of the EB scenario gets closer to the DB scenario as the amount of time passed from the beginning of the project to the reinvestment year, decreases. This also means that the scenario that considers a reinvestment after 8 years of operation, is more sensitive to all variables that affect the EB scenario, the most important one being the electric bus price.

As it can be seen in Figure 39, in the electric bus price increase 1,53 times before the DB scenario is cheaper, compared to 2,2 times as is in the case where no reinvestment is considered.

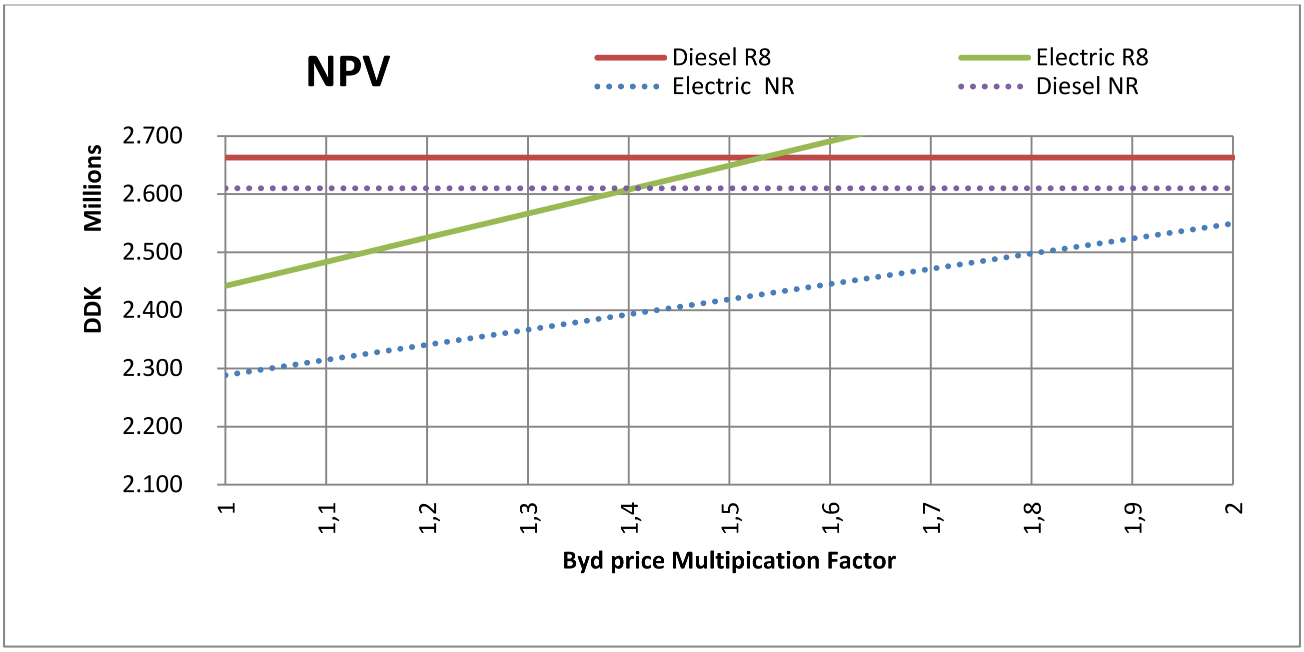


Figure 39 Net Present Value (NPV) for DB and EB scenarios, depending on the lectric bus price variation; 2012-2025 interval.considering reinvestment and scrap value; NR-No Reinvestment, R8 –reinvestment after 8 years

6. Discussion of results

As the title unveils, this section contains the findings and the discussion around them, given a specific context. The results are compared with similar solutions to be further placed into the local context. Also in this section the implementation possibilities and the local electricity supply are addressed.

6.1 The findings

Given the assumptions presented in Chapter 2 the, the total cost, emissions and externalities are presented for Diesel Scenarios in Table 40 and for Electric Scenarios in Table 41, considering city bus lines and metro bus lines. The non-discounted annual values do not include additional investment in new buses or infrastructure.

	Route	Driving Time	Travel Distance	Diesel	CO2	SCC	All cost
DB 2012		[h]	Km	[L]	[t/year]	[DDK]	[DDK]
	by bus	141.073	3.744.770	1.703.160	4.281	2.854.037	100.468.749
	metro bus	136.697	4.105.155	1.711.481	4.302	2.867.980	98.016.107
	Sum:	277.769	7.849.924	3.414.641	8.582	5.722.016	198.484.855
DB 2025	by bus	200.871	5.332.119	2.425.103	6.095	4.063.818	143.055.878
	metro bus	174.762	5.248.302	2.188.070	5.499	3.666.615	125.310.292
	Sum	375.633	10.580.421	4.613.173	11.595	7.730.433	268.366.170
DB 2025 LRT	by bus	175.775	4.665.949	2.122.122	5.334	3.556.103	125.183.140
	metro bus	98.543	2.615.834	1.233.792	2.744	1.829.502	70.420.990
	Sum	274.319	7.281.782	3.355.914	8.078	5.385.606	195.604.130

Table 40 : Total Cost, Emissions and Externalities on annual basis for DB scenarios; non discounted

	Route	Driving Time	Travel Distance	Electricity	CO2	SCC	All cost
EB 2012		[h]	Km	[MWh]	[t/year]	[DDK]	[DDK]
	by bus	141.073	3.744.770	4.793	2.210	1.473.257	78.542.193
	metro bus	136.697	4.105.155	5.255	2.422	1.615.038	76.464.462
	Sum:	**277.769**	**7.849.924**	**10.048**	**4.632**	**3.088.295**	**155.006.656**
EB 2025	by bus	200.871	5.332.119	6.825	3.146	2.097.747	111.835.000
	metro bus	174.762	5.248.302	6.718	3.097	2.064.772	97.757.240
	Sum	**375.633**	**10.580.421**	**13.543**	**6.243**	**4.162.520**	**209.592.240**
EB 2025 LRT	by bus	175.775	4.665.949	5.972	2.753	1.835.664	97.862.853
	metro bus	98.543	2.615.834	3.348	1.544	1.029.114	54.864.073
	Sum	**274.319**	**7.281.782**	**9.321**	**4.297**	**2.864.778**	**152.726.926**

Table 41 Total Cost, Emissions and Externalities on annual basis for EB scenarios; non discounted

As it can be seen in Figure 40, comparing the DB Scenarios and EB Scenarios leads to the conclusion that EB scenarios have lower cost and environmental impacts that a DB scenarios on annual basis.

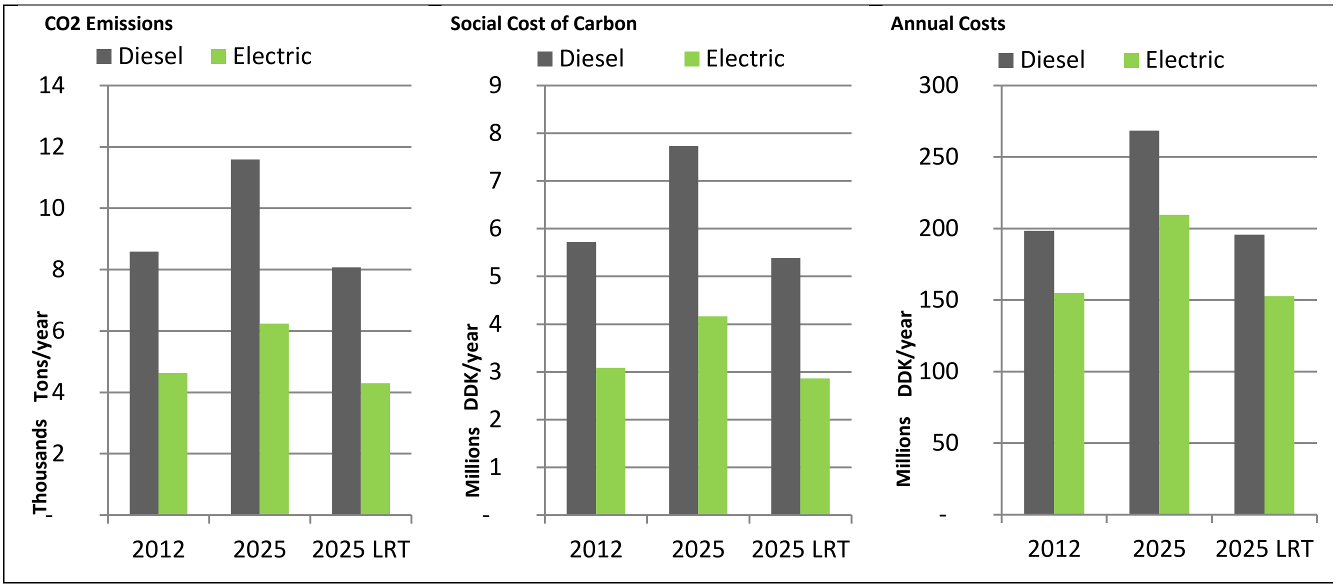


Figure 40 Comparison between DB scenarios and EB scenarios considering 0% discount rate, with respect to Total Cost, Emissions and Externalities on annual basis

Considering the Business As Usual (BAU) scenario the Diesel Bus 2012 Scenario and its evolution until 2025, as the reference case, the effects of implementing an electric bus fleet can be observed evaluating the NPV and the Annualized Cost for the two circumstances, including additional investment in new busses and infrastructure.

