# Green transition and electrification of bus fleet - The case study of Aalborg with focus on +BUS project

MASTER THESIS

Author:

**Katayoun Yousefzadeh**

Under the supervision of:

**Jakob Zinck Thellufsen**

*Sustainable Energy Planning and Management*
*The Technical Faculty of IT and Design*
*Department of Planning*
*Aalborg University*

June 04, 2020

## Table of Contents

## Abstract

The road transport sector as the main contributor to $CO_2$ emissions, caused by human activities and fossil fuel consumption, is the major challenge for climate actions in the whole world. If the target of a 40% $CO_2$ reduction in 2030 should be aimed, the challenges in this sector should also be overcome. Denmark as one of the forefront countries staying for green transition has even a high ambition to reduce $CO_2$ emissions by 70% in 2030 in all energy sectors, especially the transport sector, and become $CO_2$ neutral in 2050. However, the energy policy framework and transport-related policies have made barriers to this transition so far.

The energy efficiency, sustainability, and the security of the supply of the required fuel for the transport energy sector are also considered as other main challenges in this transition. By replacing biomass as a clean fuel for energy production, Denmark has been trying to achieve its ambitious goals through this solution. However, due to the scarcity of biomass resources, this should not be considered as a long-term solution. Therefore, another renewable source of energy is necessary to be replaced and at the same time, the needs in the transport sector can be met.

The electrification of the transport sector could provide efficient and long-term solutions for the present and day to day growing challenges in this sector. The employment of RE electricity through the smart energy system, in a collaboration between all energy sectors especially the power and transport sectors, is the key element to mitigate the $CO_2$ emissions in this sector and solve the climate challenge.

With concern to the abovementioned issues, through the technical and institutional analyses, this project has tried to investigate how the electrification of the intercity Aalborg municipality bus fleet can affect the green transition and how barriers can influence this transition. Besides, the $CO_2$ emissions saving resulted from this electrification, and the impacts on the electricity grid have been considered in this respect.

The technical analyses have been conducted through the Excel Spreadsheet and EnergyPlan simulation software. In addition to literature reviews as the main source of data collection, expert interviews have been also used to obtain more technical data in this regard. Energy scenarios have been considered for the years 2016, 2022 (the first phase of electrification), 2023 (integrating +BUS in the bus fleet), 2025, 2028 (closing down the North Jutland coal CHP plant in Aalborg), and 2030 (100% electrified bus fleet) and finally, the results of the energy system simulations have been provided.

The main results of the whole analyses have led to this conclusion that direct or battery electrification in the transport sector is the most-effective way to make a radical change and pave the way toward a green transition in the road transport sector.

If this electrification should take place, a modal shift to public transport supported by citizens in Aalborg is needed as the main influential factor. There is also a need for investment in renewable energy technologies to cover the required capacity for electrification through the employment of intelligent energy solutions and a smart energy system. However, energy-saving and less fuel consumption should be prior to RE investing. The tax system regarded $CO_2$ and electricity needs also to get reformed. Municipalities and related actors should be able and must take a role in the decision-making process and the green transition of the transport sector. And this would happen in the shadow of the governmental support through the effective and planned national political energy policies and measures. Energy development should get accelerated and advanced energy technologies need to get improved and energy technology innovations require more concern than before. If the policy would be the *frozen policy*, then the green energy goals of Denmark would not be achieved.

At last, it should be noted that COVID-19 has been the most important delimitations for this project. Under this situation and its undesired impacts on society, the transport energy sector was not an exception either. Due to that situation, no face to face expert interview was possible. Moreover, the telephone interview with the

experts except for one person was not possible either. After sending different emails to the relevant persons in the transport sector regarding city buses, and bus electrification projects in Aalborg municipality, Copenhagen, Aarhus, Italy, and the *3Emotion EU* project, only some of the emails were responded and at last, the information of just four emails could be used as a proper source for data collecting. Additionally, some had no time to answer the questions. Therefore, as a result, the lack of some relevant information could be mentioned as the main delimitation of the project, which has had an impact on the results of analyses.

| Abbreviations | |
|---|---|
| BRT | Bus Rapid Transport |
| CC | Carbon Capture |
| $CO_2$ | Carbon dioxide |
| EEA | European Environment Agency |
| ETS | Emission Trading System |
| EU | European Union |
| GHG | Greenhouse Gasses |
| HDV | Heavy-Duty Vehicles |
| OPEC | The Organization of Oil Exporting Countries |
| PPA | Power Purchase Agreement |
| RE | Renewable Energy |

# 1. Introduction

Growth in the population, economic situation, human activities and behaviors, need for mobility, more energy demand and fossil fuel intensity has resulted in a high daily level of Greenhouse gas emissions (GHG) (Energistyrelsen, 2019 a) (Hagos and Ahlgren, 2020) (Mathiesen *et al.*, 2015 a) (Energistyrelsen, 2019 b). Rising in energy consumption, as a global issue, (Madsen, 2007) resulting in a huge increment in greenhouse gas emissions, is a big challenge that the whole world is facing at the moment (State of green, n.d a) (Dansk Industri et. al, 2020).

Air pollution is the cause of climate change and millions of deaths each year, which is predominantly a result of transportation and industries. If no action is taken in the future, the effects would be even more. (State of green, n.d a)

## 1.1 Fossil fuels and Greenhouse gas emissions

Despite a total decrease in GHG emissions in the total energy supply in The European Union (EU), from 1990 (the UN base year) to 2016, the share of GHG emissions in the transport sector (the gray line) has increased from 878 in 1990 to 931 million tons in 2016 (European Environment Agency, 2018 a). It presents a rise of around 19% up to 2016 (European Environment Agency, 2018 b). The GHG emissions trend by sectors in the EU is illustrated in figure 1.

The European Union has a long-term target of GHG emissions reduction of 80-95% by 2050 (Hagos and Ahlgren, 2020). Currently, the transport sector only accounts for one-fourth of the emitted Carbon dioxide ($CO_2$) in the EU (State of green, n.d b), which is a high level of emission.

Regarding the $CO_2$ emissions in the transport sector and emissions from other energy sectors, the EU has determined a common policy framework for energy and climate for its member states (Lund, P. D. *et al.*, 2019). Under this policy framework, the EU has defined a package called "Clean Energy for all Europeans" which follows these policy goals by 2030:

• 40% reduction in $CO_2$ emission compared with 1990
• 32% share of renewable energy
• 32.5% share of energy efficiency target (European Commission, 2017).

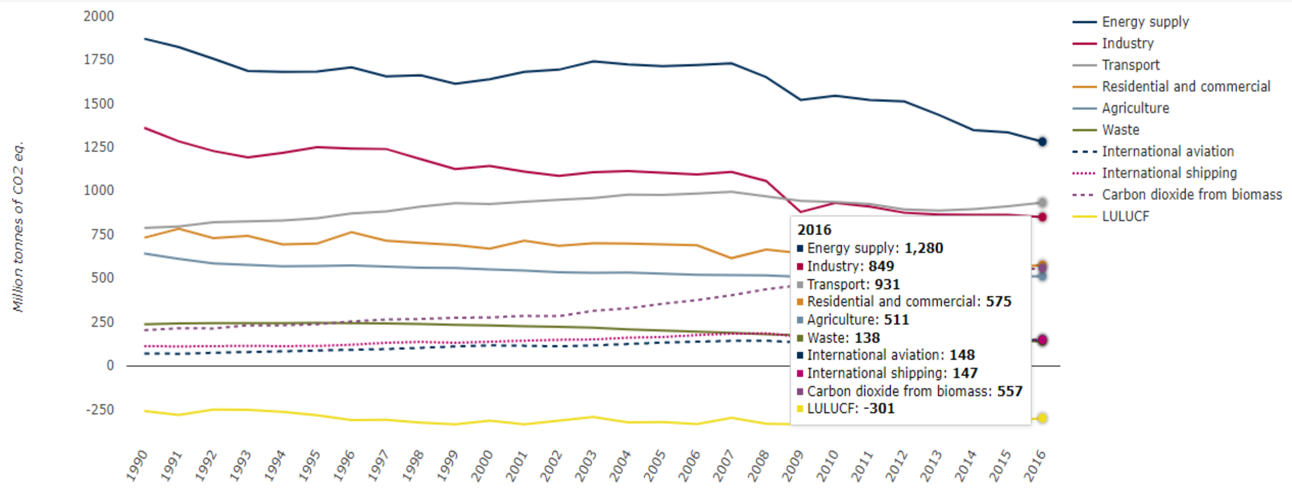


*Figure 1.The EU-28 GHG emissions by sectors, 1990-2016 [MTons] (European Environment Agency, 2018 a)*

However, each country has its national targets under international obligations and frameworks (Bramstoft, and Skytte, 2017), since energy challenges which each country faces differ from other countries. Each country must find its unique energy model to be able to make a green transition toward a low-carbon energy system. Some countries need a more strength grid infrastructure for securing a stable electricity supply, while others need to act for overall energy consumption reduction. (State of green, n.d c)

In line with the EU goals and under a national obligation, Denmark has defined a target of decarbonization of the electricity and heating sector by 2030 and 70% reduction in GHG emissions by 2030 (Andersen, 2020 a)( Danish Energy Agency, 2018 a) instead of 40% reduction. The agreement for the ambitious target of a 70% reduction in GHG emissions was concluded on a new climate law by the Danish Parliament in December 2019 (Klimarådet, 2020 a).

Besides that, Denmark should reduce GHG emissions by 39% by 2030 in non-ETS (the emissions outside the EU ETS system such as waste, agriculture, transport, households, etc) and tries aiming the target of a fossil-free transport sector by 2050 (European Commission, 2017). In other words, Denmark aims to be completely zero carbon emission and independent of fossil fuels in all energy sectors by 2050 (Danish Energy Agency, 2018 a).

As previously mentioned, more energy demand has resulted in more energy consumption. The increment in energy consumption, used by energy-consuming sectors in Denmark, is illustrated in figure 2.

The final energy consumption has had an increment from 604,01 PJ in 1990 to 644,51 PJ in 2018 (these values cannot be precisely seen in figure 2). As can be seen in figure 2, households, and transport sectors have had the highest share of energy consumption among others. The energy consumption in the household sector has been increasing from 169,33 PJ in 1990 to 192,25 PJ in 2018. This value for the transport sector has been 170,22 PJ in 1990 and 222,74 PJ in 2018. (Energistyrelsen, 2019 c)

By comparing the energy consumption in the households and transport sectors, it is clear that the transport sector stands as the biggest energy consumer in the Danish energy sector. For a better understanding, the trend of increment in energy consumption in the transport sector (Energistyrelsen, n.d d) is illustrated in figure 3.

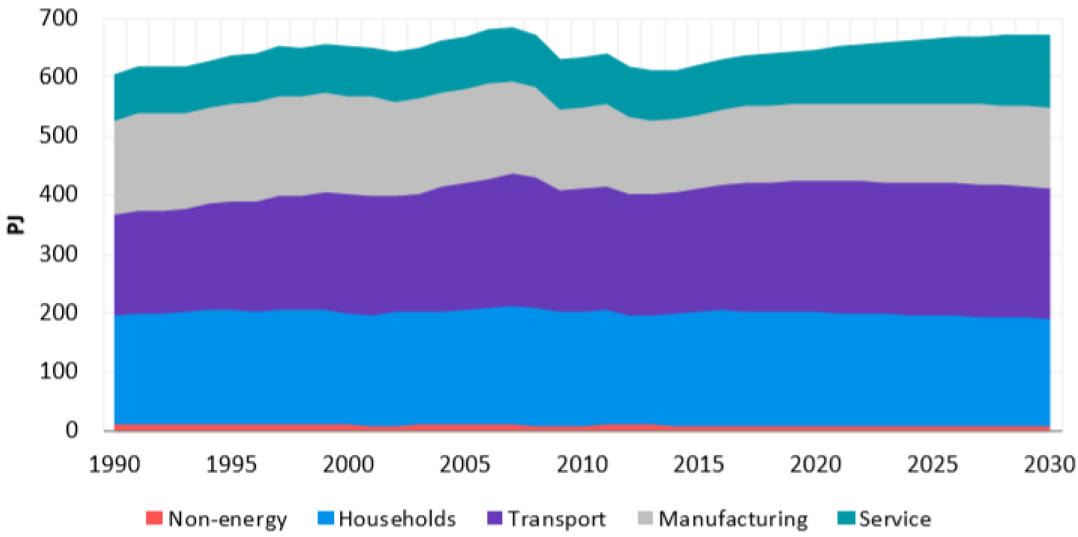


*Figure 2.Final energy consumption by the energy-consuming sectors [PJ] (Danish Energy Agency, 2018 a)*

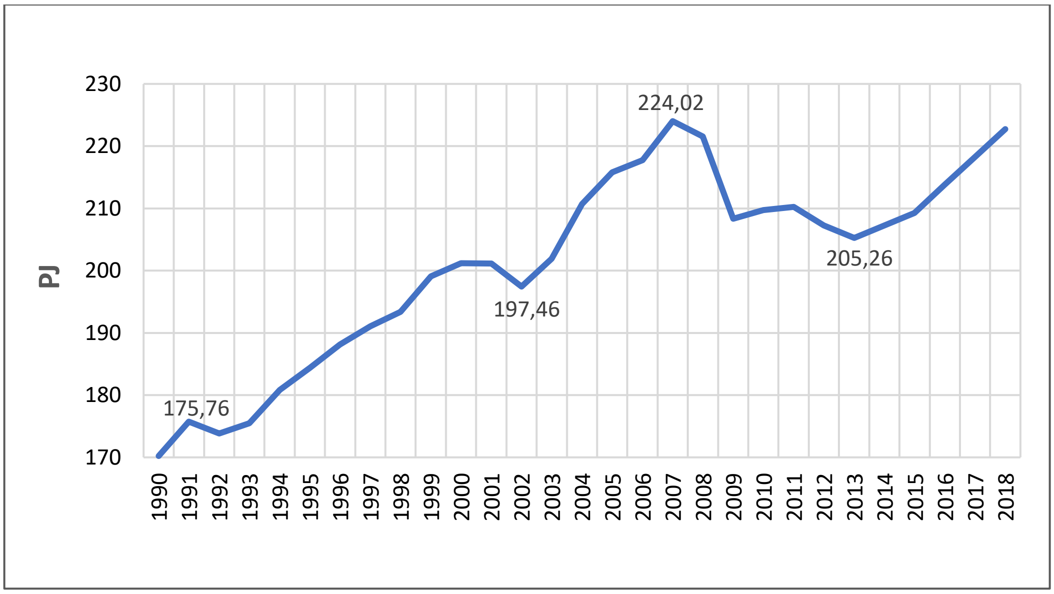


*Figure 3.The total final energy consumption in the transport sector from 1990 to 2018 [PJ] (Own figure)*

To go in further detail, the transport sector in Denmark is consists of road, rail, aviation, sea, and military transport (Danish Energy Agency, 2018 a). The energy consumption by each sector for the years 1990, 2018, and expected energy consumption in 2030 can be seen in figure 4 (Energistyrelsen, n.d d) (Energistyrelsen, 2019 c). It is clear from this figure that the road transport sector, containing passenger cars, vans, trucks, busses, and motorcycles (Energistyrelsen, n.d d), is allocating the highest energy consumption level among other transport sectors even in 2030.

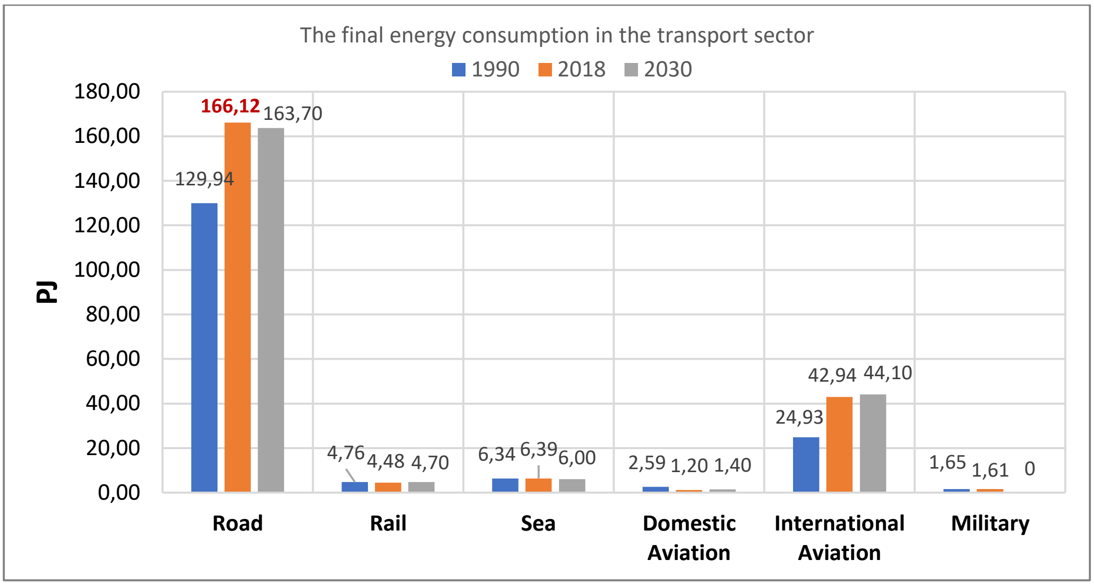


*Figure 4.The final energy consumption in the transport sector in 1990, 2018 and 2030 prediction [PJ] (Own figure)*

Among the different fuels utilized in this sector in 2018, Gas-/Diesel Oil has been contributed to the highest fuel consumption. The energy consumption by fuel types is illustrated in figure 5. It is expected that the consumption of diesel would stand around 99,6 PJ in 2030 (Energistyrelsen, 2019 c), which means that in the absence of energy measures and policies no change would happen in concern with a consumption reduction in this fuel type.

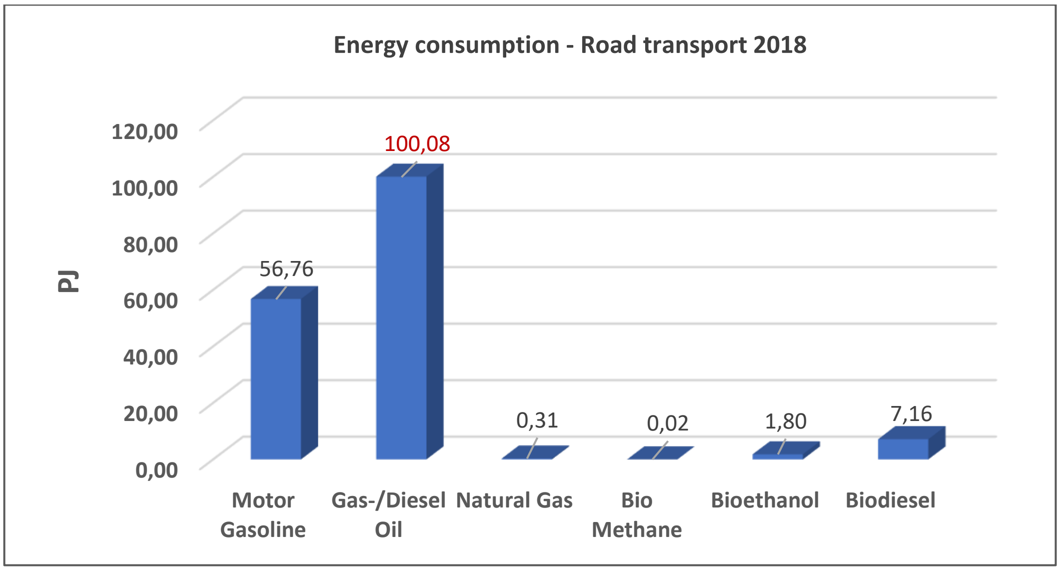


*Figure 5.The energy consumption by fuel types in the road transport sector in 2018 [PJ] (Own figure)*

From 1990 to 2014 there has been an average $CO_2$ emission reduction by 55% in all energy sectors except the transport sector. Instead, the arisen $CO_2$ emission in the transport sector has had a range of 17% to 48%. (Hagos and Ahlgren, 2020)

From the total amount of 34.511 tons of $CO_2$ emissions made in all sectors in 2018, 15.560 tons of $CO_2$ has been emitted in the transport sector caused by oil and natural gas consumption (Energistyrelsen, n.d d), which is just 1.700 tons less than half of the total emission. A comparison of these two can be seen in figure 6.

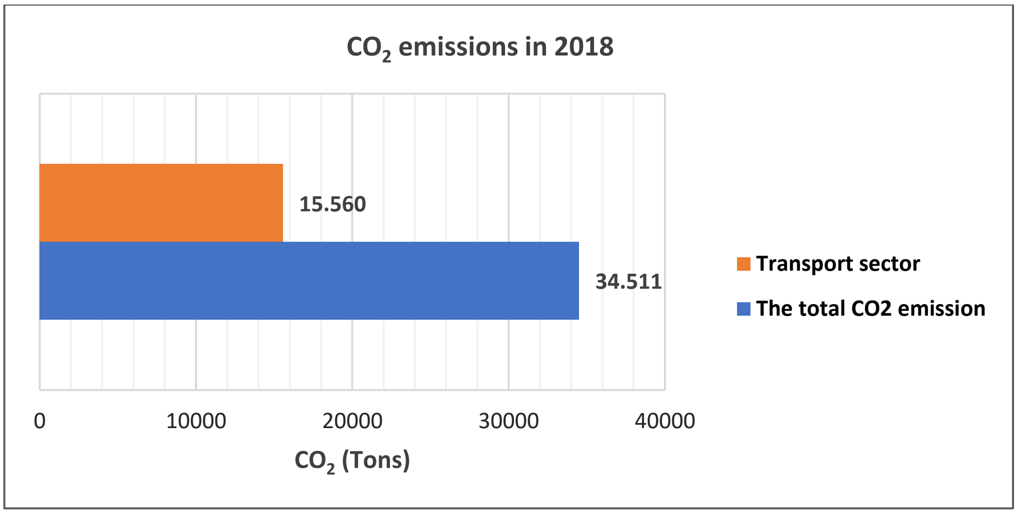


*Figure 6.The CO2 emission caused by the transport sector in comparison with the total CO2 emission in 2018 [Tons] (Own figure)*

The $CO_2$ emission in different energy sectors and expected emission reduction toward 2030 can be seen in figure 7. To reach the goal of a 70% reduction in $CO_2$ emissions the emission level in the energy sector needs a reduction of 31 to 10-12,5 million tons in 2030 (State of green, 2020 d).

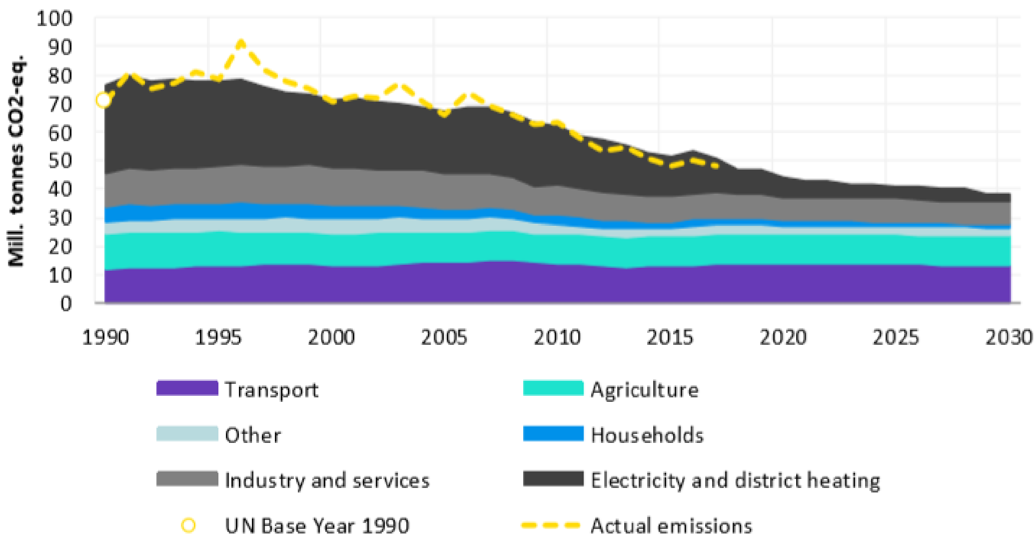


*Figure 7.CO2 emission by sectors from 1990-2030 [MTons] (Danish Energy Agency, 2018 a)*

The actual GHG emissions in Denmark in 1990 has been 70,3 million tons of $CO_2$ equivalents. According to the Energy Agency's basic projection from 2019, *BF19*, (Energistyrelsen, 2019 c) this amount would approximately fall to 38 million tons by 2030. But, then a 70% reduction from 1990 means that the $CO_2$

emissions must be reduced to about 21,1 million tons. In other words, during the next ten years, additional $CO_2$ savings of over 17 million tons would be needed. (Wittrup. S., 2020 a) The values can also be seen in figure 8.

To reach the goal of a 70% reduction of $CO_2$ emissions in the energy sector, a reduction from 31 to 10-12,5 million tons would be needed by 2030 (State of green, 2020 d). The results of analyses show that the emission level in the transport sector needs a reduction from 11,9 to 7,8 million tons in 2030 if the target of 70% emission reduction should be aimed. It means that a 4,1 million tons reduction would be needed in the absence of no new initiatives (Wittrup. S., 2020 a). This required amount of $CO_2$ reduction is also illustrated in figure 8.

| | **BF19** | **Mål** | **Reduktion** |
|---|---|---|---|
| Bygninger | 1,7 | 0,1 | -1,6 |
| Industri | 4,9 | 2,0 | -2,8 |
| El + fjernvarme | 2,9 | 1,2 | -1,6 |
| Transport | 11,9 | 7,8 | -4,1 |
| Nordsø + raffinaderier | 1,9 | 1,9 | - |
| Landbrug | 10,5 | 9,2 | -1,3 |
| Øvrige | 4,5 | 2,8 | -1,7 |
| CCS | - | -3,9 | -3,9 |
| **TOTAL** | **38,2** | **21,1** | **-17,1*** |

*Figure 8.Denmark's CO2 emissions in 2030 [Mtons] (Wittrup. S., 2020 a)*

For a better understanding and illustration of the difference between the prediction and the required $CO_2$ emissions reduction values in 2030, figure 9 is provided below.

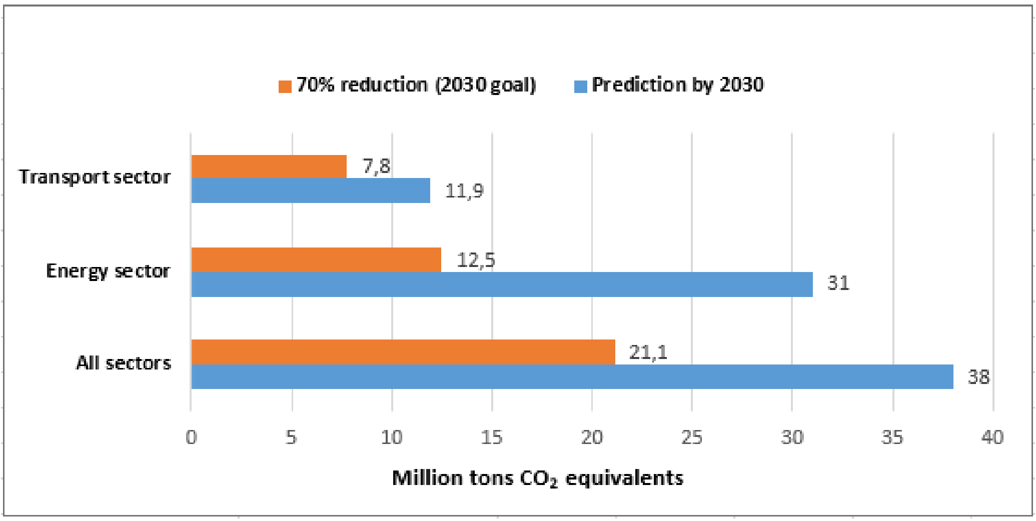


*Figure 9.Million tons of CO2 equivalents in 2030 [MTons] (Own figure)*

It is expected that in 2030 the GHG emissions would face a reduction of only 46% compared with 1990 in the absence of new energy measures (Danish Energy Agency, 2018 a). It is also expected that the transport sector would account for 34% of total emissions in Denmark in 2030 (Ahanchian, M. et al., 2019) (Energistyrelsen, 2019 a) (Mathiesen *et al.*, 2015 a).

To this end, based on the aforementioned issues, a reduction in fossil fuel consumption and a shift toward renewable energy sources would be a necessity if the goal of a 70% reduction in $CO_2$ emissions by 2030 should be gained.

## 1.2 Renewable Energy

Renewable energy sources could cover about 75 % of the world's share of energy consumption by 2030 (Madsen, 2007). Based on the statistics from (Danish Energy Agency, 2018 a), Denmark's share of RE sources is expected to reach 41% in 2020, and in 2030, 30% exceeded of the EU obligation, which would be around 54% (Energistyrelsen, 2019 a) (Danish Energy Agency, 2018 a). Since the below figure is from 2018, the exceeded share for 2020 cannot be seen in this figure.

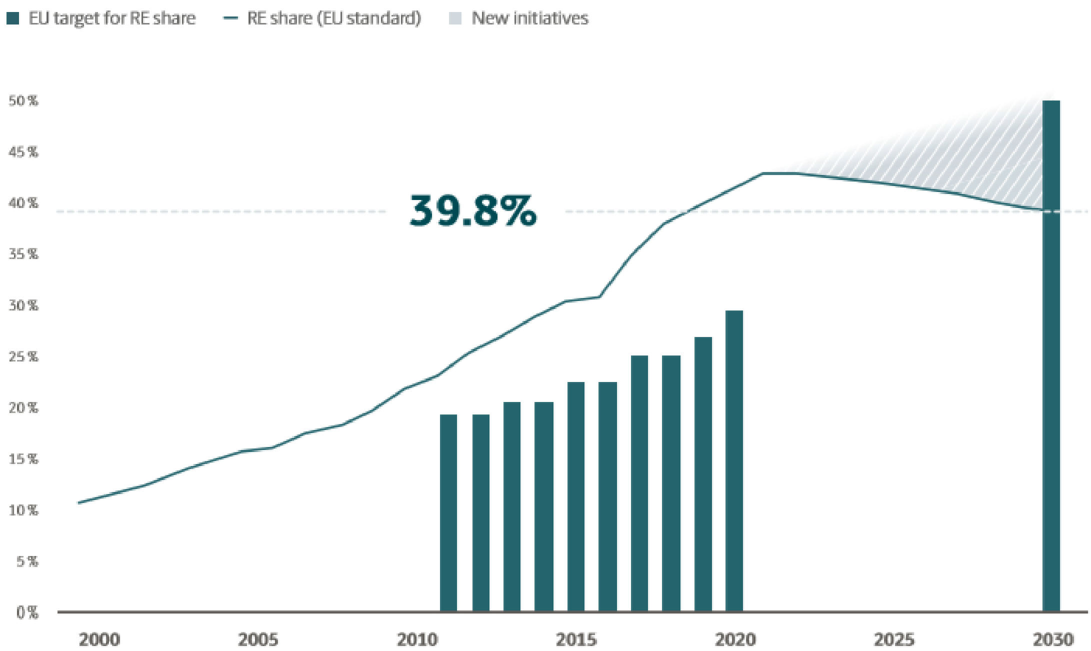


*Figure 10.Total expected Denmark's share of RES by 2030 [%] (Danish Ministry of Energy, Utilities and Climate, 2018)*

Due to more energy demand in the future, resulting in a rise in energy consumption, in the absence of new energy policies and initiatives, the RE share would get a decrement from 2020 towards 2030, around 40% in 2030. The difference in the RE share is illustrated by the shaded area (Danish Ministry of Energy, Utilities and Climate, 2018).

The calculated share of RE from 2017 until 2030, based on the definition in 'RE Directive' (European Commission, n.d) and for different energy sectors is also illustrated in figure 11.

