CHALMERS
UNIVERSITY OF TECHNOLOGY

Impact of financial incentives and deterrents on the TCO of commercially operating, long-haul trucks powered by sustainable fuels

Master's thesis in Industrial Ecology

Sumanth Sai Mikkilineni

DEPARTMENT OF SPACE, EARTH AND ENVIRONMENT
CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2021
www.chalmers.se

MASTER'S THESIS SEEX30

Impact of financial incentives and deterrents on the TCO of commercially operating, long-haul trucks powered by sustainable fuels.

Master's Thesis in the Master's Program Industrial Ecology

SUMANTH SAI MIKKILINENI

Supervisor, Chalmers: Frances Sprei

Department of Space, Earth and Environment
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2021

Impact of financial incentives and deterrents on the TCO of commercially operating, long-haul trucks powered by sustainable fuels.

Master's Thesis in the Master's Program of Industrial Ecology

SUMANTH SAI MIKKILINENI

Department of Industrial Ecology
Chalmers University of
Technology
SE-412 96 Gothenburg
Sweden
Telephone: + 46 (0)31-772 1000

Cover:
Impact of financial incentives and deterrents on the TCO of commercially operating, long-haul trucks powered by sustainable fuels.

Department of Space, Earth and Environment
Gothenburg, Sweden, 2021

Impact of financial incentives and deterrents on the TCO of commercially operating, long-haul trucks powered by sustainable fuels.

Master's thesis in the Master's Program *Industrial Ecology*

SUMANTH SAI MIKKILINENI

Department of Space, Earth and Environment

Chalmers University of Technology

Abstract

The commercial transport industry is on a path towards decarbonization by means of replacing diesel and conventional fuels with more sustainable alternatives. Biofuels are a readily available alternative to diesel. However, the industry is looking towards completely emission-free transport. Development of technologies like Battery Electric Trucks (BETs) and Hydrogen Fuel Cell Electric Trucks (FCETs) play a crucial role in this emission-free future. Many countries in the EU and many states in USA have already started initiatives that help commercial transport sector, especially the long-haul trucking industry to make the shift to sustainable alternatives. Part of these initiatives are several incentives that encourage and promote sustainable alternatives along with deterrents that discourage the use of conventional fossil fuel-based trucks.

This study aims to bring together information about the policies introduced in different countries and categorize them for easier understanding. This data is then used to perform a Total Cost of Operation (TCO) analysis for different technologies in 5 countries. This analysis sheds light on how effective these policies are in aiding the transition and also gives an idea on how sensitive the TCO is towards these incentives and deterrents. The study uses all secondary sources to collect data and performs qualitative and quantitative analysis. Majority of the study is done by conducting literature reviews and using the data collected in the calculations for TCO. The assumptions made for TCO, and all the variables considered are taken from legitimate sources and are supported by citations wherever applicable.

The original TCO analysis case proved that, with the presence of incentives, sustainable alternatives are indeed a compelling and lucrative option. However, there is a glaring need for infrastructure development in terms of manufacturing, service and refueling. Unless these aspects are not addressed even to a satisfactory level, these alternative technologies will have a hard time being adopted. Modeling the future scenarios where the infrastructure is developed and incentives are removed shows that the sustainable alternatives would have time to mature and grow in adoption rate, leading to lowering of manufacture costs, improved service and increased refueling infrastructure.

Keywords: Sustainable trucks, TCO, long-haul trucks, incentives, transport policy

Table of Contents

Figures

Tables

Acknowledgements

Firstly, I would like to thank Prof. Frances Sprei, Associate Professor, Department of Space, Earth and Environment, for being my supervisor and Examiner at Chalmers. Her stimulating guidance and profuse assistance throughout the study has been extremely valuable. I consider it a great privilege to be able to associate and work with her.

Secondly, I want to give my deepest thanks to Magnus Blinge, Research Manager, Scania Group, for initiating this thesis and providing me with the wonderful opportunity to pursue it. I consider myself lucky and am extremely grateful for the trust put in me. I would also like to extend my thanks for having an open mind towards additions and changes towards the thesis development.

I would like to thank Reno Filla, Senior Engineer, Scania Group for initiating this thesis along with Magnus and for providing multiple perspectives to work on, for the thesis. These perspectives have contributed to obtaining a clarity on the direction this study headed.

I would also like to extend my thanks to Prof. Henrikke Baumann, for her patience in listening to my queries on how to approach and develop a thesis, and answering them with profound interest. I also thank her for suggesting me with relevant opportunities in my field.

List Of Abbreviations

TCO	Total Cost of Operation
BET	Battery Electric Truck
CNG	Compressed Natural Gas
DC	Direct Current
EDV	Electric Drive Vehicle
EJ	Environmental Justice
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FCET	Fuel Cell Electric Truck
GHG	Green House Gases
HDV	Heavy Duty Vehicle
HGV	Heavy Goods Vehicle
HVO	Hydrogenated Vegetable Oil
ICE	Internal Combustion Engine
LCC	Life Cycle Costs
LLC	Limited Liability Company
MDV	Medium Duty Vehicle
MOU	Memorandum Of Understanding
NGV	Natural Gas Vehicle
NOx	Nitrogen Oxide
OEM	Original Equipment Manufacturer
PHEV	Plug-in Hybrid Electric Vehicle
PM	Particulate Matter
RED	Renewable Energy Directive
ULEV	Ultra-Low Emission Vehicle
ZEV	Zero Emission Vehicle

1. Introduction

The background talks about the current industry situation, trends, goals and insights that motivate this study to take place. It is followed by the aim of this research study. Specification of issue under investigation talks briefly about what this study looks to achieve under the aim by means of research questions. These questions, in a way, helped progress through the research work and kept the study in relevance. Later some limitations of the research study are discussed. The methodology part discusses how the research is conducted in a detailed manner.

1.1. Background

Road freight transport accounts for a significant share of global energy consumption in the transportation sector. Almost 45% of global transport energy consumption corresponds to freight transport, with heavy-duty vehicles (HDVs) using more than half of that energy (Edenhofer, 2015). Furthermore, road freight transport depends heavily on fossil fuels, with medium freight trucks and heavy freight trucks accounting for 24% of global oil-based fuel consumption (Energy Technology Perspectives 2017 – Analysis, IEA, 2017). Diesel is the main fuel used in road freight transport, accounting for 84% of all oil products in the freight transport sector; and corresponding to half of the global diesel demand (The Future of Trucks, OECD 2017).

Road freight vehicles are difficult to characterize due to the variety of vocational uses that requires a large number of sizes and configurations. However, it is considered that goods delivery from production sites to factories, industries and/or final retailers is one of the essential roles of road freight vehicles (The Future of Trucks, OECD, 2017). LDVs (light-duty vehicles), MDVs (medium-duty vehicles) and HDVs (heavy-duty vehicles) including but not limited to trucks fall under the category of road freight vehicles. In addition, the vehicle size classification for road freight vehicles varies from region to region.

Despite the small share in road vehicles, MDVs and HDVs contribute disproportionally to greenhouse gas (GHG) and air pollutant emissions and fossil fuel use, due to high vehicle fuel consumption, large annual travelled distances and long idling times (Kast et al., 2018). In the European Union, HDVs account for 30% of on-road CO2 emissions, despite representing only 4% of the road vehicle stock (Muncrief & Sharpe, 2015). Similarly in the United States, MDVs and HDVs account for 26% of transport CO2 emissions (Kast et al., 2017). Additionally, road freight vehicles produce half of particulate matter (PM) emissions and one third of NOx emissions of the transport sector in cities (Dablanc, 2011). In the United States, MDVs and HDVs are responsible for 22%, 28% and 24% of transport sector PM2.5, NOx and CO emissions, respectively (Kast et al., 2018). PM and NOx are associated with adverse health effects in human beings (WHO Regional Office for Europe, 2013); while exposure to low CO concentrations causes health problems such as headaches and light-headedness (Pollution, 2010). Furthermore, diesel exhaust gas is classified as carcinogenic to humans (Group 1) by the World Health Organization (WHO) (IARC: Diesel Engine Exhaust Carcinogenic – IARC, 2012).

Decarbonization in road freight transport will be difficult to realize (Ronan, 2015). Global road freight activity is expected to grow in the future, driven by economic development. For instance, heavy-duty truck use is expected to increase 2.7%/year between 2000 and 2030 (EV City Casebook – Urban Foresight, 2014). Increased road freight activity and high dependence on fossil fuels will cause GHG emissions from road freight transport to keep growing in the future; requiring coordinated effort by shippers, logistics service providers and policymakers to mitigate their growth (Energy Technology Perspectives 2017 – ICCT, 2017).

Potential for energy consumption and CO2 emissions reduction through the improvement of internal combustion engine efficiency and aerodynamics is significant and can be cost-effective (Transitioning to Zero-Emission Heavy-Duty Freight Vehicles | ICCT, 2017). However, in the long-term, advanced biofuels, electric-drive vehicles (EDVs) and Hydrogen Fuel-cell vehicles will be the main option to achieve deep decarbonization in road freight vehicles (Zero-Emission Trucks: An Overview of the State-of-the-Art | International Council on Clean Transportation, 2013). The time scales operating in road freight vehicle stock turnover are long. Thus, it is essential to take the dynamics of technology diffusion in the vehicle into consideration; when we determine the function of powertrain electrification in the decarbonization of road freight transport.

Many countries in the EU have started initiatives that help commercial transport sector to make the shift towards sustainable solutions. Part of these initiatives are several incentives that encourage and promote sustainable solutions and deterrents that discourage the use of conventional fossil fuel based trucks (Financing electric trucks and charging infrastructure, 2020). Truck manufacturing companies have been competitive in their attempts to bring sustainable alternatives to the market. The current market has seen substantial rise in the number of trucks that run on biofuels, while the different truck manufacturers have been partnering with multiple companies to test out Zero-Emission alternatives for different use cases.

One such company is Scania Group, where the idea for this thesis took shape. The company has a clear goal towards sustainability, which is why the department of Innovation at Scania has initiated this thesis. Parented under Traton group, Scania works closely with other brands like MAN, Navistar, etc and is a known entity of the trucking industry. The company is reputed for its undivided focus on innovation and sustainability.

Scania operates in almost every continent in the world except North America. It is no surprise therefore, to gather that the company's market presence is affected by different factors in different regions. These factors could be price, market needs, maintenance costs, government incentives for manufacture, R&D, purchase and leasing of these vehicles. To stay relevant in all the markets it operates, as well as to be ahead in the market race for sustainable alternatives, Scania is undergoing a transformation. Resulting from this strategy for sustainability is the company's participation in several projects, collaborating with customers, infrastructure providers and even other OEMs (Scania Group, 2020).

Apart from that, the company boasts a large variety of vehicles for alternatives to diesel. All of Scania's engines can run on HVO (Hydrogenated Vegetable Oil) without any modifications to the engine or powertrain. More than 40% of the bus sales are alternative to diesel. By developing alternative technologies like electrified powertrains, Hydrogen fuel cells and by developing its existing biofuel based engines for efficiency, the company aims to reduce its CO_2 emissions by 50% between 2016 and 2025 (Sustainability Ambitions and Targets, Scania Group, 2021).

1.2. Aim

The purpose of the thesis is to determine and understand how financial incentives and deterrents impact the TCO (Total Cost of Operation) of commercially operating long-haul trucks, powered by sustainable alternatives to fossil fuels. These sustainable solutions include new technologies like battery-electric powertrains, Hydrogen fuel-cells and existing technologies like biofuels. An expected outcome of this research is a sound understanding of the incentives and deterrents being used by countries (Sweden, Germany, France, UK, USA in this case), categorization of the incentives based on multiple factors. Another outcome is to be able to make a scenario analysis of the TCO with and without the incentives present, to understand how they impact the TCO overtime.