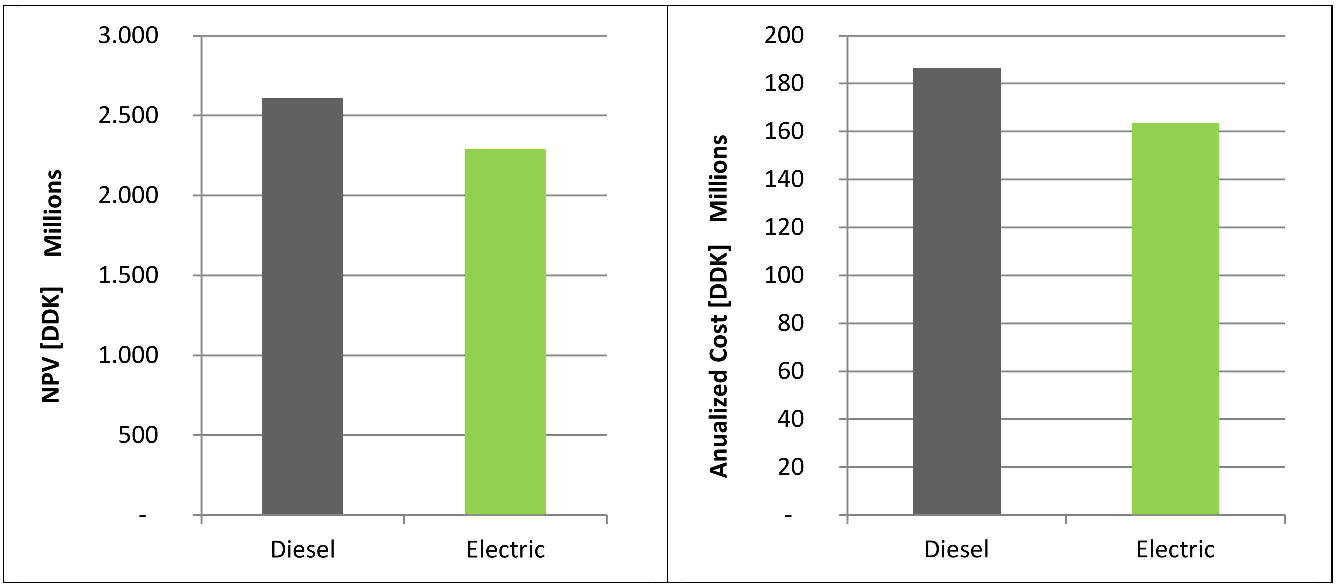


Figure 41 NPV and Annualized Cost comparison for EB and DB scenarios, Discount rate: 3%; time frame: 14 years.

As it can be seen in Figure 41 comparing the DB Scenarios and EB Scenarios leads to the conclusion that EB scenarios have lover NPV and Annualized Cost than the DB considering a 3% discount rate over a period of time of 14 years.

6.2 LRT comparison

This section intends to put the cost related findings into perspective by comparing them with the future LRT system that will be implemented in Aalborg by 2025. This section intends by no means to point which solution is better, since that would require a different approach.

According to (Andersen, Landex und Nielsen 2006) in a study for the Centre for Traffic and Transport at Technical University of Denmark, the investment cost for LRT is around 88 million DDK per km of track. The same source estimates the annual cost of the Ring 2½ light rail operation at 75 million DDK per year, and another 1.9 million DDK for externalities.

Given that the Aalborg LRT system has 12 km of tracks – about half of the 25,4 km of the Copenhagen Ring rail system – the investment cost is in the range of 1.056 million DDK, and the operation cost around 36 million DDK per year.

In other words, with the investment of about 1 billion DDK and an operation cost of 36 million DDK per year, the load on bus public transport system in brought back to 2012 levels.

As it can be seen in Figure 42, considering a time frame of 14 years and a discount rate of 3% and given the investment cost of 1.056 million DDK, and the operation cost around 36 million DDK per year, the NPV for the LRT system is 1,37 billion DDK and the Annualized Cost is 98,39 million DDK

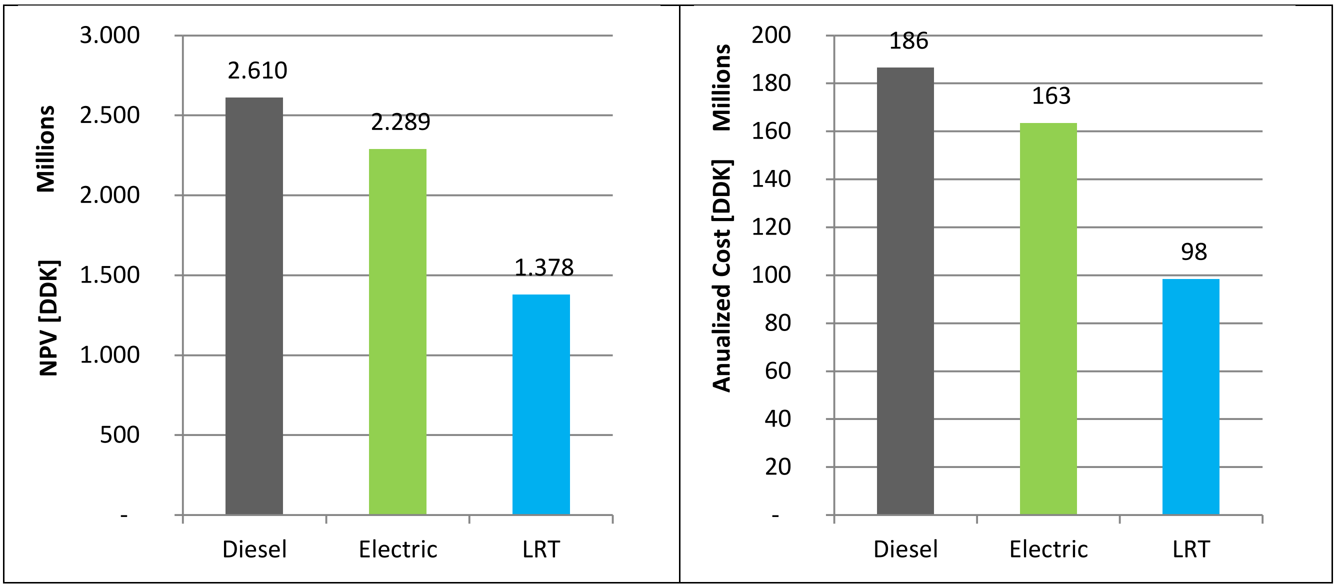


Figure 42 NPV and Annualized Cost comparison for EB, DB scenarios and LRT, Discount rate: 3%; time frame: 14 years.

According to (Trankjær 2013), one argument that added to choosing an LRT solution in Aalborg was the annual savings in bus driving time which amount to 101.314 hours – representing 26,97% of total driving hours of 2025 – and the possibility of using the difference in expenditures: investing it into the LRT system. Giving the increased transport capacity the expected driving hours for the tram in 2025 would be around 47.072 hours.

Taking into account the number of hours is based on the Danish national target of the growth of traffic in public transport at rate of 2% per year, if the LRT system would have 36.199 driving hours for 2012. In a time frame of 14 years the LRT system accumulates 579.828 driving hours, while the Diesel or Electric fleet has 4,54 million driving hours (see Figure 43).

If the cost per hour of operation considering a time frame of 14 years, is investigated (see Figure 44), the annualized cost per annualized hours of operation is more than 4 time larger for the LRT system (2.375,75 DDK/h) when compared to EB or DB scenarios. However the difference between the DB and EB scenario – from 574,93 DDK/h to 504,07 DDK/h – is less significant (13%).

The amount of hours saved by the LRT system is 101.314. This is equivalent to 58,24 million DDK if considering a cost of 574,93 DDK/h (DB case) or 51,07 million DDK if the cost is 504,07 DDK/h (EB case). The amount of hours necessary to be driven by the LRT to accomplish these savings is 40.072. Considering a cost of 2.375,75 DDK/h, this translates into an expenditure of 111,83 million DDK.