As can be seen in figure 11 despite increasing the share of renewable energy (RE) utilization in electricity and heating energy sectors, the lowest RE share is assigned to the transport sector. It means that the transport sector is still highly dependent on fossil fuels. (Danish Energy Agency, 2018 a) (Ahanchian, M. et al., 2019) (Energistyrelsen, 2019 a) (Mathiesen *et al.*, 2015 a)

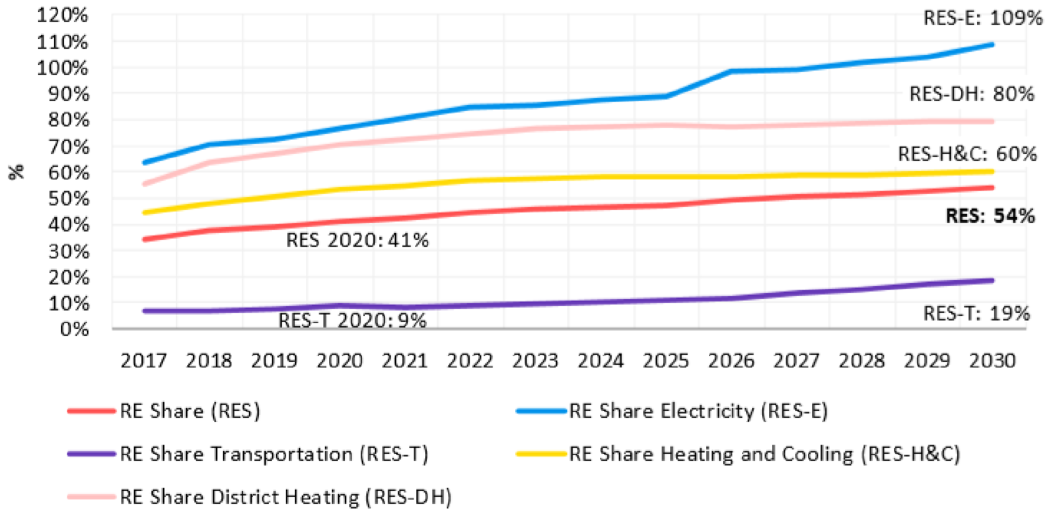


*Figure 11.RE shares in different energy sectors, 2017-2030 [%] (Danish Energy Agency, 2018 a)*

As also previously mentioned, the transport sector stands as the main contributor to $CO_2$ emission in the Danish energy system (Energistyrelsen, 2019 a) (Mathiesen *et al.*, 2015 a). Due to growth in demand, the energy consumption in the transport sector would get an increase of 0.2% annually, resulting in more GHG emissions (Energistyrelsen, 2019 a). The next section will have a look into the $CO_2$ reduction approaches.

## 1.3 $CO_2$ reduction

To reduce the $CO_2$ emission and take a transition toward a fossil-free transport, behavioral change and the modal shift should be mentioned as the two key components in this regard. Less utilization of passenger cars and instead shifting to a higher level of public transport utilization can be concerned in this respect. (Ahanchian, M. et al., 2019)

Transport demand should vary, and unnecessary journeys should come to an end. Private cars might be used differently in the future since they are the main cause of carbon emission in the transport sector. The share of private electric vehicles (EVs) should be increased, however, it makes a question of to what extent this share would get an increase. If the desire is to have sustainable mobility in the future, this would not be a final solution. (INDEPENDENT, 2020)

Relying on just technologies and fuels would not be enough for reducing the high level of current emission. Higher demand for electric vehicles could also result in other problems and new challenges. Future transport needs a shift from today's dependent car transport model. Shared and public transport and active travel should be the first choice in the future. And fewer car trips need to be supported through a cost-effective and appropriate public transport network. (IBID)

Other alternatives should be replaced with fossil fuels. However, the availability and efficiency of those alternative fuels and resources compared to fossil fuels are of great importance, since these factors would have a significant impact on the decarbonization of the transport sector. (Ahanchian, M. et al., 2019)

The high energy density of fossil fuels and cheap storage make fossil fuels more intensive. Consumers can call on for energy whenever they require it, therefore it would be easily accessible. As a result, there would be needed for less flexibility in the demand side of the energy system, which makes fossil fuels more intensive. However, due to the hazards of GHG emissions, their effects on health and climate, etc., fossil fuels should be replaced by alternative fuels. (Vad *et al.*, 2015) Additionally, alternative transport fuels could also reduce the energy system dependency on a single source of energy (Mathiesen *et al.*, 2015 b).

Further to what mentioned, another important and influencing parameter on fossil fuel reduction would be a suitable and sufficient infrastructure for deploying new and sustainable energy. However, due to the new fuel types and technological change, decarbonization of the transport sector is facing a big challenge that needs serious concern to mitigate the GHG footprint and its impact on the environment and society as a whole. (Bramstoft and Skytte, 2017) (Ahanchian, M. et al., 2019) (Lund, P. D. *et al.*, 2019)

Based on the abovementioned issues, to achieve an optimal solution, a radical change in all energy sectors and collaboration between them through smart energy grids, i.e. thermal, electricity, and gas grid would be the prerequisite condition (Lund and Persson, 2015) (Lund, 2014 a). In this respect, energy efficiency would play an important role, since higher energy efficiency could cause less energy resources consumption, resulted in more energy-saving, avoiding additional capacity investments, and minimization of the energy supply costs (Zvingilaite et al., 2012) (Danish Energy Agency, n.d).

However, to achieve the goal not only the technical innovation and development issues should be concerned, but also making the opportunities for transport technologies to emerge in the market would be of importance (Hagos and Ahlgren, 2020). New innovative and advanced solutions, which tribute the environment and mankind should be developed, get matured, and implemented (Madsen, 2007).

If the adopted policy would be the 'frozen policy' and no efforts and initiatives are taken to phase out fossil fuels from the energy system, no development would take place toward having a $CO_2$ neutral transport sector (Danish Energy Agency, 2018 a). "A frozen-policy scenario describes a scenario with existing measures in which no new policies are introduced." (IBID) Thus, it can be concluded that in the absence of efficient energy policies and initiatives, the aim of a 70% $CO_2$ emission reduction would not be achievable.

Based on the aforementioned issues, the below section tries to clarify alternative fuels for fossil fuels, as the main reason for $CO_2$ emissions.

## 1.4 Energy production and alternative fuels

Currently, due to the significant amount of fuel usage by vehicles, energy production costs are related to the fuel costs. Nevertheless, in a Smart Energy System, energy production costs are dependent on investment costs and not fuel costs. Additionally, the smart energy system could cause less fuel consumption by 75%. (Vad *et al.*, 2015) Therefore, a secure energy supply could take place through intelligent and smart integration of various RE sources in the energy system (Smart Energy Networks, 2015).

Denmark benefits a great suitable infrastructure (Alberg and Andersen, 2018) for providing a future sustainable energy system (Lund et al.,2014). Therefore, intermittent renewable energy sources, i. e wind and solar, and bioenergy, as the two main forms of energy production in Denmark, have gained much attention due to the short-term and long-term decarbonization of the transport sector (Mathiesen *et al.*, 2015 a).

Since no single energy source and technology has been found to substitute others (Hagos and Ahlgren, 2020), a combination of alternative fuels would still be required to make the path toward the decarbonizations of the transport sector in future (Mathiesen *et al.*, 2015 a).

In both IDA and DEA energy scenarios, to the purpose of meeting the transport demand in 2035 and 2050, the priority has been given to the electrification, and then to the biomass utilization for fuel production in this sector. The part of demand which is not possible to be met by direct electrification would be met by electrofuels, bio-electro fuels, and $CO_2$ electrofuels. This has been mainly due to the minimization of biomass usage to keep biomass utilization in a sustainable level aligned with the available biomass potential in Denmark

(Mathiesen *et al.*, 2015 a). An illustration of the electrofuels production process, Power to X, (Brauns and Turek, 2020) (Siemens, n.d) (DoScience, n.d) (INDEREN, n.d) is provided in Appendix D.

### 1.4.1 Bioenergy

Currently, biomass is the most common and prevailing form of renewable energy source, and it is expected that the demand for that would get increased in the future (Danish Energy Agency, n.d f). Biomass resources e.g. wood, straws, crops, etc. are generated through the ingenious photosynthesis process. Through this process carbon dioxide ($CO_2$) will be captured from the atmosphere and energy will be stored in the plant. While biomass is getting combusted, $CO_2$ will be released through the process. The amount of emitted $CO_2$ will be equal to the initial amount of $CO_2$ trapped during photosynthesis. Thus, it means that there will be no $CO_2$ net emission to the atmosphere. (Mathiesen *et al.*, 2015 a) (Madsen, 2007)

In line with the international guidelines, since the biomass resources can be reproduced by plant growth (Danish Energy Agency, 2017 c), the biomass is considered a $CO_2$ neutral, sustainable, environmental-friendly, and renewable source of energy production in the energy system. (Madsen, 2007) (Lund, H. *et al.*, 2019) (Danish Energy Agency, 2017 c) At the moment, almost 60% of the renewable energy in the EU is originated from biomass sources crops (Scarlat et al., 2019). However, biomass resources are scarce (Erb et al., 2016), and there are also other challenges regarded to the biophysical boundaries and policy restrictions (Erb et al., 2016).

Likewise, there is only a limited and inexpensive amount of biomass waste resources available in Denmark (Energinet, 2015) (Mathiesen *et al*., 2015 a). Thus, the rest of the required energy sources for energy supply should be provided by other energy sources. At the moment a high share of Denmark's required biomass resources is imported from countries outside of Denmark (Klimarådet, 2018 b). Therefore, it can be understood that the actual biomass demand is not just provided by the available domestic share, but biomass traded internationally should also be concerned (Mathiesen *et al.*, 2015 a).

Currently, two-thirds of overall renewable energy consumption in Denmark is allocated to bioenergy (Danish Energy Agency, n.d d). The share of energy consumption from biofuels in the road transport sector has been 9 PJ in 2018 (Energistyrelsen, n.d d). By comparing this share with the total energy consumption of 166,12 PJ in 2018 in the road transport segment, mentioned in section 1.1, it could be calculated that biofuels account for around 1/18 (5,5%) of total energy consumption in this segment in 2018. In 2030, it is expected that this share would increase to 9,8 PJ, which corresponds to the energy consumption of 4% by the transport sector (Danish Energy Agency, 2018 a).

Based on *IDA energy vision 2050* the realistic potential of biomass to the purpose of utilization in the energy sectors is 233 PJ. From that, a demand share of 133 PJ is expected for the transport sector in 2050. (Mathiesen *et al*., 2015 a)

Based on the abovementioned issues and concerning the available biomass resources, in the desired future zero-carbon emission energy system, the amount of ongoing fossil fuel consumption cannot be replaced with just the available biomass resources. For that reason, in contrast with DEA, IDA energy vision has considered and evaluated energy scenarios aiming less biomass consumption in the future transport system. This reduction in biomass consumption has been done through biofuels energy storage, integration of energy sectors, and utilizing other energy resources in the system. (IBID).

Further to the biomass resource limitations, there are also some disadvantages and challenges regarding biomass collection, transferring, distribution, and storage. Collecting, transportation, and distribution of biomass sources require the heavy-duty vehicles which themselves need fuels to perform the process from start to the end. (Nunes *et al.*, 2020)

Although biomass is considered a clean source of energy, the type of biomass resource and the way that biomass resources are utilized for biofuels production will influence GHG emissions. For example, whether new trees have been planted or not. But it should be kept in mind that replacing the new trees would not happen at the same speed of cutting trees and deforestation. Additionally, due to the population growth, lands could be utilized for other purposes than biomass production (Mathiesen *et al*., 2015 a) (Danish Energy Agency, 2017 c). Thus, make it assured that the biomass has been used sustainably would be of great importance.

Some researchers have mentioned in their analyses that aiming the target needs for a higher share of biofuels utilization in the transport sector (Bramstoft and Skytte, 2017) (Mathiesen *et al*., 2015 a). The reason for that has been mainly due to less price and more energy efficiency compared with electrification (Mathiesen *et al*., 2015 a). However, regarded biomass limitation resources and domestic availability, other researchers conclude the key role of biofuels as a medium-term solution and not a long-term solution (Bramstoft and Skytte, 2017) (Mathiesen *et al*., 2015 a) (Hagos and Ahlgren, 2020). Therefore, biomass fuels should be utilized when there would be no other option than employing these resources. Nevertheless, energy technologies are getting advanced every moment and other sources of energy could sustainably be applied in the energy system in a near future. (Mathiesen *et al*., 2015 a)

Due to the growth in population, resulting in more energy demand and the need for a $CO_2$ natural energy source, the demand for biofuels will get increased in the future. Thus, to maintain the security of supply and even prevention of the long-term biomass utilization impacts on the environment, electricity as another alternative source of energy production would play a significant role in this respect. (Bramstoft and Skytte, 2017) (Mathiesen *et al*., 2015 a).

### 1.4.2 Electricity

Denmark benefits a suitable energy infrastructure, providing great potential to utilize non-fuel and renewable energy sources such as wind power (onshore and offshore), photovoltaic, and wave energy for generating electricity (Energinet, 2015). These energy sources play a crucial role and would form the backbone of the Denmark energy system in the future (Mathiesen *et al*., 2015 a). Despite this plentiful opportunity, intermittent RE sources could pose a challenge to the electricity grid due to their fluctuating energy production (Danish Ministry of Energy, Utilities and Climate, 2018). Therefore, the limitation of bioenergy resources to a sustainable level mentioned also in section 1.4.1, and at the same time accommodating a large amount of fluctuated renewable energy in the grid would be of great importance. (Mathiesen *et al*., 2015 a)

If a high amount of electricity is produced and there is no consumption, the energy will disappear (Godske, 2017 a) The same would happen while not being able to export the produced excess electricity to the neighboring countries due to the congestion in transmission lines (Mathiesen *et al.*, 2015 a).
Therefore, the most cost-effective solution for excess electricity utilization would be the integration of that into the energy system. Here, the concept of Smart Energy Systems would be more prominent. (Vad *et al.*, 2015) While electricity is cost-effectively used in other sectors, especially the transport sector, it can be also traded on international electricity markets. (Mathiesen *et al*., 2015 a)

As previously illustrated in figure 11 section 1.2, due to more RE sources deployment, it is expected that the electricity share (RES-E) in 2028 would exceed 100% and reach 109% in 2030. Thereby, regarding a low share of 19% RE sources in the transport sector, (Energistyrelsen, 2019 a) there would be a great possibility of the utilization of this amount of renewable electricity in the transport energy sector. For that reason, both the electricity and the transport sector need to be well managed to facilitate the way toward the target of GHG emissions reduction (Lund, H. *et al*., 2019).

Both *IDA ENERGY VISION 2050* (Mathiesen *et al*., 2015 a) and *DEA* (Energistyrelsen, 2019 a) have had a special focus on the electrification of the transport sector. For the transport sector, DEA uses the projection '*FREM'* to model the energy consumption in this sector (Energistyrelsen, 2019 b). Based on that, the prediction of allocated electricity consumption shares for different use and the usage level in 2030 is illustrated in figures 12 and 13.

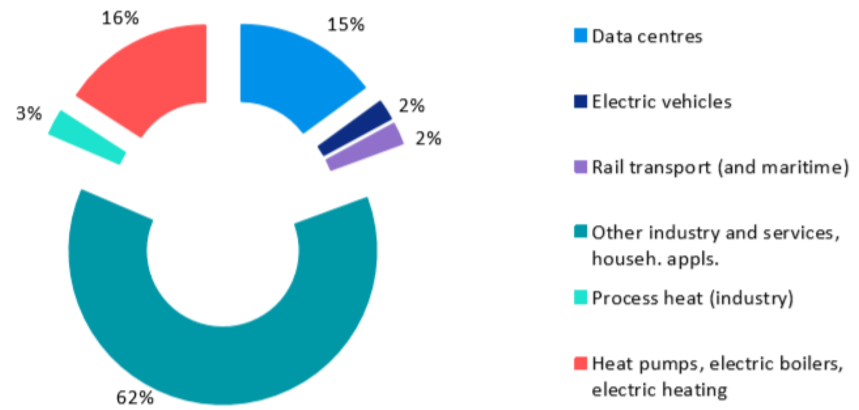


*Figure 12.Electricity consumption in 2030 [%]. The consumption does not include grid losses (Energistyrelsen, 2019 a)*

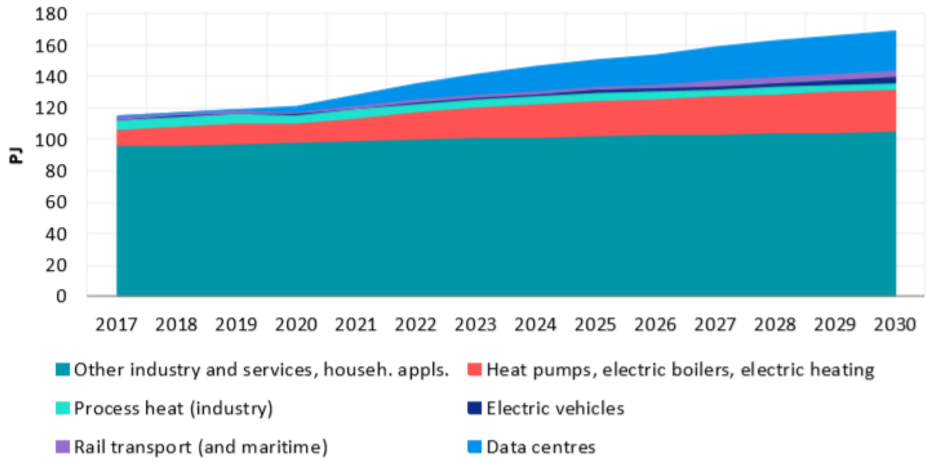


*Figure 13.Electricity consumption, 2017-2030 [PJ]. The consumption does not include grid losses (Energistyrelsen, 2019 a)*

It is clear from figure 12 that the transport sectors will contribute only 4% of electricity consumption (Energistyrelsen, 2019 a). However, the focus is mainly on electric vehicles and rail transport and not all the transport segments (Energistyrelsen, 2019 c). As can be seen in figure 14, light road and rail allocate the highest electricity consumption share and the lowest share contains the maritime and heavy load. Due to the electrification of these segments, an annual increment of the electricity consumption of 13% is expected to occur in the transport sector up to 2030 (Energistyrelsen, 2019 a). Therefore, the electricity demand would meet an increase of about 2 PJ in 2020 up to about 7,5 PJ in 2030 (IBID), which can be seen in figure 14. However, in comparison with the total electricity consumption of about 170 PJ in 2030 (IBID), figure 13, this amount of electrification in the transport sector is very low.

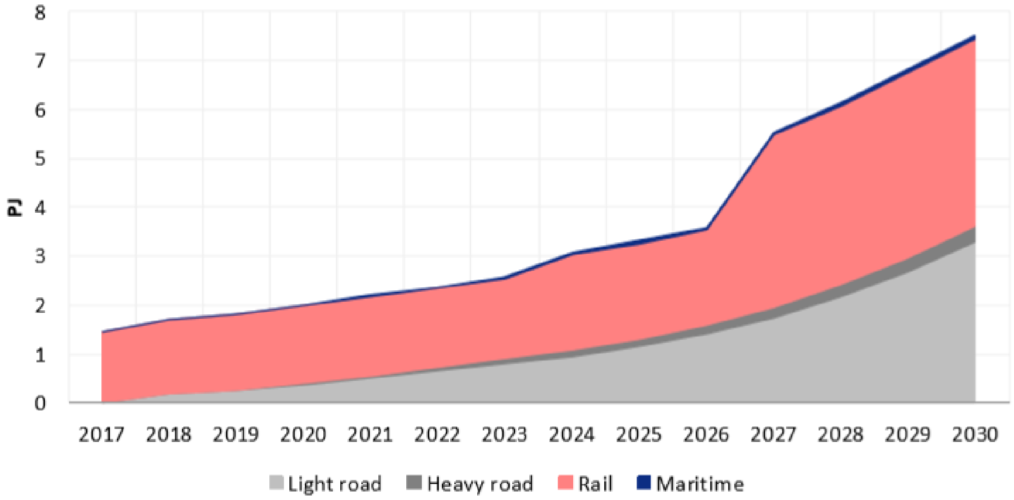


*Figure 14.Distributed electricity consumption in the transport segments, 2017-2030 [PJ] (Energistyrelsen, 2019 a)*

Likewise, in IDA's Energy Vision 2050 also mentioned in section 1.4, in the transport sector, the priority is the electrification of this sector, direct or battery electrification. However, just rail, van, and passenger car transport segments contain a large share of this electrification. The reason for that is meeting the heavy-duty vehicle electricity demand such as aviation, marine, truck, and busses is a huge challenge due to the costs and electrification challenges. (Mathiesen *et al.*, 2015 a)

As the focus in IDA has been mainly on the modal shift to rail, only 15% of the electrification has been assigned to the buses. Based on the IDA analysis, the electricity consumption by busses would reach 0,2 PJ in 2035 (Mathiesen *et al.*, 2015 a). To compare this with (Energistyrelsen, 2019 c), an electricity consumption share of 0,3 PJ for busses is expected in 2030. Based on IDA, the transport demand will get increased by 42% by 2050 and the electricity consumption is expected to reach a value of 0,5 PJ in 2050 in this sector. However, the growth rate and modal shifts, are mentioned as the two key parameters, which shape the transport demand in the future. (Mathiesen *et al.*, 2015 a) (Lund, P. D. *et al.*, 2019)

Based on what all experiences show, a plan is needed to focus on which technologies should be employed in each section in the energy system, including how much biomass should be used and how to integrate electricity and other sectors such as the transport sector as much as possible (Wittrup. S., 2020 b). To make an achievable clean energy transition in the transport sector, the electrification of this sector, biomass usage minimization, reducing the energy demand, and employing more energy-efficient technologies in this sector are the objectives that need special focus. (Mathiesen *et al.*, 2015 a) (Lund, P. D. *et al.*, 2019) (Wittrup. S., 2020 a) If the climate goal should be achieved, the only way and cheapest way to do this transition would be gained through an extensive degree of sectors' integration, i.e. smart energy system. (Wittrup. S., 2020 b)

Analyses show that it is feasible to cheaply reach the goal if direct electrification being employed in as many places as possible, especially electric busses. At the same time, large-scale synthetic fuels via the power-to-x technologies, and carbon capture (CC) and storage for the tasks that could not be solved through direct electrification must be stated. However, to do the same task, the required energy in the power-to-x process is six times more than the energy produced by wind power. For that reason and based on new analyses by Energy agency (Ea), it would be possible to save up 23 billion DKK. per year up to 2050, by focusing on direct electrification rather than going all-in power-to-x, as the European Commission recommends in its latest scenarios. (Wittrup. S., 2020 a) (Wittrup. S., 2020 b)

Regarded to the aforementioned issues, the next section would describe the experiences, concerning the electrification of busses in some municipalities of Denmark.

## 1.5 Electric busses - Experiences

In 2017, 12 Mayors from some of Denmark cities signed an agreement that from 2050, only zero-emission buses will be purchased for public transport. It was estimated that 59.000 buses were operating in those cities at that time (Godske, 2017 b).

Among other municipalities, Roskilde has been the pioneer to make this green transition in the bus fleet. *Umove East* was the winner company of the trend for adding 20 electric buses plus their service facilities in Roskilde. By phasing out all 20 diesel buses and replacing them by the electric alternative in Roskilde Municipality, on April 19$^{th}$, 2019, 1400 Tons of $CO_2$ emissions would be expected to be saved per year. This amount of $CO_2$ saving corresponds to the sudden 470 electric cars driving around the roads - each driving 20.000 km a year – within the Roskilde Municipality boundaries. (Berggreen, 2019) (Field, 2018) (Lassen J., 2018) (UMove, n.d. a)

According to Roskilde municipality calculations, this conversion would apply almost zero costs to the system. Additionally, the noise experienced by an electric bus is less than half the noise of a diesel bus. (IBID) Since the plan at that time was to charge the batteries of the buses only at the service center, batteries were chosen large and swappable. The electric busses run about 1.500.000 km a year with almost around 20 operation hours per day. Busses have a range of 300-350 km and most of the battery charging takes place at service facilities with renewable energy at night. As some routes exceed the maximum charge, some buses also need to be charged during the day. (Berggreen, 2019) (Field, 2018) (Lassen J., 2018) (UMove, n.d. a)

The service facility contains 2 containers for housing the transformers and also main charging hardware. Further to that, the busses will be plugged into 10 charging stations. All of the buses are equipped with 12 batteries with a capacity of 394 kWh, and the full charge of the battery (0-100%) takes around 2 to 5 hours. (Berggreen, 2019) (Field, 2018) (Lassen J., 2018) (UMove, n.d. a). A schematic of the service facility and charging stations is illustrated in figure 15.

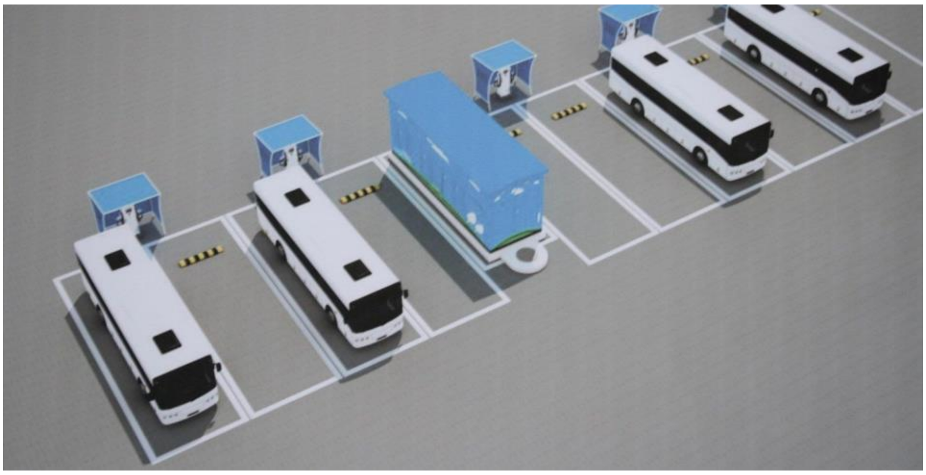

*Figure 15.A schematic of the service facility and charging stations in Roskilde Municipality (Berggreen, 2019)*

After Roskilde, Copenhagen has been the next municipality, which has made a green path toward green electric transition in bus transportation, and with the ambitious goal of being the first $CO_2$-neutral capital in 2025 (Godske, 2017 b). In the Copenhagen municipality, the focus has been first on the environmental characteristics and then the solution itself. Some municipalities have chosen to drive on hydrogen or biogas, but the Copenhagen municipality will drive on neither hydrogen nor biogas busses. (Godske, 2017 c)

48 Diesel buses, between Frederiksberg and Copenhagen municipality, have been replaced by electric busses in December 2019. By adding these new busses in the bus routes, the total 67 electric buses would run in the Copenhagen municipality. As a result, there would occur a $CO_2$ emission reduction of 4300 tons per year, which corresponds to 22 % of the total emission. (State of green, 2019 e) (Stenbaek C., 2019). One of these electric buses, with a pantograph on the roof, can be seen is illustrated below in figure 16.


*Figure 16.An electric bus in Copenhagen, charging through a pantograph- Terminal charging (Godske, 2017 c)*

Politicians in Copenhagen have a plan to electrify all the busses in the city no more than 2025. Frederiksberg municipality has the same goal as Copenhagen to run its busses on green fuels. However, the target of Frederiksberg would be in 2030. (IBID)

The largest mobility company and transition operator in Denmark, *Movia*, aims the target of “fossil-free bus traffic in 2030”. In this respect, other municipalities such as Aarhus, Sønderborg, and Aalborg have also had a collaboration with Movia and have started to follow the same path as Roskilde and Copenhagen toward the target. Therefore, 11 % of all buses in Denmark have been run on electricity by the end of 2019. There is also a plan to replace a part of the bus fleet with hydrogen and biogas if there would be no possibility of electrification. (State of green, 2019 e)

Comparing the level of 11 % for electrification of busses in 2019, with the provided level of 15 % in 2050 by IDA (Mathiesen *et al.*, 2015 a), the share of electrification of buses in the transport sector would probably exceed this level. However, it should be noted that this green transition would keep continuing if no frozen policy impacts the process.

Respected to the electrification of busses in Copenhagen, the city has a plan for operating an electric shuttle bus, under the implementation of the AVENUE project, which would drive in Nordhavn. The electric

minibus will move passengers in a closed loop containing 6 stops. This project has gotten the final approval on March 19th, 2020 and is expected to be launched in summer 2020. (Holo, n.d.)
In August 2020, the Umove East, the same Chinese transport operator of electric buses in Roskilde municipality, has a plan to start with 24 new VDL buses in Randers city (UMove, n.d b). The VDL batteries are high energy batteries that can quickly be charged through an installed pantograph on the roof. The batteries can also get charged with the plug. (VDL, n.d).

In contrast with the other 12 mayors, Herning municipality mayor has decided not to use electric busses but instead running Hydrogen busses in 2020. According to an interview that ING.DK has had with the chairman of the technical and Environmental committee, Herning municipality do not need to look at other alternatives than Hydrogen since it is a political decision. The chairman estimates that Hydrogen busses will provide a $CO_2$ reduction of 7% compared to diesel busses. He also expresses that based on the experience others have had with battery busses, there are the same problems with battery busses as electric cars. The batteries are very heavy to drive around with. "With Hydrogen, you will be able to refuel at night and drive a full day without any problem". (Godske, 2017 a)

The transition has started as well in Aalborg municipality. Alborg city, as the fourth large city of Denmark, has also invested in the employment of the electric buses in its bus fleet, in line with the national and international target of 70% less $CO_2$ emissions by 2030. At the moment and for the first time in Denmark, one ultra-capacitor powered bus and two self-driving busses are operating in Aalborg municipality. A 3rd minibus is also reserved for charging. (State of green, n.d f) Besides that, the Bus Rapid Transit (BRT) project has already been started in this municipality (Aalborg kommune, n.d a), which would further be discussed in section 6.1.2.2.

Considering all the discussed issues, this project takes its point of departure from here. Therefore, chapter 2 would further define the scope of the project, and the research question (RQ) would be provided in that chapter.

## 1.6 Summary

Growth in the population, human-related activities, behaviors, and a growing level of fossil fuel consumption has resulted in a high daily level of greenhouse gas emissions as the main cause of climate change. This is a serious challenge that the whole world is facing at the moment.

The transport sector is the main contributor to $CO_2$ emissions. Therefore, Denmark has the goal of a 70% reduction in $CO_2$ emissions in 2030. To reach the goal it is necessary to decrease energy consumption from fossil fuel sources in the transport sector. And this could take place through behavioral change and modal shift to public transportation. New fuel types, suitable infrastructure, and renewable energy-efficient technologies should also be considered and deployed in this respect.

At the moment biomass is the dominant source of energy production in Denmark. However, due to the scarcity of biomass resources other non-fossil fuel and renewable energy sources e.g from wind turbines should be concerned and applied in the energy system to the purpose of the electrification of the transport sector. And, this is a big challenge which decarbonization of the transport sector is facing. And If no action is taken now and the policy is a 'frozen policy' reaching the target would not get success and the impacts would be no compensable in the future.

## 2. Case description and the project scope

As previously mentioned in section 1.5, Aalborg is the first city in Denmark, which has employed the self-driving mini-electric bus practically in its bus fleet (State of green, n.d f). Further that Aalborg would be also the first municipality that would employ the BRT system in Denmark (Aalborg kommune, n.d a). By implementing these projects and adding more electric busses in the transport grid, Aalborg municipality aims to improve both mobility and environmental and social sustainability in the future. (State of green, n.d f) However, the barriers that Aalborg municipality would face during this transition should also be taken into consideration.

With concern to the aforementioned issues, this paper focuses on the assessment of the future impacts of the electrification of the bus fleet in Aalborg municipality, as the case study of this project, on the energy system, electricity grid, and $CO_2$ emissions saving. Based on that the research question (RQ) has been shaped:

***RQ*: *How can the electrification of Aalborg bus fleet, as a part of Denmark transport sector, make Denmark closer to the target of 70% less $CO_2$ emissions by 2030 and the 2050 goals?***

To the purpose of answering the RQ, the project needs a coherent framework. Nevertheless, different projects may use various kinds of frameworks. However, to secure answering the RQ, the following sub-questions have been prepared:

1- *How would the electrification of Aalborg bus fleet impact the energy system, especially the power grid and fuel consumption?*
2- *How much $CO_2$ emissions would be saved through the electrification of Aalborg bus fleet?*
3- *What are the influencing parameters on the electrification of Aalborg bus fleet and how they can affect the transition toward a green future transport sector?*

Based on the sub-questions, the structure of the project has been shaped, which is further described in chapter 3. Concerning the scope of the project, the delimitations of the project have been also defined in the next section.