With this thesis, part of the goal is to bring together information about the incentives and deterrents introduced and discussed by different countries, to help in the transition towards sustainable solutions. This is done not just to have a comparable idea of the incentives in different countries, but to make future research work pertaining to incentives and TCO analysis easier. Having a report on the incentives offered by different countries and the TCO analyzed by taking these incentives into consideration, provides an easier working ground for future, more intricate and theme-specific research.

The shift in technology by truck manufacturers consequently affects the customers in the form of changes in TCO. Be it individual owners of trucks, leasing services or freight haulage companies; the indirect/direct impact of incentives on their TCO is inevitable. It would be deeply insightful for truck manufacturers to know how much impact is felt by customers by mapping out how sensitive TCO is to the incentives and deterrents. Truck manufacturers have substantial data regarding the TCO of their trucks. However, the incentives for sustainable transport are becoming more prominent by the day, owing to the shift towards sustainability in the industry. This study on incentives and TCO analysis can make it easier for truck manufacturers to calculate their own versions of TCO by embedding their own data and changing the variables. This study, reduces the time and effort needed to model multiple scenarios and analyze data on future incentives.

1.3. Research Questions

To map this sensitivity, we take a step-by-step look at what we need to have in hand before we make derivations. To have a clear base for performing further analysis, we need to ask a few questions and try to look for answers. The first question provides an overarching theme on why this study and the whole industry is focusing in decarbonization and sustainable alternatives:

What is decarbonization and why is it necessary in the transport sector, specifically for heavy duty vehicles?

The answer to this gives the background to the thesis report and to the reason we put focus on this issue. Getting into the technicalities, this thesis focuses on the cost perspective and TCO, thus the next step is to look at incentives in different countries. We can ask the following questions:

What are the incentives provided for transitioning to sustainable alternatives?

Are these incentives technology specific? Or product specific? Or are they entirely different?
Where in the supply chain are these incentives aimed at?

After the incentives are thoroughly researched upon, their impact on costs is formulated, essentially modelling the TCO. For this, we aim to answer the following questions to answer:

How is the TCO impacted by these incentives and deterrents?
How does the TCO change when we vary the modelling parameters?
What happens if the incentives are removed? Will there be substantial changes in TCO?

Based on the results for these questions, we can get an overarching idea of how the industry is going forward and how the incentives and deterrents effect the TCO of different technologies.

1.4. Limitations

Scania's market is vast and is continuously expanding. It would be non-viable to look at every market and understand the business cases. The company's market in Asia and Americas is seeing increased growth. However, Europe continues to be the manufacturer's most important market. Close to 55% of the entire company's deliveries were to European customers. Therefore, it would be fitting to look at its major market and a newer market where there could be a lot of scope for development in the future. It is therefore decided Sweden, Germany, UK and France would be markets in Europe that would be focussed on and USA as a potential market. EU is serious on setting up standards for emissions and has plans to make the transport sector emission-free, for which it also supports various incentives. USA has been quite generous with its incentives to achieve its goal of emission-free transport. However, not all countries follow or implement the same laws. There are different regulations and laws in different countries, which if categorized and tabulated, could be a good source of information that could help future discussions.

As mentioned in the aim of the report, this thesis aims to look at long-haul options in particular. Scania manufactures various trucks for different regions and needs, for example 18-ton and 24-ton options for regional transport and a 40-ton option for long-haul. However, considering the long-haul option, it was decided to look at 40-ton trucks which work exclusively for long-haul transport. However, not a lot of discussion is going on currently, to bring incentives and deterrents specifically for long-haul. So, if no substantial data could be found for long-haul, the other options would be included as well.

Scania is currently researching multiple sustainable options as alternative to conventional fuels. It has multiple partnerships with Ecotrans, Transport Harry Mikkola, Volvo Group, Stena Line and Skanninge Godstransporter to use electric, biofuel-based and liquefied-gas based trucks for running their businesses (*Sustainable Transport*, Scania Group, 2021). Analysing every technology in such limited time would be impractical. Upon discussion with Scania, it was decided to look at electrification, biofuels and Fuel cells for understanding the changes in business cases. These technologies have been quite long in development and some of them have had tremendous growth in the personal transport sector in the last decade. However, the impact in commercial transport has not been equally substantial. But it is projected to grow in the coming years, more so in the coming decade.

2. Method

Here, it is described on how the research has been designed to be implemented. It also provides an idea of how data is collected and handled during the analysis. Further, it is also explained how the author has prioritized quality and credibility of information presented along with ethical reflections for the study.

2.0.1. Literature Review

The important part of methodology is literature review. The data to derive the necessary results for the thesis aim is not readily available nor is aggregated previously. It is therefore important to go through various literature to understand and collect as much data as possible for analysing how sustainable alternatives are panning out for long-haul commercial transport sector. The literature sources are of different varieties, i.e. research articles, reports by research groups, national statistics documents, etc. How these sources are handled and their pros and cons are talked about in the coming sections.

The review starts by looking at literature pertaining to decarbonising the long-haul transport sector where it is explained why the so-called decarbonisation is necessary and how it could be achieved. It outlines the different technologies being developed and implemented. It also explains the hurdles in developing and bringing the technology to mainstream usage. Later, relevant literature is collected and reviewed. This is done in the order of countries. Literature pertaining to sustainable policies and relevant data for one country are studied. This study includes collecting data on the country's plans for decarbonization, short-term and long-term emission goals, policies that support decarbonization, incentives that effect different levels of the supply chain and deterrents that discourage the use of conventional fuel trucks. Deterrents that are not in regulation but only under discussion are included in future scenario analysis to understand how successful they can be in discouraging the use of conventional fossil fuels. It is of importance for this study that the policies pertaining to long-haul trucking are focussed upon. Also, the technologies in focus are biofuels and electrification. The latter part is more specifically Battery Electric Trucks (BETs) and Fuel Cell Electric Trucks (FCETs).

All the data collected through this literature study is documented and the process is repeated for other countries. This process allows for relevance and cohesion of information when looking at and comparing the different countries and technologies. The comparison and analysis happens for the policy incentives and deterrents opted by different countries. Each country has its own strategy based on its economic, financial and regional factors.

The goal here is to categorize these policy incentives and deterrents based on the different levels of supply chain or based on technology and region. Depending on the quality and quantity of data collected, this categorization could be decided upon. However, a good starting point for the research could be by looking at incentives for R&D and at OEM level, since most of these sustainable alternative technologies are not ready for mass production and deployment. In later chapters, this categorization is tabulated, which provides a clear understanding as to how different countries are tackling the transition to decarbonization.

2.0.2. Calculations and TCO

The data on incentives is tabulated based on factors like country, what it is intended to support, how long it stays available etc. Once tabulated, it could be clearly understood where in the supply chain these incentives work on or how much of an impact they have, directly or indirectly on TCO. Impact of incentives at the R&D level or OEM level are harder to model on TCO, since it cannot be translated directly into monetary changes. The closer the incentive or deterrent is to the customer level, the easier it is to model its impact. It then becomes fairly easy to translate them into monetary changes. Since it is the TCO we need at the end, we calculate the cost of production and maintenance for the trucks based on different technologies.

A TCO is calculated by adding up the purchase price, fuel price and maintenance costs and subtracting the incentives received at the customer's end. Also, we decided upon an agreeable to real-world life-span of the trucks to be 7 years, during which the costs are calculated. The formula used in this study is derived from Kampker et al. (2018). The paper uses the below formula:

$$\mathrm{TCO} = (\mathrm{I} - \mathrm{RP}) + \mathrm{FC} + \left(\frac{\mathrm{np}}{1-(1+\mathrm{p})^{-\mathrm{y}}} * \mathrm{y} - \mathrm{n}\right) + \mathrm{z} + \mathrm{u} + \mathrm{x} + \mathrm{t} - \mathrm{s}$$

The variables in the equation are as follows:

I – Initial price of the truck
RP – Resale price of the truck at the end of useful life
FC – Fuel and energy costs along the driven kilometers
z – Insurance
u – Maintenance
x – Repair
t – Tax
s – Subsidies
The term in the parenthesis is the interest cost. The terms inside it stand for:
p – Rate of Interest
n – Number of compounding periods per year
y – Number of years

The interest cost is the amount of interest paid on the money borrowed to purchase a truck. This borrowed money usually amounts to about 80% of the initial price. However, for our calculations here, this interest cost is being neglected and we assume that the entire initial cost is borne by the purchaser and paid upfront. We can thus eliminate this variable from our equation. Thus, our equation effectively becomes:

$$\mathrm{TCO} = (\mathrm{I} - \mathrm{RP}) + \mathrm{FC} + \mathrm{z} + \mathrm{u} + \mathrm{x} + \mathrm{t} - \mathrm{s}$$

The formula is simplified and some variables are removed owing to the limitations in the data collected for this study. Another reason for simplifying the formula used has to do with the aim of the study. The main aim is to compile the incentives and deterrents introduced by different countries and to see how they impact the TCO. In order to make this understanding easier, the formula was simplified to focus on the taxes and other incentives, while also retaining the main and important financial terms that make it more realistic. Other factors like work force costs, their insurance, emergencies like accidents etc come into play for fleet management companies but could be ignored in this case.

2.0.3. Scenario Analysis & Landscape Mapping

Once we are able to relate incentives to TCO, scenario analysis is a useful process to work on estimates and calculations to derive projections of how each incentive impacts the TCO overtime. For incentives that vary over the years, the changes in TCO are calculated. This is done by assuming real world values and making predictions. For example, if a road toll is imposed for commercial vehicles and zero-emission vehicles are exempted, we can calculate how much on average a truck travels in a year and based on the toll, country and other prices, calculate how much money is saved. Also for electric or fuel-cell based trucks, the price of charging and hydrogen are different to conventional fuels.

All these factors are included for calculating cost savings as part of TCO. Based on that, we can make projections for TCO in the coming years with incentives removed. We can also add the deterrents into consideration if they are being implemented or under discussion. As part of this thesis, we make three scenarios. In the first scenario, we assumed that in 10 years' time, the price of hydrogen and electric trucks falls by 20% and the price of hydrogen fuel falls by 50% due to the technology becoming more mainstream. The second scenario assumes that all the incentives for sustainable alternatives are removed, keeping other values same as the first case. The third scenario follows upon the first two and assumes that the price of biofuel has fallen by 10% and the price of diesel has increased by 30% to be a significant deterrent.

This scenario analysis and future landscape situation are discussed after performing the TCO analysis. These scenarios provide interesting insights into how the future might look and how the transition to sustainable alternatives aids the decarbonization of the industry. This again, helps in mapping the landscape of the industry by graphing the projected change in development costs, manufacture costs, infrastructure development and the changes in TCO overtime. It also gives an idea of how much the market in different regions is volatile to change in incentives by their respective governments. It shows how important policy changes can be and if they can make or break the market change.

2.1. Data Collection

2.1.1. Source Handling

The data collected throughout this research study is secondary data. There have been some ideas on collecting primary data by conducting semi-structured interviews and engaging with the actors/consumers from the long-haul trucking industry. This would involve private owners of trucks as well as truck fleet companies. But the idea was later scrapped as the amount of data collected from them would be too randomized and less to perform any kind of analysis for the TCO.

Thus, all the data collected from different sources like reports by private firms, government websites, journals, web reports, online articles and research papers, etc. form the basis of the research work conducted, analysis made, and scenarios assumed. Although it is relatively hard to find and customize secondary data to support the research questions, efforts have been put towards finding data that is as relevant as possible to the study. Thus, for this study, the focus has been on collecting data that could not only paint the picture of scenarios for sustainable alternatives in the trucking industry, but also provide the numbers at various levels that were necessary to model the different cases of TCO. This modelling helped in understanding the current situation of the long-haul trucking industry in its transition towards complete decarbonization. It also helped in creating multiple future scenarios to understand where the industry might move, by changing variables in the numerical data collected.