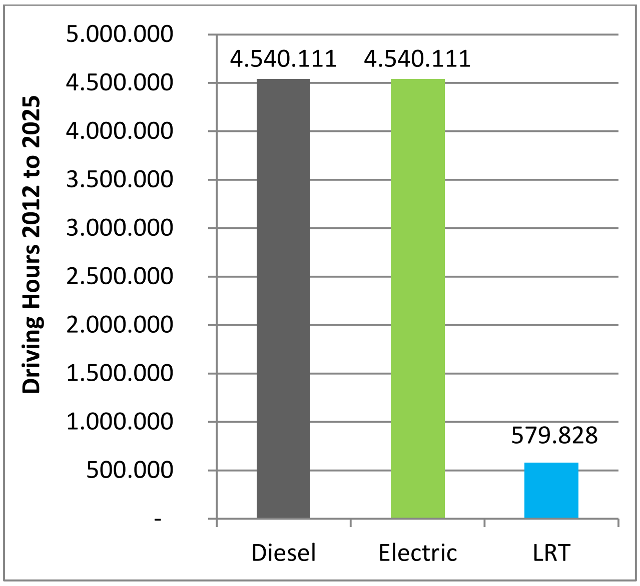


Figure 43 Comparisons between accumulated driving hours for the EB/ DB fleet and LRT system, in the time frame of 14 years.

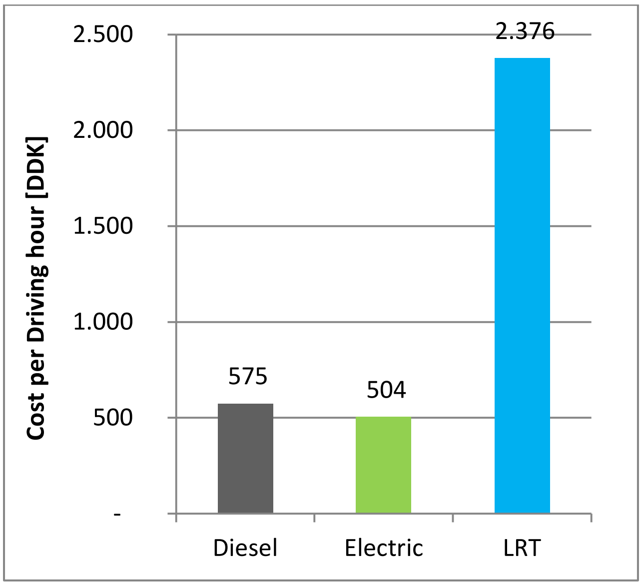


Figure 44 Annualized cost per Annualized driving hours - comparisons between EB/ DB fleet and LRT system, 3% discount rate, and a time frame of 14 years

According to data provided by (M. Jensen 2013) in 2011, 14,16 million passengers were transported during 318.044 hours at a cost of 213,58 millin DDK; or 44.5 passengers an hour at a cost of 15,1 DDK per passenger hour.

Considering a cost per hour as seen in Figure 44 (574,93 DDK/h in a DB case and 504,07 DDK/h in a EB case) the cost per passenger hour is 12,90 DDK in DB case and 11,31 DDK in the EB case (see Figure 45).

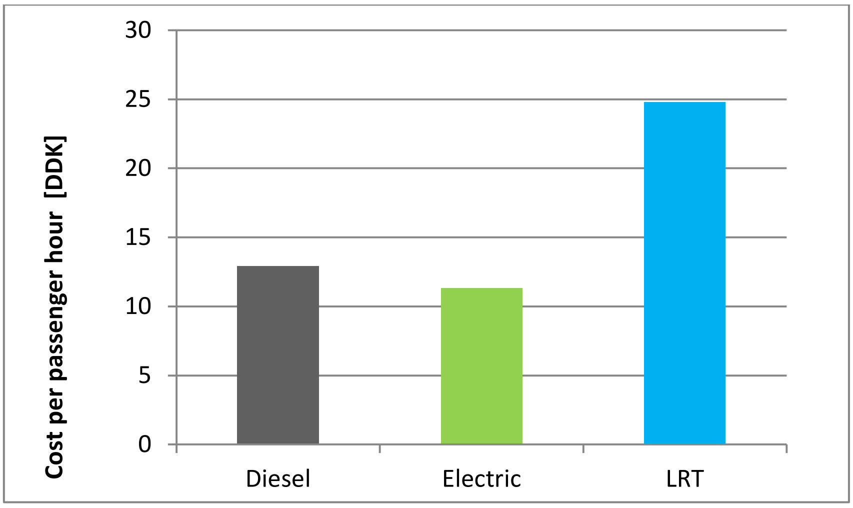


Figure 45 Cost per passenger hour comparisons between EB/ DB fleet and LRT system, considering the cost per hour of operation as the annualized cost divided by the annualized driving hours - 3% discount rate, and a time frame of 14 years

As earlier stated, the implementation of LRT in 2025, would cause a reduction in driving time of 101.314 hours, therefore 4,5 million passengers would be transported by LRT systems in 47.072

hours; at a rate of 96 passengers per hour. Considering a cost of 2.375,75 DDK/h , the LRT system is transporting commuters at cost of 24,78 DDK/passenger hour(see Figure 45).

6.3 Local electricity supply

From a sustainable development perspective, security of supply is important on long term planning. Assessing the local opportunities for developing plans should be included in any discussion that involves responsible stakeholders. From this perspective this sections looks into the local potential of Aalborg municipality of producing electricity using solar power.

A possible solution is to develop solar farms. Hover the author is considering a more urban integrated concept. Using the available roof area for all the buildings that are under public administration, or the ones that are used by the transport sector could give an additional purpose to the already existing structures and are used as a start point into the discussion.

As discussed in Chapter 2.4, at the base of this analysis is the solar atlas developed by Bernd Möller from Department of Development and Planning, Aalborg University, Denmark. According to (Möller, Nielsen und Sperling 2012), the total technical potential using all available roof area is 4,5 GWh/year in Aalborg. Areas with an insolation smaller than 600 kWh/a are excluded. The total PV potential by plant size is presented in Table 42.

Aalborg municipality:			
Plant type	Total area [m²]	Average insolation [kWh/m²/a]	Total PV production [MWh/a]
20-50m2	477.519	753	140.521
50-200m2	4.281.740	759	1.269.340
200-4000m2	8.713.050	757	2.575.530
>4000m2	1.831.920	755	540.362
Total:	15.304.229		4.525.753

Table 42 Total technical potentials exceeding 600kWh/m²/a insolation for PV, in Aalborg Municipality by plant type **(Möller, Nielsen und Sperling 2012)**

Since these results include all building in Aalborg municipality the author considered to follow the relation between building ownership and solar production.

With this in mind, using as starting point the results from (Möller, Nielsen und Sperling 2012) the next step is to restrict the available roof area only to buildings that function with respect to transportation (building code 310). The location of these buildings within Aalborg municipality is presented in Figure 46, using ArcMap 10 and data from the solar atlas.

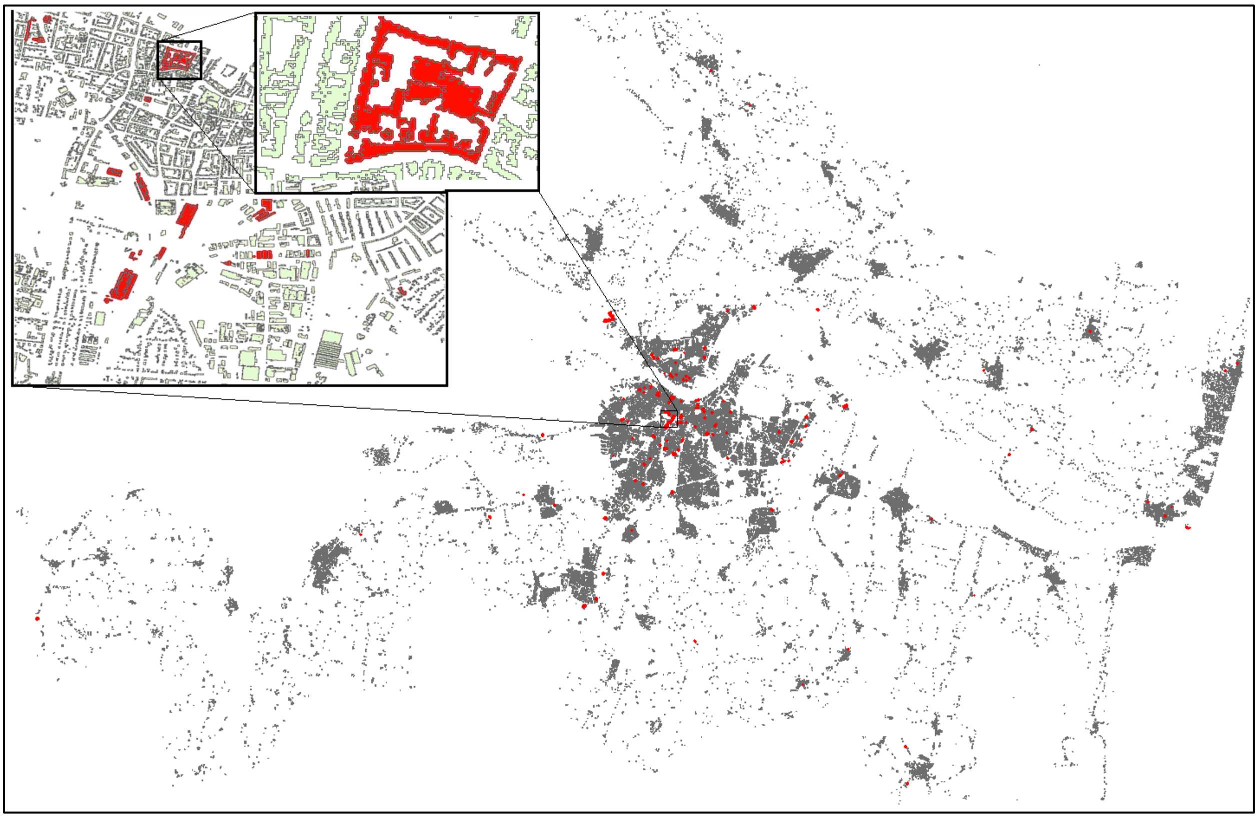


Figure 46 Location of buildings used by transport sector (code: 310), within Aalborg municipality.