### 2.1 Delimitations

By being aware that the conducted solutions and analyses in this project are not the unique way of performing this project, however, lack of time as one of the delimitations was a barrier for performing more analyses for this project.

Although the focus of the project is on the impacts of the bus fleet electrification, not all related issues have been discussed in this project. Despite the fact that the extension of the electricity grid comes with additional costs, this issue has not been taken into consideration either. Delimitations also apply to the issues regarding the methods for RE technologies expansions. The costs of the electrification of the bus fleet, including the buses and related infrastructures, and costs of the technologies e.g. investment, operation, and maintenance costs have not been considered in the analyses. Additionally, the biomass and electric prices, electricity trading costs, and health issues and health costs, are also considered as the delimitations in this project.

Since the main focus of the project is on the electricity and transport sectors, other energy sectors will not be investigated further. The electrifications of other sectors, as the natural delimitation, will not be discussed either. As an exception, to the purpose of expressing the problems caused by passenger cars, as one of the important parts of the transport system that affects the public transport sector, some related societal issues have been discussed in this respect. It should be mentioned that although other energy sectors and other segments of the transport sector have not been discussed, however, the data from the energy system of Aalborg municipality have been considered as the input data for further related analyses of buses in the transport fleet.

Issues related to biomass collection, transferring, distribution, storage, heavy-duty vehicles utilization, and the resulted costs by that are not in the scope of this project either. Therefore, although these issues are mentioned in the project, they will not be discussed in any section. Delimitation applies also to population growth, land use, and biomass production.

Another delimitation for this project has been regarded the considered type of buses. In the analyses of buses, only diesel and electric buses, and neither biogas buses nor hydrogen buses have been considered. Therefore, although Aalborg municipality has employed 6 biodiesel buses into line 2 (Greenaalborg, n.d), this issue has not been considered in the analyses. Moreover, not all possible disadvantages and benefits regarding the diesel and electric buses have been discussed in this project, e.g. noise reduction, air quality, particle pollution, etc.

At last, it should be also mentioned that electricity consumption by the supercapacitor bus and shuttlebuses (electric minibuses) in Aalborg municipality has not been considered in the analyses of Excel Spreadsheet and EnergyPlan simulations.

# 3. Research design

Depending on each sub-question need, various theories and methods have been applied to guide the project through different levels and to answer the questions.

Related theories, chapter 4, have been considered and discussed, to conduct the proper methodologies, chapter 5, for collecting the required data for analyses. The analyses consist of both institutional and technical analyses, further presented in chapter 6. Afterward, extra related issues have been discussed in chapter 7. The project conclusion is presented in section 8. And finally, some suggestions for future work are provided in section 9. The suggestions are the issues that have not been discussed in the project but could shape an area of research for a further project.

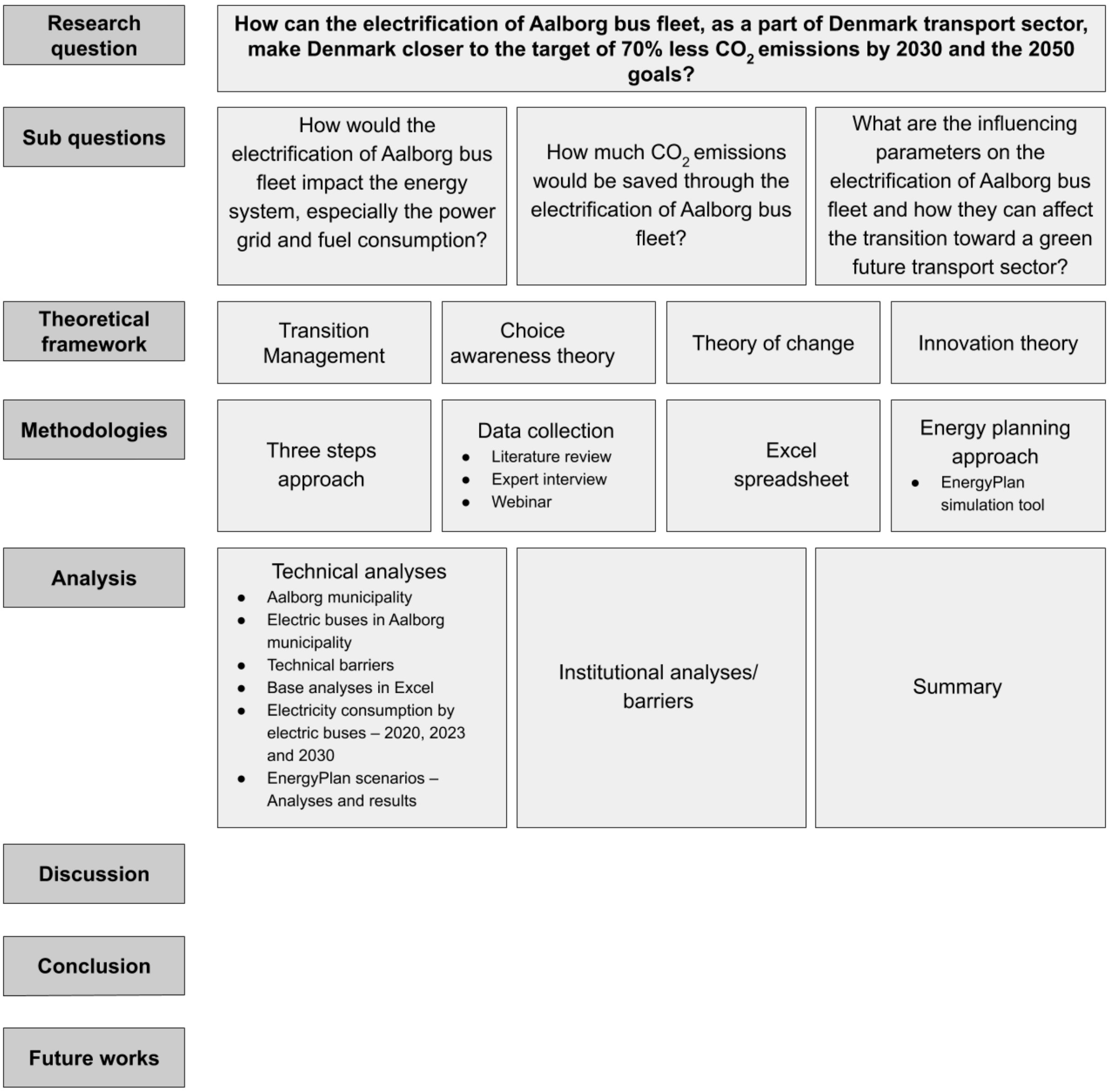


*Figure 17. Project structure (Own figure)*

# 4. Theoretical framework

In this section, a combination of relevant theories has been considered, which will be discussed in further sections.

## 4.1 The theory concept

To guide the project, analyses, and to be able to answer the RQ, relevant theories will be utilized to conduct methodologies for collecting adequate data. Consequently, the goals of the project will be obtained. (Hvelplund, 2001). This track is illustrated in figure 17.

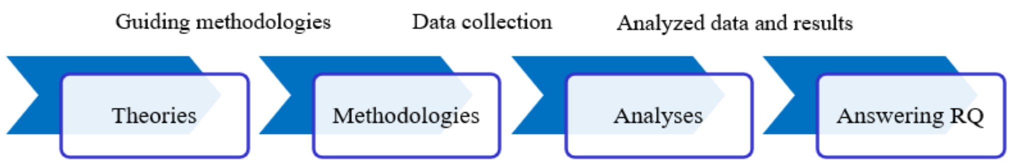


*Figure 18.Answering the RQ by utilizing the theory concept (Own figure)*

Theories make a deeper understanding and provide a better knowledge of the problem area (Hvelplund, 2001). With interrelation between research and theory, theory frames and expresses what the problem is, the possibility of looking at the problem and how to think about that problem (Neuman, 1997). Theories provide researchers the ability to obtain knowledge and information "about areas such as technological change, institutional contexts, actors, and action possibilities" (Hvelplund, 2001). Besides that, theories explain "behaviors and social events in the society together with social interactions among actors in the society" (Lumen, n.d). Therefore, relevant theories are needed to perform adequate analyses. On that account, the result of analyses will result in new policy suggestions. (Hvelplund, 2001)

## 4.2 Transition management

Transition management theory, with a sociological concept, introduces a framework for a long-term goal of sustainable development through the decision-making process. The defined framework will be used to implement governance strategies and instruments. This framework can also be used to analyze, structure, and manage the existing governance processes in society. (Loorbach, 2009) (Héritier 1999)

This theory focuses on structural change through governance activities to the purpose of a societal transition. Through this kind of governance new balance would be made "between state, market, and society and new ways" will facilitate and make possible effective solutions for the decision-making and policymaking process. Therefore, new problem definitions, new alternative ideas, ambitions, solutions, and agendas would be a regular form of this process. (Héritier 1999) (Loorbach, 2009)

Different types of governance, governance activities, influence long-term changes in society. If the governance is, a top-down governance system, then in such a system "social change can be affected by government policies". (IBID)

"Societal actors (governments, business, scientists, non-governmental organizations [NGOs], intermediary organizations) create formal and informal networks". This would happen as they have common interests. They work as networks together, since "they cannot do well without each other and that they can better achieve jointly than individually". The result would be developed decisions and strategies, which will be negotiated and implemented. This will, in turn, leas to changes in societal structures. (Héritier 1999) (Loorbach, 2009)

In such a governance system, all societal actors are aware of the opportunities, thus, can influence social change. This system creates a feasible process for effective long-term thinking and management of strategic long-term solutions. (IBID)

With concern to the theory concept, it can be said that Denmark intends a complete long-term transition in 2050 and desires to carry out a transition from fossil fuels to renewable energy sources. It is a political desire. To make this transition, all municipalities first need to make a 70% reduction in $CO_2$ emissions by 2030. In line with that policy and intention, Aalborg municipality has a target of making a possible green transition in the transport sector by 2030. Therefore, to do that, a rethinking, a strategic long-term framework for energy planning and management, and a structural political decision-making process by help from all societal actors with different levels of activity power would be needed.

## 4.3 Choice awareness theory

The Choice awareness theory is a theory at the societal level. This theory also deals with the way (*how*) that renewable energy systems should be implemented to make a radical technological change. (Lund, 2014 b). It explains that other alternatives do exist and there is a possibility of choosing those alternatives among others. And this would happen if public awareness gets raised. (Lund, 2014 c)

The theory tells that "how to be aware of the choice, thus," making it enable to debate the "common future and make better decisions." This Theory emphasizes this issue that how existing organizational interests "seek to keep radical technological changes out of the agenda at many levels." (Lund, 2014 b) *It explains how existing institutional and organizational interests often try to eliminate choices when an introduction of radical technological change is to be discussed*. In other words, a try for affecting the political decision-making process. (Lund, 2009)

"*Counterstrategies may involve the design of technical alternatives, feasibility studies based on institutional economic thinking, and the design of public regulation measures seen in the light of conflicting interests as well as changes in the democratic decision-making infrastructure*." These are the four strategies concerned with the choice awareness theory. (Lund, 2009) (Lund, 2014 b)

The core strategy in choice awareness is the statement and promotion of concrete alternatives. But the point is how the new energy system should be designed with this alternative. (Lund, 2014 c)

If people get the possibility to know about other alternatives and have the ability to act, then they will take a debate about that. Continuously interact between government and public would result in an official energy objective, which would, in turn, cause that energy plans get developed. (Lund, 2014 b) (Lund, 2014 c)

Public participation and being aware of the choice are the two key parameters that play an important role in the final decision-making process and thus the implementation of radical technological changes; new energy alternatives. (Lund, 2000)

While designing alternatives, they should be comparable concerning their capacities and energy production as central parameters. Otherwise, the new alternatives can easily be ignored. Demand saving, efficiency improvement, and utilization of renewable energy sources should all be considered in this respect. (Lund, 2014 c) (Lund, 2000)

Decision-making through a systematic analysis in an important issue that should be considered in this respect. Therefore, a concrete study should be designed in a way that can provide relevant information. Analyses should be performed for a long-time horizon to make the ability to find the best solutions that are independent of the current technological system. Moreover, the bindings of the existing technological system should also be analyzed. However, to find the necessary technical solutions, there is often a need for new organizations and institutions, considered as the main problems. (Lund, 2014 c) (Lund, 2000)

The most important point is to understand that new alternatives and changes will not emerge by themselves. “The decision-making process is shaped by various political and economic interest groups in society who strive to protect their profits or pursue their values.” If there is an execution of $CO_2$ reduction policies, it could be understood that there has been a change in technology. It is clear that it has not been the society who has done that, but something done by “the representatives of future societal interests and the representatives of potential new technologies”. (Lund, 2014 c)

To make a radical technological change, the proper choice must be chosen. There is a need for energy planning, designing, and promoting technical and coherent institutional alternatives to make the ability to promote a new alternative. (IBID)

Concerning what mentioned in section 1, i.e. the destructive impact of fossil fuels and the limited sources of biomass for energy production, and the Choice awareness theory concept, this theory has been one of the applied theories to this project. Fossil fuels should be phased out and energy production just from biomass could not be a long-term solution as resources are not sufficient. (IBID)

Concerning the theory concept, there are other alternatives than fossil fuels and biomass, here electricity, which could be employed in the energy system and be utilized as the new fuel for the buses. However, to do that, there is a need for an open political process that could raise public awareness. Thereby, electricity as another alternative could and should get presented and take debate. (IBID)

If *no other options* than biomass usage, here biofuels, would be suggested and presented, then *the only option* would be just choosing the biofuels as an alternative for fossil fuels. Without mentioning and introducing other possibilities, the best option would be biofuels. But if other alternatives get introduced and could be selected *the better option* can be chosen. Then if here, the electricity as the third option could get introduced, electrification would be better than the biofuels. However, introducing the electricity as an alternative will face “*resistance from existing organizational interests”*. As a consequence, it is of importance how to specifically design the new system. (Lund, 2014 c)

Feasibility studies should be performed to the purpose of overcoming the current institutional and political barriers and to pave the way toward a radical technological change. Thus, the technical and institutional barriers would be discussed to investigate how organizational and institutional policy measures and rules could affect the electrification of the bus fleet. Moreover, it should be investigated how the new energy system should be planned and how decision-making could influence this planning toward the radical change in the energy system. (IBID)

If debates could be taken, this would finally result in changes in the current institutions and will force politicians to set other rules, new measures and policies which would lead to a reduction of current sources usage and instead, the development of the power network and implementation of new electric buses in the fleet, which is considered as a radical change in the transport energy system. (Lund, 2000) (Lund, 2009)

## 4.4 Theory of change

This theory tries to define what the problem is and how it should be seen, what should be done, and how it is intended to be done. It explains “the links between inputs and outcomes”. (The management centre, 2016) (Center for theory of change, 2013)

People often do not pay too much attention to the little and early changes which should make the base and foundation for long-term changes. And this is because they are not clear about the upcoming changes and do not have enough knowledge of what would changes bring in the future. Therefore, the way that an organization act or want to make changes is of great importance as it could be affected by that matter. (IBID)

For some, the theory of change is considered as a technical tool. To others, it is critical thinking which explores the contexts of challenges, their views, and how changes would happen. Thus, it considers an organization's work on a particular problem which would make a difference in a wider range. (IBID)

This theory could be employed for several reasons e.g. defining a strategy in a sector or developing a strategy that defines what the needs are for the goal to be achieved. The theory could be also used for measurement and evaluation and to ensure a shared understanding. It explains that different stakeholders have a different understanding of a matter (the way of making a difference, and how challenges should be solved). In this regard, discussion and decision making about problems and challenges are considered as an important part of the problem-solving. However, the final results should be understood by all. Another reason for the employment of this theory is to communicate with funders and getting help from donors which could be a valuable instrument for implementing the projects. (IBID)

To develop a theory of change understanding the purpose of that is significantly important. Prior to all other issues, the end goal should be identified clearly. Then the components should be defined in line with the scope of the project, and those who should be involved in the process. In this respect, involving people with enough knowledge, experiences, and insight in the related area is of great importance. However, "developing a theory of change takes time and it is not something that can be done quickly in a few hours or a couple of days". (The management centre, 2016) (Center for theory of change, 2013)

There is a need for making some assumptions about how the changes would take place; such as hypothesis and practical experiences based on the others' successes. Different assumptions would result in different strategies, objectives, thus activities. The assumptions make interventions that would affect the results of the process. (IBID)

Besides making assumptions, defining the preconditions for achieving the goals and documentation of them is an important part and should be considered as a factor with significant effect. However, there is often no way to eliminate some influence parameters, for example, the economy. (IBID)
Afterward, the actions should be identified, as they are the logic links to the goals. Then the requirements for taking actions should be defined. When the action track is defined, the process to achieve the end goal would get facilitate. (IBID)

Defining and taking the responsibilities toward gaining the goal would be the next step in developing the theory and needed to be clear. The theory of change diagram could help to a better illustration of the overall change process and represents what would happen over the predefined long-time frame. (IBID)

To conclude, the theory of change is a theory for a reason, which defines what is needed to happen that changes can take place and "is the best hypothesis of how changes can be brought out". The theory of change is a part of an implementation plan and a tool that is often used with other tools utilized for planning and strategy development. A strategy Map can be named as one of these tools which investigates how the end goals can be gained. To answer theses *how*-questions, Strategy Map looks at it "from four specific perspectives: *stakeholders, capacities, learning & growth, and resources*". If the theory of change describes what is needed that change can happen, then the Strategy Map describes how it will be put into effect. (The management centre, 2016) (Center for theory of change, 2013)

Concerning the concept of the theory of change, this theory would provide a deeper understanding of the challenges regarded to the electrification of the Aalborg municipality bus fleet and $CO_2$ reduction goal. Through this theory, the below questions have been shaped to provide help for more precise answers to the RQ:

First of all, it is important to understand why $CO_2$ emission is a problem and why it should get reduced *(what is the reason for that?*) What are the short-term and long-term goals? What should be done to reach the goal? Can the goal be met by electrification of the bus fleet? Which one should be considered, direct electrification, or indirect electrification?

How should this electrification be done? What strategy and actions should be taken to reach the goal of a $CO_2$ neutral bus fleet? What would be the challenges, institutional and technical barriers, that planers would meet during the process of the electrification of the bus fleet? Has there been performed any experience in other countries or by other municipalities in Denmark? What have been the results?

What are the existing resources and what are the needs to start the process? Who should act? Who are the related stakeholders in this project that can affect the way of electrification of the bus fleet and the results of the process? Are the results of changes clear to everybody? Have people been provided with information about the project?

## 4.5 Innovation Theory

Innovation theory explains how advancements get traction, expanded and developed, and different ideas, products, technologies, and behaviors gain popularity and acceptance over time. These advancements could then finally result in new movements and reformation from creation to use. Adopting new ideas and products by different types of people on different timelines is the central idea of this theory. (Reference, n.d)

Innovation theory can be discussed from two approaches: the *technology push-model* and the *market pull-model* (Brem and Voigt, 2009) (Danish Energy Agency, 2016 e). In the *Market pull/demand-pull/need pull* the customers, individuals and groups, are not completely satisfied with the current technology. Thereby, this will result in new demands and need for problem-solving. (Brem and Voigt, 2009) In this case, the opportunities in the market will result in investments in research, development, and eventually to an innovation. Although investment is also a matter, however, currently technology development, for the most part, is related to optimizations of the components' size. (Danish Energy Agency, 2016 e)

In the *technology push-model*, it is not the market that seeks for and pulls new technologies, but that "new technologies push themselves into the market" (Danish Energy Agency, 2016 e). The motives for new technology come from research and practical knowledge and the goal is the commercial use of that. The reason for this output is the technical capability of the new technology. Thus, that does not matter whether a certain demand for that already exists or not. (Brem and Voigt, 2009)

There is a difference between the high and the low level of the 'newness' of the innovation and thus a difference "between radical innovations (*technology push*) and incremental innovations (*market pull*)" (Gerpott, 2005) (Brem and Voigt, 2009). This level of *newness* affects the attributions of innovation. A comparison of the results is illustrated in figure 18.

Considering figure 18, it could be concluded that the *technology push* can be described as both creative and destructive and with new or major improvements in both situations. In contrast, *market-pull* is considered as a replacement or substitute. (Walsh et al., 2002) (Brem and Voigt, 2009)

| Description/attribute | Technology push | Market pull |
|---|---|---|
| Technological uncertainty | High | Low |
| R&D expenses | High | Low |
| R&D duration | Long | Short |
| Sales market-related uncertainty | High | Low |
| Time-to-market | Uncertain/ unknown | Certain/known |
| R&D customer integration | Difficult | Easy |
| Kinds of market research | Qualitative-discovering | Quantitative-verifying |
| Need for change of customer behavior | Extensive | Minimal |

*Figure 19.A comparison between the attributions in Technology-push & Market-pull model (Brem and Voigt, 2009)*

However, managing innovation in both cases could get influenced by several parameters such as political (taxation, etc.), legal (business legislation, product safety, etc.), social-cultural (income distribution, education, etc.), economical (income, inflation, etc.), technological ("government spending on research, speed of technology transfer", etc.), and environmental (location, protection laws, etc.) influences. Thus, to get succeed "innovation requires collective action or efforts to create shared understandings from disparate perspectives". (Dougherty, 1992) (Brem and Voigt, 2009)

Concerning the electrification of buses and the innovation theory concept, there should be investigated that what problems would there be regarded to this electrification. Is it a technology push-model or a market pull-model? What are the needs? How is the situation of electric buses in the market? What would be the external factors that could affect this innovation? How the process of innovation could be managed? What would be the barriers? What would be the solutions? What are the issues regarded to the components' size? Could they be optimized? Who are the actors and whether they have done/do any action toward this innovation? Is there a shared understanding?

Based on the discussed theories in section 4 and what previously mentioned, the adequate methodologies presented in the next section, have been selected to conduct the analyses and to collect the required data for answering the RQ.

# 5. Methodologies

## 5.1 3 Step approach

The three-step approach can be considered as an overall method that frames and composes the whole project. These steps represent the structure of what and how the project could be formed, and which kind of obstacles might occur. The following steps present these three steps:

- *Step 1: "Design feasible and strategic technical energy scenarios"*
- *Step 2: "Analyze the concrete institutional context that influences the implementation of these scenarios"*
- *Step 3: "Design concrete policy scenarios based on the analyses from step1 and step2"*. (Djørup, 2019) (Hvelplund and Djrøpe, 2017)

Step 1 ensures that the defined energy scenarios would be performed most optimally regarded to the parameters of the scenario. Therefore, the scenarios would be the most feasible technical scenarios, which "could result in a strategic plan for" implementation of the chosen energy scenario and will facilitate the way. (Djørup, 2019) (Hvelplund and Djrøp, 2017)

Step 2 would help to investigate and reveal what kind of obstacles the energy scenarios would face and how the institutional context would influence the implementation of the technology scenarios and employing new technologies. This context includes policies, markets, and regulations. (IBID)
A better understanding and knowledge of the institutional context results in a better understanding of how the energy system structure can influence the transition and make the way of success easier. To make a transition toward the desired energy system in the future, the institutional context and structure need a change. Thus, a change in the current policies and markets would be necessary. (IBID)

Step 3 would be the result and conclusion of the first two steps, which provides suggestions for the integration of the most optimal and feasible energy technology scenario (IBID).

Further to the 3 step-approach as the overall method, Data collection as another important method will be described in the next section.

## 5.2 Data collection

Data are divided into two categories, i.e. Primary data and secondary data. Primary data are such data that are actively collected through observation, questionnaires, interviews, etc. Secondary data are those which have been collected by others such as statistics and informative documents. (Kanstrup K., 2011)

While collecting data, it is of importance that the data would be both valid and reliable. It means that the data should be relevant and also trustable. Data validity refers to where the data comes from. And reliability in data is based on making a comparison between collected data from different sources and thereby extracting new information that can be applied to the analyses of the project. Official documents from government and documents, researches such as scientific articles from experts and interviews with experts are all sort of sources which can be used in this respect. (IBID)
Further to what mentioned above, data can be also split into two categories of quantitative and qualitative data. The quantitative data are those which are measurable and could be placed on a scale. The qualitative data focus more on individual answers and quality, thereby it would not be possible to compare one's answer to the others. Additionally, the qualitative data provide an understanding to answer the what, why, and how questions. (IBID)

Based on what mentioned, the literature review and expert interview are the two main sources of data collection in this project, presented in the next sections.

### 5.2.1 Literature review

To gain background knowledge about the research area, especially the transport sector, the main source for data collection has been the literature review. This has been done through different articles and websites and the main sources have been IDA energy vision 2050 (Mathiesen *et al.*, 2015 a), Basis fremskrivning (Energistyrelsen, 2019 a), Aalborg energy vision (Lund, H. *et al*., 2019), opdatering-af-driftsoekonomi-for-plusbus-m-tilhoerende-notat (COWI, 2018) and Nordjyllands Trafikselskab - Udbud af bustrafikken i Aalborg (Andersen J. *et al*., 2019). The *Ingeniøren* website (ING.dk) has been also used to obtain the latest information regarding energy, technologies, and the transport sector.

### 5.2.2 Expert interview

The main goal of an expert interview is to know about the expert's point of view and the perspective of an experience. Thus, to carry out a good and useful interview, both interviewer and interviewee must be well-informed about the subject. (Brinkmann and Tanggaard, 2010)

The interview can be conducted through a structured or semi-structured interview. In a structured interview, the questions are previously defined by the interviewer. In this case, the interviewee has not the possibility of adding his idea and should just answer the questions by answering the specified and provided items. In contrast, in a semi-structured interview, the questions are open for the respondent and besides the interview-guide, the interviewee could also add extra information and provide more detailed answers to the questions. Therefore, the conversation would result in a dialogue and not a monologue. (IBID)

Based on the aforementioned issues, some semi-structured expert interviews have been conducted through emails and one through telephone to collect more information and obtain extra knowledge about the technical and institutional issues regarding the electrification of the bus fleet in Alborg municipality, and the related short-term and long-term plans. The contacted persons/companies/organizations, and navigated interviews are further provided in Appendixes A, B, and C.

### 5.2.3 Webinar

Online webinars as another method for data collection have been also used to collect extra related information about the climate and energy sectors, especially the transport sector. The links to the webinars is provided in the *References*.

## 5.3 Excel Spreadsheet

The Excel Spreadsheet has been also utilized as one of the methods for both data collection and a tool for analysis. It has been used as the base tool for analyses to calculate the required input data for the EnergyPlan simulation software, further discussed in section 5.4.1.

## 5.4 Energy Planning approach

*"Energy planning is an optimal combination of energy sources to satisfy demand"* (Zarate, 2009) and "*includes finding a set of resources and energy conversion equipment to meet the energy demand"* (Hiremath *et al.*, 2007). Generally, energy planning aims to make a balance between energy demand and energy supply (Gaardmand, 1980). However, to do the tasks, the energy system faces some challenges. Therefore, an organization of the energy systems through the energy elements utilization and making coordination between all energy sectors, and the implementation of new strategies and energy policies would be necessary to achieve energy balance in the system. (Mougouei and Mortazavi, 2017)

Based on the abovementioned issues, one of the aims of this project is to match the electricity demand of electric buses and to supply the required electricity from the desired resources. Therefore, it is necessary to investigate whether and how the electricity demand by electric buses would be met.

The prognostic approach as one of the energy planning approaches (Gaardmand, 1980), applied to this project, tries to foresee the impact of a future energy plan on the energy system. In this project, the target is to investigate and predict how the employment of electric buses would impact the Danish green transition; effects on the electricity grid, and the $CO_2$ emission reduction.

To the purpose of energy planning, there are different programs which are available and can be utilized to do the tasks. Therefore, there is a possibility to model energy scenarios in different ways. (Connolly et al., 2010) To the aim of performing technical analyses in this project, the EnergyPlan simulation tool has been selected among other programs. Further issues in this respect are discussed in the next section.

### 5.4.1 EnergyPlan simulation tool

Besides other tools and what mentioned in the previous section, the *EnergyPlan* tool has been utilized to perform technical simulation analyses for the considered energy scenarios.

"The main purpose of the EnergyPLAN model is to analyze the energy, environmental, and economic impact of various energy strategies." (EnergyPLAN, n.d)

EnergyPlan has been selected as it has been used for "*analysing the integration of renewable energy in various systems"* and for more than 100 energy systems in Denmark (Connolly et al., 2010). It is an open-source and user-friendly *"tool for designing energy planning strategies on a national or regional level"*, which is able to simulate the whole energy system. Since it also includes the transport sector, it is an ideal and perfect tool for analyzing scenarios for a 100% carbon emission-free energy system (IBID), therefore much suitable for the analyses of this project.

Moreover, EnergyPlan can simulate the current and future of energy systems. Investigation of fuel consumption and total cost of the energy system including the investment costs, annual costs of more RE implementation, and the energy exchange income are such outputs of the program. (IBID)

EnergyPlan has previously been used for analysing the large-scale integration of renewable and fluctuating energy sources such as wind, surplus electricity management, and performing energy strategies for sustainable development. Additionally, in contrast with other tools that optimize the investment cost of a given system, EnergyPlan optimizes the energy system operation. The optimization of the energy system would be performed based on a one-year calculation that doesn't take more than a few seconds. (IBID) Since the electric busses would have an impact on the future Danish energy system and society, analyses would be conducted through a socio-economic operation strategy.

#### 5.4.1.1 Technical simulation vs. Market simulation strategy

In the market simulation, the intention and focus are to design the energy system based on the cheapest fuels and at the minimum cost. In contrast, in the technical simulation, the energy system simulation is based on less fuel consumption and a more efficient energy system. (EnergyPLAN, n.d) (Connolly, 2015)

In this project, all the scenarios for the simulation of the energy system have been designed under the technical simulation strategy. Thereby, as also previously mentioned in *delimitations*, the Danish electricity price and taxes have not been considered in the simulation of the scenarios. Other taxes such as $CO_2$ tax has not been considered either.

Based on all the aforementioned issues, the research problem has been analyzed, which the results of the analyses are provided in the next section.

# 6. Analyses

The analyses in this section are divided into the two main categories, technical analyses, and Institutional analyses. Through the analyses, the problem area will be discussed in detail. Therefore, besides technical issues, political issues would be also investigated to make the ability to provide the best policy suggestions.
It should be noted that in the technical analyses ‘,’ has been considered and utilized as a decimal point and ‘.’ Has been utilized as a separator.

## 6.1 Technical analyses

### 6.1.1 Aalborg municipality

This section will provide more thorough information about the Aalborg municipality plans and the transport section with concern to the potential energy supply capacities.

Cities want to get rid of diesel fuel and reduce $CO_2$ emissions (Valmot, 2017). To limit air pollution, it is essential to run the municipal public transportation on sustainable and renewable energy sources (State of green, n.d g).

The suitable energy infrastructure in Aalborg municipality, make it possible for Aalborg to facilitate its way through the smart energy system toward the green transition in the transport sector and even being a front runner in this concern. Aalborg municipality has many potentials RE sources in the form of wind power, solar, geothermal, biomass, and waste energy as well as surplus heat, which can be used for electricity production and further utilization in the transport sector. The total installed power in the municipality has been 158 MW at the end of 2018. There is also a plan for an extra capacity of 60 MW in the future. (Lund, H. *et al*., 2019)

However, analyses have shown that this level of capacity, nearly 220 MW, is not sufficient to achieve the Alborg municipality to its target of having a 100% renewable energy system. For that reason, an extra capacity of around 380 MW, i.e. a total electricity capacity of 600 MW, based on Aalborg's share of national electricity, would be needed to reach the municipality to its aim. (Lund, H. *et al*., 2019)

It is expected that the total energy consumption for the transport sector will be reduced from around 7704 TJ (2140 GWh) in 2018 to approximately 5029 TJ (1397 GWh) in 2050, which includes domestic and foreign traffic. To cover the demand, the combination of renewable energy with energy efficiency is the main point of Aalborg municipality interest. Producing green fuels based on hydrogen and electricity from wind power and solar cells would be an important element in the Aalborg energy system. However, Aalborg municipality has meager resources of biomass per capita than the country as a whole. Therefore, Aalborg should make it possible to cover the transport sector energy demand with the available biomass resources in the municipality, which corresponds to Aalborg’s share of the total Danish biomass resources. (Lund, H. *et al*., 2019)

Aalborg municipality's share of the total Danish biomass share (including straw, wood, biogas, and biodegradable waste) is around 6200 TJ/year (1720 GWh) (Lund, H. *et al*., 2019), which is based on a population share of 3.7% from 2106 (Thellufsen, et al., 2019). Therefore, the biomass resource utilization should not exceed this amount unless local crops could be obtained (resulting in lower food production), the waste incineration capacity gets an expansion, or a significant amount of biomass be imported into the municipality (Lund, H. *et al*., 2019).