Collecting data through secondary sources led to some concepts being explained in a limited fashion in them, which led to scouting for more literature just to gather more data on the concepts explained in the previous reports. This led to the creation of a chain of sources which involved the main-secondary sources and those that were used to understand some complementing concepts from the main-secondary sources. These could be looked at as secondary-to secondary sources and could be called as tertiary sources. During the initial stage of the study, collection of secondary data was performed to understand the current scenario of the trucking industry as a whole and the level of decarbonization it is aiming for. It also gave a background on the different types of technologies being researched to achieve this desired decarbonization.

This initial data collection also helped in framing clearer research questions and to understand how the study should be planned out. Given the scope of the study and the limited amount of time, it would not have been appropriate to conduct the analysis for all the regions that Scania operates in, nor would it have been appropriate to look at all the different technologies and landscapes that might potentially impact the future if this particular industry.

2.1.2. Data Analysis

As discussed before in the previous chapters, the main purpose of this study is to gather and compile data on policy incentives and deterrents introduced by different countries to support the decarbonization of the trucking industry. Thus, the data is collected and compiled into different categories. While performing the study, the data study was conducted on a country basis. All the data regarding the policies and development in one country were looked at. This information is gathered, and the study progressed to the next country.

After collecting all the relevant information required for the analysis of TCO, the gathered country-wise data has been tabulated based on country, incentive and deterrent introduced, type of incentive and the drive for introducing the said policy. This table created an easy-to-understand reference and comparison on what path different countries are taking to achieve decarbonization. This process, if followed for other countries, could result in a very insightful database of policies in different countries, without having to research for each individual country. This also happens to be the major reason for creating this table.

As for the TCO analysis chapter, the information regarding the policies like taxes, subsidies, grants have already been collected and documented in previous chapters. The formula used has been introduced along with the source. However, there were some factors that are not constant and change on a daily basis. These include the prices of fuels and electricity. These values, although vary for each country, also vary every day. For the purpose of the analysis, the values taken were the most updated values on the day and the time of performing the analysis. These can easily be changed and modified to obtain relevant results at any time in the future. Collecting results by changing the variables forms a part of sensitivity analysis. During this study, a few scenarios have been assumed and a sensitivity analysis has been performed to see how TCO changes when the prices or incentives change.

2.2. Structure

A lot of care and analysis went into structuring this report. It is important to keep the report well-structured so that every section is linked and connected to the preceding and succeeding sections and forms a seamless flow of information.

To be able to do this, a few research questions were drafted to guide the research as it progresses. The answers to each of these questions provides the final answer needed to complete the research. They also provide a clear idea on the necessary research and analysis that needs to be done to arrive at the desired end state.

The report starts off with an introduction to the thesis topic to help establish some background for the reader. Then, the aim is described followed by the research questions and the limitations of the research. The method of collecting and analysing the data and performing the TCO calculations is mentioned in the Method section. This section also talks about how different scenarios can be modelled and how the TCO landscape can be mapped for future conditions by taking some close-to-real life scenarios.

The section on data collection provides clarity on how data is collected throughout this research and what kinds of data is taken into consideration. It further explains how the sources are handled and how this data is analysed. Furthermore, the sections on quality of research and ethical reflections provide insights into how this thesis put focus on creating a neutral and fact-based report along with what ethical implications this research work might have.

With that, the report goes to explain about the two different technologies that are researched during this study. Since the countries to look at were decided, the report looks at each country in a different section, dealing with the individual country's policies and frameworks. The report first looks at European countries, starting with Germany, followed by Sweden and France. Then, UK, followed by states in USA.

The different policies and initiatives in each of these regions are looked at for different types of sustainable fuels and powertrains like biofuels, battery electric and fuel cell electric powertrains. All the policies, incentives and deterrents pertaining to these technologies and countries mentioned are talked about in detail. Later, these incentives and deterrents are categorized into a table with multiple factors to define and differentiate the policies from one another. This tabulation makes it easy to access the data in less time.

The information gathered for the policies and countries is utilized in performing the TCO calculations. All the baseline assumptions made and formulae used are clearly mentioned and referenced well. After the results of TCO analysis, a sensitivity analysis is performed, where three real-world scenarios are created and the TCO are modelled for each of these scenarios. Since, there wasn't enough time and resources available to look further into overhead catenary trucks, a relevant study was found and the results of that study were considered and extrapolated for this research.

Finally, the report ends with a discussion about the results obtained and the different scenarios followed by a conclusion of what can be inferred from the study and possible trends for the future.

2.3. Quality of Research

It is important for every research to be valid and reliable in terms of the data collected and results obtained. When a similar study is conducted by following the same methods, similar results should be obtained (Gibbert et al., 2008). This proves that the quality of research conducted is up to the mark.

The author's understanding is that the said results would be obtained considering the data gathered and analysis performed. The reason for this is the presence of high level of consistency while gathering data needed for the research and also the consistency in performing real-to-life situational TCO analysis. The research was performed in a similar fashion for each country that was dealt with. All the technologies that were included in the research were studied for individual countries in an orderly fashion. This eliminated the case of ambiguity and confusion while collecting information from secondary sources.

When it comes to analysis of the collected data, it should be understood that there is scope for limitless scenarios that could be developed and analyzed. This means that the final result is bound to vary, and the inferences interpreted differently. But, since there is this intrinsic flexibility in performing the analysis, it is asserted that the level of replicability must be deemed based on the data gathered during this study and not on the development of future scenarios or newer data which was not available during the course of this study.

When it comes to validity of the research performed, it is only relevant to question the integrity of discussions and conclusions (Bryman & Bell, 2003). Thus, it infers that the findings of the study should provide relevance to the concepts being studied (Easterby-Smith et al., 2015). However, it is to be noted that the intention of performing the TCO and scenario analysis is not to provide accurate and exact predictions for the future, but rather to give a close-to-life situational understanding of the current scenario and trends. The future is uncertain and there are definitely multiple ways of interpreting the development based on different perspectives. Therefore, there is a chance to develop multiple scenarios, which could be argued as valid.

Easterby-Smith et al. (2015) suggests that researchers should make sure that a sufficient number of perspectives have been considered during the collection of data. The author seconds the opinion. During the course of this research, multiple perspectives have been considered wherever necessary, while gathering data. Collecting information on the policies introduced does not need any perspectives. But different views are indeed needed to understand how these policies are impacting the transition in the industry. These perspectives were mentioned, and their sources were cited, wherever relevant. Also, while performing TCO analysis, in order to understand how the future might look at, multiple scenarios were considered. Each scenario takes hold of different perspectives and combined; they all provide a good picture of what the future might hold for the industry.

2.4. Ethical Reflections

Wallen (1996) states that researchers need to take responsibility for their study and the results their studies yield. It is important to consider the ethical aspects since the science and research of modern age have the potential to impact many aspects of actors that are affected directly and indirectly by the study. There will also be a profound impact on the society, which is why ethical aspects and reflections have been part of every stage of this research study.

This study aims to provide a neutral and unbiased view of the data collected and analysis made. There may be ethical consequences of a study. To progress in an impartial and ethical fashion, asking the following questions made the approach and drive for this study clearer.

Are there any ethical problems with this study?
What are those and how can they be overcome?
If they cannot be overcome, is the project worth the consequences?

As an overarching question, we ask the following at multiple stages:

Why should we carry out this study/this stage of the study?
What value do we achieve?

Answering the above questions, this study looks not just at analysis reports and statistics, but also research papers, journals and online articles. Even if not in a great way, some of these papers or journals might have a minor level of bias towards a particular policy or incentive or technology. This could be because of the author's personal opinion on the findings, their intent to support a particular policy or technology or the results of their analysis. In order to avoid this bias to spread into this report, every reference handles in this study is treated with impartial eye and have only been referred to collect scientific findings and data but not the report's outlook or perspective on the data.

By doing so, the ethical aspect of having an unbiased and neutral study environment was achieved. The data collected was taken from sources without any inference to the source's support for a particular technology or policy. Once the data is collected and analysis is made, the inference made in this study are only based on the scientific evidence obtained from the analysis and not from any personal opinion or prejudice. In order to support the commitment to ethical neutrality and to better safeguard the secrecy of the company this thesis is associated with, all data collected, is from publicly available and open sources. This takes away the issue of having to safeguard the confidential data as there is nothing of that sort to deal with.

This thesis study is conducted to provide a better understanding on where different countries stand in their push to decarbonization and which technologies are amongst the most favoured in this transition. Based on the data collected and the analysis made, the thesis study provides a neutral and scientific analysis-based view of the current industry scenario. The future scenarios modelled as part of the study are taken close to real-world and in deeper sense, imaginary situations. Therefore, the should not be adjudged for their credibility but rather the focus should be on the fact-based findings these scenarios yield. If these scenarios might happen in the future or not, is a question unanswerable. The responsibility of taking inference from these scenarios to predict future situation should held by individuals making the inferences and predictions.

The sole aim of this thesis, once again, is to provide documented and evidence based analysis on the current trend of the industry and to make future research and analysis work easier by providing a base to work on. At no stage, is this thesis intended to affect any individual or organization in any manner. It is only meant to be a value addition to the research field by providing credible information and neutral and impartial analysis of data.

3. Alternative Technologies

The transport sector is usually and regularly pointed to as a major energy consumer, as it accounts for about 29% of final energy consumption and 25% of entire global GHG emissions. Emissions from transport have risen by 71% since 1990, and the trend is predicted to continue increasing in the coming years. At the same time, the Paris Agreement set the goal of remaining below a 2 °C rise in temperatures and many governments have set targets for each sector of their economies (*Key Aspects of the Paris Agreement | UNFCCC*, 2018).

Policy makers have always considered a variety of strategies to reduce and mitigate the emissions and conventional fuel usage from commercial transport sector, especially in Medium and Heavy-Duty trucks (Council et al., 2010). A key strategy for this was to improve the vehicle efficiency. However, the growing need for commercial transport and the plateauing of efficiency of conventional fuel drivetrains meant the need to look for sustainable alternatives. Although these alternative fuel trucks are currently limited in number (*California Air Resources Board*, 2015), some studies suggest that a large number of such trucks are necessary to mitigate the worse effects of climate change, reduce emissions and achieve decarbonization (Williams et al., 2014). Below, we discuss some of the crucial alternative fuel technologies that can usher the industry into the path of decarbonization.

3.1. Biofuels

The growing constraints over crude oil resources have greatly contributed to biofuels emerging as a reliable and renewable alternative for road transport fuels. Examples of biofuels include ethanol, biodiesel, biogas and they can emit less CO2 compared to conventional fossil fuels, depending on the feedstock and production process. Biodiesel has, in general, emissions that are 78% lower than conventional diesel (Tyson, 2005). This advantage of biofuels has been under research and newer versions have been hitting the market. We now have three generations of biofuels available and each has its own advantage and disadvantage in terms of availability, sustainability and emissions. Traditional biofuels that come from food sources are deemed to reduce greenhouse gas (GHG) emissions by 19-48% when compared to conventional fuels. Advanced biofuels, which are second and third generation biofuels, are made from non-food biomass, cellulosic fibres, algae, etc, and have the potential to reduce emissions by 100% (Muñoz et al., 2016).