As it can be seen in Figure 46, most of the buildings investigate are located within the Aalborg city limits. Table 43 presents the annual production for all roof areas and also for the roof areas larger than 500 and 1000 m² for buildings used in transport sector.

Roof area	Total area [m²]	Total PV production [MWh/a]
All	145.344	14.094
>500 m²	109.081	10.763
>1000 m²	76.357	7.624

Table 43 Aalborg municipality; Technical potential for roof area and annual solar production for buildings used in transport sector (code 310)

Total technical potential roof area is 145.344 m² with an annual production of 14.094 MWh/year. The annual production exceeds the highest annual demand of 13.543 MWh/year of EB25 scenario.

With respect to the cost of producing this amount of electricity, as it can be seen in Figure 47, the levelized production cost is around 1,75 DDK/kWh, if using all the available roof area of the all buildings related to transportation use. The costs of electricity production is calculated as the levelized production costs (LPC), which express the average cost of generating one unit of electricity during the useful lifetime of 25 years, including annualized investment, at a 5% interest rate.

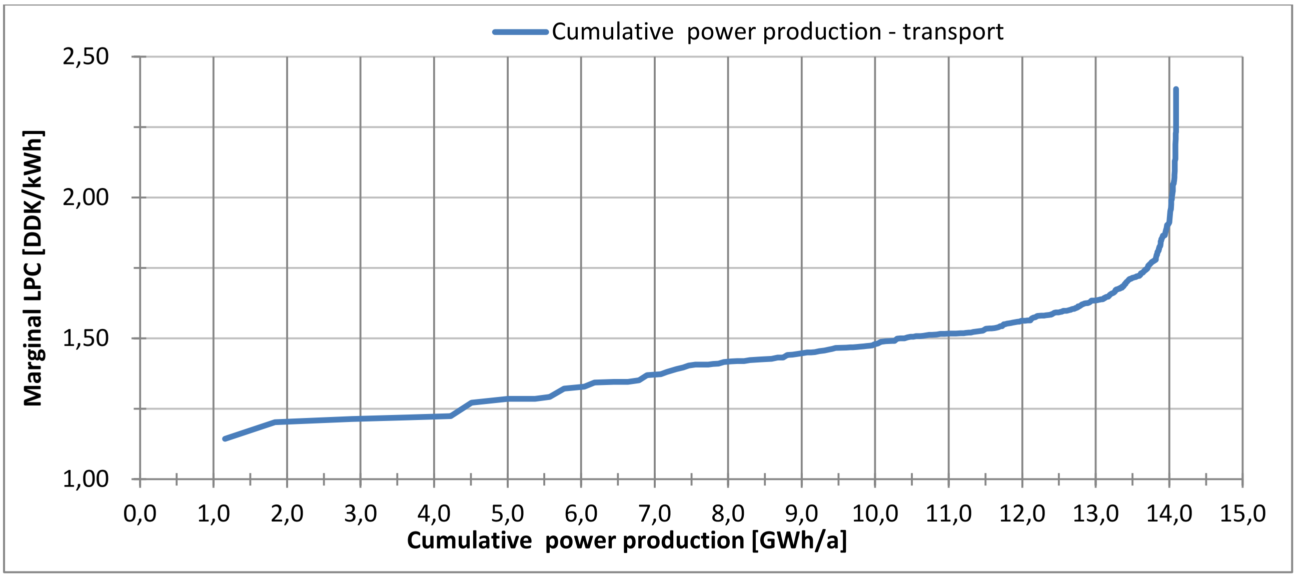


Figure 47 Marginal Levelized production costs of cumulative PV for all buildings within transport sector in Aalborg municipality at 5% interest rate.

There are three important aspects that are shown in Figure 47:

- The costs of electricity production increases with the cumulative power production;
- A large proportion of the cumulative power production potential is within a narrow low cost band;
- The marginal LPC for producing 13,5 GWh (1,72 DDK/kWh) is below 2,2 DDK/kWh, which according to (Forbes 2012) is the price consumers pay in Denmark.

Another building group is formed by institutions with public use: Cultural buildings, Schools, Hospitals, Kindergartens, and other public institutions. The location of these buildings within Aalborg municipality is presented in Figure 48.

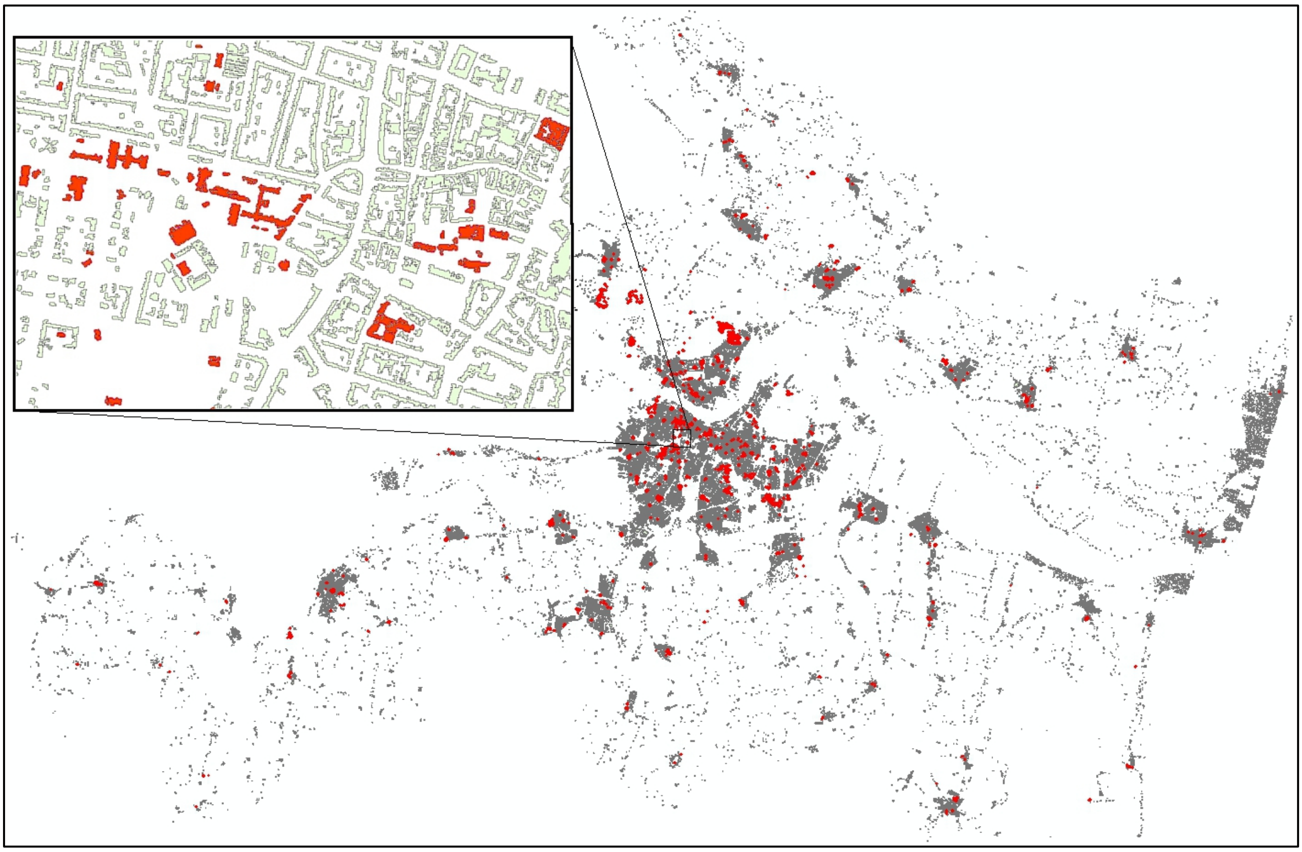


Figure 48 Location of buildings used in public sector: Cultural buildings (code 410), Schools (code 420), Hospitals (code 430), Kindergartens (code 440), and other public institutions (code: 490); located within Aalborg municipality.