For that reason, the municipality has a plan to cover the demand for cars, trains, ships, and aircraft segments with biomass, and instead, busses should be electrified (Thellufsen, et al., 2019) (Lund, H. *et al*., 2019). There is also no plan for employing hydrogen busses either (Interview, 2020 a) (State of green, n.d f). More thorough information about electric buses in Aalborg municipality is furthered provided in section 6.1.2.

However, electrification of busses would also result in more electricity consumption in the grid. The electricity consumption has been 1150 GWh in 2018, and it is expected that it would reach a level of around 1450 GWh in 2050, which means that a total increase of almost 26% would occur by 2050. Since energy consumption in Aalborg municipality is meeting an increase, thus the focus is mainly on energy saving and energy efficiency improvement (Lund, H. *et al*., 2019). To that reason, employing more advanced and improved batteries in electric busses could result in a reduction in energy consumption in the system.

Aalborg municipality has a plan to replace all diesel buses with new $CO_2$ neutral buses by 2030 (Interview, 2020 b) (Interview, 2020 c), starting from 2020 (Henriksen, 2019) (Intego, n.d). At the moment, 100 contract busses are running in Aalborg municipality. As it is currently 10-12 years since the last service for buses was offered (diesel buses plus a handful of biogas buses), it is expected that after the upcoming re-tender of the city bus services in Aalborg, Aalborg municipality will carry out a green change of bus operation. (Interview, 2020 a)

Running diesel buses has been actually due to the reason that electric buses were not mature enough to be employed for a large-scale operation at that time, i.e. summer 2010. However, it is expected that either electric or hydrogen buses, as it currently appears, will be the possible technologies in the future. It is expected that a number of buses will be transferred from the existing contracts, which will in principle have to run until they are of an age at which they are naturally phased out. As a result, some new zero-emission busses would probably start operating in August 2022. (Interview, 2020 a) (Interview, 2020 b)

In the intervening period, i.e. up to 2022, busses will probably have to run on a fossil-free synthetic diesel. However, Aalborg municipality does not know the final requirements for operations and equipment until the tender material is completed. (Interview, 2020 a)

### 6.1.2 Electric busses in Aalborg municipality

#### 6.1.2.1 Super capacitor-based electric bus

In 2019 under no contract, Aalborg municipality in collaboration with Aowei ran test operation with an ultra-capacitor powered electric bus, which is still running and drifts passengers. The ultra-capacitor powered electric bus charges with a maximum power of 350 kW in the urban space and 15 kW at the storage facility. (Interview, 2020 a) (Pedersen, 2019) (Henriksen, 2019)

The special thing about this electric bus is that the energy is stored in a super capacitor, which is installed on top of the bus. The super capacitor is an electronic component for energy storage. The difference between a super capacitor and the more well-known lithium-ion battery, used in other electric busses in Denmark, is that the super capacitor can be charged much faster and allows for more charges without degenerating. In contrast, a super capacitor needs a bit more space in comparison with other lithium-ion batteries. (Pedersen, 2019)

When the bus driver brakes, the bus will get charged and energy will not be wasted as heat. Thus, it will function very well in rush hours. (Pedersen, 2019) (Henriksen, 2019)

With a 40-kWh supercapacitor, the 12-meter long bus drives a range of 30 to 40 km on one charge, with a maximum speed of 60 km/h. However, there is one problem that if there is only 10% of power left on the battery, then the bus will no longer run. (Pedersen, 2019) (Henriksen, 2019)

Charging facilities are set up at the terminals, Aalborg Airport, and Sigrid Undsets Vej respectively. Charging the supercapacitor takes just 6 minutes and is done by connecting a pantograph on the roof of the bus to the charging facility (Pedersen, 2019) (Henriksen, 2019), as illustrated in figure 19.


*Figure 20.Super capacitor-based electric bus in Aalborg (Pedersen, 2019)*

The charging would take place significantly faster than a bus with a lithium battery. The bus can continue running as far as the infrastructures, charging stations, are available along the route. It only takes 6 minutes to charge from 0 to 100%. It will often be a charge of 50 to 100% in practice, which takes less than 3 minutes. (Intego, n.d) It means that after the bus will get fully charged, it will have a turn for 11 km and a return for 11 km, then it can get charged 50% in 3 minutes instead of getting a full charge in 6 minutes.

While comparing the supercapacitor bus with an ordinary electric bus, the ordinary bus with a lithium battery needs to be charged a couple of times during the day and typically several hours at a time, thus several buses would be needed for covering the same route all day. Therefore, a supercapacitor bus needs to store enough energy (electricity) for just a single trip, which is exclusively good for the environment. Further that, the supercapacitor has a smaller size than the lithium batteries, as half, and double lifespan. (Intego, n.d) This will result in no need for replacement of the ultracapacitor pack in a short time (Chariot e bus, n.d). Thus, considering all features, supercapacitors can be a good solution for city buses with short routes. (Intego, n.d)

During the test period, the supercapacitor electric bus will run partly on Line 12 between Aalborg Airport, Kennedy Arkaden, and Aalborg University, and partly on Line 2 (Pedersen, 2019).

### 6.1.2.2 The BRT (Bus Rapid Transition) project / +BUS

Aalborg city is developing, and it faces several traffic challenges. There is already pressure on both public and car traffic, which are the cause of 79% of the traffic in Aalborg city (Plusbus, n.d a). Therefore, the plan is to solve the specific challenges for the city's traffic through the implementation of the BRT project, as the backbone of traffic in the city (Region Nord Jylland and Aalborg kommune, n.d a). The future design of the Plusbus can be seen in figure 20.

Each Plusbus equals to 100 private cars (Aalborg kommune, n.d a). The transfer from car to public transport by the establishment of the Plusbus project would amount to about 140.000 car trips per year (Aalborg kommune, n.d b). Therefore, it can be concluded clearly that all cities need to follow a radical upgrade of green public transport if the problems issued by private cars should get solved. (Region Nord Jylland and Aalborg kommune, n.d a)

However, a BRT project or '*bus on train conditions'* is a far more complicated project than normal supply of bus traffic. It contains an infrastructure element and the Plusbus project may contain newer types of buses when the buses are integrated into the bus fleet. (Andersen J. *et al*., 2019) (Aalborg kommune, n.d b)

*Figure 21.The future of Plusbus in Aalborg city (Grunert R., 2020)*

The BRT project in Aalborg is a collaborated project between Aalborg municipality, as the builder, the Region of North Jutland, North Jutland Traffic company, Ramboll company, and COWI company (Aalborg kommune, n.d b) (Aalborg kommune, n.d a). Since the contract of buses in Aalborg would expire in 2020, expected to be extended to 2021, an assessment of several aspects in connection with the upcoming bus service offerings in Aalborg City started in 2018 (Andersen J. *et al*., 2019).

Based on the analyses and concerning other's experiences, light rails projects in Aarhus and Odense municipalities (Aalborg kommune, n.d a), the BRT system was considered as the best option for the transport system in Aalborg municipality (Aalborg kommune, n.d c) (Aalborg kommune, n.d a).

Denmark's first BRT connection, Aalborg Plusbus (+BUS), is planned to be opened in 2023. Aalborg Plusbus is a high-class bus service that will drive on a 12 km stretch from the Racecourse through the city center to New Alborg University Hospital. (Aalborg kommune, n.d c) (Aalborg kommune, n.d a) The considered route is illustrated in figure 21.

It is an environmentally friendly bus service, that provides shorter travel time and creates a greater connection between transport and urban development. Plusbus drives in its own lane, has a priority in traffic lights, and a level-free entry and exit. (Plusbus, n.d a) (Aalborg kommune, n.d c) (Plusbus, n.d b)

In the last analyses for buses performed by COWI in 2018, two material types are considered for the buses, the *24 m Gas Hybrid Van Hool ExquiCity from Malmö* and *full electric 18 m Mercedes Citea SLFA 181e fra Köln*. These two materials have been selected since they were the most reliable environmentally friendly buses on the market. (COWI, 2018). However, in this project, only the electric buses are considered in the analyses.

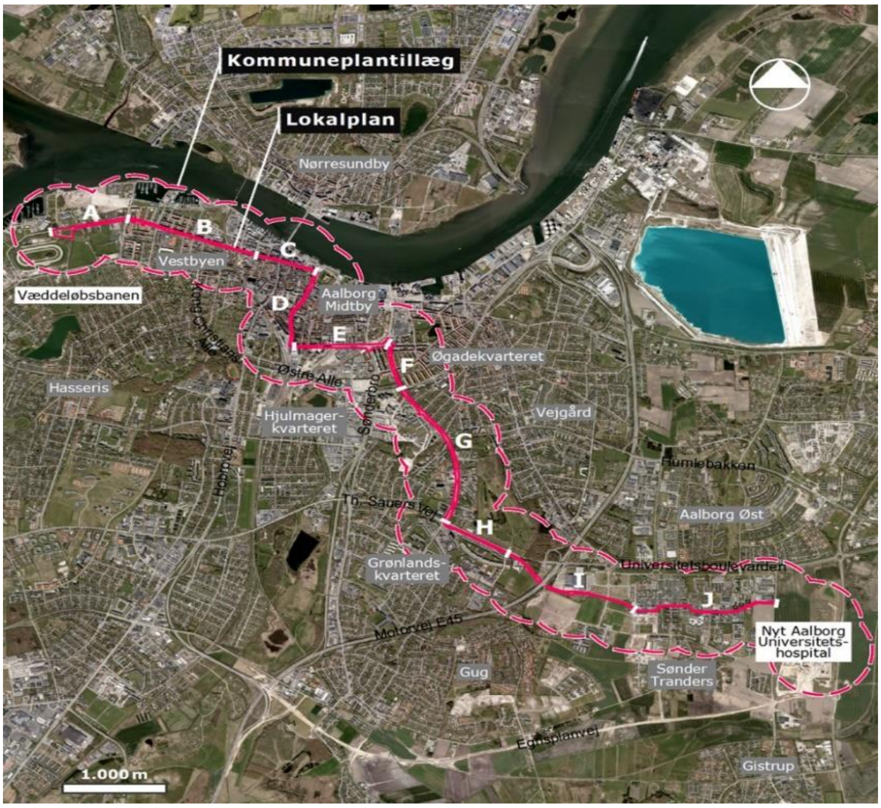


*Figure 22.+BUS route (Nordiske Medier, n.d)*

The 18 meters buses have a capacity of 150-200 passengers and must move through the city from west to east. This number of passengers has been considered due to annual growth of 2% corresponding to the experienced annual growth in the urban bus network over the last three years. (Aalborg kommune, n.d c) (Plusbus, n.d a) (Plusbus, n.d b) (COWI, 2018) However, based on the new analyses in *Klimasvar* this growth in traffic should be minimized at least to 1,6% if the target of 70% less $CO_2$ emissions in 2030 should be reached (Vad *et al.*, 2020).

With a drive up to 50 km/h and an average of 21-22 km/h, the whole route takes approximately 30 minutes and creates a connection between the individual districts. There is assumed that 23 stations would be built across the Aalborg city and there would be only 7.5 minutes between the buses. As a result, the passenger's traveling becomes more efficient. (Aalborg kommune, n.d c) (Plusbus, n.d a) (Plusbus, n.d b) (COWI, 2018) Since BRT buses run without travel card equipment on board, thereby so much time could be saved. Passengers should instead check-in and out at one of the new stations. (Grunert R., 2020 a) However, due to several economic parameters, no special materials still have been considered for the +BUS project (Andersen J. *et al.*, 2019). A comparison of some attributes for different bus materials is illustrated in figure 22.

It is expected that a minimum of 8 buses would drive per hour, but significantly higher when there are many passengers. The Plusbuses would operate 19 hours daily, on all days of the week (Aalborg kommune, n.d b) (COWI, 2018) However, the project is facing some challenges which should overcome before the integration of busses in the bus fleet. (Andersen J. *et al.*, 2019)

| | | | Elektricitet | | | |
|---|---|---|---|---|---|---|
| | Diesel | Gas | Depotladning | Terminal-opladning | Opportunity charging | Brint |
| Emissioner lokalt | | | | | | |
| Lyd / Vibrationer | | | | | | |
| Anskaffelsespris pr. bus | | | udskiftning af batteri medregnes / ca. hvert 6 år | | | |
| Pris drivmiddel | | | | | | brint som industri-biprodukt? |
| Vedligehold bus pr. år | | | | | | |
| Vedligehold bus livstid | | | | | | |
| Afskrivning bus | brugstid 8 år | | brugstid > 20 år | | | brugstid > 20 år |
| Daglig driftstid pr. bus | | | | | | ? |
| Udviklingspotentiale i bussernes levetid | | | høj potentiale mht. batteri-ydeevne | | | |
| Infrastruktur | | | | decentrale ladestationer | | kompleks og pladskrævende |
| Risiko /teknisk kompleksitet (materiel og infrastruktur) | | | | | | |
| Erfaringer i Danmark | | | | 2 busser MOVIA | | |

*Figure 23.A comparison of buses attributes (Andersen J. et al., 2019)*

Buses must be powered by a battery that is largely dimensioned for the required range of buses operation, 300 km per charge. Nevertheless, since electricity consumption is almost dependent on vehicle weight, the battery capacity would be of great importance. Besides these issues, battery life is still an area with a high level of uncertainty, but great technological development is expected in the coming years. (IBID)

The way that batteries should be charged is an area that needs a special focus. In this respect, the two possible methods, depot charging, and terminal charging, for both normal and long buses and their pros and cons are discussed below.

- **Depot charging:**

In the case of depot charging the buses only get charged at depot stops at night and possibly for a few hours during the day. The advantages are that the charging infrastructure only has to be established in the depot and it is relatively cheap. However, buses must have the heaviest batteries. Since some of the buses are constantly charging, more buses would be needed in an intensive operation. (Andersen J. *et al*., 2019) (Gisvold S., 2020)

After about 6 years (2.700 recharges) the batteries' performance would be approximately 85% of the original capacity. Since there is a demand for used batteries for stationary use, the batteries could be replaced with the newer one earlier than the end of the lifetime. As a result, due to new battery performance, a lighter battery model can be used. (Andersen J. *et al*., 2019)

- **Terminal charging:**

At terminal charging (*quick charge stands*) pantographs are established at the end stations. Hereby, the batteries on the bus can get reduced in size, since the recharging process takes place throughout the day. As it was mentioned previously, MOVIA has experiences with this solution (Andersen J. *et al*., 2019) (Aalborg kommune, n.d a) (Gisvold S., 2020).

in the case of pantograph solution, the range affects the number of operating buses and the number of required pantograph units, which are needed to be put up. For smaller buses, in the case of terminal charging more buses must be used than similar diesel operation, but fewer than through depot charging. This is due to the fact that a little longer time has to be set for terminal stays, which is especially noticeable in an intensive operation.

However, the battery size can be further reduced by *opportunity charging* where the bus recharges along the route at charging stations located at selected stops. (Andersen J. *et al*., 2019)

In the case of street charging (opportunity charging) and charging at the end terminals, queuing can arise at the pantographs in concern with delays (IBID), as it has been experienced in Aarhus. Additionally, street-level charging infrastructure becomes dependent on the municipality permits. Therefore, it will be too risky for bus operators to choose this option as a charging solution. (Andersen J. *et al*., 2019)

In the case of utilizing long buses, extra time for charging at terminals or pantographs on the route could also cause problems. It might be necessary that the buses run in the garage in the middle of the day for battery charging. This problem could be solved by employing more buses in the bus fleet. However, it would result in more costs. (IBID)

In the case of street charging (opportunity charging), the need for the charging of the bus will gradually decrease during the day. However, If the battery charge reaches below the minimum charge of 20%, the bus must drive in the garage, which will cause an operating problem in the middle of the day. (IBID)

Based on overall economic, technical, and environmental assessments the opportunity charging would be too expensive mainly due to the development of the battery technology in the future and the time that busses are integrated into the bus fleet. (IBID)

Besides all aforementioned issues in this section, it should be also noted that although the mobility improvement for travelers in public transport would be a beneficial socio-economic issue, reduced accessibility for car traffic would be a socio-economic disadvantage. (Grunert R., 2020 b)

### 6.1.2.3 SmartBus Project (Self-driving mini electric busses/Shuttle buses)

As earlier mentioned in section 1.5, Aalborg Municipality is the first municipality in Denmark which is now operating with driverless mini electric busses, in Aalborg east (State of green, n.d f). Alborg municipality has set up the framework for supporting the researches and development of the project for the implementation of this technology and its effects on society. (Holo, n.d b)


*Figure 24.Shuttle bus – Aalborg (Holo, n.d c)*

The electric self-driving bus project, as a part of a future and larger project for urban development, was officially launched 5th of March 2020 in Alborg East. The project objective is to help to promote the development of sustainability in the area. Moreover, it aims to create local ownership of the electric minibuses. (IBID). This shuttle bus can be seen in figure 23.

After almost 5 years of planning and application process, in December 2019, the permission was given to Danish company Holo and for the first time in Denmark to make experiments with self-driving buses (Holo, 2020 e) .

The SmartBus project has been a result of a collaboration between Aalborg municipality, Aalborg University, Nordjyllands Trafikselskab, bus manufacture Navya, and Holo as the operator of the autonomous technology (Holo, n.d b). Aalborg municipality and Holo, in a collaboration with bus manufacture Navya, have prepared and mapped the route as well as conducting tests (Holo, 2019 d. Holo). The regulations such as bus speed, priority zones, bus stop stations, etc. have been plotted into the virtual map of the buses and it has been tested before the operation and driving with passengers. (Holo, 2019 c)

In a route of 2.1 km with 10 stops, two electric minibuses operate simultaneously with a speed of 18 km/h, in Astrupsti in Alborg east, to move a maximum of 11 passengers, all weekdays from 7:00 to 21:00. There is a 15 min interval between any arrival and departure. (Holo, n.d b). The battery charging takes 5 hours after driving about 8 hours driving (Josefsen, 2020).

### 6.1.3 Technical barriers

Today the main barrier for electric bases remains as the bus range, also previously mentioned in sections 6.2.1.1 and 6.2.1.2. The bus speed, driving style, weather condition, and temperature can all have impacts on the battery range. (Valmot, 2017)

The bus weight has also proved to be a challenge while the buses are charged through a pantograph. Since the buses stand every time at the same place, therefore it is important that the substrate is enough hard and has sufficient bearing capacity. Thus, if buses would be many and they would need for instant charging, the charging time and battery weight could further cause problems in asphalt. (Gisvold S., 2020)
Another challenge would be the battery capacity. The battery capacity would also be affected by the number of take-offs and stops along the route and also the number of passengers on board. (IBID)

In addition to the above challenges, due to the increase in electricity demand in the future, new investments in renewable energies would be needed to cover the electricity demand by the new electric buses in the fleet. (Distrup, 2020) Thus, Aalborg municipality needs to invest in more capacity in the power grid, if the electricity demand by electric cars and electric buses could be supplied. This could, in turn, cause other problems which would be further mentioned as an institutional barrier, in section 6.2.

In the BRT project, the instrument for check-in and out would not be installed in the buses. This is now considered as one of the challenges that this project could face in the future. However, stands would still be required to check-in and out. Aalborg has to invest in a lot of travel card stands in the stations, which arise the risk of becoming redundant if the travel card turns into an *APP* on the mobile phone in the future. (Grunert R., 2020 a)

For that reason, the Ministry of Transport and Housing has recently received an external analysis of possible development tracks for the further development of the planned routes and travel card system toward a *unified digital mobility service.* (IBID)

Another challenge would be deciding about the batteries charging method, charging at both charging stations in the selected locations and in the depot at night (*overnight charging*), or exclusively at the depot. The decision will be dependent on having enough information about the length of the routes and the number of passengers. If there is a mistake in the calculations, the fault would lead to the risk that the batteries will get out of charge. (Kollektivtrafik, 2019)

If the diesel buses arrive late at the end of the route, the lost time could be compensated by an immediate beginning of the return trip. However, this does not apply to an electric bus. If an electric bus arrives late at the end of the route, it may continue running late. This would, therefore, lead to poor system reliability. Likewise, delays could happen due to frequent charging, which could not take place on time. Nevertheless, no matter which case happens, delays could cost too expensive for public transportation. (MacKechnie, 2019)

Suitable extra battery capacity should also be considered, so the bus can handle the days under extraordinary conditions (Kollektivtrafik, 2019). However, traditionally the capacity of batteries is expected to be reduced to 80% after almost 7 years. (Movia, 2016)

Through recharging during the night at a depot, the bus is charged with a manual connection. Such a solution requires a medium charging power per bus, and the depots will, therefore, need a very large and costly connection to the electricity grid if many buses are to be charged simultaneously. (IBID)

Another challenge would be the bus type and battery model. Since the technology is rapidly evolving, there is a risk that today's solutions would be less attractive or be outdated in a short time. (IBID)

Despite advancements in battery technologies and a reduced necessary battery charging time, electric buses may still need to get charged around 5 minutes after running for about 32 km to 48 km (MacKechnie, 2019).

### 6.1.4 Base analyses in Excel

As previously mentioned in section 5.3, the base calculations and analyses have been performed in the Excel Spreadsheet. The total weekly driving hours by city buses and metro buses in Alborg for 2012, and a prediction for 2025, concerning an annual passenger growth of 2%, provide the base data for further analyses. The total weekly driving hours of buses in 2012 and 2025 are illustrated in tables 1 and 2. 2012 has been considered as the reference scenario for the analyses of the section. The analyses in this section provide the input data for the next section, the energy scenarios simulations in the EnergyPlan tool. These data include diesel consumption by diesel buses and electricity consumption by electric buses, operating buses in each line, for the identified years. Calculations have been performed to investigate the electricity demand by electric buses, the impacts on the electricity grid and energy system in Aalborg, and the CO2 emissions-saving resulted by employing electricity buses in each case year/scenario.

Based on the information from (Tiberiu, 2013) provided by NT, 70 diesel buses have been considered in the fleet in 2012. Right now, Aalborg municipality has 120 buses which should all be replaced by electric buses in 2030 (Interview, 2020 b).

In 2023, 29 full-electric buses (+BUS) should be added to the bus fleet, which must be replaced with the buses in lines 2 and 16. Although line 16 would be abolished, parts of the path should still be compensated by lines 15 and 18 and by buses which operate in diesel. This would also apply to some parts of line2 which should be added to lines 12 and 14. (COWI, 2018) (Andersen J. *et al*., 2019) For that reason, diesel buses in line 16 have not been converted to electric buses in the analyses of 2023. Instead, this line has been assumed to be phased out in 2030.

*Table 1.Total weekly driving hours in 2012 / NT- 2013 (Tiberiu, 2013)*

| 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 2.Total weekly driving hours prediction for 2025 / NT- 2013 (Tiberiu, 2013)*

| 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** |

| | *Rute* | *total Driving Hours* | Km |
|---|---|---|---|
| 2025 | by bus | 200.871 | 5.332.119 |
| | metro bus | 174.762 | 5.248.302 |
| | Sum: | 375.633 | 10.580.421 |

As the new trend for buses starts in 2022 (Interview, 2020 a), there is a possibility of the injection of new electric buses in the fleet in this year. Since the operating diesel buses are normal city buses (mostly +13 meters buses) (Interview, 2020 c), and because the +18 meters electric buses would have a higher capacity than the current diesel buses, it has been assumed that just 31 electric buses would be added to the fleet in 2022.

It is clear from table 1 that line 1 has a high weekly operation i.e. a high diesel consumption. Therefore, it has been assumed that the electric buses in 2022 would be first replaced in line 1. Line 11 has been also considered to be electrified in 2022 due to no applied change in the driving plan caused by the implementation of +BUS in 2023. Another reason for not considering all buses has been mainly due to this fact that not all diesel buses could be phased out in 2022. It has been also assumed that the newly considered electric buses added to the fleet in 2022 are from the same model utilized for +BUS, 18 meters *Citea SLFA 181e*.

Considering what mentioned above, it is assumed that 50% of the bus fleet would be electrified by 2023. This value for the bus fleet electrification has been also mentioned in one of the expert's interviews (Interview, 2020 c). With respect to the total number of 120 buses, it could be concluded that the number of extra electric buses employed in the fleet would be 60 in 2030. The reason for that has been with the assumption that the remaining diesel buses would have been reached to the age that could be phased out and mainly due to the target of Aalborg municipality for 70% $CO_2$ reduction in its transport sector and being completely electrified in 2030.

In the analyses, the weekly driving hours prediction for 2025 from (Tiberiu, 2013) has been considered as BAU (Business As Usual), since all buses are diesel buses and no new technology and change in the bus types have been considered. For that reason, another case/scenario for the year 2025 has been conducted, considering a total number of 60 electric buses (31 electric buses in 2022 and 29 in +BUS in 2023) added to the fleet by 2023, in addition to the remaining diesel buses in 2025.

Based on the values from table 1 and 2 the increased operation in kilometer (per year per line) has been calculated (Table 3):
¤ The year duration from 2012 to 2025 = 13 years
¤ The number of weeks per year = 48
¤ Operating 22 km per hour by diesel buses (Interview, 2020 b)
¤ The electric buses injection in the bus fleet each year i.e. taking out the yearly kilometers driven in diesel (this issue can be seen for years 2022 & 2023 in table 3)
¤ The increase in km per year per line = ((the value in 2025 - the value in 2012)/13)*48*22

*Table 3.Increase in km per year per line (Own table)*

| Line | 2012 Weekly driving hours | 2050 Weekly driving hours | Increase in km (per year per line) | 2022 Weekly driving hours | 2023 Weekly driving hours |
|---|---|---|---|---|---|
| 1 | 1348,8 | 1726,70 | 30.697,11 | 0 | 0 |
| 2 | 1074 | 1623,20 | 44.611,94 | 1074 | 0 |
| 11 | 344,7 | 515,70 | 13.890,46 | 0 | 0 |
| 12 | 368,3 | 537,30 | 13.728,00 | 368,3 | 368,3 |
| 13 | 387,9 | 528,80 | 11.445,42 | 387,9 | 387,9 |
| 14 | 425,3 | 692,00 | 21.664,25 | 425,3 | 425,3 |
| 15 | 289,5 | 394,00 | 8.488,62 | 289,5 | 289,5 |
| 16 | 263,6 | 377,30 | 9.235,94 | 263,6 | 263,6 |
| 17 | 405,2 | 759,80 | 28.804,43 | 405,2 | 405,2 |
| 18 | 45,1 | 45,10 | 0 | 45,1 | 45,1 |

The zero value for line 18 means that there has been no growth from 2012 to 2025 in this line. Through the values in column 4, *The total yearly increase in diesel operation* has been calculated. This has given a value of *182.566,15* km.

Based on the values from table 3, and the total yearly increase in diesel consumption, *the total annual operation in diesel (km) by each line per year* has been calculated (Table 4). Through that, *the annual diesel used* (Liter) from 2012 to 2030, and *CO2 emissions* caused by diesel consumption have been also calculated, which results can be seen in table 4.

If it is assumed that:
The annual operation in diesel (km) in 2012 = SUM (Weekly hours) *48*22 = 5.229.734 (Column 2, Table 4)
The annual operation in diesel (km) in another year/scenario = B (Colum2, Table 4)
The total yearly increase in diesel operation (km) = *182.566,15*
Increase in operation (km/per year per line, considering the operating kilometers for the line numbers in the fleet in that year) = C (Column 4, Table3)

Then B= 5.229.734 + (*182.566,15**(year of B-2012)) + C

*Table 4.* ***The annual operation and diesel used in the bus fleet, and CO2 emissions (Own table)***

| Year | The annual operation in diesel (Km/year) | The annual diesel used (Liter/year) | Annual CO2 emissions (Tones/year) | Buses in the fleet |
|---|---|---|---|---|
| 2012 | 5.229.734 | 1.936.939 | 4.921 | 70 |
| 2016 | 5.959.999 | 2.207.407 | **5.608** | |
| 2019 | 6.507.697 | 2.410.258 | 6.124 | 0 Electric /120 Diesel |
| **2022** | 7.010.808 | 2.596.596 | **6.597** | 31 Electric (Line 1 & 11) /89 Diesel |
| **2023** | 7.104.175 | 2.631.176 | **6.685** | 60 Electric (Line 2, 1, 11) /60 Diesel |
| **2025 (BAU)** | **10.580.421** | **3.918.674** | **9.956** | **120 Diesel** |
| **2025** | 7.290.908 | 2.700.336 | **6.861** | 60 Electric/60 Diesel |
| 2028 | 7.290.908 | 2.700.336 | 6.861 | 60 Electric/60 Diesel |
| 2029 | 7.290.908 | 2.700.336 | 6.861 | 60 Electric/60 Diesel |
| **2030** | 0 | 0 | **0** | 60 Electric/60 Diesel |

The results of the analyses are also illustrated in figure 25.

As the traffic network in Aalborg municipality would change after 2025 (COWI, 2018), it has been assumed that there would be no more passenger growth after 2025. For that reason, no change in the total operation (km) can be seen from 2025 to 2029.

The annual diesel used has been calculated (Table 4) based on this assumption that each diesel bus consumes 2,7 liters diesel fuel per kilometer operation (Interview, 2020 b) (Folketinget, 2016). Afterward, the $CO_2$ emissions, caused by the amount of diesel consumed by the operating diesel buses, for each year have been obtained (Table 4). It has been assumed that 945 grams of $CO_2$ would be emitted by per kilometer driving in diesel (Midttrafik, 2016). The results of the diesel consumptions and $CO_2$ emissions from 2012 to 2030 can be seen in figure 25.

By comparing the $CO_2$ emissions from 2016 to 2022 in Table 4, it can be seen that there has been a reduction in $CO_2$ emissions by 989 tones. However, from 2022 to 2023 although 29 more electric buses have been integrated into the fleet and 50% of the diesel buses have been replaced by electric buses, the $CO_2$ emissions have gotten increased by 88 tons. As an important result, this has happened due to the growth in passenger numbers resulting in more operation by diesel buses, consequently more CO2 emissions.

Since the growth in passenger numbers is continuing from 2023 to 2025, the $CO_2$ emissions would raise during this period. However, as mentioned above, due to the change in the traffic plan from 2025 and with concerning no more passenger growth after 2025, the $CO_2$ emissions would have a fixed value until 2030, when all diesel buses are phased out.

Comparing the results of 2025 and 2025(BAU), with 656 tons $CO_2$ emissions in difference, obviously shows how the energy system, here the transport sector, can be influenced in the absence of energy policies. Therefore, with concern to the current problem, using the theory of change concept, CO2 emissions, and transport sector targets and challenges, and considering the transition management, and choice awareness theory concepts, it can be concluded that if fossil fuel is chosen as the fuel for buses i.e. diesel, the impacts on society and climate would be too much mainly due to the CO2 emissions caused by diesel consumption. Therefore, a transition from fossil fuels to renewable energy sources will be necessary. This would happen with help from actions by all actors, and by making a debate regarding the employment of other renewable and sustainable energy sources such as RE electricity. Thereby, the decision-making process by e.g. Aalborg municipality and energy-relevant actors will get influenced.