Nevertheless, it is important to note that the first-gen biofuels, which come from food sources, have been deemed harmful for their impact on food crops and their prices, land usage changes and damage to the ecology. Owing to this reason, they have been denounced and some EU governments have redirected the public subsidies to advanced biofuels that are made from non-edible vegetable products and waste products. However, the large-scale adoption of advanced biofuels is not entirely certain both for long-term and for near future. In fact, trilateral negotiations between the EU Commission, the EU Parliament, and the EU energy ministers have revealed contradictory views about the future of advanced biofuels. In September 2013, the EU Parliament 2013 (*EUR-Lex - 52013AP0357 - EN - EUR-Lex*, 2013) called for a 6% limit on crop-based biofuels by 2020, rather than the 10% initial target in the 2009 Renewable Energy Directive (RED) European Parliament and Council, 2009 (*EUR-Lex - 32009L0028 - EN - EUR-Lex*, 2009). The Parliament also proposed a 2.5% binding incorporation target for advanced biofuels by 2020. However, in June 2014 (*Transport, Telecommunications and Energy Council*, 2014), the EU energy ministers came to a different agreement, proposing to increase the limit on first-generation biofuels to 7%, and to have no compulsory objective, defined for advanced biofuels.

More recently, in the fall of 2016, the EU Commission proposed a revision to the 2009 RED for establishing new goals for the 2021-2030 period for renewable energy, energy efficiency, and renewable transportation fuels. This set of proposals, known as the post 2020 EU Renewable Energy Directive (RED II), circumscribe two objectives. First, to promote advanced biofuels with a binding mandate, and second, to cap the share of first-generation biofuels with a 3.8% maximum incorporation rate in road transport. This new direction of the EU Commission could imply significant slowing of the biofuels industry in some member states since some proposed no binding mandate for advanced biofuels. In this context, Members of the European Parliament (MFPs) decided, in January 2018 to amend some of these proposals (*Texts Adopted - Promotion of the Use of Energy from Renewable Sources*, 2018). According to these proposals, the contribution of first-generation biofuels would remain at a 7% limit by 2030. However, for advanced biofuels, a 1.5% binding mandate has been fixed by 2021, increasing it to 10% in 2030. Note that with the 2009 RED, without a compulsory objective for advanced biofuels, member states only had to encourage the transition towards second-and third-generation biofuels, and to respect a minimal incorporation rate of 0.5% in road transport.

These lower ambitions are a result of the concerns of the EU biofuels industry and also a cause for concern about the long-term profitability. Nevertheless, the most recent negotiations seem to be sending a clear message to the biofuels industry about a growth only from sustainable advanced fuels, such as waste-based biofuels, not from food crops (Sarasa & Doumax, 2018). The major investments in this field would be towards manufacturing cleaner biofuels and towards R&D into their development.

3.2. Electrification

3.2.1. Battery Electric Trucks (BETs)

Electric trucks are fast becoming a potent alternative to diesel trucks. Their low costs of maintenance and zero local emissions pitch them as a superior alternative to conventional fossil fuel trucks. These trucks run on electric powered which comes from high-density batteries fitted to the truck. They have no tail-pipe emissions and can run silently.

According to Güldas (2019), the year 2018 was a major milestone for the trucking industry. It was in this year that the electrification of trucking industry took official introduction. Although electrification for commercial transport industry has gained a lot of traction since, the market hasn’t yet seen any disruption by long-range BETs. The technology and infrastructure are still being developed and are on track to enter full-fledged market release in the coming years. Companies like Volvo, Tesla, Scania, Mercedes, etc. have announced their foray into the BET segment. Some showcased their electric trucks which would go into production soon and some have even launched a few electric options in the market. With many countries setting up their emission targets and decarbonization goals, it has become essential for them to create policy incentives for this technology to see mass-market appeal and for the supporting infrastructure to be established.

Many states in USA have announced multiple incentives to attract more customers towards purchase and use of BETs. They have also set regulations on the sale of BETs and are trying to limit the sale of diesel-powered trucks to achieve their decarbonization goals. As for Europe, the policy in relevance to BETs is currently focused on optimizing the technology and developing the market. Future challenges and major investments for this technology would include testing and improving the reliability and durability of the batteries, reducing the weight and volume, improving battery densities and efficiency, cost reductions and improving the charging infrastructure (*Mobility and Transport*, European Comission, 2016).

These standards and regulations put pressure on established truck manufacturers to ramp-up the research for sustainable alternatives and offer sales for such vehicles. The current pace of development in the battery technology and the falling prices due to improved manufacturing processes mean a renewed hope that electric drivetrains could be a major part of the transition to sustainable and decarbonized road freight industry.

3.2.2. Overhead Catenary Trucks

BETs, although a superior option to diesel in terms of emissions, still have the downside of range and charging times. The cost and weight of the batteries required to support long-haul distances and a heavy-weight trailer is not a cheap and easy solution. This sweet spot is proving to be a hurdle for BETs to penetrate the long-haul trucking industry. This is where Overhead Catenary Trucks come into the picture. This technology is not any new groundbreaking idea, but rather an intelligent implementation of a tried-and-tested formula. The trucks will be fitted with pantographs that draw in power from overhead catenaries like electric locomotives. They also have a relatively smaller capacity battery that charges up using the electricity from overhead lines and can store it for usage on roadways without catenaries. It has been in trail runs in parts of Sweden and Germany and has the possibility to become a substantial and reliable part of long-distance freight haulage.

Reports like Mareev et al. (2018) have shown that under certain real-world conditions, the energy consumption by this kind of trucks is close to that of battery trucks and much less when compared to conventional diesel trucks. Projects like ENUBA 1 and 2 (Lehmann et al., 2016 and *EHighway – Solutions for Electrified Road Freight Transport*, 2017) were conducted to test the feasibility of this technology. These projects include the trail and testing of this technology on a designated stretch of highway in regions in Germany.

The infrastructure costs include the building of catenaries and substations either in the continuous configuration or sectional configuration, which is also the major investment during the scale-up of this technology. A continuous configuration entails building overhead catenaries throughout the length of the highway section, that was intended for use of this technology. A sectional configuration is when the catenaries are strategically placed along the highway, only broken down into smaller stretches. Since there is an overhead catenary powering the electric motors and charging the battery, there is no fear of running out of charge when driving on highways and the traction battery present can be of a lower capacity compared to conventional BETs. This reduces the cost of the battery to be put, which eventually reduces the cost of the truck. Furthermore, the battery can be replaced by a Fuel cell stack, thereby creating another hybrid alternative.

Although, it looks like a reliable solution, this technology has not garnered as much traction as conventional BETs, around the world. The reason, partly, could be the investment in building the catenaries over long-stretches of highways. It is easier to do that in denser regions like Europe but is not very practical in vast areas like USA.

3.2.3. Hydrogen Fuel Cells

Another potential sustainable alternative is using Hydrogen Fuel-Cell Electric Trucks. These trucks contain 1 or 2 hydrogen tanks. They also carry fuel cell stacks that create electricity by an electro-chemical process using the hydrogen stored in the tanks and the oxygen present in the air. The electricity generated by the fuel cells is used to power the trucks. The only emission that comes out during the running of these trucks is pure water. The reason for growing interest in this technology is the similarity in attributes to conventional trucks, like refuelling patterns and infrastructure (*How Does a Hydrogen Fuel Cell Electric Truck Work?*, Scania, 2021). However, the feasibility of using hydrogen fuel cells on various weight classes and platforms of trucks in a way that does not compromise the range nor performance is not entirely researched upon (Kast et al., 2018).

A few challenges to implement this technology include packaging and storing the hydrogen on-board, refueling infrastructure and its reliability, the range and performance proportions and electric motor to name a few. There is a definite possibility for hydrogen fuel cell technology to be implemented in medium and heavy-duty trucks to offer a zero-emission alternative to conventional fuel trucks. However, it is easier said than done.

Analyzing the market economics, costs for capital and business considerations are some of the important topics to be discussed for policy makers (Kast et al., 2018). Major investments for this field are in R&D to make this technology more efficient, refueling infrastructure and sustainable manufacturing of hydrogen.

4. Policies in Germany

Trucks and many other freight vehicles form the backbone of the export-driven economy in Germany. However, the increasing growth in volume of freight traffic has been the cause of increased pressure towards reaching emission reduction targets in the transport sector, which also lags behind in reaching its climate targets (*Road Freight Emissions in Germany*, CLEW, 2018). The heavy-duty truck industry needs a broader mix of transport and political solutions to make Germany's road freight sector more sustainable.

Over 95% of the country's CO2 emissions in transport sector come from road traffic. A third of this is from long and short-haul freight trucks (*Air and Climate Pollution from Freight Traffic*, 2021). These emissions even increased slightly during the past few years owing to reduced usage of biofuels and growing boom in the country's economy. Despite the introduction of a nationwide road toll for freight trucks in 2005, the traffic volume has grown so much as to outpace the economic growth since then.

Delgado et al. (2017) suggests that there many ways of bringing down carbon emissions in road freight transport like introduction of hybrid trolley trucks to exhaust pollutant limits to green freight programmes. It states that electrification of freight logistics could help cut emissions by a significant percentage and aid in reaching the 38% emission reduction targets (*Germany's Greenhouse Gas Emissions and Energy Transition Targets*, 2014) set for the country.

There are strategies and pilot projects aimed at promoting the switch to alternative fuels, redesigning the toll systems to benefit zero-emission and low-carbon trucks and increasing the diesel tax. None of these programs have reached mass usage yet and are currently under pilot and testing phases. The policies and deterrents are discussed in detail below.

4.1. Policy for Market Development and Maturity

The German government employs, what it calls, a 'Transformational Pathway'. This means that the pressures on industry should be low so that new innovations can be adopted and do not entirely replace existing options. What it means for the German automobile industry is that in a future system, the current German manufacturers and suppliers still exist without getting replaced. This is because the country is home to many manufacturers in the road freight industry. Thus, German policy makers are tasked to create only enough pressure to incentivize the German industry to transition towards sustainable mobility without causing any destabilization. There are significant investments into the technological competitiveness of its own automotive industry and the cost-efficient manufacturing of power train components. These measures imply a strategy that leaves enough time for the German vehicle manufacturers to adapt and start selling EVs in Germany as well as elsewhere.

The ministry has presented an 'Integrated Package' of measures, which consists of three elements namely vehicle funding, infrastructure deployment and lastly regulatory framework. In substance, this package depends hugely on the forecast availability and technological constraints of the various sustainable drivetrain technologies. This package is not treated as final but will be regularly updated on the basis of trends. Additionally, the Ministry also says that this package forms the basic framework for the future direction of Climate Policy in sustainable drivetrains in road haulage in Germany, over the period until 2030. Figure 1 below is the depiction of roadmap for drivetrain technologies in the future of mobility.

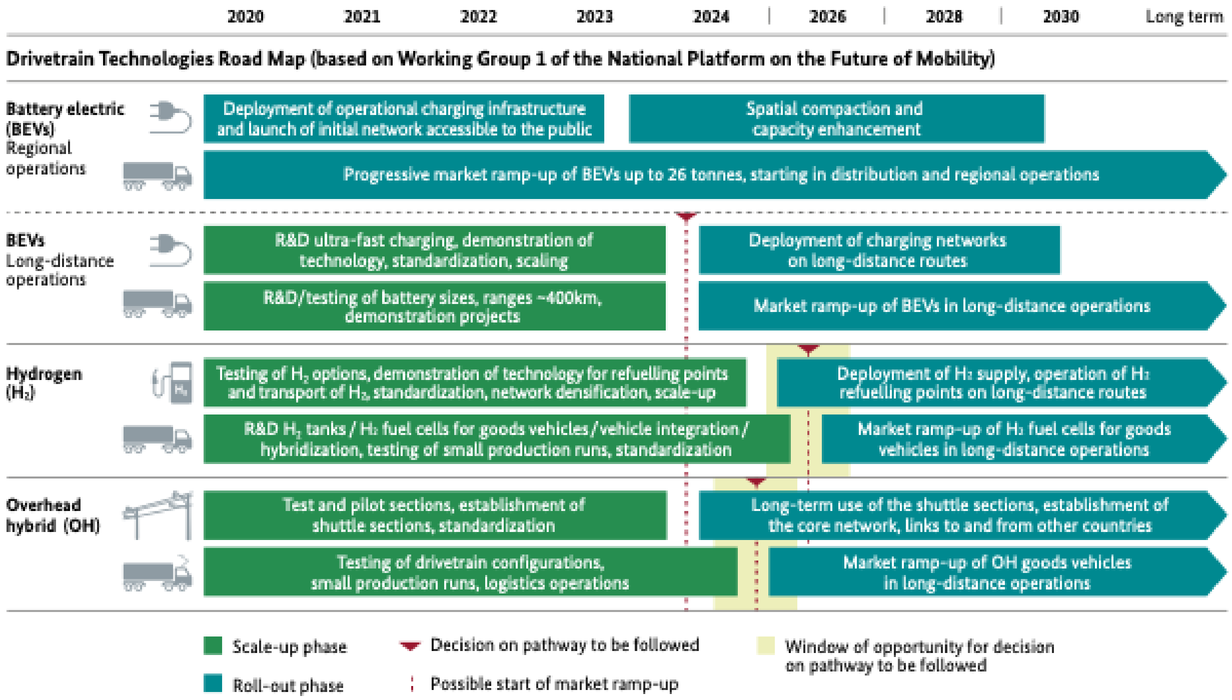

Figure 1: Roadmap of drivetrain technologies in Germany. Source: BMVI - An Overall Approach to Climate-Friendly Commercial Vehicles, 2020.