As it can be seen in Figure 48, most of the buildings investigate are located within the Aalborg city limits. Table 43 Table 44 presents the annual production for all roof areas and also for the roof areas larger than 500, and larger and equal than 1000, 2000, 3000, 4000 m², for buildings used in public sector.

Roof area	Total area [m²]	Total PV production [MWh/a]
All	667.484	64.686
>500 m²	463.306	45.683
≥1000 m²	341.844	34.035
≥2000 m²	235.013	23.635
≥3000 m²	198.643	20.032
≥4000 m²	147.448	14.909

Table 44 Technical potential for roof area and annual solar production for buildings used in public sector: Cultural buildings (code 410), Schools (code 420), Hospitals (code 430), Kindergartens (code 440), and other public institutions (code: 490); located within Aalborg municipality

Total technical potential roof area is 667.484 m² with an annual production of 64.686 MWh/year. The annual production for the PV farms with technical potential roof area larger or equal to 4000 m², exceeds the highest annual demand of 13.543 MWh/year of EB25 scenario.

The marginal levelized production costs of cumulative PV for all public buildings in Aalborg municipality is presented in Figure 49.

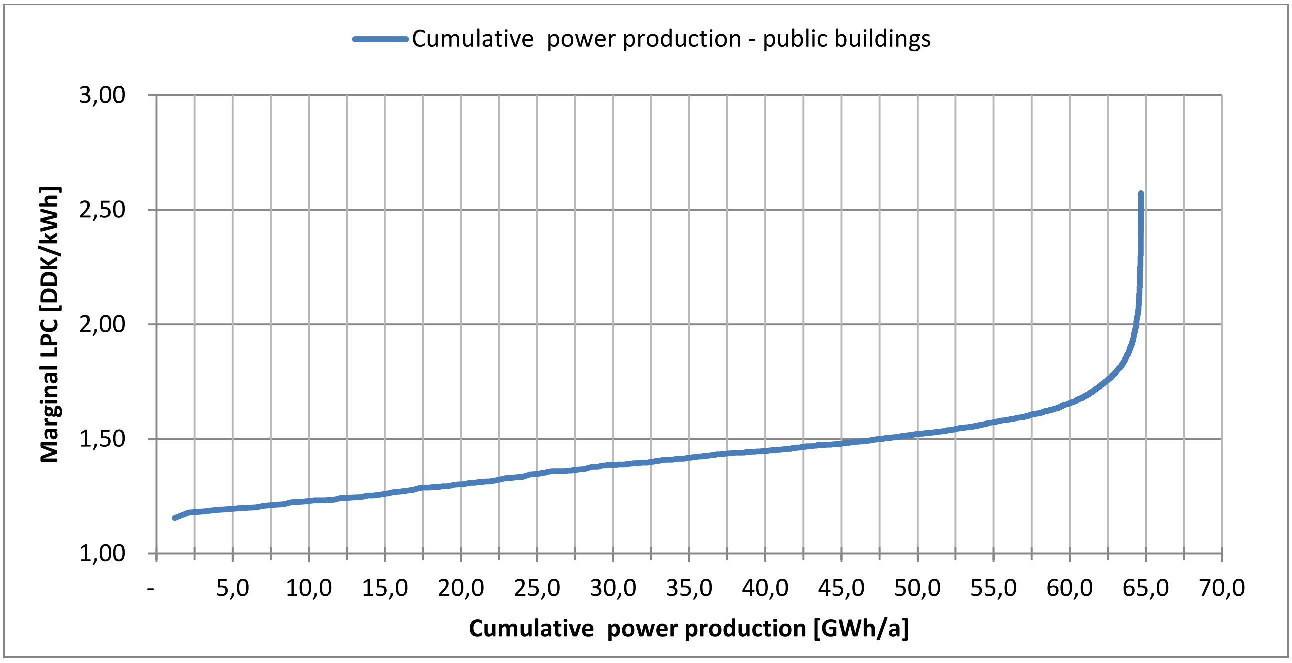


Figure 49 Marginal Levelized production costs of cumulative PV for all public buildings in Aalborg municipality at 5% interest rate.

With respect to the cost of producing 13.543 MWh/year, as it can be seen in Figure 50, the levelized production cost is around 1,25 DDK/kWh, if using only the buildings related to public sector use that have roof areas larger or equal to 4000 m².

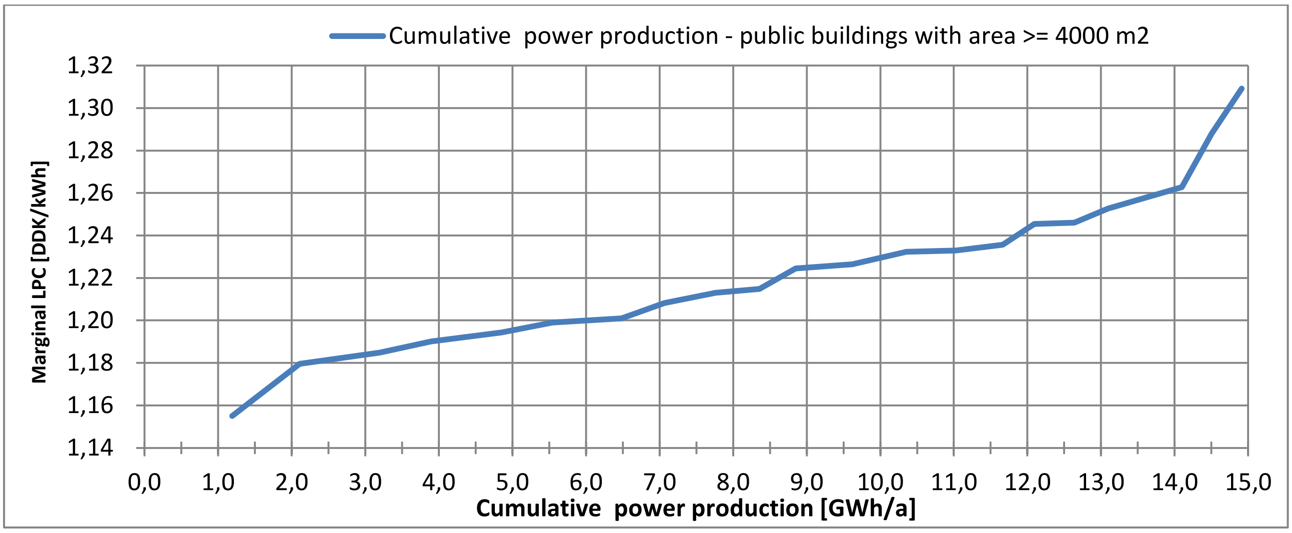


Figure 50 Marginal Levelized production costs at 5% interest rate of cumulative PV for all public buildings in Aalborg municipality, that have roof areas larger or equal to 4000 m²

There are two important aspects that are shown in Figure 50:

- The costs of electricity production increases with the cumulative power production;
- The marginal LPC for producing 13,5 GWh (1,26 DDK/kWh) is below 2,2 DDK/kWh, which according to (Forbes 2012) is the price consumers pay in Denmark.

Given this data it is possible to produce locally the more than 13 GWh annually. Clearly this does not imply that the fleet can run entirely on solar produced electricity produced on daily basis. Hover this highlights the potential of the municipality and with proper implementation mechanisms this potential can be used to increase the sustainability of an electric bus project.

6.4 Possible Implementation Strategies

According to data from (M. Jensen 2013) the revenues are about 52,6 million DDK and cover 53% of the expenses that amount to 99,4 DDK for the Metro Bus line. For the city-, service-, basic-, and night bus lines the revenues – 64,18 million DDK cover 56% of the expenses that amount to 114,17 million DDK.

Clearly some lines are more profitable than others. If assuming that the passengers' preference for bus public transport will remain constant throughout the years, it is clear that the level of subsidization will be around 44%-47%.

It could be also stated that the subsidizer also pays for introducing about 10.000 t of CO2 yearly if considering the case of a diesel bus fleet. In a more dramatic formulation it can be stated that the subsidizer pays the passengers to damage the environment. If the subsidizer is the government, this body will also have to pay for finding and implementing measures that will deal with environment associated damages.

Phasing out subsidies for fossil fuels has been one of the G20 agreements in Pittsburg, USA in 2009. According to (OECD 2011) a joint report by IEA, OPEC, OECD and World Bank on fossil-fuel and other energy subsidies, prepared for the G20 Meeting of Finance Ministers and Central Bank Governors, over 250 individual mechanisms that effectively support fossil - fuel production or consumption in the 24 OECD countries were identified, having an aggregated value in the order of 45-47 billion USD / year, between 2005-2010.