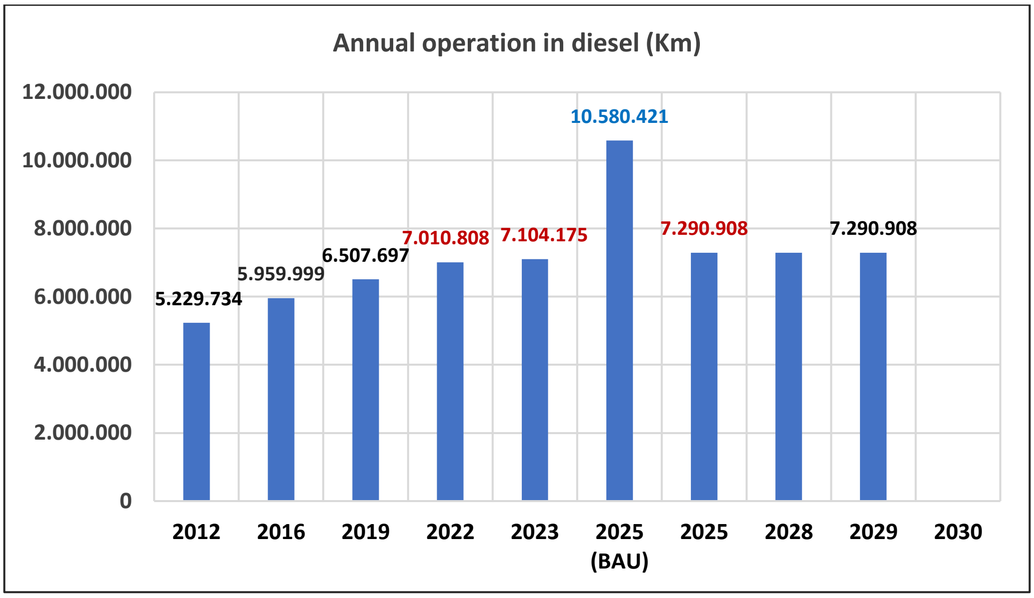


*Figure 25.Annual driving kilometers in diesel (2012-2030) [km] (Own figure)*

However, to make this green transition and to the purpose of having a 100% electrified bus fleet and a green transport in 2030, with concern to the choice awareness theory and theory of change, a rethinking by different stakeholders, and the government green strategies to support effective energy solutions cannot be ignored. Therefore, developed decisions and strategies must be implemented to make a radical change, and this green transition from fossil fuel to a renewable and sustainable transport system. Once more, concerning the theory of change, and choice awareness theory concepts, citizens in Aalborg municipality can through a better choice, changing behavior, (respecting innovation theory concept), and using public transportation support electrification of the bus fleet and green transition. This support will result in the development of electric batteries and buses and pushing new and more efficient technologies to the market. Therefore, the way to a green electrified Aalborg bus fleet in 2030 will be facilitated.

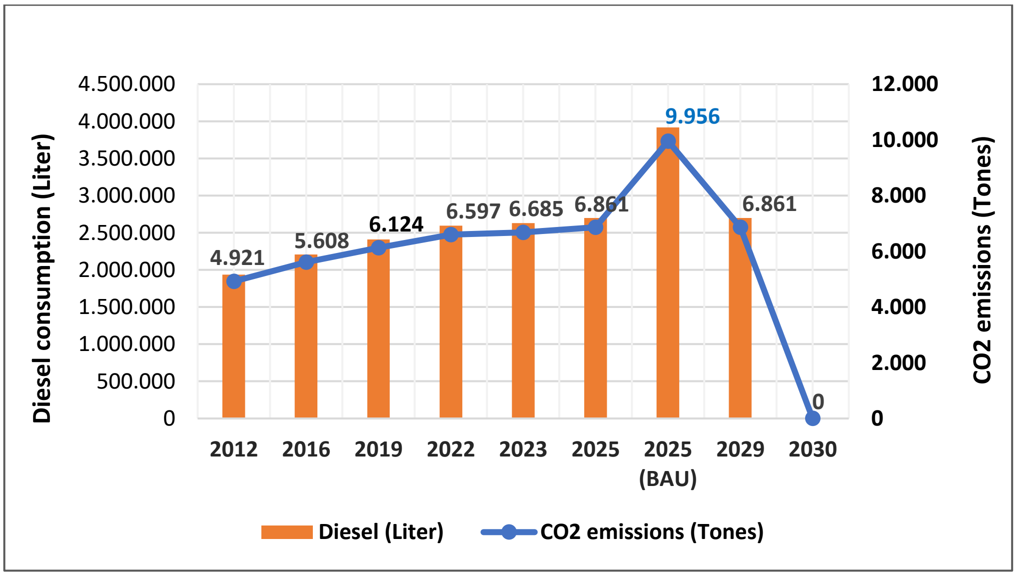


*Figure 26.The diesel consumption and CO2 emission (2012-2030) (Own figure)*

As all the CO2 emissions happen by diesel consumption, it is clear from figure 25 that by 100% electrification of the bus fleet in 2030, no CO2 would be released by buses. Therefore, diesel consumption and CO2 emissions will both have a zero value in 2030.

### 6.1.5 Electricity consumption by electric buses – 2020, 2023 and 2030

To be able to perform energy scenarios to be applied to EnergyPlan in the next section, it is necessary to calculate the electricity consumption by buses for each scenario-year. This will be done through taking out the diesel consumption by defined lines i.e. lines 1, 11 in 2022, 2 in 2023, and finally rest of the diesel buses in 2030.

Since no precise information has been available regarding the electricity consumption by the 18 meters electric bus model used for +BUS, the electricity consumption has been considered 1,8 kWh per kilometer, which is the approximate average electricity consumption by 18m (Sustainable BUS, n.d). As the buses are fully electric, thereby, heating the bus will not take place through biodiesel. For that reason, an extra 20 percent of electricity consumption has been considered for heating the bus. (IBID) This would give a total electricity consumption of 2,16 kWh/Km.

Rely on the COWI analyses for +BUS, the 29 electric buses would have a total yearly operation of 62.300 hours (COWI, 2018) (Interview, 2020 d). Based on that, the total yearly hours of driving per electric bus has been calculated by dividing this value by 29, which has given a value of 2.148 hours.

As +BUS drives 11,5 km in 32 minutes (COWI, 2018), then it could be calculated that one electric bus drives 23 km in a one-hour duration. Based on this value, the total operation (km) by 29 buses can be calculated, which gives the value of 1.432.900 km (62.300*23).

Approximate average electricity consumption by one 18m bus = 1,8 (kWh/Km)
Electricity usage considering 20% of electricity for heating = 2,16 (kWh/Km)
Total annual hours of driving by 29 buses = 62.300 (h)
Operation (per bus per hour) = 23 (Km)
Total operation per year- 29 buses (Km) = Total hours of driving per year- 29 buses * Driving distance per bus per hour = 1.432.900 (km)
Thus:
Annual electricity consumption by 29 buses (kWh) = Total driving distance per year- 29 buses (km) * Electricity consumption, considering 20% of electricity for heating = 3.095.064 (kWh) = 0,0031 (TWh)

Based on the calculated electricity consumption by each +BUS, and the calculated values for diesel buses operation (km/year) from the previous section, the required electricity demand by other buses has been calculated.

Using column 2, table 3, and column 4, table 3, and in the same way, described in section 6.1.4, the annual operation (km) for line 1 and 11 in 2020 has been calculated.

*Line 1*: Yearly operation = 1.731.303 (km)
*Line 11*: Yearly operation = 2.189.664 (km)

As mentioned previously in section 6.1.4, each diesel bus consumes 2,7 liters diesel fuel per kilometer operation (Interview, 2020 b) (Folketinget, 2016). Considering that, the amount of diesel that will be taken out of the bus fleet has been also calculated, further illustrated in table 5.

Through Yearly operation (km), the electricity consumption by these 2 lines, with the same assumption for electricity consumption by electric buses i.e. 2.16 kWh/km and in the same way for +BUS, has been calculated.

As mentioned above, the total annual hours of driving by one 18m electric bus has been calculated 2.148 (h)

Therefore, The annual operation per 18m electric bus = 4.640 (Km). Therefore:

Electricity consumption by line 1= 3.739.616 (kWh/Km)
Electricity consumption by line 11= 2.189.664 (kWh/Km)

In the same way, the electricity consumption by the rest of the buses (lines 12,13,14,15,16,17 & 18) or the remaining 50% in the fleet in 2030 has given the result of 3.521.020 km. Through that, the electricity consumption in 2030 (the summation of electricity consumption in 2022, 2023, and the rest of buses in 2030) has delivered a total result of 20.352.263 kWh. The results of the above analyses are illustrated in table 5 and figure 27. The electricity consumption can also be seen in MWh in figure 28.

*Table 5.The electricity consumption by electric buses in 2022, 2023 and 2030 (Own table)*

| Electricity consumption / Diesel saving | Line 1 & 11 | Line 1, 11 & 2 | Line 1,11,2 & rest of diesel buses |
|---|---|---|---|
| | 2022 | 2023 | 2030 |
| **Yearly operation (km)** | 2.234.211,69 | 1.432.900 | 3.987.854,03 |
| **The amount of diesel saved (Liter/year)** | 827.485,81 | 530.703,70 | 1.476.982,97 |
| **Electricity consumption (kWh)** | 4.825.897,26 | 7.920.961,26 | 21360623,22 |
| **Electricity consumption (TWh)** | 0,0048 | 0,0079 | 0,0214 |

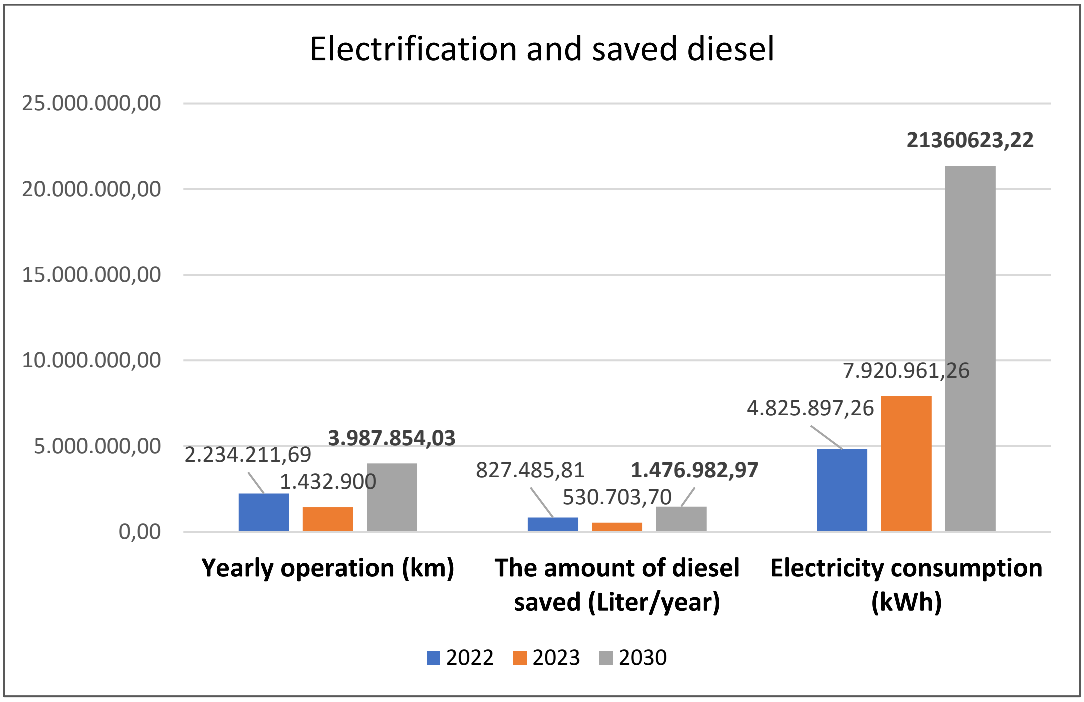


*Figure 27.Electrification and saved diesel (Own figure)*

It is clear from the results, how the electrification of the bus fleet results in more diesel saving i.e. less fossil fuel consumption. The most diesel saving occurs in 2030 when the whole but fleet is electrified. Once again, and with referring to the applied theories to the project, it can be emphasized how effective policy measures and technological change can lead to fossil fuel saving, the main cause of CO2 emissions. Therefore, it can be concluded again that in the lack of new innovative energy systems and technologies achieving the target of 70% in 2030 would not get succeed.

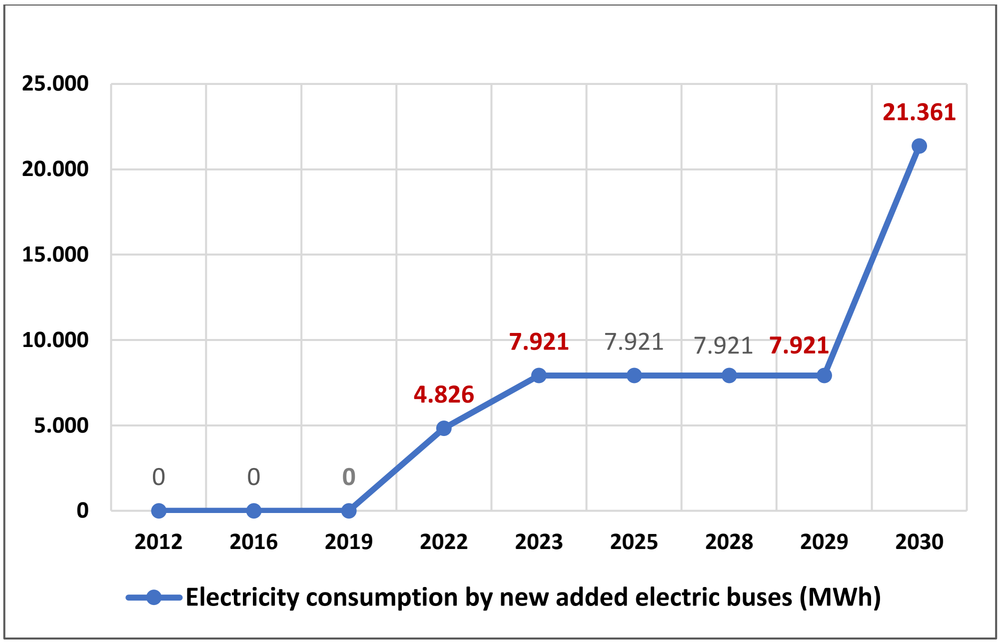


*Figure 28.The electricity consumption from 2022 to 2030 [MWh] (Own figure)*

To the purpose of a better and together observation of all results, the below table has been also provided.

*Table 6. Fuel consumption and CO2 emission (2012-2030) (Own table)*

| Year | CO2 emissions (Tones) | Diesel (Liter) | Electricity (MWh) |
|---|---|---|---|
| 2012 | 4.921 | 1.936.939 | 0 |
| 2016 | 5.608 | 2.207.407 | 0 |
| 2019 | 6.124 | 2.410.258 | 0 |
| 2022 | 6.597 | 2.596.596 | 4.826 |
| 2023 | 6.685 | 2.631.176 | 7.921 |
| 2025 | 6.861 | 2.700.336 | 7.921 |
| 2025 (BAU) | 9.956 | 3.918.674 | 0 |
| 2029 | 6.861 | 2.700.336 | 7.921 |
| 2030 | 0 | 0 | 21.361 |

The two zero values considered in table 6, for diesel consumption and $CO_2$ emissions, means that phasing out the diesel buses and replacing them by electric buses will result in no more $CO_2$ emissions caused by diesel buses in the bus fleet of Aalborg. Once more to the same results and considering theory concepts mentioned in the previous section, in the absence of sustainable and strategic planning and proper decision-making, no radical change would take place in the energy system. Therefore, more fossil fuel consumption will result in more $CO_2$ emissions.

By utilizing the obtained results in this section, the technical simulation of the energy system in EnergyPlan has been conducted through different scenarios, discussed in the next section.

### 6.1.6 EnergyPlan scenarios – Analyses and results

The analyses in this section have been performed for the energy system scenarios from 2016 to 2030. The year 2016, without the diesel buses in the fleet, has been considered as the reference scenario, based on the input data driven from PlanEnergi 2016. The below scenarios are further discussing in separate sections.

- 2016 (Without diesel buses)
- 2016 (With diesel buses)
- 2022 – (First phase of electrification - 25.8% electrification)
- 2023 scenario – BRT STARTS (Second phase of electrification - 50% electrification)
- 2025
- 2025 BAU (Business as Usual)
- 2028 (Without North Jutland coal CHP plant /Nordjyllandsværket)
- 2030 scenario – (100% electrified fleet - without Nordjyllandsværket)
- 2028 scenario (With Nordjyllandsværket)
- 2030 scenario – (100% electrified fleet - With Nordjyllandsværket)

The first step to perform analyses has been identifying the energy demand and supply for the base scenario. This issue has been also mentioned previously in section 5.4, energy planning approach. To do the task, the values for production capacities and efficiencies, and demand data values have been extracted from PlanEnergi 2016. These values have been considered in the base scenario, 2016 without diesel buses, in EnergyPlan. Based on the driven data the below table has been provided.

*Table 6.Base data- Production capacities (driven from PlanEnergi)*

| Supply Source | Electric capacity (MW-e) | Thermal capacity (MJ/s) | Efficiencies |
|---|---|---|---|
| Nordjyllandsværket (condensing mode operation) | 380 | - | 0,47 |
| Nordjyllandsværket (backpressure mode operation) | 323 | 422 | Electric: 0,39<br>Thermal: 0,51 |
| Decentral CHP | 21,6 | 30 | Electric: 0,39<br>Thermal: 0,55 |
| Central power plant | 21,6 | - | 0,39 |
| Wind power (onshore) | 125 | - | 0,3 |
| Photo Voltaic | 14 | - | 0,3 |
| Boiler | - | 531 | Capacity factor: 0,22 |
| Boiler | - | 531 | Capacity factor: 0,08 |

Besides the supply data, demand data should also be identified. The demand values are presented in the below table. The demands include demand for electricity, heat, industry/fuel, and transport.

*Table 7.Demand Data (driven from PlanEnergi)*

| Demand | (TWh/year) |
|---|---|
| Electricity | 1,493 |
| District heating G3 | 1,46 |
| District Heating G2 | 0,15 |
| Coal (Industry) | 5,6 |
| Oil (Industry) | 216 |
| Natural gas (Industry) | 0,64 |
| Biomass (Industry) | 1,85 |
| JP (Jet Fuel) | 0,43 fossil / biofuel 0 |
| Diesel /DME | 1,015 fossil / 0,06 biofuel |
| Petrol / Methanol | 0,54 Fossil / 0,02 biofuel |

For each of the below-conducted scenarios, the obtained results of the diesel and electricity consumption in the year of the scenario have been applied from section 6.1.4 and 6.1.5, the calculated values taken from the Excel Spreadsheet. The electricity demand in each scenario has been added under the Demand tab > Electricity > Additional electricity demand. The diesel demand in each scenario has been added to the base diesel value of 1,015 TWh in 2016, defined in Table 7, which includes diesel consumption in all transport segments exclude buses.

The annual diesel used, applied to each scenario, are the same values from table 4, section 6.1.4. However, to be able to use these values in EnergyPlan they had been converted from kWh to TWh. One liter of diesel contains 10 kWh energy, which based on that the new capacities have been calculated and provided in the below table.

*Table 8.Diesel consumption in each scenario (Own figure)*

| (TWh/year) | 2016 | 2022 | 2023 | 2025 (BAU) | 2025 | 2028 | 2030 |
|---|---|---|---|---|---|---|---|
| Diesel demand | 1,0371 | 1,0410 | 1,0413 | **1,0542** | 1,0420 | 1,0420 | 1,0150 |
| Electricity demand | | 0,0048 | 0,0079 | | | | 0,0214 |

It should be noted that, in the scenario analyses, the fossil fuel and biofuel consumption by other transport segments have been also used as the input data to EnergyPlan.
To the purpose of a comparison of all energy system simulations results, the same output parameters are considered for all scenarios. It should be also mentioned that *Coal*, *Natural gas (Ngas)*, and *Biomass* consumptions by households have not been considered in the results i.e. the fuel consumption in households has been subtracted from the total fuel consumption.
The final results of the analyses are further discussed and illustrated in section 6.1.5.10.

### 6.1.6.1 Scenario 2016 (Without diesel buses) – The reference scenario

This scenario is considered as the base scenario. The diesel consumption by other transport segments except buses are considered in this scenario. Therefore, in further scenarios, the extra diesel consumption by bus segment will be added to this value. The results for this scenario are illustrated in the table below.

*Table 9.The reference scenario (Scenario 2016 without diesel buses) (Own table)*

| | |
|---|---|
| Max electricity demand capacity (MW) | *266* |
| Total fuel consumption (TWh/year) | 19,78 |
| $CO_2$ emissions (MT) | 4,464 |
| RES share of PES (%) *include biomass* | 26,2 |
| RES share of electricity production (%) *include biomass* | 20,9 |
| Coal consumption (TWh/year) | 8,78 |
| Ngas consumption (TWh/year) | 1,39 |
| Biomass consumption (TWh/year) | 4,6 |

### 6.1.6.2 Scenario 2016 (With buses)

The values in this scenario are the same as the reference scenario, except the added calculated diesel consumption by all buses in 2016, from section 6.1.4. As a result of adding the diesel buses in the energy system, there has been an increase in the total fuel consumption of 0,01 TWh/year. More diesel consumption has, in turn, resulted in more $CO_2$ emissions, an increase of 0,008 Mtons.

*Table 10.Scenario 2016 (With diesel buses) (Own table)*

| | |
|---|---|
| Max electricity demand capacity (MW) | 266 |
| Total fuel consumption (TWh/year) | 19,81 |
| $CO_2$ emissions (MT) | 4,472 |
| RES share of PES (%) *include biomass* | 26,2 |
| RES share of electricity production (%) *include biomass* | 20,9 |
| Coal consumption (TWh/year) | 8,78 |
| Ngas consumption (TWh/year) | 1,39 |
| Biomass consumption (TWh/year) | 4,6 |

### 6.1.6.3 Scenario 2022 (Electrification, phase 1)

As mentioned previously, 25,8% of the bus fleet is electrified, i.e. 31 new electric buses are employed in the fleet to operate instead of diesel buses in lines 1 and 11. However, other diesel buses in the fleet have been kept working. The extra electricity demand, by new electric buses, has been added to the electricity demand in scenario 2016 with diesel buses.

*Table 11.Scenario 2022 (31 electric buses employed in the fleet) (Own table)*

| | |
|---|---|
| Max electricity demand capacity (MW) | 267 |
| Total fuel consumption (TWh/year) | 19,82 |
| $CO_2$ emissions (MT) | 4,476 |
| RES share of PES *includes biomass* (%) | 26,1 |
| RES share of electricity production (%) *include biomass* | 20,8 |
| Coal consumption (TWh/year) | 8,79 |
| Ngas consumption (TWh/year) | 1,39 |
| Biomass consumption (TWh/year) | 4,6 |

There can be seen in table 7, although two bus routes have been electrified, the $CO_2$ emission has increased in comparison with the previous scenario, 2016 with diesel buses. This has happened mainly due to more fuel consumption (diesel), as a result of passenger growth. The total fuel consumption has had an increase of 0,01 TWh/year. This increase in fuel consumption has caused by 0,01 TWh increment in coal consumption which can be also seen in the above table.

By comparing the *RES share of PES* and *RES share of electricity production* in scenarios *2020* and *2016 with buses*, and 0,1 reduction in *2020*, it could be understood that the required electricity for buses has been supplied from non-renewable sources i.e. from coal.

There has been defined two CHP plant in EnergyPlan, Nordjyllandsværk, and waste incineration. The main fuel used by Nordjyllandsværk is coal. Further that he predefined strategy for fuel consumption by waste incineration plant is 1.Coal/2.biomass. By comparing the fixed biomass and Ngas consumption in the two scenarios *2020* and *2016 with buses*, it could be concluded that the required electricity has been supplied by one or two of these plants and from coal.

### 6.1.6.4 Scenario 2023 (Electrification phase 2 / +BUS)

The extra electricity demand by new 29 electric buses (+BUS) has been added to the electricity demand in the 2022 scenario. 50% of the fleet is now electrified and the remaining diesel buses are still operating in the fleet.

*Table 12.Scenario 2023 (+BUS - 50% electrified bus fleet) (Own table)*

| | |
|---|---|
| Max electricity demand capacity (MW) | 267 |
| Total fuel consumption (TWh/year) | 19,82 |
| $CO_2$ emissions (MT) | 4,478 |
| RES share of PES (%) *include biomass* | 26,1 |
| RES share of electricity production (%) *include biomass* | 20,8 |
| Coal consumption (TWh/year) | 8,8 |
| Ngas consumption (TWh/year) | 1,39 |
| Biomass consumption (TWh/year) | 4,6 |

Once more, in this scenario, despite the electrification of 50% of the bus fleet, the passenger growth would result in more $CO_2$ emissions.

It should be mentioned that coal consumption has also has had an increase of 0,01 TWh, which could be due to the same issue mentioned in the previous section, the electricity supply from non-renewable sources. It should be also noted that, in this scenario and the scenario for 2022 the *Maximum electricity demand capacity* has had an increase of 1 MW comparing with both scenarios in 2016.

### 6.1.6.5 Scenario 2025

In this scenario, the same 60 electric buses from 2023 are operating in the fleet and no extra electricity demand has been added. However, the arisen diesel consumption from 2023, by the remaining 50% diesel buses, has been added as the extra diesel consumption.

*Table 13.Scenario 2025 (Own table)*

| | |
|---|---|
| Max electricity demand capacity (MW) | 267 |
| Total fuel consumption (TWh/year) | 19,83 |
| $CO_2$ emissions (MT) | 4,478 |
| RES share of PES (%) *include biomass* | 26,1 |
| RES share of electricity production (%) *include biomass* | *20,8* |
| Coal consumption (TWh/year) | 8,8 |
| Ngas consumption (TWh/year) | 1,39 |
| Biomass consumption (TWh/year) | 4,6 |

Concerning the same obtained value for coal consumption in comparison with the 2023 scenario, it could be understood that no more coal for electrification has been used in this scenario. The reason for that is due to the same number of electric buses and the required coal for electrification of buses. However, due to more diesel consumption in this scenario, *the total fuel consumption*, has had an increase of 0,01 compare with the scenario in 2023. This fuel consumption includes biomass but excludes RES.

#### 6.1.6.6 Scenario 2025 (Business as Usual)

This scenario is conducted as a BAU scenario, with this assumption that no electric buses would be employed in the fleet. Thereby, the diesel buses would keep operating with consideration of passenger growth and increment in diesel consumption from 2016.

The coal consumption in this scenario has the same value as 2016, before electrification. In another word, less coal, 0,01 TWh, is consumed in this scenario in comparison with the scenarios for 2022, 2023, and 2025 with a part of electrified buses in the fleet. Thereby, the RES share of electricity production has more value of 0,1% compared with the scenario from 2022 to 2025.

*Table 14.Scenario 2025 (BAU) (Own table)*

| | |
|---|---|
| Max electricity demand capacity (MW) | *266* |
| Total fuel consumption (TWh/year) | 19,82 |
| $CO_2$ emissions (MT) | 4,474 |
| RES share of PES (%) *include biomass* | 26,1 |
| RES share of electricity production (%) *include biomass* | 20,9 |
| Coal consumption (TWh/year) | 8,78 |
| Ngas consumption (TWh/year) | 1,39 |
| Biomass consumption (TWh/year) | 4,6 |

#### 6.1.6.7 Scenario 2028 (Without North Jutland coal CHP plant in Aalborg)

As it has been assumed that no extra growth in the passenger numbers would happen after 2025, therefore, the same diesel consumption from scenario 2025 has been applied to this scenario. The electricity consumption has been also assumed the same values from 2025.

The difference between this scenario and scenario 2025 is that the considered capacities for the *North Jutland Coal CHP plant (Nordjyllandsværk)*, have been considered zero in this scenario. Since the required fuel for energy production by this plant is mainly provided by coal, there has been decided that the plant should be closed down in 2028. Thus, the capacities of the plant for electricity and heat have been considered zero values in this scenario. It means that the electricity demand by electric buses which could be supplied from this source, would not be further available in the energy system.

*Table 15.Scenario 2028 (Without North Jutland Coal CHP plant) (Own table)*

| | |
|---|---|
| Max electricity demand capacity (MW) | 267 |
| Total fuel consumption (TWh/year) | 18,76 |
| $CO_2$ emissions (MT) | 3,844 |
| RES share of PES (%) *include biomass* | 27,6 |
| RES share of electricity production (%) *include biomass* | *20,8* |
| Coal consumption (TWh/year) | 5,78 |
| Ngas consumption (TWh/year) | 3,34 |
| Biomass consumption (TWh/year) | 4,6 |

It is clear from the table that by closing down the coal plant the coal consumption has had a significant decrease, which has resulted in less $CO_2$ emissions. Although the *total fuel consumption* has fallen by 1,07 TWh compared with the value in scenario 2025, however, the *Ngas consumption* has risen by a value of 1,95 TWh. It means that the lost electricity production caused by the closing down of the Nordjyllandsværk should be supplied from another source i.e. Natural gas power plant. Therefore, the electricity demand by electric buses would be supplied by the Ngas power plant.

#### 6.1.6.8 Scenario 2030 (Without North Jutland coal CHP plant in Aalborg)

Likewise, 2028 scenario, the North Jutland Coal CHP plant has not been considered in this scenario. But in this scenario, the remaining buses in the fleet are all electrified. Thereby, the total amount of electricity consumption by buses had been considered as the extra electricity demand in the system. The simulation of the energy system, in this case, investigates how the required electricity of buses, the whole fleet, would be supplied by other sources.

By looking at the *Maximum electricity demand capacity* in this scenario and comparing that with the previous ones, it could be seen that the electricity demand capacity has been increasing from the scenario 2022, the first phase of electrification. *Total fuel consumption* has been decreased due to the electrification of other diesel buses in the fleet, thus less fossil fuel consumption. The lowest minimum level of $CO_2$ emissions takes place in this scenario due to the same reason, complete electrification of the bus fleet. Another reason for less $CO_2$ emissions is due to the elimination of the Nordjyllandsværk from the energy system.

However, by 100% electrification of the bus fleet in 2030 and without the Nordjyllandsværk, the required electricity demand by buses need to be supplied from other sources, like the scenario 2028 and from Ngas power plant.

*Table 16.Scenario 2030 (Without North Jutland Coal CHP plant) (Own table)*

| | |
|---|---|
| Max electricity demand capacity (MW) | 269 |
| Total fuel consumption (TWh/year) | 18,72 |
| CO2 emissions (MT) | 3,834 |
| RES share of PES (%) *include biomass* | 27,7 |
| RES share of electricity production (%) *include biomass* | 20,6 |
| Coal consumption (TWh/year) | 5,78 |
| Ngas consumption (TWh/year) | 3,34 |
| Biomass consumption (TWh/year) | 4,6 |

Another issue in this scenario is the *RES share of electricity production- include biomass*, which has fallen 0,2%, compared with the scenario in 2028. As can be seen from the tables for scenarios from 2016 to 2030, the *RES share of PES- include biomass RES* has increased while the *share of electricity production- include biomass* has decreased. It means that although the biomass share for energy production, has been used in other sectors and not for the electrification of buses. It can be also seen from the table by looking at the *Biomass consumption* value for scenarios from 2016 to 2030.

#### 6.1.6.9 Scenario 2030 (With North Jutland coal CHP plant in Aalborg)

Another scenario for 2030 has been also conducted with this assumption that the North Jutland coal CHP plant would not be closed down in 2028, but the bus fleet is completely electrified. Considering this scenario has been mainly to investigate how the energy system would look like if there is a political opposition against closing down the Nordjyllandsværket.

*Table 17.Scenario 2030 (With North Jutland Coal CHP plant) (Own table)*

| | |
|---|---|
| Max electricity demand capacity (MW) | *269* |
| Total fuel consumption (TWh/year) | 19,81 |
| CO2 emissions (MT) | 4,477 |
| RES share of PES (%) *include biomass* | 26,2 |
| RES share of electricity production (%) *include biomass* | 20,6 |
| Coal consumption (TWh/year) | 8,83 |
| Ngas consumption (TWh/year) | 1,38 |
| Biomass consumption (TWh/year) | 4,6 |

In this case, the *coal consumption* value and the $CO_2$ emissions have their maximum values among other scenarios. However, 0,01 TWh/year less Ngas would be consumed in this scenario. *Total fuel consumption* and *RES share of PES- include biomass* would also be backed to the same level in *2016 with buses*. *RES share of electricity production- include biomass* would have the same value in the scenario 2030 without Nordjyllandsværket.

#### 6.1.6.10 Visualization of the results and conclusion

Critical excess electricity production (CEEP) has had a zero value in all scenarios. In other words, there has been no amount of the produced electricity which couldn't have been exported due to the shortcomings in the electricity grid border connections.

despite the electrification of 50% of the bus fleet, the passenger growth would result in more $CO_2$ emissions.