In figure 1, for long-haul, the BEV, H_2 fuel cells, over-head gantries with hybrid technology are in the scale-up phase until atleast 2024, only after which they will enter the roll-out phase. From this, it is clear that any means of sustainable powertrains for long-haul are currently not in roll-out phase. It is also important to observe that there is another factor of ‘decision on pathway to be followed’, only after which it enters the roll-out phase. This means that there will a mini-phase where the most viable alternative will be picked and followed, to enter the roll-out phase, after the scale-up phase.

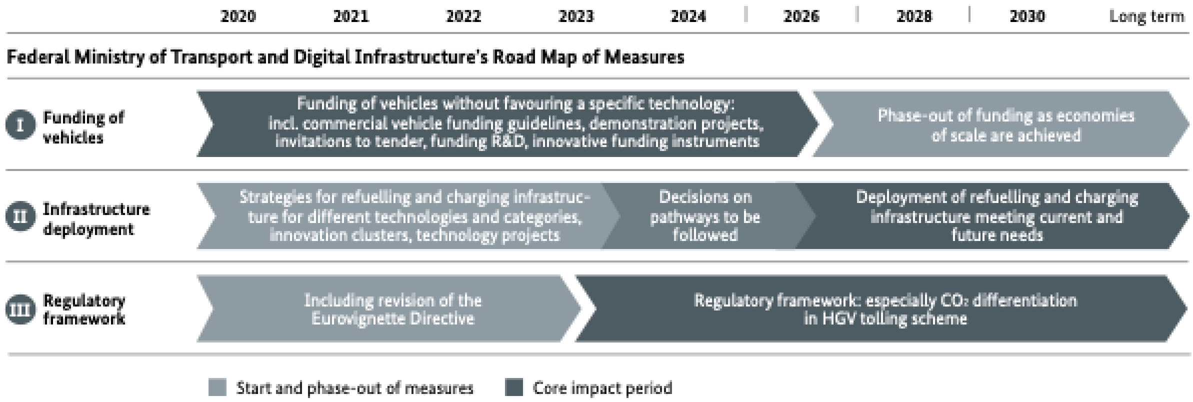

Figure 2: Road map of measures. Source: BMVI - An Overall Approach to Climate-Friendly Commercial Vehicles, 2020.

Figure 2 depicts the Transport Ministry's plan for funding, infrastructure deployment and regulatory framework for these technologies to be brought to everyday use.

As observed in figure 2, the funding for all technologies and R&D goes on until 2026, after which they will slowly be phased out. This is not entirely rigid and can be updated based on the technological and resource constraints. The Ministry has stated that by the summer of 2021, it will identify various use cases for heavy road transport and evaluate the data collected on the road tolls for the said purpose.

4.2. Policy Framework Development

In addition to the funding and infrastructure deployment, there will also be an appropriate and robust regulatory framework for use in the case of alternative fuel commercial vehicles. This framework will, on an initial stage, address the high-costs and the pressure created by cost competitiveness in the road haulage sector. This framework is supposed to not favor any specific type of technology. It will be developed largely based on the inputs and lessons from the scale-up stages. The regulatory core will be 'Differentiation of Heavy Goods Vehicles (HGVs) tolls by CO_2 emissions' emitted from these goods vehicles. This means that, for the first time, there will be a new mark-up fee levied on the toll, which depends on CO2 emissions. Parallelly, commercial vehicles that emit no CO2 and those that only emit minimal CO2 by running on sustainable biofuels are supposed to be granted a 75% reduction of infrastructure charge like road tolls and parking charges, compared to those with highest level of emissions. This also applies to hybrid vehicles. Not favoring a specific technology gives equal chance for every alternative technology to develop and possibly have mass-market appeal. Regarding road tolls, the goal is to introduce the CO2 differentiated tolls, starting 2023. These tolls will bring in more specific regulations based on different classes of emissions, sizes and the type of fuel used. More information on this newer system is yet to be released by the government.

The running costs of alternative drivetrain options are strongly influenced by energy prices. Taxes and charges also impact the prices of electricity-based fuels. The government is looking to examine and modify the governance tools to facilitate the market ramp-up of climate-friendly commercial vehicles. It also includes the National Hydrogen Strategy for the production of sustainable and green hydrogen. The government is also looking to develop incentives specific to utilizing electricity as a transport fuel.

4.3. Incentives for Vehicular Purchase

The German government in 2003 agreed on compensation arrangements of a total of € 600 million per year (Vierth et al., 2017) of which about € 100 million amounts to assistance programs for creation of incentives to purchase cleaner trucks. Part of these incentives were the subsidies given for the purchase of cleaner Euro 5 and Euro 6 trucks depending on the size of the fleet, capacity of the truck and emission class. However, at the moment, there are no subsidies available as Euro 6 became compulsory and Euro 7 is planned for 2025.

However, there have been some newer incentives being granted by the government for purchase of sustainable alternatives (*New Support Programme for More Energy Efficiency and CO2 Savings in Road Freight Transport*, BAG, 2018). According to the German Federal Ministry of Transport and Digital Infrastructure (*An Overall Approach to Climate-Friendly Commercial Vehicles*, BMVI, 2020), there will be a significant market ramp-up of commercial vehicles with sustainable alternative drivetrains without favouring any specific technology. The second part of the previous sentence is the important one to discuss. The Federal government is taking steps to make sure not one technology is favoured and is attempting to make all the alternatives economically competitive. Funding Guidelines for Energy-Efficient/Low-Carbon Heavy-Duty vehicles have been around since 2018. These have been aiding in the purchase of commercial vehicles with capacity higher than 7.5 tonnes that are subject to road tolls and those that are powered by CNG, LNG, Hydrogen fuel cells and battery run/hybrid vehicles. This funding for sustainable alternative drivetrain commercial vehicles is going to be significantly expanded, according to the report by the Ministry. Funding specifically for the purchase of commercial vehicles with sustainable alternative drivetrains has been set to € 1.16 billion for the period of 2021 to 2023. This funding is supposed to include the refuelling and charging infrastructure in the future, as funding and timeframe expands and when the technology reaches roll-out phase.

According to this funding program, fleet owners and individual owners can be granted a maximum funding of 40% of the additional investment costs required when compared to a conventional truck. This amount may not exceed € 12,000 for biofuels and € 40,000 for electric drivetrains.

4.4. Incentives for Research and Development

The Transport Ministry also in its report, has clearly stated that the funding for research and development projects will continue to be possible within the scope of existing programs like National Hydrogen and Fuel Cell Technology Innovation Program, Electric Mobility Funding Guidelines. However, how much of funding could be granted, or a detailed plan for the same is not discussed. One important concept that is currently being tested is Germany’s e-highway. This is financed by the country’s 2020 Climate Action Program. Under this test, trucks use a catenary system to charge their batteries and also propel the drivetrain as they drive along on a 5km stretch of highway. This pilot project is run by Siemens and Volkswagen Group Innovation with academic support by several universities and encompasses trucks in real-life use at selected haulage companies.

4.5. Deterrents Introduced

Back in 1994, Germany, Denmark and the Benelux entered into a cooperation called the Eurovignette, which introduced the time-based Eurovignette. The Eurovignette is a directive that sets the rules for charges on infrastructure for heavy-duty trucks (Dir. 1993/89/EWG). It initially charged trucks over 12 tonnes, which later got extended to trucks over 3.5 tonnes in 2006. Under the new changes to Eurovignette, the time-based tolls will be changed to distance-based tolls. Which means the vehicle will be charged for the number of kilometers it travelled rather than how long it stayed on the roadway network (*Europe Changes the Eurovignette, Extending It to All Kinds of Vehicles* - Bilogistik, 2018). However, keeping aside the history and current trends, Germany left this co-operation in 2003.

This was to introduce its own distance-based tolls for trucks over 12 tonnes, applicable on the German motorways and other major public roads. Due to technical issues, the implementation of this toll was delayed from end of 2003 to the beginning of January 2005. This caused heavy losses in revenue, almost equivalent to toll revenues in 2006. In the year 2012, the German toll road network comprised of about 13,039 km, which roughly translates to 5.6% of the entire road network in the country. In June 2015, an additional 1,100km was added to this. A differentiating factor for Germany's toll system was it also depended on the number of axles and Euro class. The level of toll has been increased several times since 2005. But, since 2015, the tolls have decreased. This is because the federal transport infrastructure report calculated that toll costs are exceeding the infrastructure costs (*Alfen et al. 2014.)* These tolls and the conditions can be seen in figure 3 below. All the toll rates depicted are calculated in Euro cents/km.

1		2	3		4
Emission class	*Proportion of toll rate * for external costs* Air pollution	*Proportion of toll rate * for external costs* Noise pollution	Axle and weight class	*Proportion of toll rate * for infrastructure*	Toll rate *
Euro 6	1,1	0,2	7,5–11,99 t	8,0	9,3
			12–18 t	11,5	12,8
			>18t to 3 axles	16,0	17,3
			>18t from 4 axles	17,4	18,7
Euro 5, EEV 1	2,2	0,2	7,5–11,99 t	8,0	10,4
			12–18 t	11,5	13,9
			>18t to 3 axles	16,0	18,4
			>18t from 4 axles	17,4	19,8
Euro 4, Euro 3 + PRC 2**	3,2	0,2	7,5–11,99 t	8,0	11,4
			12–18 t	11,5	14,9
			>18t to 3 axles	16,0	19,4
			>18t from 4 axles	17,4	20,8
Euro 3, Euro 2 + PRC 1**	6,4	0,2	7,5–11,99 t	8,0	14,6
			12–18 t	11,5	18,1
			>18t to 3 axles	16,0	22,6
			>18t from 4 axles	17,4	24.0
Euro 2	7,4	0,2	7,5–11,99 t	8,0	15,6
			12–18 t	11,5	19,1
			>18t to 3 axles	16,0	23,6
			>18t from 4 axles	17,4	25,0
Euro 1, Euro 0	8,5	0,2	7,5–11,99 t	8,0	16,7
			12–18 t	11,5	20,2
			>18t to 3 axles	16,0	24,7
			>18t from 4 axles	17,4	26,1

** All information on toll rate and toll rate proportions are in cents per km.*

*** PRC – Particulate reduction classes are retrofitting standards to reduce particulate emissions. For category D, PRC 1 or higher is required; for category C, PRC 2 or higher is required.*

Figure 3: Toll rates based on Euro standards. Source: (Toll Collect | Toll Rates, 2021)

The toll costs from this table are used in the calculations for TCO in this study. For most part, the Euro 6 costs are considered, and since this study focuses on heavy-duty trucks with capacity higher than 18 ton, the costs for that particular weight class are considered.