According to Danish Ministry for Climate, Energy and Buildings, Denmark joined the struggle to phase out the support for fossil fuels along with ministers from Finland, Norway, Sweden, Switzerland, Ethiopia and New Zealand under the name of "Friends of Fossil Fuel Subsidy Reform" (Klima-, Energi- og Bygningsministeriet 2012).

Subsidizing public transport can be considered an indirect mechanism that effectively support fossil fuels use, if the public network is fossil fuel based.

If Aalborg municipally would decide to support the implementation of a electric bus fleet by subsidizing the same percentage of expenditures as in the case of existing diesel fleet, not only it would pay less over the period 2012-2025 (see Figure 51), but will also actively work on reducing fossil fuel subsidies and negative impacts on environment.

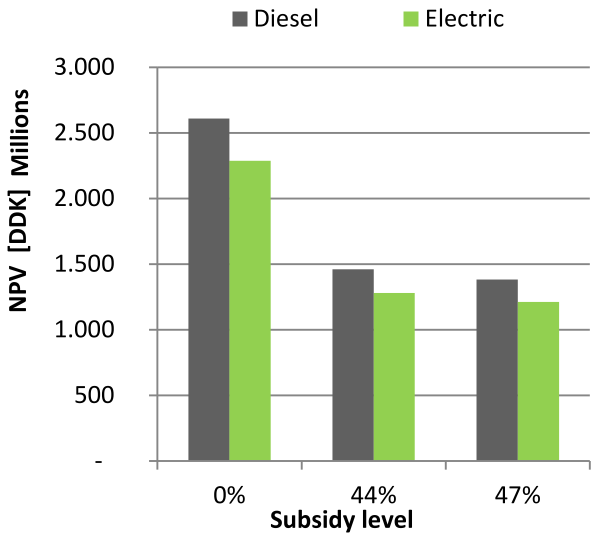


Figure 51 Comparison between the NPV of DB and EB scenarios 2012-2025, considering different levels of subsidization

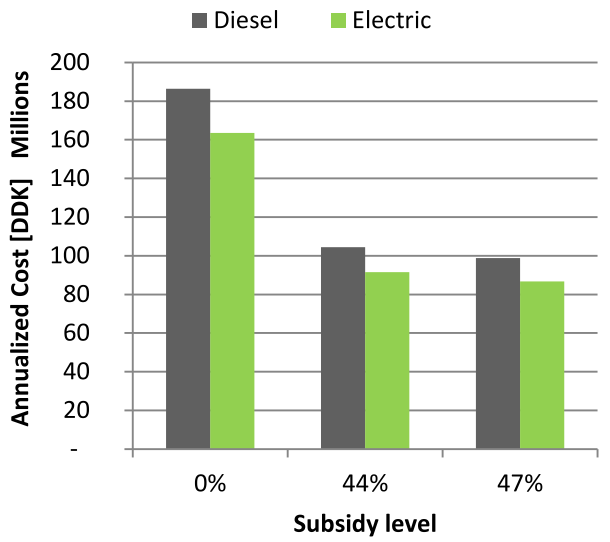


Figure 52 Comparison between the annualized cost of DB and EB scenarios 2012-2025, considering different levels of subsidization

Another form of support mechanism for an electric bus fleet could be a net metering scheme.

If taking into account the data from Figure 50 and Table 44, building solar farms necessary to deliver 13,5 GWh/year at a LPC of 1,26 DDK/kWh would require an area of 147.448 m². If the net metering scheme would require that the balance between electricity consumed and the electricity produced to be accounted for at the end of the year, the electricity provider could function as a storage mechanism.

This solution for using form self-generated electricity, from local solar farms is 4,5 times more expensive than just buying electricity (general mix 0,280 DDK/kWh). However, even at this price level, the NPV of the EB scenarios is a bit lover that the one of the DB scenario (see Figure 53).

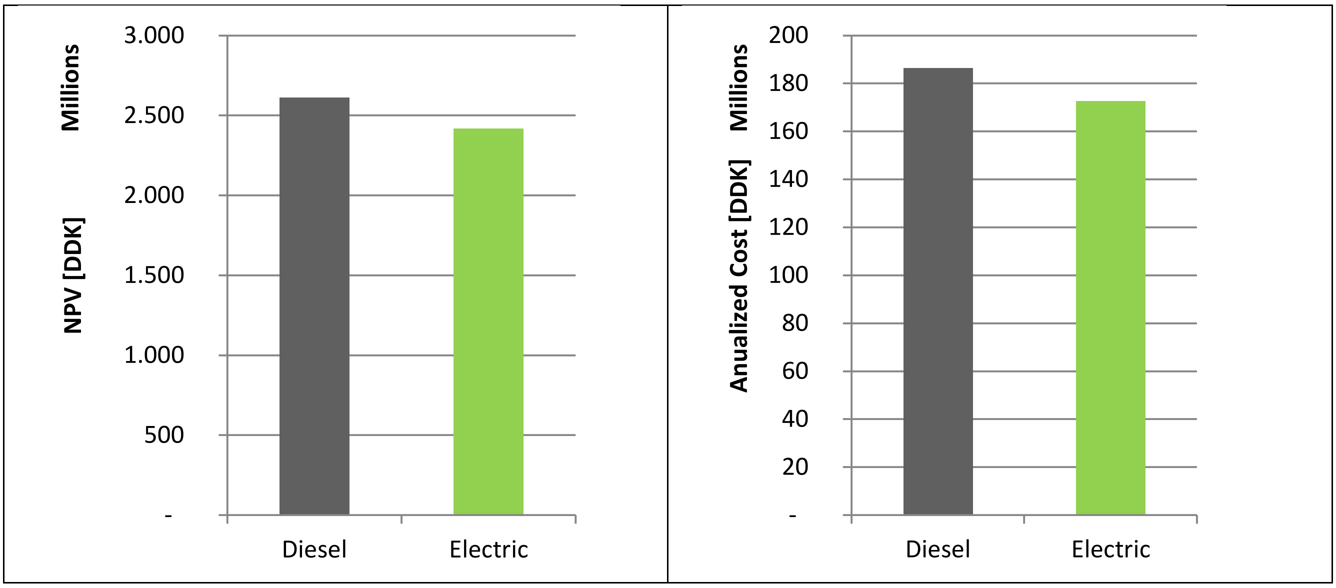


Figure 53 NPV and Annualized Cost comparison for EB and DB scenarios for an electricity price of 1,26 DDK/kWh

Another form of support mechanism could be designed for house hold consumers with small roof areas available for PV production. Using also a net metering scheme, the bus company would purchase the surplus electricity offering in return "travel benefits" for the passengers involved in the scheme. This travel benefits could be anything form free tickets, preferential tariffs for tickets or free travel time.

Whit respect to not technological factors several key stakeholders have been highlighted in Table 45, Table 46 and Table 47. These stake holders would have interests in developing or on the contrary, suppressing the EB project.

Stakeholders with direct interests	Area of interests
Director Group (AK, RN and NT)	Finances; Preliminary analysis
The steering committee for future public transport in Northern Jutland	Working for "Collective Traffic Plan" and "The Future Runs on Rails"
Working Group for Aalborg Light rail	Works for Aalborg Light rail project
North Jutland Traffic Association Board	Traffic development
North Jutland Region / Traffic and Infrastructure	Traffic planning
Growth Forum Forum for regional business.	Financial support for concrete projects and initiatives that will contribute to the creation a Northern Jutland through growth and balance
Public Transport Authority	Interested but must continue to be informed and consulted
Ministry of Transport	Interested but must continue to be informed and consulted
Consultancy Company	Professional expertise through the process
Stakeholders with direct interests	Area of interests
Borgmesterforvaltningen (City Master Management)	Interaction with the overall planning and development

Aalborg Kommune Planning Group	Responsible for Aalborg's municipal planning
Aalborg Kommune Traffic Group	Responsible Aalborg's traffic planning
Aalborg Kommune Environmental Group	Environmental Protection and Sustainable Development
Aalborg Kommune Sustainability and Energy Division	Implementing Sustainability Strategy
Aalborg Municipality - Public Transport	Planning municipal bus routes
Politicians in North Jutland	Elections – public support
Aalborg Mayor	Elections – public support
Aalborg Airport	Access to and from airport
Fuel distributors and retailers	Economic
Service companies	Economic

Table 45 Main stakeholders with direct interests

Stakeholders with indirect interests	**Area of interests**
Local Authority Contact Committee (KKR)	Ensure political support
Aalborg University	Better access
Aalborg Industries and Chamber of Commerce	Economic growth; optimize infrastructure through road, rail, sea and air
University Hospital	Better access
Kennedy Arcade Owner	Economic
The public	Optimized transport,
Gigantium	Better access to and from
Aalborg Congress and Culture Centre	Better access to and from. Big events in Gigantium
Architecture Forum	Local interest concerning. construction and planning,

Table 46 Main stakeholders with indirect interests

Stakeholders with indirect interests	**Area of interests**
UCN	Access to and from
Aalborg Gymnasium	Access to and from
Danish Librarian School	Access to and from
Aalborg Technical college	Access to and from
Visit Aalborg	Truism
Various residents and housing associations	Access
Disabled Association / Aalborg's disability department	Access to city areas
Pensioners Association/ Aalborg's Elderly Chamber	
Developers at University / University Hospital	Future passengers. Influenced by both the construction and operation.