Figure 27 shows the total fuel consumption in the energy system. Although half of the buses in the fleet have been electrified by 2023, due to every year's expansion in the passengers' number (passenger growth) and extended driving in kilometers up to 2025, more fuel would be required to supply the fuel demand by buses (more diesel) in 2022, 2023 and 2025 compared with *2016 with buses*. On the other hand, the decrease in *RES share of electricity production* (figure 28) and increment in *$CO_2$ emissions* (figure 29) means more *coal consumption* (figure 30) is required to supply electricity demand by buses. Concerning the results, it can be concluded that in the absence of strategic planning, to the purpose of reducing the less fossil fuel consumption caused by passenger growth, and in the lack of on-time employment of sustainable and energy-efficient technology solutions, how the impacts of that can be significant.

The maximum fuel consumption would take place in *2025* when the passenger growth had been assumed at maximum level and electricity demand by buses would be supplied by Nordjyllandsværket coal CHP plant.

In the absence of the Nordjyllandsværket coal CHP plant resulting in the fuel shortage in the energy system, the required electricity by electric buses would necessarily be supplied from other sources e.g. Ngas power plant, which means more *Ngas consumption* from 2028 (figure 31). Another proof for that is the reduction in *RES share of electricity production*, illustrated in figure 28.

The minimum fuel consumption would happen in 2030 when the Nordjyllandsværket has been closed down. It could be also understood from the figure 27 that the Nordjyllandsværket has lonely a fuel consumption of around 1 TWh/year.

Closing down the Nordjyllandsværket and no more growth in passengers' numbers after 2025 result in the lowest $CO_2$ emissions levels in 2028 and *2023 without Nordjyllandsværket*, illustrated in figure 29.

In contrast, if the coal CHP plant would not be closed, then the required electricity for buses would be supplied from this plant which would, in turn, results in the highest $CO_2$ emissions level in the energy system, 4,477 Mtones compared with 3,834 Mtones in *2030 without Nordjyllandsværket*.

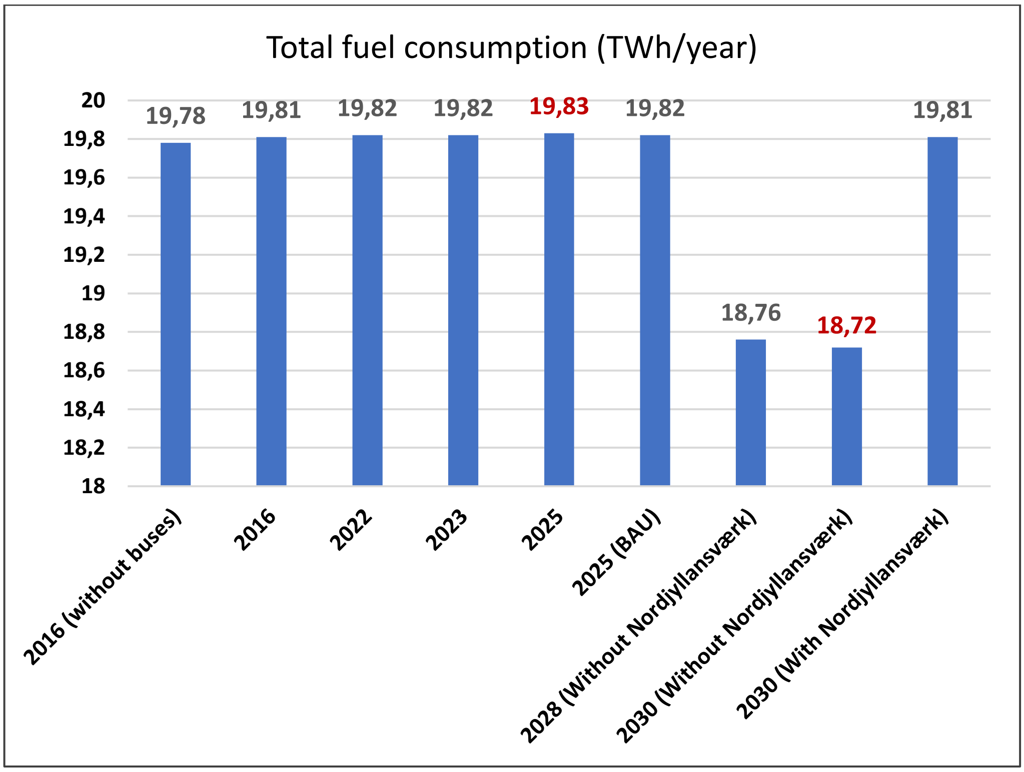


*Figure 29.Total fuel consumption [TWh/year] (Own figure)*

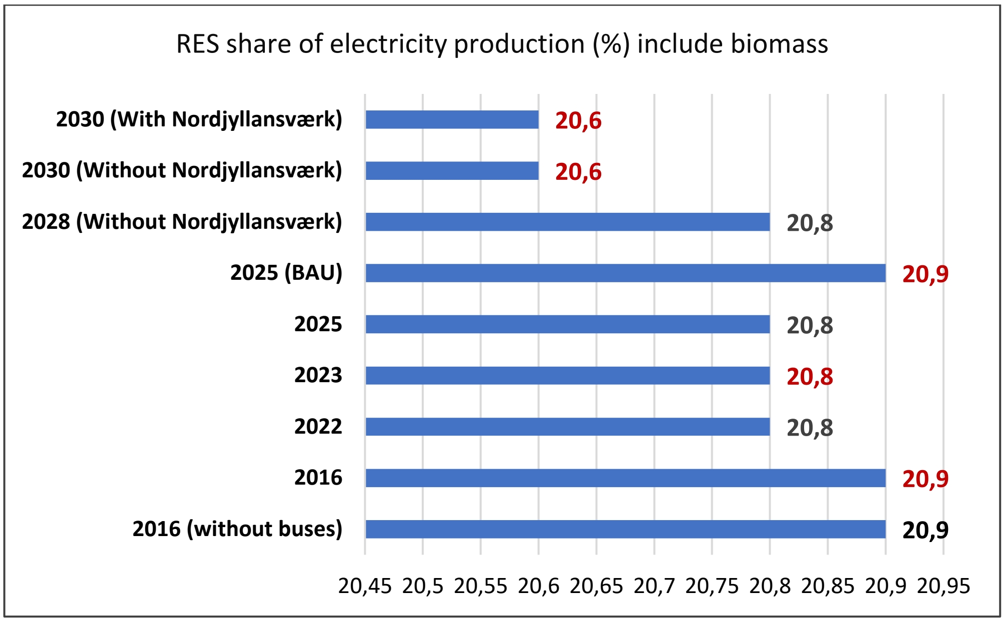


*Figure 30.ES share of electricity production [%] include biomass (Own figure)*

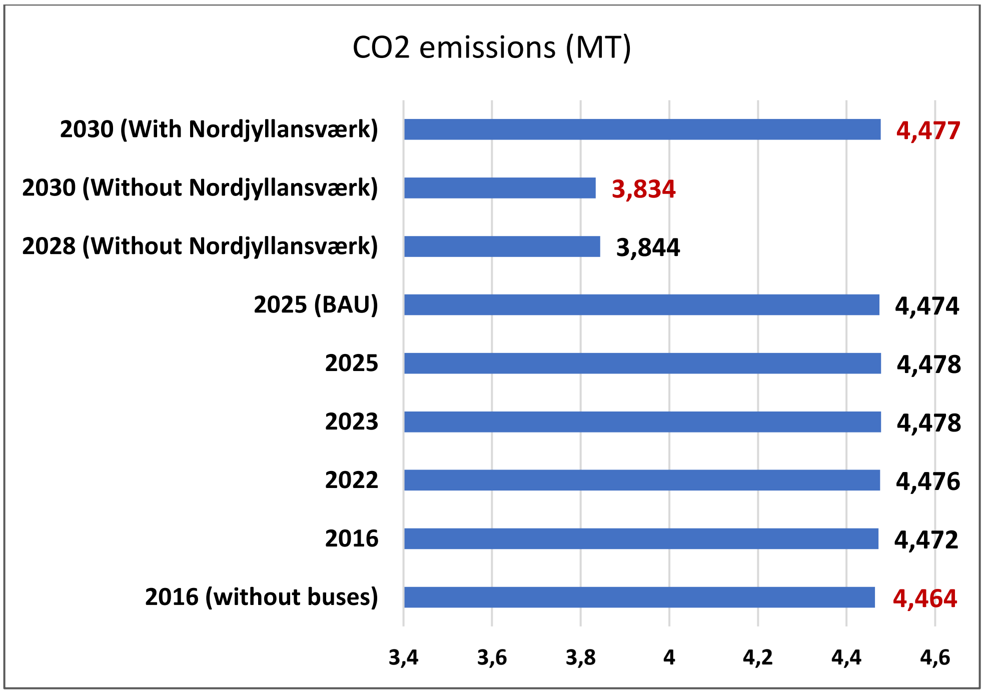


*Figure 31.CO2 emissions [MT] (Own figure)*

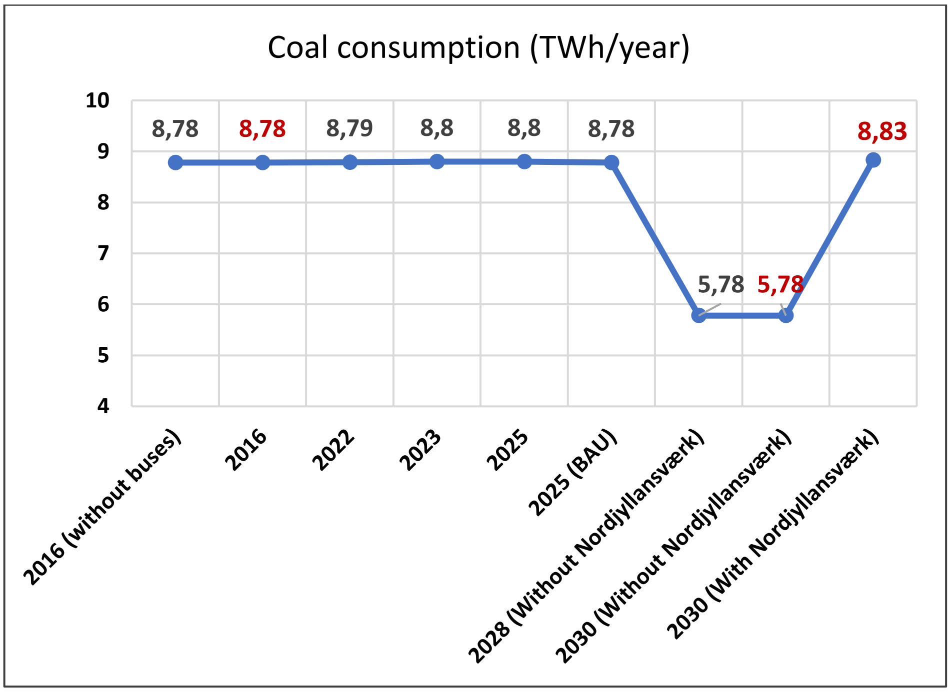


*Figure 32.Coal consumption [TWh/year] (Own figure)*

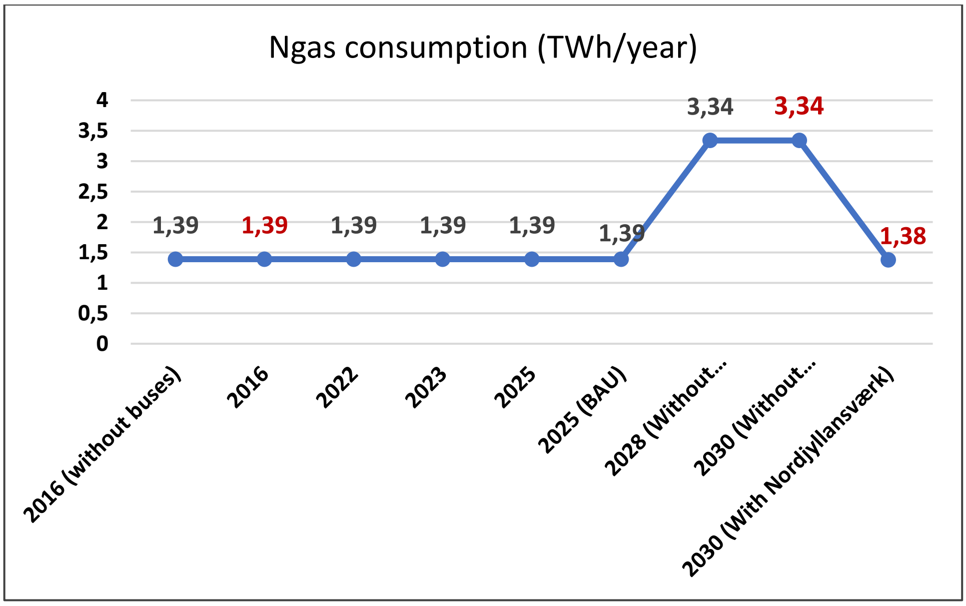


*Figure 33.Natural gas consumption [TWh/year] (Own figure)*

As it is illustrated in figure 32, the *maximum electricity demand* occurs in 2030, the year in which all buses are electrified. By comparing the capacities in 2030 and *2016 with buses*, it could be understood that a 3 MW more capacity would be required to supply the electricity demand by all buses. However, it looks like from the results that the required electricity capacity for the electrification of buses would not be provided by renewable sources. The results show that the needed capacity would be supplied by Nordjyllandsværk coal CHP plant up to 2028, and by Ngas power plant after closing down the Nordjyllandsværk. Thereby, concerning all the energy targets in 2030 and 2050 to supply the required electricity demand capacity of buses, there is a need for 3MW more capacity investment in the power grid and from 100% RE sources.

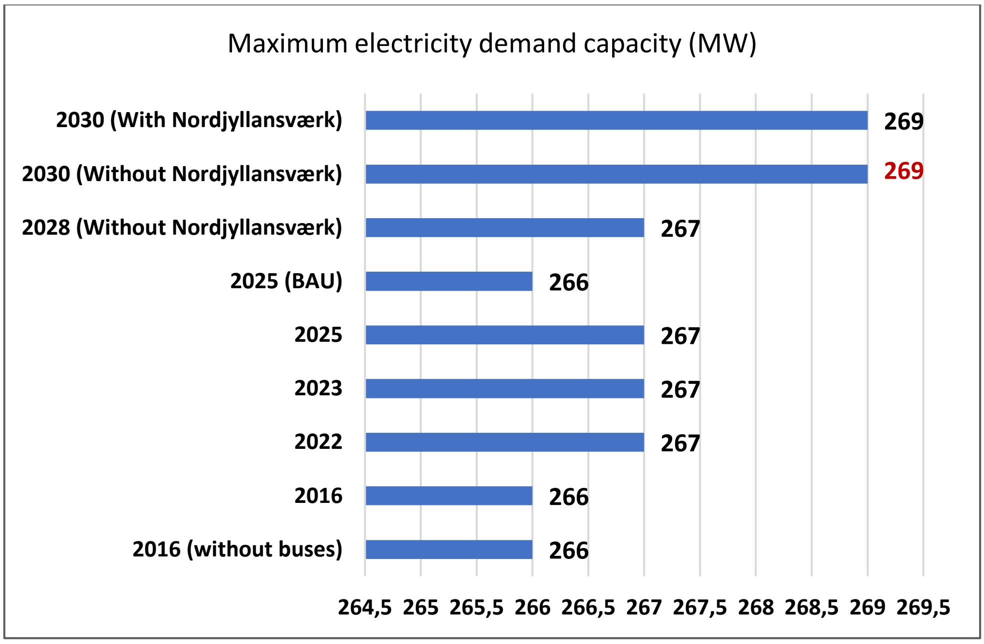


*Figure 34.Maximum electricity demand capacity [MW] (Own figure)*

## 6.2 Institutional analyses/ barriers

Public transportation is considered as a key element to improve the economic development and the quality of life of the citizens in a region. The strategies for efficient public transportation are defined based on important criteria such as the citizens' needs, citizens' sensibilities, region's topography, environmental preoccupations, historical development, economic barriers, etc. At the same time, the new technologies and transport styles and services are getting appeared, which are highly promising for the development of the strategies for regional public transport. (AVENUE, n.d a) Here the focus is on both sustainability and innovation (Holo, 2019 f).
In general, fewer cars, even electric cars, should be employed in the transport fleet and instead, public transportation must get improved (Grunert R., 2020 c). People's knowledge about the situation, social problems, and social acceptance of other sustainable technologies and methods of commuting would play a significant role in this respect. (Holo, 2019 f)

In vehicles with room for five, the whole capacity is poorly utilized, often with only one or two people in vehicles. Instead, self-driving minibuses and buses can reduce traffic caused by private cars by providing mobility services for more people and in a more sustainable way. Rush hour can be reduced by 80 to 90% by replacing the empty passenger cars with shared, self-driving vehicles or route buses. As a result, a huge amount of $CO_2$ would be saved (Sorgenfrei, 2019).

Moreover, the disappearance of cars can free up areas and give place for employing cleaner and effective public transportation in the future. In this way, the regions and municipalities can provide better services and at the same time save more energy resources and more money on energy production and operation. (IBID) As a result, the produced electricity for electrification of private passenger cars can be utilized for the electrification of other parts of the transport sector, resulting in less capacity investment.

Based on the calculations from the ministry of transport and housing, it is far cheaper to use public transport than to use a car. However, many people choose to take the car. It is partly because public transport is often slower, less flexible, and more difficult to take door-to-door services compared to private cars. (Olifent, 2020) Thereby due to the very limited options and services that cannot answer the passengers' constantly increasing needs (AVENUE, n.d b) many are willing to pay to save time (Olifent, 2020). The passengers need to be satisfied with the public service quality to take that as a better option of commuting (AVENUE, n.d b). However, it should be kept in mind that technological development would have a great impact on how people commute in the future (Olifent, 2020).

There is a good potential of revolutionizing public transportation services landscape by the use of autonomous vehicles in the future. Employing these vehicles in public transportation in some urban and suburban areas could provide more sustainable services in the transport sector. (AVENUE, n.d c.)

The mini-buses project in Alborg, as a kind of public transport service, has been implemented through a collaboration between different partners. This collaboration is a sort of OPI (Offently and Private Innovation) partnership (Holo, n.d b), a partnership-based collaboration between public and private parties (Udbudsportalen, n.d).

In this collaboration, the aim is to innovate and develop public solutions (IBID). Supervision of the daily bus operation in Aalborg municipality is carried out by the municipality's public transport department (Nordjyllandstrafikselskab, n.d). The municipality gains access to new technology and knowledge, while the private parties get information about users' needs, to be used for the development of new public services or products. Furthermore, OPI is characterized by a high degree of user involvement and the overall framework for the project will be defined and set by the specification of citizens' requirements. (Udbudsportalen, n.d) In this respect, the governments' climate partnerships with business are an obvious opportunity to support the development and experiments of self-driving solutions (Sorgenfrei, 2019)

Besides the aforementioned issues in this section, the integration of electric buses meets some other sort of barriers. At the moment, price and the current tax structure remain as the main barriers to the implementation of electric buses in the bus fleet (Danskenergi, n.d).

If Denmark wants to ensure that the road transport segment would also contribute its corresponding share of $CO_2$ reduction, supplementary national policies should be also applied to the transport sector. Thus, to reduce the costs and emissions, a combination of cost-effective tools and technologies should be employed in this sector (Ea Energy Analyses, 2015).

Most recently, there have been some discussions about making changes in the tax structure. The tax structure still faces some shortcomings especially concerning the $CO_2$ taxes and general electricity taxes. Tax reform is a way of integrating green change with the business cycle which will result in green growth (Bjerg L., 2020).

The marginal price for $CO_2$ emission has been around 105-120 kr./tons in 2018 (Bilde H., 2018) with an increase up to around 150 kr./tons in 2019. It would probably get a value of 3 to 4 times higher than today, which would be around 600 kr./tons, but fist from 2021. (Thuesen, 2019) However, it is still very low and requires a gradual increment at least up to 1000 kr./tons. (Ea Energy Analyses, 2015). Some economists have recently proposed a $CO_2$ tax of 1250 kr./tons. Though, the climate council in its first statutory advisory report to the government has proposed the politicians a significant high $CO_2$ tax of as much as 1500 kr./tons and has emphasized on employing that as the main element to force top polluters to pay for what they do. (Wittrup. S., 2020 c)

"The Danish Council on Climate Change is an independent body of experts that advises on how the transition to a low-carbon society can be done cost-effectively so that in the future we can live in a Denmark of very low greenhouse gas emissions while maintaining welfare and development." (Klimarådet, 2020 a)

As mentioned above, besides $CO_2$ tax, electricity taxes are considered as another obstacle (Bjerg L., 2020). Danish electricity taxes are the highest in the EU. 50% of electricity in Denmark comes from sustainable energy sources, predominantly wind turbines. But the special Danish tax system makes it more complicated to support the electrification of the transport sector in this way. Electric buses have to pay total electricity charges of 91 øre/kWh, which corresponds to a cost of 49 million DKK annually. (Movia, 2016) A General lowering in electricity taxes is necessary if a green transition in the energy sectors is desired (Bjerg L., 2020).

Moreover, improved framework conditions are required for charging infrastructure. Additionally, the efficiency requirement for buses should also be set. (Danskenergi, n.d)

It should be also mentioned that on 13. April this year after months of falling oil prices, the Organization of Oil Exporting Countries (OPEC), managed an agreement of a 10% reduction in global oil production. This could probably affect accelerating the employment of the electric buses in the bus fleet shortly. (Bjerg L., 2020)

The climate council also has pointed out a need for a broad political expression to the society to get informed of what would be their rights after 2025, for example no longer being able to buy passenger cars on fossil fuels. Further to that, there has been proposed a greenhouse gas tax to be applied to petrol and diesel in 2030; thus, a 4 kr./liter increase in price. As a result, people would take a cleaner transport vehicle to commute. However, overall it is predicted that it would hardly hit the lowest income groups. (Wittrup. S., 2020 c)

As mentioned above, the price functions as a barrier to the integration of the electric buses in the fleet. According to a report from Bloomberg New Energy Finance (BNFF) in 2019, the price of lithium-ion batteries has seen a staggering 87% drop between 2010 and 2019, illustrated in figure 34.

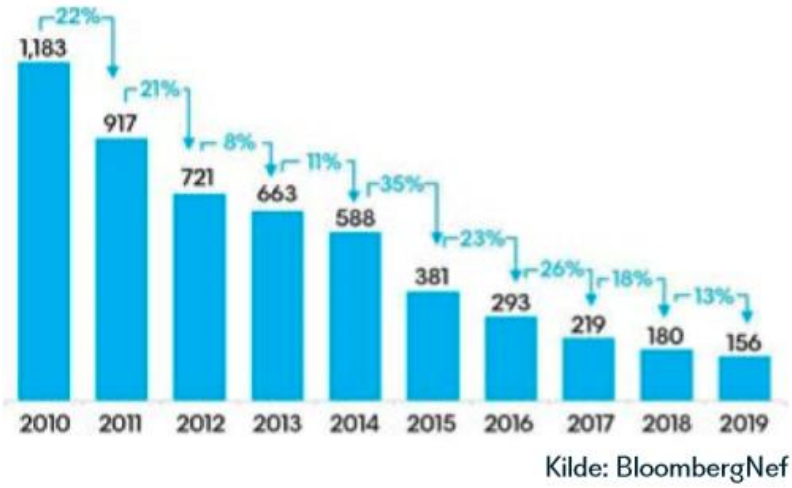


*Figure 35.The average price for lithium-ion batteries [$/kWh] (Distrup, 2020)*

However, the same report predicted a further halving in 2020. Although electric batteries have faced a reduction in price, they remain as one of the obstacles in this respect. Therefore, support for the development of more efficient and sustainable batteries through investment in research and innovation would be of importance in this respect. This would, in turn, results in a reduction in batteries costs as well. This area is already undergoing strong development and is expected to continue over the next few years. (Distrup, 2020)
Regarding the prices, a study also indicates that a 1:1 replacement of diesel buses with electric buses will increase operating costs in public transport by 5% (COWI, 2018).

Further to what mentioned, charging stations are also considered as one of the challenges for implementing the electric buses in the fleet, also previously mentioned in section 6.1.2.2.

Electric buses are generally more expensive than diesel buses, and there is also a need for investments in charging infrastructure, both for station and depot charging. Thereby, the length of the contract period needs an agreement of all related parties, and it takes a longer time in comparison with diesel buses. (Kollektivtrafik, 2019)

Traditionally, the contract for diesel buses runs for six years, with the possibility of two years extension three times. The contract time for electric buses will run for ten years, with the possibility of a two years extension. Therefore, considering that the bus life, the depreciation period, must match the contract period is of importance. (IBID)

The municipality's approval for setting up the charging instruments in the street is one of the challenges that electric bus operators are facing at the moment. Taking the municipality permit is a long procedure, which makes the green transition harder. If the goal is a green transport sector, municipalities should make this process simpler and instead focus on accelerating this procedure to benefit the climate. (Sorgenfrei, 2019) Besides that, the ownership of the charging facilities is also another challenge that affects the implementation of electric buses (Andersen J. *et al*., 2019).

Regarding the RE technology utilization, the Danish climate council has stated in its report that if the goal of the 2030 transition, a 70% $CO_2$ reduction, should be achieved, along with more long-term strategic effort, existing renewable technologies should be implemented immediately, otherwise the goal would not be achieved. (State of green, 2020 h)

As previously mentioned in section 6.1.3, Aalborg municipality needs to invest in the power grid, to supply electricity demand by electric buses. Adding more capacity and investment in new infrastructures, for example, new wind parks, etc., depends on the decision-making process by politicians. There should be decided when and where the new infrastructures should be set up. Since the municipalities are not able to decide themselves (Grunert R., 2020 c) in this field, as they do with the heat production or construction, it would significantly affect the process of the infrastructure development of the power grid. This would, in turn, influence the integration procedure of the electric buses in the fleet. Since the municipalities have so little influence on this area, this has been one of the reasons why the transport sector has been so slow to get started. To reach the high ambitions, both technologies and solutions should be present at the place, and it is a political issue, not a technological issue. (IBID)

Another issue is concerned with the social acceptance and perception of the need for the implementation of new wind farms. The location of wind turbines would be a matter and recognized as a common problem, so-called '*NIMBY effect'* (Not in My Yard), *that* will affect the decision-making process. (Cronin et al., 2015) In this respect, supporting the *local ownership* of renewable energy projects could be a solution for that matter. Thereby, Aalborg municipality, as a government authority, would be able to enter an early dialogue with the project developers, citizens, and energy companies to ensure a good planning process. (Lund, H. *et al*., 2019)

Experts in Aalborg's energy vision has pointed to *PPA* (Power Purchase Agreement), as an instrument for compensating the lack of the required electricity capacity. They have expressed that municipalities and especially, here Aalborg municipality, should not be isolated, and cross-border connections could be utilized as a good solution for electricity production challenge. (Lund, H. *et al*., 2019)

.PPAs are agreements which are settled between large electricity consumers and project developers of green electricity. This will provide the project developers the security of the project returns, resulting in cheaper green electricity. Therefore, PPA is a market that needs to give strength. Furthermore, PPAs will also assure the electricity buyers (consumers) to contribute and give a handout to the green transition. (Danskenergi, 2019)

It should be kept in mind that all neighboring countries are considerably affected by each other. Therefore, the electricity prices in countries around Denmark would influence the electricity price in Denmark. (Danish Ministry of Energy, Utilities and Climate, 2018)

If the ambition is a green transition, then it must be paid for. Investments are not possible without paying the cost, and the green transition costs will be paid by the taxpayers and energy consumers at the end. Therefore, achieving this transition at the lowest possible cost is of great importance. (IBID)

However, all challenges need government support, strategic national planning, and national transport plans to overcome. (Bjerg L., 2020) (Grunert R., 2020 c) (Andersen, 2020 b)

## 6.3 Summary

Denmark already has a unique position in providing innovative and creative solutions across energy sectors. Cities want to get rid of diesel and reduce $CO_2$ emissions. Electric buses are what passengers need and want in the future, and this market is going to grow faster. Therefore, accelerating the process for more new energy technologies innovation by supporting innovations and research sector is of great importance. (Valmot, 2017) (Falkengaard, 2020)

Besides that, the tax system should also support the innovation sector to facilitate the investment for the green transition, especially in the transport sector. The analyses for the electrification of buses also demonstrated that to the purpose of the electrification of the whole bus fleet, an electricity capacity investment of 3 MW from RE sources would be necessary.

Moreover, if electric buses want to be introduced in Denmark, it is a prerequisite that politicians and decision-makers provide equal conditions like other EU member countries for electricity consumers in the transport sector.

The transition from black transport to green mobility is possible, but it requires support from the sector interest groups and politicians, otherwise, it will not get success. Therefore, the investment in the electricity grid and grid development plans need a close collaboration with the municipalities. (Sorgenfrei, 2019) (Distrup, 2020) (Webinar, 2020 a) (Webinar, 2020 b)

Besides what mentioned, new measures are needed to “encourage the use of public transport” (Transport and Environment, 2018).

# 7. Discussion

The project of the electrification of buses in Alborg faces some sort of uncertainties, which could affect the result of analyses.

The analyses in this project face a high level of uncertainties respected to the number of diesel buses that could be phased out and be replaced with electric buses. Phasing out the old diesel buses firstly depends on their current age and their lifetime, and not all of the diesel buses in the fleet have the same age. Some of them cannot be phased out due to the costs that should be compensated before their lifespan (e.g. purchase, operating and maintenance, etc.).

The other problem would be the market situation. Injection of new electric buses also depends on whether the old diesel buses could be sold to the market. And it would be hard to make a prognosis now. Another issue which should be considered in this respect would be the different bus operators, whom they decide about when diesel buses should be phased out.

Besides the issues discussed above, the assumptions made in the analyses, for the yearly operation hours and driving (kilometers) by buses, could significantly impact the result of analyses of this project. These issues address another part of uncertainties regarding the calculated electricity consumption by electric buses.

It should be also taken into consideration that due to technology and battery advancement in the future, and at the time of the injection of buses in the fleet, the electricity consumption per kilowatt-hour by new electric buses would probably be half of the considered values in the analyses. *'Mercedes-Benz eCitaro'*, as the winner of 2020 among other city buses manufactured by *DAIMLER* company, has been stated as the starting point for technological steps in the future of urban battery-electric buses productions. The technical features of the new coming model of *'Mercedes-Benz eCitaro'* in 2021 with a battery capacity of 330 kWh, (Sby, n.d) would certainly affect the result of analyses if this model would be used instead. However, more advanced electric bus models would emerge in the market, while implementing the +BUS.

Another issue assigns to the new hydrogen city bus. Aalborg municipality has employed a new hydrogen bus for route number 17, operating from Maj 2020, which should pass a three years test period. The reason for that is the *'3Emossion project'* funding project by the EU, to test the operation of hydrogen buses in the bus fleet. Depends on how the results would be, there will be decided whether it would keep operating in the route or not. However, this issue has not been considered in the analyses of this project.

Further to what mentioned in section 6.2, there are some uncertainties associated with the capacity level of electricity production by coal-fired plants, the future fuel prices and electricity price, the number of electric vehicles (Evs), and the required electricity consumption. They might all affect the implementation of electric buses. The level of import and export of electricity is also another issue in this respect. (Mathiesen *et al.*, 2015 a)

The projection of a higher level of electricity consumption by the end-users with a 26% increase in consumption from 2018 to 2050 (Lund, H. *et al*., 2019), a yearly increase of about 0.8%, would result in the need for more electricity supply, thus more electricity capacity. Consequently, the expansion in the electricity grid (transfer and distribution) would also be needed. Therefore, due to political issues mentioned in section 6.2, this would reflect a challenge in the energy system in the future. It should be noted that the annual increase in total electricity consumption has been ignored in the analyses of this project.

Passenger growth would also affect electricity consumption by electric buses. However, it has been also ignored in the analyses.

The electricity consumption by giant data centers would be another issue regarded the required capacity need for electricity supply as they would have an impact on the whole Denmark energy system. (Energistyrelsen, 2019 a) However, generally, the energy-saving in all energy sectors by end-users, whether through the consumption pattern or efficient energy measures, could significantly reduce electricity consumption. This would, in turn, lead to more available energy to be used for the development of the energy sector, and especially the transport sector.

Currently, many energy meters could be installed on the end-user side and make it possible to gain knowledge about resource consumption (Danskenergi, n.d). In this way, planning for new energy system investments could be conducted in a more efficient manner.