5. Policies in Sweden

Sweden's transport sector is one of the highest emitters of greenhouse gases in the country, along with manufacturing and households. The country has an ambitious long-term target of achieving net zero GHG emissions by 2045 at the latest. The country also has interim emission targets of lowering its emissions by 40%, 63% and 75% of 1990 level by 2020, 2030 and 2040 respectively.

Notable goal amongst others, is to reduce the emissions from domestic transports by atleast 70% by 2030, compared to 2010 emission levels (*The Swedish Climate Policy Council*, 2020). Domestic transport in the country accounts for a third of the entire GHG emissions. Majority of this is owed to heavy-good vehicles and cars. Sustainable renewable fuels, infrastructure for alternative fuels including electrification form a predominant part of significantly reducing GHG emissions, for Sweden to reach its climate targets (Persson, 2020).

There will be a need to extensively electrify a majority of the transportation sector, especially road transport system and a switch to the use of sustainable alternatives to conventional fossil fuels. In a longer perspective according to Persson (2020), road transport should mainly be electrified. This makes way for renewable fuels available for other transport sectors like aviation and shipping.

In the transport sector, Sweden implements multiple instruments at both EU level and national level. There are pricing instruments and subsidies along with regulations to promote the use of sustainable alternative fuels and also to improve and expand the refuelling and charging infrastructure for these sustainable alternatives. More details on these policies, regulations and incentives are discussed below.

5.1. Policy on biofuels

According to the Pump act (Riksdagsförvaltningen, 2005), all gasoline and diesel points of sale are mandated to provide atleast one additional type of renewable fuel. This act led to an increase in the fuel stations for E85 variety of Ethanol (Riksdagsförvaltningen, 2006.). Although being technology-neutral, this act became a driver for a specific technology, in this case the cheaper option of Ethanol. Figure 4 below (Fagerström & Anderson, 2019.) shows how the CO2 tax exemption and Energy tax reduction for high-blend biofuels and biogas has helped in strong scaling up of HVO and biogas-based vehicles (*Ett nationellt centrum för samverkan*, F3 centre, 2021).

Policy instrument	Research and Development	Demonstration and Pilot plants	Scale-up	Dissemination
Reduction obligation. Indicative reduction of 40% to 2030	None	None	Strong	Strong, Mature technologies with high GHG-performance
CO_2 tax exemption and energy tax reduction for high-blend biofuels and biogas	None	None	Strong, Have resulted in up-scaling of HVO and biogas	Strong
National vision and target	Weak	Weak	Weak	Weak
Sustainability requirements	None	None	Weak , Development is focused to waste and residual from forest	Strong , Technologies that can be double-counted.
Public procurement of transport	Weak, some effects on buss development.	Weak / none	Weak	Weak, Towards mature technologies
Other R&D: The Ethanol programme, Demonstration support, etc.	Strong	Strong	None	None
Other policies for fuels: The Pump-act, Klimp, Klimatklivet, Urban environmental agreements.	None	None	Weak, Mostly related to biogas.	Strong , Towards mature technologies
Other policies for vehicles: Bonus-malus, super-environmental cars, etc.	None	None	None	Strong , Towards mature technologies and electricity

Figure 4: Policy instruments and analysis. Source: Fagerström & Anderson, 2019

The country also has regulations regarding fuel quality for blends in gasoline and diesel to be used in Internal Combustion Engines (ICE). Sweden also has great access to biomass, which is advantageous for biofuel production from domestic raw materials. This can also lead to added value in the form of fuel security for the future and exports & imports (Persson, 2020).

5.1.1. Tax exemption for biofuels

According to Article 8.4 in the Directive 92/81/EEG, tax exemption is allowed for carbon dioxide neutral fuels. So far this tax exemption has been necessary in order to increase the share of biofuels in the market, however the cost has been very high for the emission reduction accomplished, nor has the contribution of technical development been sufficient to lower the costs. (Riksrevisionen, 2011).

The Swedish government also introduced 'Reduktionsplikt' (Regeringskansliet, 2020) which mandates fuel suppliers to reduce GHG emissions from fossil fuels by the involvement of biofuels. The Swedish government is also planning on increasing the regulation levels under Reduktionsplikt. The level of reductions that are being planned are a level of 28% for gasoline and 66% for diesel by 2030 (Skogsindustrierna, 2021). This could benefit trucking industry as the majority of fossil fuel used is diesel, and a reduction of 66% is a substantial amount.

Pure biofuels and higher blends have been exempted from both Energy tax and CO2 tax since 2002 until the end of 2020. However, it was decided to prolong the tax exemption for another year, i.e., from 01 January 2021 to 31 December 2021 owing to EU rules (*State Aid*, European Commission, 2020). This is expanded on a yearly basis and a lot of discussion goes on, to determine how this affects long-term planning.

5.2. Other Instruments

5.2.1. Transport subsidy

Transport subsidy can be granted to transports of a distance at minimum of 401 km for freight transport on rail, road or sea within certain industries for the four northernmost counties in Sweden. However, this instrument today is not assorted to environmental policy, but with small changes, it could be. Rather the aim is to promote regional development within northern Sweden (Tillväxtverket, 2011).

Apart from this, there are obligation schemes, environmental restriction zones, delivery windows, performance-based standards and other knowledge-based instruments which are treated as 'soft instruments', since they are unconditional. These may or may not impact the TCO directly, but it is extremely hard to model the impact.

5.3. Deterrents Introduced

5.3.1. Carbon tax on fuels

Carbon taxes on fuels are common in many countries. It is an effective instrument for generating incomes to the state at a low cost. In Sweden, a tax on energy, carbon and sulphur is charged on fuels and electric power, with the only exception of fuel for air travel. The tax is levied per kg of CO2 emitted and is calculated based on the amount of fossil carbon and sulphur present in the fuel. The effectiveness of the fuel taxes is dependent on price and driving distance elasticities. However, a modest increase in fuel tax isn't a good instrument because the increase must be drastic in order to have an apparent effect. Additionally, freight transports are less sensitive for price increases (SIKA, 2004). This means that freight transport will effectively continue even when the price of diesel increases by a small factor. The potential for future carbon reductions from freight transports due to carbon taxes are not easily to forecast, therefore no estimates for the freight transport sector has been found. It is likely that price increases to a large extent (or in their entirety) can be passed on to transport buyers.

5.3.2. Congestion taxes/charges

Congestion taxes or charges are used to reduce traffic in areas with high density, in order to improve accessibility and reduce carbon emissions Under 2006 the "Stockholm trial" was launched as a test. In 2007 the charge was made permanent and was also introduced in Goteborg in 2013. Charged are Swedish vehicles on weekdays between 6:00 and 18:30. The charges are differentiated according to rush hours. For freight transports this resulted in a decrease in vehicle mileage. For the heavy lorries there was a decrease with 7.8% within the charge zone and a decrease of 1.58% within the county (Miljöavgiftskansliet, 2006). The environmental effects showed a decrease in CO2-emissions from inner city traffic by 14% (Eliasson et al., 2009). In a 5-year assessment study it was shown that traffic volumes over cordon 2011 were reduced by 20% compared to reference 2005 (Börjesson et al., 2012).

5.3.3. Vehicle tax and Road fee/infrastructure fee/HDV fee

Vehicle tax and road fee are instruments that influence the choice of vehicle and have long term impact due to the life span of the vehicles. The vehicle tax is differentiated according to environmental and safety standard.

Sweden joined the Eurovignette in 1998. According to Skatteverket, (2010), the trucks registered in Sweden are charged on an annual basis, while the trucks from outside the country have a choice to pay on a variable basis like daily, weekly, bi-annually etc. The foreign trucks pay the charge when they utilize the road and infrastructure pertaining to Eurovignette and other motorways in Sweden. The tariffs for different trucks depend on the number of axles and emission classes. The figure 5 below shows the annual tariffs in 2021 (skatteverket.se, 2021).

Toll table for 1 January to 31 December 2021

EURO class	No more than three axes Annual fee	At least four axes Annual fee
0	SEK 14,534	SEK 24,368
I	SEK 12,633	SEK 21,093
II	SEK 11,001	SEK 18,346
Iii	SEK 9,565	SEK 15,939
Iv	SEK 8,697	SEK 14,503
V and EEV	SEK 8,222	SEK 13,707
VI or cleaner	SEK 7,747	SEK 12,912

Figure 5: Annual Tariffs for trucks. Source: skatteverket.se, 2021

A notable aspect regarding infrastructure fee from Trafikverket (2012) indicates that a 50% increase in driving cost will lead to the required reduction in CO2 emissions for both cars and freight transport. It also suggests that this increase in driving costs can be imposed as Carbon tax or Infrastructure fees.

5.4. Incentives for Research and Development

The Swedish government also provides funding for research in greener mobility under the FFI initiative (*About FFI | Vinnova*, 2016). Also called as Strategic vehicle research and innovation program, it provides around SEK 1 billion per year in funding for research and development activities.

6. Policies in France

The transport sector in France accounts for 27% of the entire GHG emissions. The French transport sector is to reduce its carbon footprint by more than 6% in total, between 2019 and 2023 (SNBC, 2018) while compensating for its insufficient efforts over 2015-2018 period (Le Quéré, 2019). Heavy-duty vehicles (HDVs) are a strategic focal point for reducing net transport-sector emissions. In France, the HDV fleet is a big carbon emitter, and so the focus is on freight-carriers to intensify their efforts in reducing these emissions. HDVs emit as much as half of the private vehicles fleet with 60-times-fewer vehicles (CGDD, 2019). Speaking numerically, HDVs account for 6.3% of the national carbon footprint whereas private cars account for 15.7%.

France's new Mobility Law (Loi Mobilites) requires the full decarbonization of the entire road-freight industry by 2050. Upto 30% of new trucks in France will need to be zero-emission by 2030 to fully decarbonize the road freight industry in the next 30 years (*Electric Trucks Could Be Cheaper than Fossil Ones by 2024 in France,* Transport & Environment, 2020). In order to support this transition, the government of France has introduced several policies and incentives. These incentives are said to promote the adoption and usage of sustainable alternative trucks. They are discussed in detail below.

6.1. Policy on Biofuels and Natural Gas

France seems to favor natural gas, although not being a biofuel. The 2017 French Mobility conference set the objective of 30% of the national truck, bus and coach fleet to run on natural gas by 2030. Policies praise natural gas owing to its high energy-to-carbon ratio, which offers great potential to reduce GHG emissions, even while keeping usage statistics same (Khan et al., 2015; Rose et al., 2013). It is worth noting that no scientific consensus on the net environmental benefits of natural gas as a transportation fuel has been reached yet. Its profitability in comparison to diesel is still being discussed (Hao et al., 2016; Krupnick, 2010). And even if the environmental goal could be achieved, the decisive factor remains economic (Sharma and Strezov, 2017).

For a limited time, the country granted partial exemption from excise tax for the first-generation biofuels but later removed it. Also, it debated the application of reduced excise tax rate to second-generation biofuels in a similar way as for diesel, in order to reduce the competitiveness.

6.2.Incentive for Vehicular Purchase

The French government, starting 2021, will grant hauliers a direct incentive/rebate of € 50,000 for the purchase or lease of sustainable alternative trucks (*France to Grant €50,000 for the Purchase of Electric and Hydrogen Trucks*, Trans.info, 2020). This can also be combined with another package supported by the state, where, if the vehicle falls under certain categories, a substantial deduction in the taxable income of the company is possible. These vehicles must utilize energy from natural gas and biomethane fuel, ED95 fuel with minimum 90% ethyl alcohol of agricultural origin, hydrogen, electrical energy, a combination of natural gas and diesel (since Jan 1, 2020) and B100 fuel (since Jan 1, 2020). It is also mandated that these vehicles must be assigned to company's business (*Déduction Exceptionnelle*, 2021). The amount of aid is 40% (maximum of € 50,000) for those that have authorized weight of over 3.5 tonnes. These incentives combined can amount to about € 100,000.