Table 47 Main stakeholders with potential interests

From the last category diesel suppliers would lose somewhere between 31 to 42 million DDK pre year. If a discount rate of 3% is considered along with a 14 year time frame, the annualized losses would be 29,18 million DDK. It is expected that their representatives to pace great efforts in lobbying against the EB project giving the fact the NPV of their loses would be around 408 million DDK.

Giving the fact that the busses come with a maintenance contracts the companies that used to service the diesel buses would also have annualized losses of 11 million DDK, while the NPV of the loses would be around 163 million DDK.

7. Conclusions

If looking back at the history of cars in general, and at the introductory data in Chapter 1, the penetration of fossil fueled cars on market was helped by the increasing need to travel, affordable fuel and large scale use while the setback for electric cars was the low range. Current technological developments have reached the point where the tides are about to be turned against the fossil fuel powered cars, if have not been turned already. What is seems to be missing is the political strength to implement new technologies for the fear of losing momentum in economic growth.

But are there technologies and solutions that are economically feasible and cheaper than the existing ones? At least for what the public transport sector in Aalborg is concerned, this section tries to provide a part of the answer.

Before answering the main research question the first sub question have been answered. The answer to the first sub question (*Is the EB solution cheaper than the existing situation?)* in presented in Figure 54.

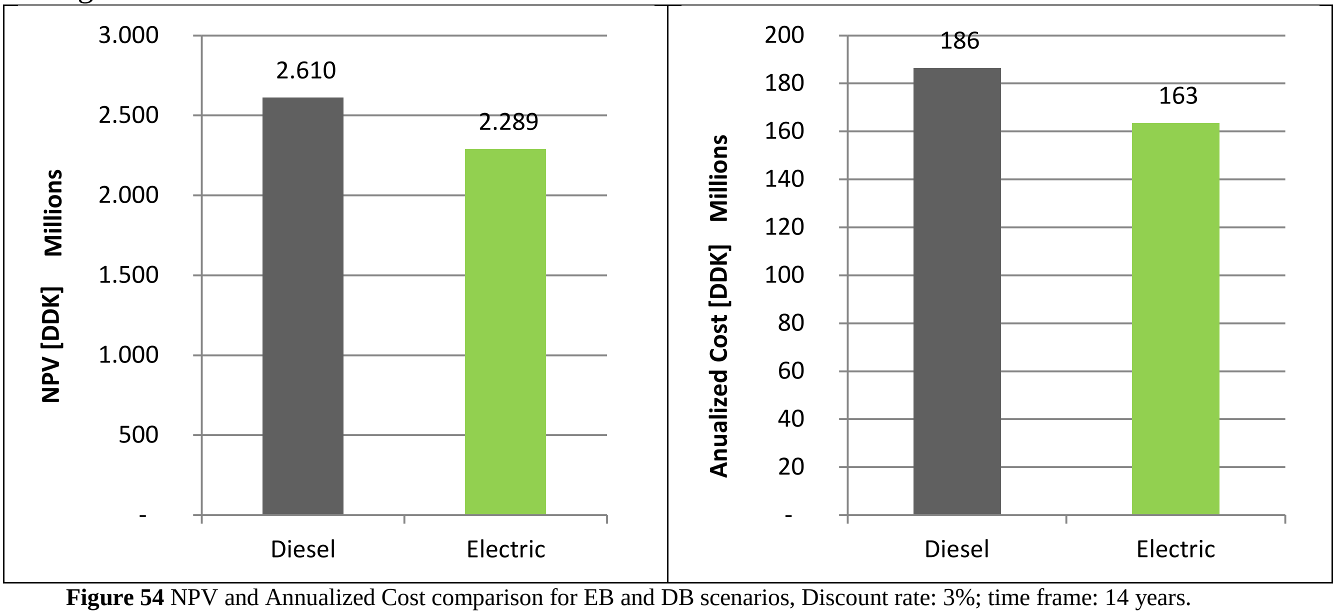


Figure 54 NPV and Annualized Cost comparison for EB and DB scenarios, Discount rate: 3%; time frame: 14 years.

With an NPV value of 2.289 million DDK the Eclectic Bus scenario is cheaper with 321 million DDK that the Diesel Bus scenario, over a time frames of 14 years.

The Annualized cost of the EB scenario is 163 million DDK being cheaper with 23 million DDK that the DB scenario.

The answer to the second sub question that takes into account the environmental perspective (*What is the electric consumption of the EB fleet?)* is presented in Figure 55. The electric consumption increases form 10,05 GWh/year to 13,54 GWh/year.

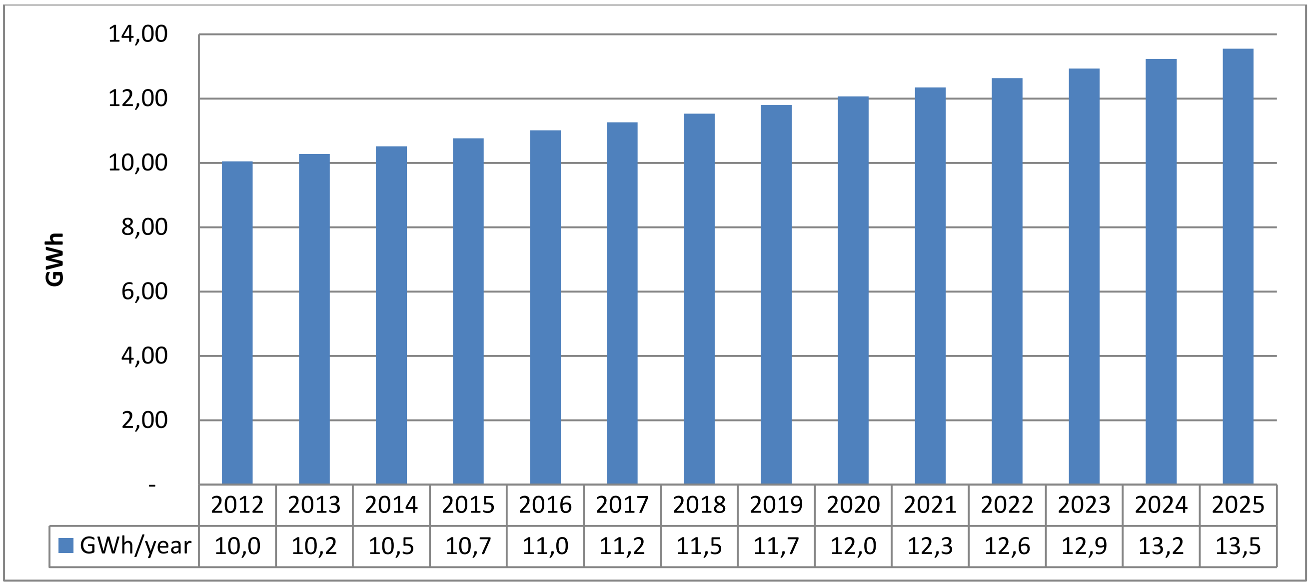


Figure 55: EB fleet electric consumption between 2012-2024.

The answer to the third sub question that takes into account the environmental perspective (*Can the needed electricity be generated locally?)* is presented in Figure 56.

All potentially available roof area (145.344 m²) from buildings used in transport sector in Aalborg municipality, can produce on yearly basis 14,09 GWh and can cover the maximum electricity demand generated by the EB fleet.

Public buildings with roof areas larger than 4000 m² situated in Aalborg municipality can produce 14,90 GWh and can cover the maximum electricity demand generated by the EB fleet during a year.