With concern to the applied theories in this project, the problem, a high level of $CO_2$ emissions caused by the road transport sector and fossil fuel consumption as the main reason for that, had been clarified. The long-term goal of a $CO_2$ neutral bus fleet transport in Aalborg had been defined, and proper methodologies for collecting adequate data for further analyses had been utilized in that respect. The data had been analyzed and the required actions and action policies by related actors had been defined. Through the theory concept and considered theories, technical and institutional barriers for the green target of 100 electrifications of the Aalborg bus fleet had been investigated. The objective of the project has been presenting energy effective solutions to the purpose of a radical change and a green transition from diesel fuel to renewable electricity, utilized for the electric buses in the fleet. There has been tried to show how citizens in Aalborg as part of the stakeholders' network can influence the process of decision making by acting, changing their behavior, and selecting the right choice. There has been also tried to show how rethinking and innovative energy policies and technologies can result in emerging sustainable technologies in the market/society. However, despite all the considered issues, in the lack of government support by providing the national and international sustainable and effective framework, and green energy policies, the decision-making process can be influenced. As a result, the green transition toward the long-term goal of a 100% electrified bus fleet cannot be achieved.

Based on all the discussed issues, the next section provides the final conclusion of the analyses in this project.

## 8. Conclusion

To make a green transition and achieve the ambitious target of a 70% $CO_2$ reduction in 2030 and the long-term goal of a $CO_2$ neutral land in 2050, Denmark needs a radical restructuring of fossil fuel consumption and a holistic system perspective in all energy sectors especially the transport sector, as the main contributor to $CO_2$ emissions.

To achieve the goals of long-term solutions, a strategic national plan, and targeted national energy measures accompanied by a suitable framework and changes in energy policy are required. And the new policy measures will not be set unless through governmental support.

Future regulations should be adopted in a way that infrastructure could be expanded in time for tomorrow's needs and without any oppositions that make delay in the decision-making process. In this respect, the municipalities must be given the opportunities that can decide in all energy sectors especially the transport sector.

Aiming the targets needs to take place by employing a higher share of renewable energy (RE) sources, deploying more innovative energy technologies, and energy-efficient measures in the energy system. Through that, the energy demands would get reduced and this would, in turn, result in less need for new investments in RE capacities. Therefore, energy-saving in all sectors must be prior to the RE investments and through intelligently interconnected sectors, a smart energy system. Smart energy systems must be employed as the central element to facilitate the way toward a Danish $CO_2$ neutral energy system.

Although the prioritization is with energy-saving, with a growth in electricity consumption and electrification of the transport sector in the future, the investments in electricity production from RE sources would be necessary and inevitable. However, local and political oppositions should not be ignored.

Based on the first results from Excel spreadsheet calculations regarding $CO_2$ emissions caused by diesel buses in the fleet, the $CO_2$ emission could reach a considerable level of 6861 tons by 2030 in comparison to the 5608 tons $CO_2$ emissions level in 2016. It means that despite the 50% electrification of the bus fleet by 2023, and 100% up to 2030, that passenger growth would be the main cause of diesel consumption by buses resulted in more $CO_2$ emissions.

The result of analyses from Excel spreadsheet calculations also demonstrated that around 1.480.000 liter can be saved by utilizing electric buses and electricity consuming around 21.000 MW in 2030.

By comparing the results of $CO_2$ emissions calculations in EnergyPlan in 2016 (without diesel buses) with a value of 4464 tons and 2030 (With Nordjyllandsværket) with a value of 4477 tons, and by an assumption of a fixed value of coal consumption by Nordjyllandsværket, it could be again concluded that due to passenger growth not too much $CO_2$ would be saved in the period from 2016 to 2030.

Since no more electrification had been done in the fleet from 2023 to 2030, resulting in more CO2 emissions, therefore it is necessary to act sooner and seriously, otherwise, the goal of a 70% reduction in CO2 emissions would not be realized.

Another result of the analyses led to knowing this issue that 100% electrification of the bus fleet in 2030 would result in a 3 MW more electricity demand capacity compared with that level in 2016. The analyses also demonstrated that the required capacity would be supplied from non-renewable sources such as coal by North Jutland coal CHP plant (Nordjyllandsværket) up to 2008, and from Natural gas power plant from 2028 when the Nordjyllandsværket would be closed down in 2028. With concern to the energy targets of 2030 and 2050, it means that to supply the required electricity demand by buses, there is a need for 3 MW capacity investment in the power grid from 100% renewable sources.

Thereby, regarded to what mentioned, the growth in traffic networks should get decreased as sooner as it is possible. Modal shifts, behavioral change, and more employment of public transportation, utilizing sustainable technologies followed up with climate strategies, must be part of the future green transition. Therefore, the energy demand in the transport sector would decrease. However, the prerequisite for behavioral change is the existence of reliable and effective public transport services.

Additionally, to make a green transition in the transport sector, more governmental support for investments in research and accelerating innovations for new sustainable technologies improvement would be of great importance. Although, technologies are getting advanced year by year and new battery models will be emerged in the market and be replaced by the old ones, however, no waste of time is permissible. The green transition costs and it needs to be paid for.

More incentives and ambitious regulations are needed to make the transition toward possible electrification of the energy sectors, especially the transport sector and public transportation. The employment of RE electricity in the transport sector is the key element to mitigate the $CO_2$ emissions in this sector and solve the climate challenge. Due to the scarcity in biomass resources, thus, biomass utilization should be limited and should not be considered as a long-term solution. For that reason, the electrification of the transport sector should be developed towards the green transition, and direct electrification must be ensured wherever possible.

To solve the climate challenge a shared understanding of the green opportunities, which are in line with the future green transition goals and facilitate the development of that, is necessary by all actors, citizens, and not just energy producers. In this respect, Danish municipalities and companies should be able to take a role in this transition, and collaboration between all actors is a necessity.

If the policy would be the frozen policy and the case would be business as usual, aiming the climate targets cannot get succeed. The tax system must also get reformed. High $CO_2$ taxes and much lower taxes on electricity from RE sources needed to reach Aalborg and Denmark to their green goals.

Technical barriers regarded the facility chagrining stations should also be supported by more investment and by making the decision-making process simpler to allow the energy investment companies and technology producers to act toward green transition.

## 9. Future works

- **The impact of the BRT project in Aalborg – City development and job opportunities**
  The BRT project makes facilities for more housing due to city development. Therefore, more job creation would take place by employing this project.

- **Covid-19 effect on $CO_2$ emissions:**
  Working from home and its impacts on fuel consumption, and $CO_2$ emissions caused by transport vehicles can shape another area of research.

- **Future of suburban buses – biogas and hydrogen as the fuel**
  Due to the challenges regarding fuel type and fuel energy efficiency, biogas, and hydrogen usage as fuel for suburban buses can be investigated.

- **Supercondunsor city buses**
  The investigation of supercapacitor electric base buses as a replacement for diesel city buses can also make an area for future work.

- **Electric batteries recycling**
  The battery recycling is one of the research areas which has gotten attention nowadays. After passing some years of electric batteries employment in buses, and many times of charging and discharging, batteries would not have the same efficiency as before. For that reason, they can be utilized as a source of electricity storage for other purposes.

- **Renewable electricity investment in the transport sector – Artificial intelligent (AI)**
  Electricity consumption forecasting through AI can be used as a method for investigation of the required electricity by end-user consumers, resulting in a more efficient way for the investment in the new RE electricity capacities.

- **The electrification of the heavy-duty vehicles in the transport sector – PtX and Carbon Capture (CC)** Indirect electrification as a solution for the electrification of the heavy-duty vehicles in the transport sector can be investigated. The pros and cons of that along with the resulted costs can be evaluated for a future free $CO_2$ emissions transport sector.

- **Electric buses and diesel buses, and the impacts on citizens' health**
  Noise, pollution, and emissions caused by diesel buses are considered as issues with negative impacts on citizens' health, which inject huge yearly costs to the health care system. Therefore, the replacement of electric buses with diesel buses can have a considerable impact on citizen's health and reduction of the related costs.

### Acknowledgments

I wish to show my deep gratitude and appreciation to my supervisor, Jakob Zinck Thellufsen at Aalborg University, for providing me valuable data that I used in my project, guiding me patiently throughout my project, and helped me to finalize it. I would like to extend my appreciation and gratitude to Susan Bundgaard Jensen, project leader at Nordjyllands Trafikselskab (NT), Jesper Schultz, project leader for BRT Project (+BUS) at Aalborg Municipality, Morten Jensen, Traffic planner for the public traffic at Aalborg municipality, Peter Hoy, Senior Project Manager at COWI Aalborg and Jesper Christensen, Chefredaktør at Transportnyhederne.dk, Magasinet Bus, Latsbilnyhederne.dk in Aarhus, who helped me by providing data and information through interviews. I would also like to express my gratitude and appreciation to professors, Henrik Lund, Poul Alberg Østergaard, and Brian Vad Mathiesen at Aalborg University. The help and guide from Steffen Nielsen at Aalborg University is also greatly appreciated.

## References

**Aalberg and Andersen, 2018**. Alberg, Poul, and Anders N. Andersen. “Economic feasibility of booster heat pumps in heat pump-based district heating systems”. *Energy* 155: 921-29. https://doi.org/10.1016/j.energy.2018.05.076. Accessed: 26-02-2020.

**Aalborg kommune, n.d a**. Aalborg kommune. “Denmarks første BRT-forbindelse”. Aalborg kommune. URL: https://www.epaper.dk/impetusgruppen/brt2019. Accessed: 16-04-2020.

**Aalborg kommune, n.d b**. Aalborg kommune. ”Ansøgning om puljemidler fra Pulje til investeringer i kollektiv bustrafik, 1. ansøgningsrunde”. URL: https://www.aalborg.dk/media/7574280/ansoegning-trafikstyrelsen-final.pdf. Accessed: 17-04-2020.

**Aalborg kommune, n.d c**. Aalborg kommune. ”Plusbus”. URL: https://www.aalborg.dk/trafik-og-transport/plusbus. Accessed: 16-04-2020.

**Ahanchian, M. et al., 2019**. Ahanchian, Mohammad, Jay Sterling Gregg, Jacopo Tatini, Kenneth Bernard Karlsson. “Analyzing effects of transport policies on travelers’ rational behavior for modal shift in Denmark, Case Studies on Transport Policy”. Elsevier, 7(4), pp. 849–861. https://doi: 10.1016/j.cstp.2019.07.010. Accessed: 05-03-2020.

**Andersen, 2020 a**. Andersen, Ulrik. ”Grønnere regnemodel kan gøre kollektiv trafik mere attraktiv”. ING. URL: https://ing.dk/artikel/groennere-regnemodel-kan-goere-kollektiv-trafik-mere-attraktiv-232544. Accessed: 05-03-2020.

**Andersen, 2020 b**. Andersen, Ulrik. ”Eksperter: Se på svenskerne, når I skal planlægge fremtidens trafik”. ING/MOBILITYTECH. URL: https://pro.ing.dk/mobilitytech/artikel/eksperter-se-paa-svenskerne-naar-i-skal-planlaegge-fremtidens-trafik-5686. Accessed: 26-02-2020.

**Andersen J. *et al.*, 2019**. Andersen, Jesper, CLUA, Knud Trubbach, JPD. ”NORDJYLLANDS TRAFIKSELSKAB – UDBUD AF BUSTRAFIKKEN I AALBORG”. RAMBOLL. ’19. oktober 2018’. Revision 2. Nordjylland Trafikselskab and Aalborg Kommune. URL: https://www.aalborg.dk/media/9638709/1100033132_udbud_af_kollektiv_trafik_aalborg_rapport.pdf. Accessed: 17-04-2020.

**AVENUE, n.d a**. AVENUE. “WHAT IS AVENUE PROJECT?”. URL: https://h2020-avenue.eu/summery/#toggle-id-1. Accessed: 28-03-2020.

**AVENUE, n.d b**. AVENUE. “WHAT IS AVENUE PROJECT?”. URL: https://h2020-avenue.eu/summery/#toggle-id-4. Accessed: 28-03-2020.

**AVENUE, n.d c**. AVENUE. “Autonomous vehicles”. URL: https://h2020-avenue.eu/. Accessed: 28-03-2020.

**Berggreen, 2019**. Berggreen, Jesper. “The First Municipality In Denmark To Convert To Electric Buses Gets Closer To Launch”. CleanTechnica. URL: https://cleantechnica.com/2019/01/21/the-first-municipality-in-denmark-to-convert-to-electric-buses-gets-closer-to-launch/. Accessed: 15-02-2020.

**Bilde H., 2018**. Bilde Hinrichsen, Michael. “Markant hop i prisen på CO2-udledninger”. Dansk Energi. URL: https://www.danskenergi.dk/nyheder/markant-hop-prisen-pa-co2-udledninger. Accessed: 15-04-2020.

**Bjerg L., 2020**. Bjerg Lillevang, Liv. ”Ugens energi: Aftaler om ladestandere og olieproduktion falder på plads, mens politiske aktører giver bud på vejen til grøn vækst”. URL: https://pro.ing.dk/gridtech/artikel/ugens-energi-aftaler-om-ladestandere-og-olieproduktion-falder-paa-plads-mens?utm_source=newsletter&utm_medium=email&utm_campaign=gridtech. Accessed: 17-04-2020.

**Bramstoft and Skytte, 2017**. Bramstoft, Rasmus, and Klaus Skytte. “Decarbonizing Sweden’s energy and transportation system by 2050”, *International Journal of Sustainable Energy Planning and Management*, 14(January), pp. 3–20. https://doi: 10.5278/ijsepm.2017.14.2. Accessed: 21-02-2020.

**Brinkmann and Tanggaard, 2010**. Brinkmann, Svend and Lene Tanggaard. “Kavlitative metoder: En grundbog. Kbh: Hans Reitzel, First edition. URL: https://www.google.com/books?hl=da&lr=&id=GMZY0OFtxH8C&oi=fnd&pg=PA17&dq=Brinkmann+and+Tanggaard,+2010+kvalitative+metoder&ots=uD-L5t_JQz&sig=9rBqzzQc1s9yxkccms6vorC8iIk. Accessed: 17-04-2020.

**Brem and Voigt, 2009**. Brem, Alexander and Kai. Ingo. Voigt. “Integration of market pull and technology push in the corporate front end and innovation management-Insights from the German software industry”. *Technovation*, 29(5), pp. 351–367. DOI: 10.1016/j.technovation.2008.06.003. URL: https://findresearcher.sdu.dk:8443/ws/portalfiles/portal/102507452/Technovation_Br_Vo.pdf. Accessed: 19-02-2020.

**Center for theory of change, 2013**. Center for theory of change. “What is Theory of Change? | Theory of Change Community”, pp. 1–13. URL: http://www.theoryofchange.org/what-is-theory-of-change/. Accessed: 25-03-2020.

**Chariot e bus, n.d**. Chariot e bus. “Supercapacitor electric bus”. URL: https://zero.no/wp-content/uploads/2019/09/24-Chariot-Motors-Norway.pdf. Accessed: 21-03-2020.

**Connolly et al., 2010**. Connolly, David, Henrik Lund, Martin J. Leahy, Brian Vad Mathiesen. “A review of computer tools for analyzing the integration of renewable energy into various energy systems”. Applied Energy. VL. 87. URL: https://vbn.aau.dk/en/publications/a-review-of-computer-tools-for-analysing-the-integration-of-renewable-energy-into-various-energy-systems(1a69ff60-e650-11de-abf1-000ea68e967b).html. Accessed: 14-04-2020.

**Connolly, 2015**. Connolly, David. “Finding and Inputting Data into EnergyPLAN – (The FIDE Guide)”. Version 5. URL: https://energyplan.eu/wp-content/uploads/2013/06/Finding-and-Inputting-Data-into-the-EnergyPLAN-Tool-v5.pdf. Accessed: 14-04-2020.

**COWI, 2018**. COWI. “OPDATERING AF DRIFTSØKONOMI FOR +BUS”. URL: https://www.aalborg.dk/media/9638710/opdatering-af-driftsoekonomi-for-plusbus-m-tilhoerende-notat.pdf. Accessed: 16-04-2020.

**Cronin et al., 2015**. Cronin, Tom, Bonnie Ram, Jim Gannon, Christian Thuesen, Esmir Maslesa, Joana Geraldi, Niels Erik Clausen, Melanie Kreye. “Public acceptance of wind farm development:
Developer practices and review of scientific literature – Wind2050 WP3 Deliverable 1“. DTU Wind Energy. Department of Wind Energy. URL: https://backend.orbit.dtu.dk/ws/files/116509713/DTU_Wind_Energy_E_51.pdf. Accessed: 02-

05-2020.

**Danish Ministry of Energy, Utilities and Climate, 2018**. Danish Ministry of Energy, Utilities and Climate. “Denmark: Energy and climate pioneer”. URL: https://en.efkm.dk/media/12032/denmark_energy_and_climate_pioneer_pdfa.pdf. Accessed: 22-02-2020.

**Danish Energy Agency, 2018 a**. Danish Energy Agency. “Denmark’s Energy and Climate Outlook 2019: Denmark’s Energy and Climate Outlook”, p. 73. URL: http://www.ens.dk/outlook. Accessed: 05-03-2020.

**Danish Energy Agency, n.d b**. Danish Energy Agency. “The Danish energy model: Innovative, efficient and sustainable”. URL: https://ens.dk/sites/ens.dk/files/Globalcooperation/the_danish_energy_model.pdf. Accessed: 18-02-2020.

**Danish Energy Agency, 2017 c.** Danish Energy Agency. “Denmark’s Energy and Climate Outlook 2017”. URL: https://ens.dk/sites/ens.dk/files/Analyser/denmarks_energy_and_climate_outlook_2017.pdf. Accessed: 06-02-2020.

**Danish Energy Agency, n.d d**. Danish Energy Agency. “Facts about bioenergy in Denmark”. URL: https://ens.dk/en/our-responsibilities/bioenergy/facts-about-bioenergy-denmark. Accessed: 24-02-2020.

**Danish Energy Agency, 2016 e**. Danish Energy Agency. “Technology data for energy plant for electricity and district heating generation”. 2016. Version no: 0001. URL: https://ens.dk/sites/ens.dk/files/Analyser/Technology_data_catalogue_for_el_and_dh_0001_pdf. Accessed: 19-02-2020.

**Danish Energy Agency, n.d f.** Danish Energy Agency. “Biomass”. URL: https://ens.dk/en/our-responsibilities/bioenergy/solid-biomass. Accessed: 27-02-2020.

**Danskenergi, n.d**. Danskenergi. ”Katalog for barrierer og løsningsforslag fra Platform for Smart Energi”. URL: https://www.danskenergi.dk/sites/danskenergi.dk/files/media/dokumenter/2017-08/Katalog_for_barrierer_og_loesningsforslagPlatformForSmartEnergi.pdf. Accessed: 28-04-2020.

**Danskenergi, 2019**. Danskenergi. ”Renewable Energy Outlook 2019 – Renewable Energy Perspectives to 2035”. https://www.danskenergi.dk/sites/danskenergi.dk/files/media/dokumenter/2019-06/Renewable_Energy_Outlook_2019.pdf. Accessed: 29-04-2020.

**Dansk Industri et. Al, 2020**. Dansk industri, Dansk Maritime, DanskeRederier, DAPO, Dansk Miljøteknologi, Miljø og Følevareministeriet. ”Clean Air Vision”. URL: https://stateofgreen.com/en/uploads/2018/05/Clean_Air_Vision.pdf. Accessed: 07-02-2020.

**Distrup, 2020**. Distrup, Dare. ”Sektorkobling – Nøglen til fremtidens bæredygtige energisystem (2020)”. URL: https://daredisrupt.com/sektorkobling/. Accessed: 24-04-2020.

**Djørup, 2019**. Djrøp, Søren. Policies and regulation: Integration on the supply side. “100% Renewable Energy Transition: Pathways and implementations”.URL: https://books.google.dk/books?id=qrfLDwAAQBAJ&pg=PA52&lpg=PA52&dq=Dj%C3%B8rup,+2019+3+step+approach&source=bl&ots=coe8kMMPLQ&sig=ACfU3U38I23YJzwZTE8G9Rjan7o8W3sM3g&hl=da&sa=X&ved=2ahUKEwiirfC_u8_pAhVB4aQKHV1XDRYQ6AEwCnoECAoQAQ. Accessed: 26-03-2020.

**DoScience, n.d**. DoScience. “Biogas Plant Design”. URL: https://paksc.org/pk/biogas-plant-design/. Accessed: 31-05-2020.

**Dougherty, 1992**. Dougherty, D. “Interpretive barriers to successful product innovation in large firms”. Organization Science 3 (2), 179–203, p. 195. Accessed: 19-02-2020.

**Ea Energy Analyses, 2015**. Ea Energy Analyses. “ GREEN ROADMAP 2030“. Ea Energy Analyses. URL: https://www.ea-energianalyse.dk/en/publications/1459-green-roadmap-2030/. Accessed: 27-04-2020.

**Energinet, 2015**. Energinet. “Energy Concept 2030 – Summary”. URL: https://energinet.dk/-/media/Energinet/Analyser-og-Forskning-RMS/Dokumenter/Analyser/Notat---Energy-concept-2030---English-Summary.pdf. Accessed: 11-02-2020.

**EnergyPLAN, n.d**. EnergyPLAN. ”Introduction”. URL: https://www.energyplan.eu/training/introduction/. Accessed: 18-02-2020.

**Energistyrelsen, 2019 a**. Energistyrelsen. ” Basisfremskrivning”. URL: https://ens.dk/sites/ens.dk/files/Analyser/bf19.pdf. Accessed: 05-02-2020.

**Energistyrelsen, 2019 b**. Eneriystyrelsen. ”Fremskrivning af transport”. J nr. 2019-35. URL: https://ens.dk/sites/ens.dk/files/Analyser/b5_transport.pdf. Accessed: 05-02-2020.

**Energistyrelsen, 2019 c**. Energistyrelsen. ”bf19_transport_detail.xlsx”. Energistyrelsen. URL: https://ens.dk/sites/ens.dk/files/Analyser/bf19_transport_detail.xlsx. Accessed: 05-02-2020.

**Energistyrelsen, n.d d**. Energistyrelsen. ”tabeller2018_-_tables2018.xlsx”. URL: https://ens.dk/sites/ens.dk/files/Analyser/tabeller2018_-_tables2018.xlsx. Accessed: 05-02-2020.

**Erb, K., Lauk, C., Kastner, T. *et al.*, 2016.** Erb, Karl-Heinz, Christian Lauk, Thomas Kastner, Andreas Mayer, Michaela C. Theurl & Helmut Haberl. ”Exploring the biophysical option space for feeding the world without deforestation”. *Nat Commun* 7, 11382 (2016). https://doi.org/10.1038/ncomms11382. Accessed: 28-02-2020.

**European Commission, n.d**. “Renewable energy directive”. European Commission. URL: https://ec.europa.eu/energy/topics/renewable-energy/renewable-energy-directive/overview_en. Accessed: 27-02-2020.

**European Environment Agency, 2018 a**. European Environment Agency. “GHG emissions by sector in the EU-28, 1990-2016”. Last modified 31 May 2018. URL: https://www.eea.europa.eu/data-and-maps/daviz/ghg-emissions-by-sector-in#tab-chart_1, 2018. Accessed: 10-02-2020.

**European Environment Agency, 2018 b**. European Environment Agency. “Greenhouse gas emissions by aggregated sector”. Last modified 19 Dec 2019. URL: https://www.eea.europa.eu/data-and-maps/daviz/ghg-emissions-by-sector-in#tab-chart_1, 2018. Accessed: 10-02-2020.

**European Environment Agency, 2019 c**. European Environment Agency. “Landscapes in Transition. An account of 25 years of land cover change in Europe”. URL: https://www.eea.europa.eu/publications/landscapes-in-transition. Accessed: 21-02-2020.

**Falkengaard, 2020**. Falkengaard, Mathias Julius. “Rapport: Sektorkobling kan mindske CO2-udledning med 22 mio. ton”. Energiwatch. URL: https://energiwatch.dk/Energinyt/Politik___Markeder/article11893223.ece. Accessed: 27-02-2020.

**Field, 2018**. Field, Kyle. “Roskilde Is 1st City In Denmark To Convert Bus Fleet To Electric”. CleanTechnica. URL: https://cleantechnica.com/2018/03/19/municipality-roskilde-first-denmark-convert-bus-fleet-electric/. Accessed: 15-02-2020.

**Folketinget, 2016**. Folketinget. URL: https://www.ft.dk/. Accessed: 08-03-2020.

**Gaardmand, 1980**. Gaardmand, Arne. “plan and politik – om fysisk plalægning og dens muligheder for at være med til afklaringen af nye samfundsmål”. Hans Reitzel. ISBN: 807 412 3650 5. URL: https://bibliotek.dk/da/work/870970-basis%3A05564379. Accessed: 15-04-2020.

**Gerpott, 2005**. Gerpott, T.J. “Strategisches Technologie und Innovationsmanagement”. Scha¨ffer-Poeschel, Stuttgart. URL:

https://www.google.com/books?hl=da&lr=&id=fyPRDwAAQBAJ&oi=fnd&pg=PR9&dq=Strategisches+Technologie+und+Innovationsmanagement%E2%80%9D.+Sch%C3%A4ffer-Poeschel,+Stuttgart&ots=xkaSQhvlTU&sig=FRPmkOunJZdybokKQTTWlb6oono. Accessed: 19-02-2020.

**Gisvold S., 2020**. Gisvold Solberg, Mari. ”Tunge busser og blød asfalt har været en kæp i hjulet på norske elbusser – beton kan være løsningen”. ING. URL:// https://pro.ing.dk/mobilitytech/artikel/tunge-busser-og-bloed-asfalt-har-vaeret-en-kaep-i-hjulet-paa-norske-elbusser?utm_source=newsletter&utm_medium=email&utm_campaign=mobilitytech. Accessed: 15-04-2020.

**Godske, 2017 a**. Godske, Bjørn.”Herning kommune vil have brintbusser: »Strøm kan jo ikke lagres i ledningerne«”. ING. URL: https://ing.dk/artikel/herning-kommune-vil-have-brintbusser-stroem-kan-jo-ikke-lagres-ledningerne-205925. Accessed: 01-03-2020.

**Godske, 2017 b**. Godske, Bjørn. “12 borgmestre lover at købe rene miljøbusser fra 2025”. ING. URL: https://ing.dk/artikel/12-borgmestre-lover-at-koebe-rene-miljoebusser-2025-207664. Accessed: 25-03-2020.

**Godske, 2017 c**. Godske, Bjørn. ”København køber nye busser: Vi stiller krav til funktion frem for teknologi”. ING. URL: https://ing.dk/artikel/koebenhavn-koeber-nye-busser-vi-stiller-krav-funktion-frem-teknologi-207829. Accessed: 15-02-2020.

**Greenaalborg, n.d**. Greenaalborg. ”Biogasbusser i Aalborg”. Center for Grøn Omstilling – Miljø- & Energiforvaltningen, Aalborg Kommune. URL: https://grontaalborg.dk/projekt/biogasbusser-i-aalborg/. Accessed: 01-04-2020.

**Grunert R., 2020 a**. Grunert Rantorp, Christian. ”Aalborgs BRT-busser får ikke rejsekortstandere om bord: Så meget tid kan busserne spare”. ING. URL: https://pro.ing.dk/mobilitytech/artikel/aalborgs-brt-busser-faar-ikke-rejsekortstandere-om-bord-saa-meget-tid-kan. Accessed: 20-03-2020.

**Grunert R., 2020 b**. Grunert Rantorp, Christian. ”Transportøkonom om BRT-projekt: »Målt i forhold til investeringens størrelse er projektet det værste, jeg nogensinde har set«”. ING. URL: https://pro.ing.dk/mobilitytech/artikel/transportoekonom-om-brt-projekt-maalt-i-forhold-til-investeringens-stoerrelse. Accessed: 09-03-2020.

**Grunert R., 2020 c**. Grunert Rantorp, Christian. ”Aarhus Kommune om grøn transport: Vi ved ikke, hvordan vi skal nå 2030-mål.”.URL: https://pro.ing.dk/mobilitytech/artikel/aarhus-kommune-om-groen-transport-vi-ved-ikke-hvordan-vi-skal-naa-2030-maal?utm_source=newsletter&utm_medium=email&utm_campaign=mobilitytech. Accessed: 15-04-2020.

**Hagos and Ahlgren, 2020**. Hagos, Dejene Assefa, and Erik O. Ahlgren. “Exploring cost-effective transitions to fossil independent transportation in the future energy system of Denmark”. *Applied Energy*. Elsevier, 261(November 2019), p. 114389. https://doi: 10.1016/j.apenergy.2019.114389. Accessed: 20-03-2020.

**Henriksen, 2019.** Aagaard Henriksen, Christian. ”Lader op på få minutter: Moderne el-bus kører første tur a Aalborg”. TV2nord. URL: https://www.tv2nord.dk/aalborg/lader-op-pa-fa-minutter-moderne-el-bus-korer-forste-tur-i-aalborg. Accessed: 06-03-2020.

**Héritier, 1999**. Héritier, Adrienne. “Policy-Making and Diversity in Europe: Escape from Deadlock”. Cambridge University Press, 28. Nov. 1999 – 113 sider. URL: https://books.google.dk/books?id=13BYDd8v-DUC&dq=(H%C3%A9ritier+1999)&hl=da&source=gbs_navlinks_s. Accessed: 19-02-2020.

**Hiremath *et al.*, 2007**. Hiremath, R. B., N. H. Ravindranath, S. Shikha. “*Decentralized energy planning; modeling and application – a review”.* Renewable and Sustainable Energy Reviews, 11 (2007) 729–752. URL: http://Wgbis.ces.iisc.ernet.in/biodiversity/pubs/ces_pubs/pubs_2007/theme3_24.pdf. Accessed: 15-04-2020.

**Holo, n.d a**. Holo. “Testing autonomous mobility solutions in a new way”. URL: https://www.letsholo.com/nordhavn. Accessed: 17-02-2020.

**Holo, n.d b**. Holo. “Welcome to the SmartBus in Aalborg East – Denmark’s first driverless bus”. URL: https://www.letsholo.com/aalborg-east. Accessed: 19-02-2020.

**Holo, 2019 c**. Holo. “Holo becomes the first company with permission to operate autonomous vehicles in Denmark”. URL: https://www.letsholo.com/news/holo-becomes-the-first-company-with-permission-to-operate-autonomous-vehicles-in-denmark. Accessed: 19-02-2020.

**Holo, 2019 d.** Holo. “Grønt lys til de selvkørende busser i Aalborg Øst”. URL: https://www.letsholo.com/news/selvkrende-i-aalborg-ost. Accessed: 19-02-2020.

**Holo, 2020 e**. Holo. “Transportminister indvier den selvkørende bus i Aalborg Øst”. URL: https://www.letsholo.com/news/transportminister-indvier-den-selvkrende-bus-i-aalborg-st?fbclid=IwAR2bXXBlllh50mA4yFa5y9fl1uw1HxvQEvAIsLo3_BxZ4lsu7WTpIiZL_RY. Accessed: 19-02-2020

**Holo, 2019 f**. Holo. “Testing autonomous mobility solutions in a new way”. URL: https://www.letsholo.com/nordhavn. Accessed: 28-03-2020.

**Hvelplund, 2001**. Hvelplund, Frede. “*Electricity Reforms, Democracy and Technological Change: (electricity systems, “market liberalization” reforms, internationalization, and the need for new democratic governance systems – the Danish case).* Aalborg: Department of planning. Aalborg University, 2001. ISBN: 8790893271. URL: http://people.plan.aau.dk/~lund/Study/EM7/FS/HvelplundElectricityReformsBook.pdf. Accessed: 12-02-2020.

**Hvelplund, 2017**. Hvelplund, Frede and Søren Djrøp. “Multilevel policies for radical transition: Governance for a 100% renewable energy system”. Volume: 35 issue: 7, page(s): 1218-1241. Aalborg University. URL: https://journals.sagepub.com/doi/abs/10.1177/2399654417710024. Accessed: 26-03-2020.

**INDEPENDENT, 2020**. Harry Cockburn. “Climate crisis: Government unveils ‘unprecedented’ vision of future travel on walking, cycling and public transport”. URL: https://www.independent.co.uk/environment/climate-crisis-uk-public-transport-travel-cycling-driving-cars-a9431441.html. Accessed: 29-03-2020.