Cansino et al., 2018 shows that France has implemented multiple incentives to promote the use of sustainable alternatives to conventional fuel vehicles which include commercial as well as personal transportation vehicles. Among these incentives is the freedom for individual regions to enable a 50% exemption of the one-time registration fee for the purchase of new vehicle with sustainable alternative propulsion system. As for incentives and deterrents for commercial transport vehicles alone, battery electric vehicles are exempt from ownership tax.

6.3. Incentives for Infrastructure Development

The bottlenecks to development of sustainable alternatives-powered vehicles include lack of sufficient infrastructure like the small network of gas stations, charging infrastructure, support and service system.

As part of decarbonizing initiatives, France also installed 1250 charging points for cars in 20 cities by the year 2012. By 2015, this number has increased to around 10,000. This number is reaching 40,000 by 2021 (*France*, 2020). In France, the government and state-owned companies play an active role in construction of EV charging stations, most of which are eligible for a 30% subsidy (Hall & Lutsey, 2017). Following up on this, the government also plans to install charging stations for higher-capacity charging, to be used for MDVs and HDVs.

6.4. Incentives for Research

As for financing research in the field, the programs for research, experimentation, and innovation in land transportation (PREDIT) financed EV research projects for a net worth of € 107 million (2009-2010). The state-controlled Fonds Stratégique d'Investissement (FSI) provides loans for innovative R&D projects (Cansino et al., 2018).

6.5. Deterrents for conventional fuels

With the aim of reaching the EU target of having biofuel penetration target of 10% in the energy supply mix for road transportation by 2020, France has debated and implemented deterrents and policies to make it a possibility. This was also supplemented by the gradual increase in prices for conventional fossil fuels over the years, now resulting in the price of biofuels to be similar or in some cases less than that of conventional fossil fuels (Doumax et al., 2014).

In the year 2015, France has also set the ambitious target of increasing the share of renewable energy in the transport sector to a level of 15% by 2030, in which conventional biofuels are believed to contribute to a large extent (Baudry et al., 2018). To achieve the switch to sustainable alternatives, France has to phase out the diesel fuel rebate and utilize an allocated share of the generated revenue to lower the taxes on labor and set up an investment fund for purchase incentives of sustainable alternatives (*Electric Trucks Could Be Cheaper than Fossil Ones by 2024 in France*, Transport & Environment, 2020).

Another policy that is under discussion is the Carbon Tax. It is debated that carbon tax also increases the profitability of refueling stations that are used to make a larger number of NGV segments competitive comparatively to conventional fuels (Morrison et al., 2018).

France currently also has a tolling system for majority of its national highways. This tolling system is one of the most complex. It varies not just by size, class and weight of the truck but also on the route the truck is on. Different highway routes have different toll rates which make it almost impossible for us to estimate even the average toll value. The country has multiple toll collecting companies that do the calculations for trucks by scanning their barcodes and levying the toll charges. Although this system is bringing in good revenues of more than € 10 billion (*Statistics - Asecap Corporate*, 2020), it is extremely hard to model in the TCO analysis. Also, since majority of freight haulers pay their tolls as part of their entire fleet maintenance, we also consider this toll costs to be part of maintenance costs, for our modelling scenarios.

7. Policies in United Kingdom

The UK haulage industry is adding a gross value of € 144.31 billion to the entire UK economy. 89% of all goods transported in Great Britain are moved by road. There are more than 34,000 road haulage companies trading in the UK. These are just some facts to show the importance of road haulage industry in UK.

In the UK, the government has aggressive emission targets by 2030 and having net zero emissions by 2050. It is convinced that the majority of greenhouse gas emission is contributed by transport (*Provisional UK Greenhouse Gas Emissions National Statistics 2017*, 2017). Trucks in the UK emit about 25% of entire CO2 emissions in the transport sector. GHG emissions from road transport make up around a fifth of UK GHG emissions (*Road Transport and Air Emissions,* Office for National Statistics, 2019). It is therefore only fitting to invest in decarbonizing this industry to achieve a significant reduction in emissions for the country.

7.1. Policy on Biofuels

During 2007-09 biofuels became a contentious sector for several reasons. The 2003 EC Biofuel Directive had set an ambitious indicative target for 5.75% of transport fuel to come from biofuels by 2010 (EC, 2003). In 2008 the European Commission proposed a similar mandatory target for transport fuel to come from renewable energy (including biofuels), plus a 10% target by 2020. This proposal raised the stakes for claims about environmental benefits, especially in debates leading to the Renewable Energy Directive (RED) (EC, 2009). During the time this bill was introduced, UK was part of the EU and it looked to follow the regulations. However, it is known that UK is not a part of EU anymore, but no changes to policies on biofuels have been announced, nor new policies discussed.

7.2. Policy for Electrification

The UK government has established an ambitious roadmap to be world leader in EV design, development and manufacture, and to be one of the most attractive locations for EV-related inward investment in the world (*Ultra-low carbon vehicles in the UK GM*, HM Government, 2009, *Driving the future today strategy for ultra-low emission vehicles in the UK*, OLEV, 2013).

The UK government initially published an ultra-low emission vehicle (ULEV) strategy for personal vehicles to encourage the growth in the ULEV market in 2009. The ULEVs are the vehicles that emit less than 75 g of CO, per kilometer travelled, the vast majority of which are hybrid electric or pure electric. A strategy called "Driving the Future Today" was published in September 2013 and committed to cutting carbon emissions from transport, aiming at zero emission for nearly all cars and vans by 2050. The key elements of the proposed package for supporting ULEVs during 2015-2020 were set out in the following year (*Investing in ultra-low emission vehicles in the UK, 2015 to 2020*, OLEV, 2014). The Automated and Electric Vehicles Bill 2017-2019 was introduced in the House of Commons in October 2017, which also intended to help deliver the zero-emission aim of 2050 (*Automated and electric vehicles bill 201719*, Department of Transport, 2017).

The government has continuously published some grant schemes to incentivize the development of EVs as well. The grant for plug-in cars and vans was launched in 2011 and the grant structure has reformed since March 2016 (Office for Low Emission Vehicles, 2015; Office for Low Emission Vehicles, 2016.). The price will get reduced by grants when buyers pay for EVs approved by the government. EVs are categorized into several groups and the allocated grant relies on the category of EV and the government is in discussion to include Light-Duty and Heavy-Duty trucks in the future (*Low-Emission Vehicles Eligible for a Plug-in Grant*, 2021). In October 2016, the government committed an additional £4 million to the plug-in van grant scheme, extending the eligibility to larger electric trucks.

7.3. Government Strategy for EV Infrastructure

The development of EV infrastructure has been encouraged since 2009 (*Ultra-low carbon vehicles in the UK GM*, HM Government, 2009; Transport for London, 2015; *Carbon Plan*, HM Government, 2011). In 2014, the Alternative Fuel Infrastructure Directive was agreed by the European Union (EU), and the UK is legally bound to implement the requirements although having voted to leave the EU in June 2016 (*Consultation on proposed transposition of alternative fuels infrastructure directive government response*, Department of Transport, 2017). Besides, the Bill in October 2017 allowed the government to regulate, if necessary, to improve the consumer experience of EV charging infrastructure, to ensure the provision at key strategic locations and to require that charging points have "smart" capability (*Automated and electric vehicles bill 201719*, Department of Transport, 2017). According to the government response on the proposed "Directive" in September 2017, the government will publish National Policy Framework (NPF) to present information on the current quantity, spread and reach of alternative fuels infrastructure across the UK (e.g., EV charging points) and outline the future development of the infrastructure.

The UK Department for Business, Energy and industrial Strategy has announced a government-led fund of £ 54 million, for electric trucks and hydrogen-powered buses. Three projects in England, Wales and Northern Ireland are to receive the funding with the long-term goal of removing 45 million tons of carbon emissions. The bulk of this funding, about £ 31.9 million, has been assigned to develop electric propulsion systems, specifically for heavy goods vehicles, in Cwmbran, Wales (*UK Government Co-Funds Electric Truck, Hydrogen Bus Projects*, S&P Global Platts, 2021).

A series of grant schemes have continuously sprung up since 2010. The government set up the plugged-in places (PIPs) scheme in 2010 to match funding for local business and public sector consortia to build their own electric charging points for electric cars (*Lessons learnt from the plugged-in places projects*, OLEV, 2013). The scheme ceased the operation in 2013 and its successors are separate installation grants for public sector bodies and local authorities focusing on the workplaces and on-street residential charging points, respectively. Specifically, these grant schemes refer to the guidance for consumers or applicants, installers and manufactures. Minimum technical specification for manufacturers of charging point units is particularly pointed out. Authorized installers, approved charge-point models and eligible vehicles are also listed in the schemes.

Furthermore, the government has pledged £80 million to improve the charging infrastructure for EV owners and £30 million to study, design and develop revolutionary vehicle to grid (V2G) technologies (OLEV, 2016).

UKEMS, short for the 'UK Electric Motorway System' will facilitate and build the required infrastructural support for the road network across the UK. It includes infrastructure for overhead catenary system as well as charging infrastructure for Heavy Duty Vehicles (HDVs) as well as other smaller electric vehicles. The desired outcomes are believed to be achieved through a four-phase program which starts with an £80 million pilot project. Further, it leverages the lessons learnt in Italy, Sweden and Germany to delve into the issues of policy, taxation and implementation in the UK.

The proposed pilot project of laying a 40km lane in South Yorkshire must be completed by 2025 in order to ensure that the main 3-phase rollout of the infrastructure begins. Each construction phase in the aforementioned infrastructure rollout will require 2 to 3 years of time for planning, design, procurement and so on. Shown in figure 6, is an example rollout phase along with its estimated costs. Notably, the aggregate cost incurred by the final network is projected to be about £19.3 billion and covers more than 65% of the total HGV-kms in the United Kingdom (UK).

By employing battery electric power to travel to and to from the network and for urban operations, the carbon intensity of the electric grid reduces and thus, a very high level of decarbonization of the road freight sector would be achieved (The Centre for Sustainable Road Freight, 2020).

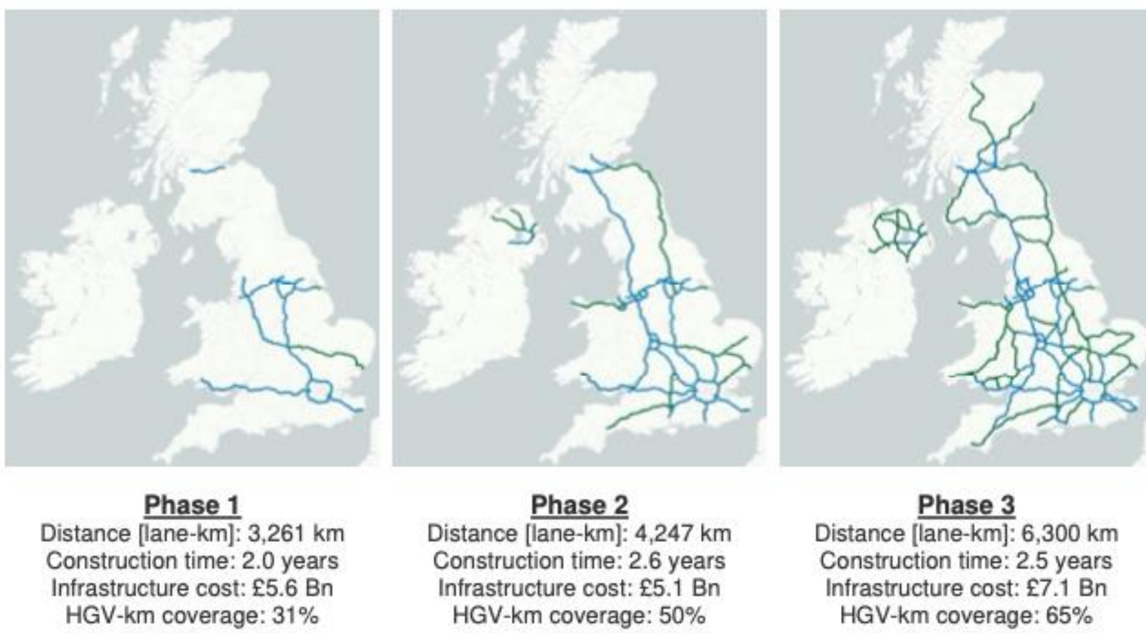

Figure 6: Rollout phases with estimated costs for UKEMS Project. Source: The Centre for Sustainable Road Freight, 2020

8. USA

Many states in USA have implemented their own version of decarbonization goals and policies. However, owing to time constraints, this study looked into 4 states where major changes have been proposed to decarbonize the transport sector. Policies supporting the decarbonizing of long-haul, heavy-duty commercial transport, can be especially noted from these policies implemented in these four states. The states being discussed are California, Massachusetts, New York and Pennsylvania.