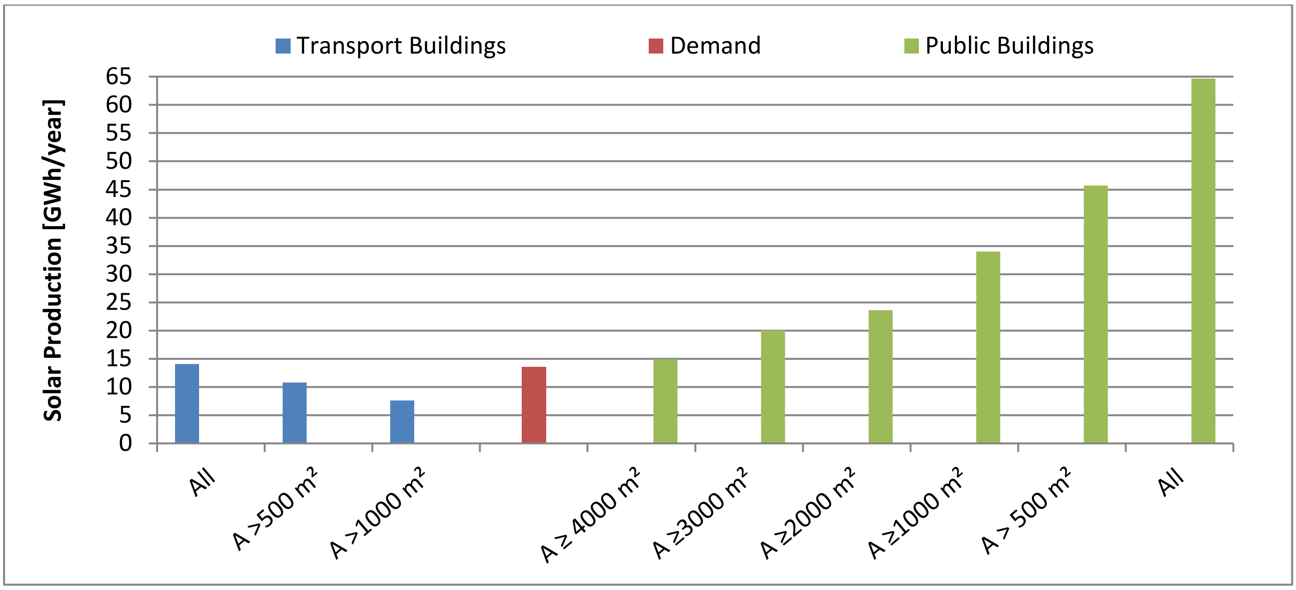


Figure 56 Maximal demand for year 2025 compared with the annual solar production for roof areas belonging to buildings used in transport sector (code 310) and public sector: Cultural buildings (code 410), Schools (code 420), Hospitals (code 430), Kindergartens (code 440), and other public institutions (code: 490); located within Aalborg municipality

The answer to the forth sub question taking that takes into account the environmental perspective (*What are the environmental implications for the EB alternative compared with the existing situation?)* is presented in Figure 57 and Figure 58. Implementing the EB fleet would reduce the CO2 emmisosn generated in a time frame of 14 years form 140.205 tons to 75.577 tons. The impact on environment expressed as the social cost of carbon can be reduced from 75 million DDK to 40 million DDK. The values presented take in to account the life cycle assessment for both Diesel and electricity.

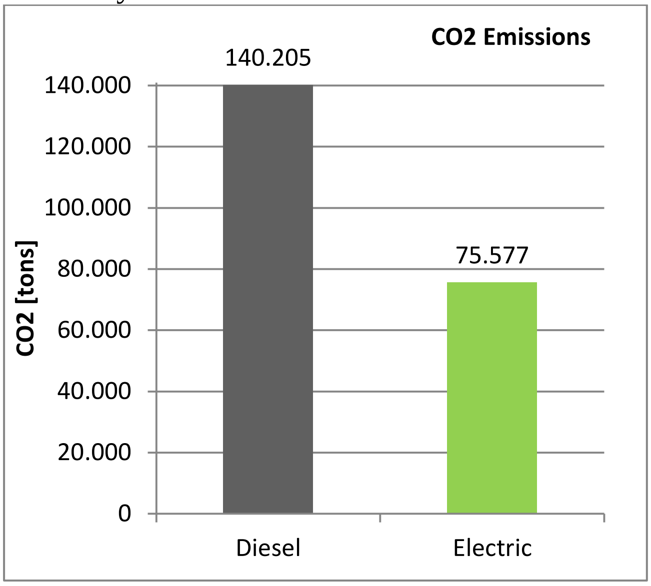


Figure 57 CO2 emission comparison for a 14 year time frame between DB and EB scenario

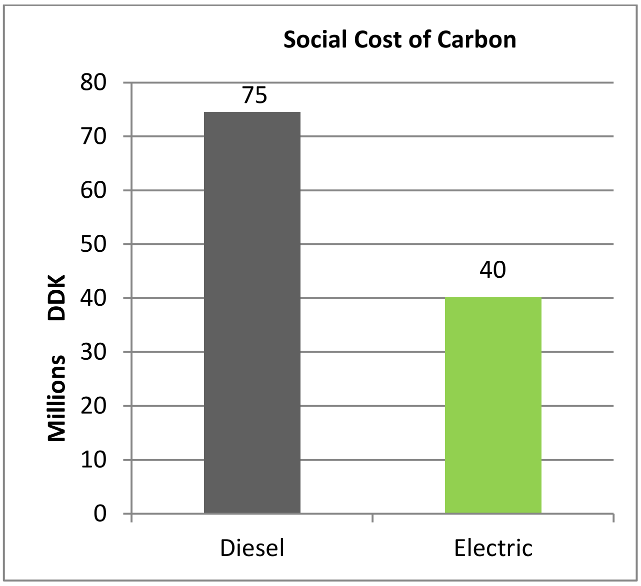


Figure 58 Social Cost of Carbon comparison between DB and EB scenarios considering thesocial cost of realizing one T of Co2 at 666 DDk , a time frame of 14 years and a discount rate of 3%

Emissions generated in DB scenarios during a time frame of 14 years (see Figure 59) like carbon dioxide (CO2), particle matter (PM), nitrogen oxides (NOx), hydrocarbons (HC), carbon monoxide (CO), are not present in EB scenario as seen In Figure 60.

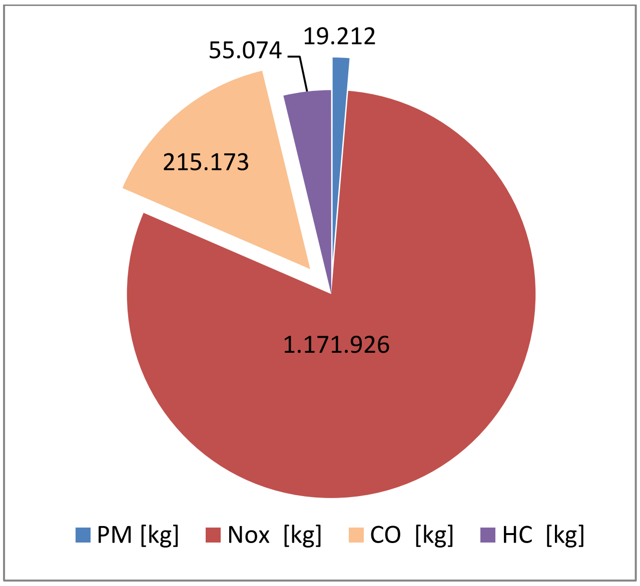


Figure 59 Other emissions generated in DB scenarios during a time frame of 14 years : carbon dioxide (CO2), particle matter (PM), nitrogen oxides (NOx), hydrocarbons (HC), carbon monoxide (CO)

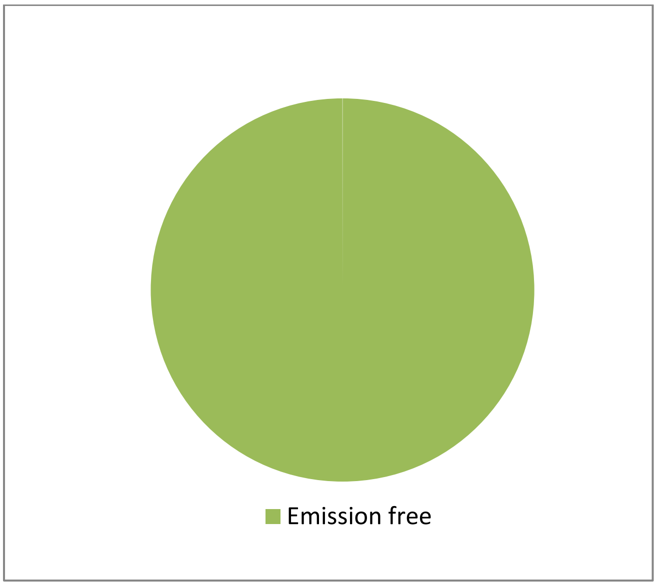


Figure 60 Other **e**missions generated in EB scenarios during a time frame of 14 years: carbon dioxide (CO2), particle matter (PM), nitrogen oxides (NOx), hydrocarbons (HC), carbon monoxide (CO)

The answer to the main research question if the *Electric Busses can be a sustainable alternative to Aalborg's current diesel based Public Transport System, is yes it can, at least form an economic and environmental perspective.*

Future works could dive deeper into aspects as how to smartly integrate an electric bus fleet into Aalborg’s energy system, and how this fleet would affect it.

Another interesting aspect to be investigated is if the bus fleet can provide energy power backup for critical systems and services in case of power failure.

Further aspects for investigations are related to the wind potential of Aalborg municipality and how wind generated electricity could be used to power the fleet. Also a mix between solar and wind generated electricity could be a better alternative to choosing one renewable source only.

Other aspects of investigation should cover the field of alternative fuels.

Also the social aspect of using electric buses and how the commuters react to these new technologies could provide new insights on how these technologies could be better integrated and accepted in urban communities.

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