**INDEREN, n.d**. INDEREN. ”The benefits of biogas”. URL: https://inderen.es/the-benefits-of-biogas/. Accessed: 31-05-2020.

**Intego, n.d**. Intego. “Power to Aalborg’s first electric bus”. URL: https://intego.dk/images/downloads/english/Power_to_Aalborgs_first_electric_bus.pdf. Accessed: 24-04-2020.

**International Energy Agency, 2017**. International Energy Agency. “Technology roadmap – Delivering Sustainable Bioenergy”. URL: http://www.ieabioenergy.com/wp-content/uploads/2017/11/Technology_Roadmap_Delivering_Sustainable_Bioenergy.pdf. Accessed: 28-02-2020.

**Interview, 2020 a**. Susan Bundgaard Jensen, Projektleder at Nordjyllands Trafikselskab. 27-02-2020**.**

**Interview, 2020 b.** Morten Jensen, Trafikplanlægger for den kollektive trafik, Aalborg Kommune. 23-04-2020.

**Interview, 2020 c.** Telephone interview with Jesper Schultz, Projektleder for BRT Project (+BUS), Aalborg Municipality. 15-05-2020.

**Interview, 2020 d.** Peter Hoy, Senior Project Manger at COWI Aalborg. 26-05-2020.

**Josefsen, 2020**. Josefin, Hjalte**.**”Første selvkørende busser slippes løs i Aalborg”. ING. URL: https://ing.dk/artikel/foerste-selvkoerende-busser-slippes-loes-aalborg-232598. Accessed: 06-03-2020.

**Kanstrup K., 2011**. Kanstrup Kjær, Nina. “Data indsamling, Bearbejding og formidling”. URL: http://forlaget94.dk/cms/wp-content/uploads/F94-DOSAP-2013-K1-Prove2.pdf. Accessed: 12-04-2020.

**Klimarådet, 2020 a**. Klimarådet. ”Klimarådet: Ny rapport om vejen til 70-procentsmålet i 2030”. URL: https://www.klimaraadet.dk/da/nyheder/klimaraadet-ny-rapport-om-vejen-til-70-procentsmaalet-i-2030. Accessed: 10-03-2020.

**Klimarådet, 2018 b**. Klimarådet. ”The Role of Biomass in the Green Transition”. URL: https://klimaraadet.dk/sites/default/files/downloads/klimaraadet_theroleofbiomassinthegreentransition_english.pdf. Accessed: 24-02-2020.

**Kollektivtrafik, 2019**. kollektivtrafik. “El-busser kræver en anden planlægning”. URL: https://www.kollektivtrafik.dk/el-busser-krog230ver-en-anden-planlog230gning/778. Accessed: 01-04-2020.

**Lassen J., 2018**. Lassen Jørgensen, Kristoffer. ”Roskilde først med elektriske busser på alle ruter”. ING. URL: https://ing.dk/artikel/roskilde-foerst-med-elektriske-busser-paa-alle-ruter-211032. Accessed: 15-02-2020.

**Loorbach, 2009**. Loorbach, Derk. *“Transition Management for Sustainable Development: A Prescriptive, Complexity-Based Governance Framework*”. Governance 23(1):161 – 183. https://doi: 10.1111/j.1468-0491.2009.01471.x. URL: https://www.researchgate.net/publication/229815520_Transition_Management_for_Sustainable_Development_A_Prescriptive_Complexity-Based_Governance_Framework. Accessed: 03-04-2020.

**Lumen, n.d**. Lumen. “Theoretical Perspectives”. URL: https://courses.lumenlearning.com/scociology/chapter/theoretical-perspectives. Accessed: 12-02-2020.

**Lund, 2000**. Lund, Henrik. “Choice awareness: the development of technological and institutional choice in the public debate of Danish energy planning”. Journal of Environmental Policy & Planning, 2:3, 249-259. URL: https://www.tandfonline.com/doi/abs/10.1080/714038558. Accessed: 29-02-2020.

**Lund, 2009**. Lund, Henrik. “Renewable Energy Systems: The Choice and Modeling of 100% Renewable Solutions”. Aalborg Universitet. URL: https://books.google.dk/books?id=9A9AIG4K0ssC&pg=PA13&lpg=PA13&dq=Counterstrategies+may+involve+the+design+of+technical+alternatives,+feasibility+studies+based+on+institutional+economic+thinking,+and+the+design+of+public+regulation+measures+seen+in+the+light+of+conflicting+interests+as+well+as+changes+in+the+democratic+decision-making+infrastructure&source=bl&ots=xAjXhdYeSU&sig=ACfU3U3W_btyCGMLrAG3x6599zJU-7ItdQ&hl=da&sa=X&ved=2ahUKEwiS2cTzn8_pAhWIy6QKHbk7BSwQ6AEwAHoECAoQAQ. Accessed: 29-02-2020.

**Lund, 2014 a**. Lund, Henrik. “Renewable Energy Systems – A smart Energy system approach to the choice and modeling of 100% renewable solutions.” ISBN: 978-0-12-410423-5, 2nd edition. Academic Press, 2014. https://doi: 10.3303/CET1439001. Accessed: 28-02-2020.

**Lund, 2014 b**. Lund, Henrik. “Renewable Energy Systems (Second Edition) – A Smart Energy Systems Approach to the Choice and Modeling of 100% Renewable Solutions, Chapter 2 – Theory: Choice Awareness Theses”. 2014, Pages 15-34. https://doi.org/10.1016/B978-0-12-410423-5.00002-X. Accessed: 18-02-2020.

**Lund, 2014 c**. Lund, Henrik. “Renewable Energy Systems (Second Edition) – A Smart Energy Systems Approach to the Choice and Modeling of 100% Renewable Solutions, Chapter 3 – Methodology: Choice Awareness Strategies”. 2014, Pages 15-34. https://doi.org/10.1016/B978-0-12-410423-5.00003-1. Accessed: 18-02-2020.

**Lund and Persson, 2015**. Lund, Rasmus, Urban Persson. “Mapping of potential heat sources for heat pumps for district heating in Denmark Mapping”. Energy, Elsevier vol. 110, 1 September 2016, P. 129-138. https://doi.org/10.1016/j.energy.2015.12.127. Accessed: 23-03-2020.

**Lund *et al*, 2014**. Lund, Henrik, Sven Werner, Robin Wiltshire, Svend Svendsen, Jan Eric, Frede Hvelplund, and Brian Vad. ”4th Generation District Heating (4GDH) Integrating smart thermal Grids into Future Sustainable Energy System”. *Energy* 68: 1-11. https://doi.org/10.1016/j.energy.2014.02.089. Accessed: 24-02-2020.

**Lund, H. *et al*., 2019**. Lund, Henrik, Jakob Zinck Thellufsen, Poul Alberg Østergaard, Steffen Nielsen, Karl Sperling, Søren Roth Djørup, Peter Sorknæs, Arne Remmen, Søren Knudsen Kær, Lasse Rosendahl."Smart Energy Aalborg: Energivision for Aalborg Kommune 2050". Institut for Planlægning, Aalborg Universitet. URL: http://referater.aalborgkommune.dk/Pdf.aspx?pdfnavn=20392421-20924644-1.pdf&type=bilag&id=109420. Accessed: 05-02-2020.

**Lund, P. D. *et al.*, 2019**. Lund, Peter D. *et al*. "Pathway analysis of a zero-emission transition in the Nordic-Baltic region", *Energies*, 12(17), pp. 1–20. https://doi: 10.3390/en12173337. Accessed: 20-02-2020.

**MacKechnie, 2019**. MacKechnie, Christopher. " An introduction to electric buses". URL: https://www.liveabout.com/electric-buses-introduction-2798839. Liveabout. Accessed: 28-03-2020.

**Madsen, 2007**. Madsen, Michael. "The role of biomass in the future global energy supply", (November). Paper presented at World Energy Congress – Youth Symposium, Rom, Italy, 11/11/2007 – 15/11/2007. https://vbn.aau.dk/ws/portalfiles/portal/14071392/MichaelMadsen_WEC_Youth_Programme_paper.pdf. Accessed: 05-02-2020.

**Mathiesen *et al.*, 2015 a**. Mathiesen, B. V., Lund, H., Hansen, K., Ridjan, I., Djørup, S. R., Nielsen, S., Sorknæs, P., Thellufsen, J. Z., Grundahl, L., Lund, R. S., Drysdale, D., Connolly, D., & Østergaard, P. A., 2015. "IDA ' s Energy Vision 2050: A Smart Energy System strategy for 100% renewable Denmark". Department of Development and Planning. Aalborg University. https://vbn.aau.dk/ws/portalfiles/portal/222230514/Main_Report_IDAs_Energy_Vision_2050.pdf. Accessed: 05-02-2020.

**Mathiesen *et al.,* 2015 b**. Mathiesen, Brian Vad, Dave Drysdale, Julia Fernandez Chozas, Iva Ridjan, David Connolly & Henrik Lund. "*A Review of Smart Energy Projects & Smart Energy State-of-the-Art"*. Department of Development and Planning, Aalborg University. URL: https://vbn.aau.dk/en/publications/a-review-of-smart-energy-projects-amp-smart-energy-state-of-the-a. Accessed: 23-03-2020.

**Brauns and Turek, 2020**. Brauns, Jörn, Thomas Turek. "Alkaline Water Electrolysis Powered by Renewable Energy: A Review". MDPI. Processes 2020, *8*(2), 248; https://doi.org/10.3390/pr8020248. Accessed: 31-05-2020.

**Midttrafik, 2016**. Midttrafik. " Midttrafiks Miljøkatalog". URL: https://www.midttrafik.dk/media/4408/miljøkatalog-2016.pdf. Accessed: 01-03-2020.

**Mougouei and Mortazavi, 2017**. Rahimi Mougouei, Farzad, Mahdieh-sadat Mortazavi. **"***Effective approaches to energy planning and classification of energy systems models".* URL: dergipark.gov.tr./download/article-file/361729. Accessed: 15-04-2020.

**Movia, 2016**. Movia. "Forsøg med store elbusser". Trafikselskabet Movia ved Victor Hug. URL: https://www.moviatrafik.dk/media/6124/slutrapport-forsoeg-med-store-elbusser.pdf. Accessed: 31-03-2020.

**Neuman, 1997**. Neuman, W. Lawrence. "Social research methods: qualitative and qualitative approaches". 7. Edition. ISBN: 0205193560, 3. Boston: Allyn and Bacon, 1997. URL: http://letrunghieutvu.yolasite.com/resources/w-lawrence-neuman-social-research-methods_-qualitative-and-quantitative-approaches-pearson-education-limited-2013.pdf. Accessed: 31-03-2020.

**Nordiske Medier, n.d**. Nordiske Medier. URL: https://f.nordiskemedier.dk/2azq4jaen78v2tmb.jpg. Accessed: 16-04-2020.

**Nordjyllandstrafikselskab, n.d**. Nordjyllandstrafikselskab. "Om NT". URL: https://www.nordjyllandstrafikselskab.dk/Om-NT. Accessed: 01-03-2020.

**Nunes *et al*., 2020**. Nunes, L. J. R., T. P. Causer, and D. Ciolkosz. "Biomass for energy: A review on supply chain management models", *Renewable and Sustainable Energy Reviews*. Elsevier Ltd, 120(December 2019), p. 109658. https://doi: 10.1016/j.rser.2019.109658. Accessed: 01-04-2020.

**Olifent, 2020**. Olifent, Louise. ”Tog og bus er billigere, men vi tager alligevel bilen”. URL: https://pro.ing.dk/mobilitytech/artikel/tog-og-bus-er-billigere-men-vi-tager-alligevel-bilen-6089?utm_medium=email&utm_source=pro.ing.dk&utm_campaign=tipenven. Accessed: 24-03-2020.

**Pedersen, 2019**. Berg Badstue Pedersen, Maria. ”Superkondensator lagrer energi i bussen i Aalborg”. Energy Supply. URL: https://www.energy-supply.dk/article/view/665208/superkondensator_lagrer_energi_i_bussen_i_aalborg. Accessed: 22-03-2020.

**Plusbus, n.d a**. plusbus. “Om Plusbus”. URL: https://plusbus.dk/om-plusbus/. Accessed: 16-04-2020.

**Plusbus, n.d b**. plusbus. “Anlæg”. URL: https://plusbus.dk/anlaeg/. Accessed: 16-04-2020.

**Reference, n.d**. Reference. “What Is Innovation Theory? URL: https://www.reference.com/world-view/innovation-theory-975c80b47a82dfb3. Accessed: 27-03-2020.

**Region Nord Jylland and Aalborg kommune, n.d**. Region Nord Jylland, Aalborg kommune. ”+BUS AALBORG – Byens nye livsnerve”. URL: https://www.aalborg.dk/media/4551217/plusbus_brochure.pdf. Accessed: 16-04-2020.

**Sby, n.d**. Sby. “Winners”. Milano – Italy. URL: https://www.sustainablebusoftheyear.com/winners/. Accessed: 29-04-2020.

**Scarlat, N. *et al.*, 2019**. Scarlat, Nicolae, Jean-Francois Dallemand, Nigel Taylor, Manjola Banja, Javier Sanchez Lopez, Marios Avraamides. “Brief on biomass for energy in the European Union”. *Publications Office of the European Union*, (February), pp. 1–8. https://doi: 10.2760/546943. Accessed: 28-02-2020.

**Secretariat-General, 2016**. “European Commission. 2017 commission work programme – key documents”. URL: https://ec.europa.eu/info/publications/work-programme-commission-key-documents-2017_en. European Commission. Accessed: 20-02-2020.

**Siemens, n.d**. Siemens. ”Power-to-X”. URL:// https://new.siemens.com/global/en/products/energy/topics/power-to-x.html. Accessed: 31-05-2020.

**Smart Energy Networks, 2015**. ”Vision for Smart Energy in Denmark”, p. 8. URL: http://www.smartenergynetworks.dk/uploads/3/9/5/5/39555879/vision_for_smart_energy_in_denmark_-rd%26d.pdf. Accessed: 28-02-2020.

**Sorgenfrei*, *2019***. Sorgenfrei, Peter. ”Debatindlæg: Klimavenlig transport skal op i gear med selvkørende samkørsel”. Holo. Bragt i Altinget 18 november 2018. URL: https://www.letsholo.com/news/debatindlg-klimavenlig-transport-skal-op-i-gear-med-selvkrende-samkrsel. Accessed: 29-03-2020.

**State of green, n.d a**. State of green. “Clean Air – Reducing air pollution caused by traffic and industries and improving indoor climate”. URL: https://stateofgreen.com/en/sectors/clean-air/. Accessed: 07-02-2020.

**State of green, n.d b**. State of green. “Sustainable transportation and urban planning – Integrating an intelligent and holistic approach to city planning and transportation management to create more sustainable cities”. URL: https://stateofgreen.com/en/sectors/transportation-urban-planning/. Accessed: 10-02-2020.

**State of green, n.d c**. State of green. “Powering our future with sustainable energy”. URL: https://stateofgreen.com/en/sustainable-energy-to-power-the-future/. Accessed: 19-02-2020.

**State of green, 2020 d**. State of green. “Power-to-X is key to achieving substantial CO2 reductions”. URL: https://stateofgreen.com/en/partners/state-of-green/news/power-to-x-is-key-to-achieving-substantial-co2-reductions/. Accessed: 21-03-2020.

**State of green, 2019 e**. State of green. “New fleet of electric buses in Copenhagen as two central bus routes go green”. State of green. URL: https://stateofgreen.com/en/partners/state-of-green/news/new-fleet-of-electric-buses-in-copenhagen-as-two-central-bus-routes-go-green/. Accessed: 15-02-2020.

**State of green, n.d f**. State of green. “Mobilising an urban district with self-driving busses”. URL: https://stateofgreen.com/en/partners/city-of-aalborg-helps-develop-concepts-of-sustainable-cities/solutions/mobilising-an-urban-district-with-self-driving-busses/. Accessed: 20-02-2020.

**State of green, n.d g**. State of green. “Public transportation”. URL: https://stateofgreen.com/en/sectors/transportation-urban-planning/urban-mobility/public-transportation/. Accessed: 10-02-2020.

**State of green, 2020 h**. State of green. “New report maps the road to the 2030 70 percent goal”. URL: https://stateofgreen.com/en/partners/state-of-green/news/new-report-maps-the-road-to-the-2030-70-per-cent-goal/. Accessed: 10-03-2020.

**Stenbaek C., 2019**. Stenbaek Christoffersen, Jonas. ”Regeringen vil bruge 75 millioner på at udbrede hovedstadens bustrend til hele landet”. Berlingske. URL: https://www.berlingske.dk/hovedstaden/regeringen-vil-bruge-75-millioner-paa-at-udbrede-hovedstadens-bustrend. Accessed: 15-02-2020.

**Sustainable BUS, n.d**. Sustainable BUS. “News”. URL: https://www.sustainable-bus.com/. Accessed: 24-03-2020.

**Tiberiu, 2013**. Tiberiu, Tulucan. “Is the Future Electric? Electric Busses, a Sustainable Alternatives for Alborg’s Public Transport System”. URL: https://projekter.aau.dk/projekter/files/77297107/mp_final_from_word_AAU.pdf. Accessed: 08-03-2020.

**Thellufsen, et al., 2019**. Thellufsen, J. Z., Henrik, Lund, Peter Sorknæs, , Steffen Nielsen & Poul Alberg Østergaard. ”*Documentation for Scenarios in the 2050 Aalborg Energy Vision”*. Energiplanlægning, Institute for plalægning. Aalborg Universitet. URL: https://vbn.aau.dk/files/301521870/Documentation_for_Scenarios_in_the_2050_Aalborg_Energy_Vision.docx. Accessed: 08-02-2020.

**The management centre, 2016**. The management centre. “Theory Of Change”. URL: https://www.managementcentre.co.uk/theory-of-change-3/. Accessed: 25-03-2020.

**Thuesen, 2019**. Thuesen, Eskil. ”Regnemetoder og klima – CO2-prisen er 10 til 20 gange for lav”. URL: https://ing.dk/blog/regnemetoder-klima-co2-prisen-10-20-gange-lav-227349. Accessed: 15-04-2020.

**Transport and Environment, 2018**. Transport and Environment. “CO2 EMISSIONS FROM CARS: the facts”. Brussels – Belgium. URL: https://www.transportenvironment.org/sites/te/files/publications/2018_04_CO2_emissions_cars_The_facts_report_final_0_0.pdf. Accessed: 20-04-2020.

**Udbudsportalen, n.d**. Udbudsportalen. “Offentlig-privat innovation. URL: https://udbudsportalen.dk/udbudsguiden/offentlig-privat-innovation/”. Accessed: 29-03-2020.

**Umove, n.d a**. ”Umove Øst A/S har vundet El busser i Movia udbud A16 Roskilde”. Umove. URL: https://umove.dk/news/da/story/1013_umove-%C3%B8st-a-s-har-vundet-el-busser-i-movia-udbud-a16-roskilde. Accessed: 15-02-2020.

**Umove, n.d b**. Umove. “Umove A/S vinder den store pakke i MT53 udbuddet hos Midttrafik”. Umove. URL: https://umove.dk/news/da/story/1016_umove-a-s-vinder-den-store-pakke-i-mt53-udbuddet-hos-midttrafik. Accessed: 17-02-2020.

**Vad *et al.*, 2020**. Lund, Henrik, Brian Vad Mathiesen, Jakob Zinck Thellufsen, Peter Sorknæs, Iva Ridjan Skov. “IDAs Klimasvar: Transport- og energiløsninger 2030”, Udarbejdet af forskere fra Aalborg Universitet i dialog med IDAs Klima ad hoc-udvalg. Ingeniørforeningen, IDA. URL: https://vbn.aau.dk/ws/portalfiles/portal/332267652/IDAs_klimasvar_2030.pdf. Accessed: 22-05-2020.

**Vad *et al.*, 2015**. Mathiesen, Brian Vad, David Connolly, Henrik Lund. “Smart Energy Europe – From a Heat Roadmap to an Energy System Roadmap”. Aalborg Universitet. URL: https://vbn.aau.dk/ws/portalfiles/portal/229433535/Smart_Energy_Europe_2015.pdf. Accessed: 23-03-2020.

**Valmot, 2017**. Valmot, Odd Richard. ”Kæmpebatteri giver elbus rækkevidde på 300 km”. URL: https://ing.dk/artikel/kaempebatteri-giver-elbus-raekkevidde-paa-300-km-207733. Accessed: 08-02-2020.

**VDL, n.d**. VDL. “VDL BUS & COACH CELEBRATES MILESTONE OF 50 MILLION ELECTRIC KILOMETRES AND INTRODUCES NEW BATTERY PACK”. URL: https://www.vdlbuscoach.com/en/news/archive/vdl-bus-coach-celebrates-milestone-of-50-million-electric-kilometres-and-introduces-new-battery-pack. Accessed: 18-02-2020.

**Walsh et al., 2002**. Walsh, S.T., B.A. Kirchhoff, S. Newbert. “Differentiating market strategies for disruptive technologies”. IEEE Transactions on Engineering Management 49 (4), 341–351. Accessed: 19-02-2020.

**Webinar, 2020 a**. Afholder: Erhvervslivets Klimaalliance. ”Sektorkobling er nøglen til fremtidens bæredygtige energisystem”. 17-04-202. Kl. 10.30 til 12.00.

**Webinar, 2020 b**. Afholder: DI Energi. ”FRA KUL- TIL KLIMAUNION”. 05-05-2020. KL. 13.00 TIL 15.00.

**Wittrup. S., 2020 a**. Wittrup, Sanne. “Energianalytikere: Klimamål kræver turbo på teknologiudviklingen”. ING. URL: https://ing.dk/artikel/klimamal-kraever-turbo-pa-teknologiudviklingen-232510. Accessed: 05-03-2020.

**Wittrup. S., 2020 b**. Wittrup, Sanne. ”Eksperter til politikerne: Pas på med sektoropdelte klimastrategier”. ING. URL: https://ing.dk/artikel/eksperter-politikerne-pas-paa-med-sektoropdelte-klimastrategier-233428. Accessed: 25-03-2020.

**Wittrup. S., 2020 c**. Wittrup, Sanne. “De vigtigste punkter i Klimarådets anbefalinger”. URL: https://pro.ing.dk/gridtech/artikel/de-vigtigste-punkter-i-klimaraadets-anbefalinger-5875. Accessed: 10-03-2020.

**Zarate, 2009**. Zarate, Pascale. Raphaele Thery. “Energy Planning: a multi-level and multicriteria decision making structure proposal”. https:// doi.org/10.1007/s10100-009-0091-5. Accessed: 16-04-2020.

**Zvingilaite et al, 2012**. Zvingilaite, E., Ommen, T. S., Elmegaard, B. & Frank, M. L. ”Low temperature district heating consumer unit with micro heat pump for domestic hot water presentation”. District energy development center, in proceedings of the 13th international symposium om district heating and cooling (pp. 136-143). URL: https://backend.orbit.dtu.dk/ws/portalfiles/portal/33439225/Zvingilaite_LOW+TEMPERATURE+DISTRICT+HEATING+CONSUMER+UNIT+WITH+MICRO+HEAT+PUMP+FOR+DOMESTIC+HOT+WATER+PREPARATION.pdf Accessed: 28-02-2020.

# Appendix A

## Email Interview / Expert interview

Susan Bundgaard Jensen / Projektleder, Nordjyllands Trafikselskab 27-02-2020

**<u>Buses in Aalborg municipality</u>**

*1- Hvor mange busser kører i Ålborg kommune?*
Ca. 100 kontraktbusser

2- *Hvor mange el-busser kører i Ålborg kommune?*

Ingen i kontrakt. Aalborg Kommune kører dog (i samarbejde med Aowei) pt testdrift med en ultra-capacitor powered elektrisk bus. Jeg forventer, at vi efter det kommende genudbud af bybuskørslen i Aalborg får gennemført en grøn omstilling af busdriften, men da det på nuværende tidspunkt er 10-12 år siden kørslen sidst har været udbudt, kører der (udover en håndfuld biogasbusser) udelukkende dieselbusser på linjerne. Den ultra-capacitor powered elektriske bus, som pt testkører i Aalborg, lader med en max ladeeffekt på 350Kw i byrummet og 15 Kw på depotanlægget.

*3 - Hvad har der været for problemer (politiske og tekniske) som vi ikke kan se so mange kørende elbuser i Ålborg kommune?*

Det er udelukkende et spørgsmål om, at det er lang tid siden, at kørslen har været i udbud. Og dengang var eldrift ikke moden til storskaladrift. Jeg forventer, at når vi genudbyder kørslen (sandsynligvis med kontraktstart i august 2022) så vil det være med krav om nulemissionsdrift. Her vil enten el eller brint som det ser ud pt, som udgangspunkt være de mulige teknologier.

*4 - Var der nogen politiker der har stoppet projekter eller problemet har vært på grund af mangel for noget energi resourcer eller infrastruktur?*
Nej. Men da kørslen i sin tid blev udbudt med driftsstart i sommeren 2010 var el-teknologien ikke moden til storskaladrift. Derfor blev der blot, som praksis var den gang, udbudt med krav om dieseldrift. Men det er klart, at nu, hvor vi står i den situation at kørslen skal til at genudbydes, så forholder vi os selvfølgelig til de fremtidige drivmidler.

*5 - Hvorfor er den kaldt ultra-capacitor? Er der noget specielt i forhold til denne slags bus?*
Du kan eksempelvis læse mere her
<u>https://www.energysupply.dk/article/view/665208/superkondensator_lagrer_energi_i_bussen_i_aalborg</u>.

6 - *Du havde skrevet at der er 100 busser i drift nu. Så I 2022 I forventer at alle af dem vil være zero emission?*

Nej. Kørslen bliver udbudt med krav om nulemissionsdrift. Men der overdrages en række busser fra de eksisterende kontrakter, der som udgangspunkt vil skulle køre indtil de har en alder, hvor de naturligt udfases. I denne mellemliggende periode vil de sandsynligvis skulle køre på et fossilfrit syntetisk diesel. Men de endelige krav til drift og materiel kender vi først, når udbudsmaterialet er i mål.

# Appendix B

## Email Interview / Expert interview

Morten Jensen – Trafikplanlægger for den kollektive trafik – Aalborg Kommune 23-04-2020

**The operating supercapacitor bus in Aalborg city**

- *How many diesel buses are currently operating in Aalborg municipality/ Aalborg city?*
App. 120

- *When would the diesel buses get phased out of the Aalborg transport sector?*
All diesel buses will be phased out from 2022 to 2030

- *How many electric buses (maybe supercapacitor electric bases) do you decide to run in Aalborg by 2030?*
And by 2050? How is the plan?
All buses will be zero-emission buses by 2030.

- *Why has there been employed only one electric bus/supercapacitor in the bus fleet, although other municipalities such as Aarhus and Copenhagen have already been operating electric buses?*
The bus operation is tendered every 6-8 years. There will be a new tender the end of the year, to begin operation summer 2022.

- *Why is it only Aalborg which has employed this technology in its bus fleet?*
It is a new technology.

- *How many hours does it drive during the day?*
It is in operation from 7 to 16 weekdays.

- *What are the battery features?*
The bus is equipped with a supercap. The bus can run 30-40 km on one charge. You can read more about it here: https://zero.no/wp-content/uploads/2019/09/24-Chariot-Motors-Norway.pdf

- *How many times should it get charged during the day?*
The bus is charged every time it arrives at Aalborg Airport.

- *What happens if the bus gets some failures during its drive, as it is a fully electric bus? Is there any reserve bus for that?*
The bus driver will call the garage and they will send their maintenance crew.

- *Do you have any prediction of how much CO2 would be saved through the replacement of a diesel bus by a supercapacitor bus?*
A normal diesel city bus runs approx. 2-3 km pr. Liter fuel and drives approx. 22 km pr. Hour.

- *Are there or would be there any barriers to implement more of them in the fleet? (Technical or institutional barriers)*
Mainly economical

- *Would it be possible to have some solar cells installed on the bus roof?*
Theoretically yes. But most of the space on the roof is used for technical installations.

# Appendix C

**<u>Data collection – The contacted Persons/Companies/Organizations</u>**

Susan Bundgaard Jensen, Projektleder / Nordjyllands Trafikselskab (NT)

Jesper Schultz, Projektleder / BRT Project (+BUS) - Aalborg Municipality

House of energy – Supercapacitor bus in Aalborg

Morten Jensen, Trafikplanlægger for den kollektive trafik / Aalborg Kommune

Peter Hoy , Senior Project Manager / COWI Aalborg , +BUS Report

Jesper Christensen, Chefredaktør / Transportnyhederne.dk, Magasinet Bus, Latsbilnyhederne.dk – Aarhus

AOWEI – Supercapacitor buses

Sustainablebusoftheyear.com – Electric buses

HOLO.com - Minibuses in Aalborg (Shuttle buses in Aalborg)

Vadoetorno.com – Electric buses

Sustainable-bus.com – Electric buses

Maria Vestergaard, Team coordinator / SMART Mobility Team – Department of Mobility - Aalborg Municipality – Mini electric buses – NOVYA

Birgitte Skøtt Lenstrup, Chefkonsulent / Movia Trafikselskabet – Direktionsekretariat- Kommunikation og Presse

Christian Twitchett, Konsulent / Regional Udvikling – Sekretariat for Regional Udvikling

State of green – Minibuses in Aalborg

3Emotion.eu – Hydrogen Buses Project

# Appendix D

## Power to X

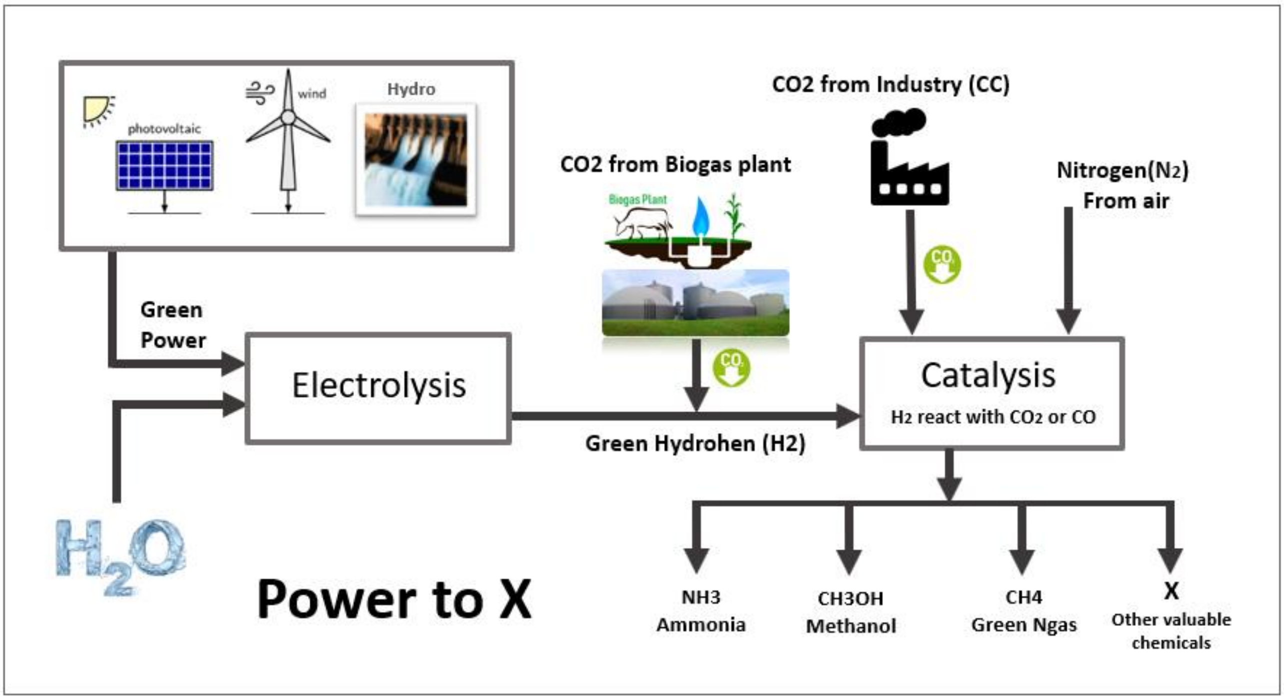


*Figure 36.Power to X (Own figure)*