8.1. Policies in California

On June 25th, 2020, the California Air Resource Board (CARB) voted on its proposed Advanced Clean Trucks rule. This rule mandates that around 60% of all the new medium and heavy-duty trucks that would be sold in the state must be completely emission free or Zero Emission Vehicles (ZEVs) by the year 2035. This rule is believed to set the first electric vehicle standard for trucks in the country and would create a market for about 500,000 new electric trucks by the year 2040.

This Advanced Clean Trucks rule has been evaluated by Energy Innovation and the Environmental Defense Fund, using the California Energy Policy Simulator (EPS). It was found that this policy could create $ 7 - $ 12 billion in savings for fleet operations and atleast $ 9 billion in public health benefits across the state by the year 2040 (*California Accelerates Clean Transportation Policy, Targeting 500,000 Electric Trucks By 2040*. Forbes, 2020).

Electric trucks have been in use through the 2010s and have been focused on intracity uses, such as delivery vehicles that make many stops, as well as trucks used for port and airport operations. The driving cycles of these trucks share many of the characteristics of the driving cycles of intracity buses, making them good fits for electrification.

8.1.1. Incentives for Hydrogen Fuel Cell Trucks

Fuel cell drainage trucks, handling equipment from members of the FCHEA like Toyota, Nuvera and Cummins subsidiary Hydrogenics have been deployed quite early in the ports of Long Beach and Los Angeles and with these, California is seeing huge scale investments in the growth of the hydrogen future. These market developments are encouraged by strong and reliable support from the state and a commitment for the success of this clean energy technology. Events of the recent past have further solidified California's leadership in hydrogen and fuel cells as a path toward a clean energy future. These include a number of governmental programs and funding to improve the market presence and dependence on clean hydrogen for transport.

The California Energy Commission (CEC) in September 2020 announced a Notice of Proposed Award (NOPA) that aims to fund dozens of new hydrogen station projects which will be developed by Shell, First element fuel & Iwatani. In fact, many companies have shown a keen interest in building hydrogen stations. The idea grew so popular that five extra companies submitted proposals that were approved, but the program could only fund three of them. Although subject to final approval, the NOPA, awarded a total of $115 million to fund 36 of initial stations meant hydrogen refuelling. However, the project has the potential to fund 87 additional stations.

The CEC, in October, sanctioned a $384 million plan that focuses on investments in the clean transportation sector. This boosts the adoption of zero-emission trucks and cars. Among others, $70 million were set aside to fund the infrastructure required for hydrogen fuelling. It is a significant step and is expected to support clean transport in California alongside fuel cells and hydrogen.

8.1.2. Grants for Vehicular Purchase

8.1.2.1.Heavy-Duty Zero Emission Vehicle (ZEV) Grant -Santa Barbara County

The Air Pollution Control District of Santa Barbara County, also known as SBCAPCD, allocates grants to balance the costs of zero-emission heavy-duty vehicles that reduce on-road emissions in Santa Barbara County. Eligible schemes include the substitution of commercial automobiles, transit buses, authorized emergency vehicles, conveyance refrigeration units, et cetera. Purchases of battery electric or vehicles powered by the hydrogen fuel cell are allowed and the grant can vary from $ 45,000 to $ 120,000, depending on the type of technology and use cases (*Straight Truck*, 2021.).

8.1.2.2.Heavy-Duty Zero Emission Vehicle (ZEV) Replacement Grant

The South Coast Air Quality Management District (SCAQMD) offers grants for the replacement of eligible class 8 heavy-duty vehicles with ZEVs. Grants may cover up to 75% of non-government project costs and up to 100% of government project costs up to $2,700,000 in total. Eligible vehicles include freight trucks, drayage trucks, waste haulers, dump trucks, and concrete mixers. Grants are awarded on a first-come, first served basis. The program is funded by California's portion of the Volkswagen Environmental Mitigation Trust (*Alternative Fuels Data Center: Hydrogen Laws and Incentives in California*, 2020).

8.1.2.3.Heavy-Duty Truck Emission Reduction Grants -San Joaquin Valley

SJVAPCD, or the San Joaquin Valley Air Pollution Control District, is responsible for the management of the Truck Replacement Program. This program provides funding and enables fleets to purchase modern zero-emission, hybrid or low NOx (oxides of nitrogen) vehicles and replace old vehicles with ones that emit less.

Funding can be availed for the undermentioned projects:

- Replacement of old diesel trucks or those manufactured with the model year(MY) 2009 which meet/exceed the NOx emissions standard set in 2010 with new vehicles which are hybrid, have low NOx emissions or zero-emission.
- Procurement of brand new low NOx, hybrid or zero-emission trucks.

The amount and size of incentives varies with weight class and fuel type. In fact, fleets may be eligible to receive up to 35% of the vehicle cost as compensation for new diesel trucks.

To qualify and avail of this incentive, the trucks considered eligible for replacement must be garaged in the San Joaquin Valley Air Pollution Control District (SJVAPCD). Ideally, they should have operated for not less than 75% of the time in California and at least 50% of the time in the SJVAPCD for the previous two years. New replacement trucks must be operated in California 90% to 100% of the time and within the SJVAPCD 50% of the time (*Alternative Fuels Data Center: Hydrogen Laws and Incentives in California*, 2020). The maximum incentive amount available is $ 20,000 per truck (*Grant and Incentive Programs*, 2020).

8.1.3. Incentives for Infrastructure Development

Results of a recent research study reveal that, at high scale, adding electric charging infrastructure to medium-duty delivery truck would roughly cost $27,000 per truck and $70,000 per long-haul freight truck. The costs sum up to about 10% of the total ownership cost. (*Estimating the Infrastructure Needs and Costs for the Launch of Zero-Emission Trucks*, International Council on Clean Transportation, 2019).

In order to help raise funds for refuelling infrastructure and heavy-duty charging, the state government and several partners have worked together. (*The Path to Zero Emission Trucks in California*, 2019):

- The VIP (Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project) has been funded by cap-and-trade revenue earned through CARB. It was implemented in partnership with CALSTART from 2009. The project provides incentives of up to $30,000 per vehicle for charging equipment or $100,000 per vehicle for hydrogen fuelling equipment for fleets purchasing heavy-duty ZEVs.

- Provisions for infrastructure are included in many of the demonstration programs funded by cap-and-trade funds. For instance, the $45 million LIGHTS project, short for the Low Impact Green Heavy Transport Solutions with Volvo and Greenlots, also involves charging stations which are united with on-site storage and solar installed at warehouses across the region of Southern California.

- The California Energy Commission (CEC), in 2018, awarded a grant of $23 million for hydrogen and charging infrastructure for freight vehicles at the Ports of Los Angeles and Long Beach.

- Powered by the approval of the California Public Utilities Commission, California's three largest investor-owned utilities -Southern California Edison, Pacific Gas & Electric, and San Diego Gas & Electric -are investing close to $700 million in medium-and heavy-duty charging infrastructure, potentially covering up to 18,000 charge points.

8.1.4. Notable Deterrents

Earlier in June of 2020, The California Air Resources Board (CARB) adopted a rule that requires truck manufacturers to transition from diesel engine to zero-emission options beginning in 2024, and requiring all new trucks sold in California to be zero-emission by 2045. CARB's action on medium-and heavy-duty vehicles offers an opportunity for the power of fuel cells to demonstrate their value, particularly in scalability, long-range, and short-refueling time needed for these markets. This is especial timely given the recent launch of Hyundai's fuel cell truck and Toyota's development of a fuel cell Class 8 heavy-duty truck, not to mention the slew of other companies developing fuel cell trucks such as Cummins, Nikola, Kenworth (in partnership with Toyota, and Hyundai's NEPTUNE concept) (*California Policy Update*, 2020).

8.1.4.1. Low Carbon Fuel Standard

California introduced a Low Carbon Fuel Standard (LCFS) which requires that the carbon intensity in transport fuels must be reduced by a minimum of 10% by the year 2020. The California Air Resource Board (ARB) also regulated that reduction in carbon intensity is through a blend of corn-derived ethanol by 10% (*Alternative Fuels Data Center: Biodiesel Laws and Incentives in California*, 2020).

8.2. Policies in Massachusetts

On 14 July, 14 other states joined Massachusetts as a promise to boost the market for larger electric vehicles. The move is crucial to power all new pickup, long-haul, delivery, and box trucks with electricity by 2050.

In addition, transit and school buses are also expected to be zero-emission vehicles. In June, the Massachusetts Department of Energy Resources (DOER), decided to include commercial and non-profit fleets in the Commonwealth electric vehicle rebate program & Massachusetts Offers Rebates for Electric Vehicles (MOR-EV) (*Massachusetts Joins Multistate Pledge for Zero-Emission Trucks, Buses*, 2020).

The governors of Connecticut, Rhode Island, Massachusetts and the mayor of the district of Columbia agreed and signed a Memorandum of Understanding in December 2020; the MoU was aimed at making a collective effort to reduce motor vehicle pollution by a minimum of 26% in 2032.

They will also be the first to launch the Transportation and Climate Initiative Program, which requires large gasoline and diesel fuel suppliers to buy allowances in a cap-and-trade plan. Essentially, there will be a limit on how much carbon dioxide companies can emit. After reaching its cap, a company can pay the government a certain amount of money to go beyond that limit. How many allowances a company can purchase will decline each year (Electric Truck Rebates Expanded in Massachusetts, 2021).

8.2.1. Incentives for Vehicular purchase

On Feb. 16, 2021, Charlie Baker, the governor of Massachusetts announced that the Massachusetts Offers Rebates for Electric Vehicles, i.e., the state's electric vehicle rebate program would be expanded.

The expansion now includes light-, medium-and heavy-duty electric trucks. The program will have $10 million dedicated to fund electric trucks. Therefore, all purchases of medium-and heavy-duty electric trucks will be deemed rebate-eligible after Feb 16. Funding upto 90,000 USD will be provided in rebates for a tractor-trailer purchase.

On the lower end, electric pickup trucks will be deemed eligible for a $7,500 rebate. As per a news release, the rebate values will see a decrease over time. This is an expected outcome due to the highly likely cheaper costs of new electric vehicles with advanced technology. Fleets belonging to the private, commercial and public domains are also eligible for the rebates.

The incentive declines by 15% after a specific number of rebates/vouchers have been used up within each class. Such a structure motivates vehicle owners to act sooner. The figure 7 shows how the rebate amount declines. This encourages faster adoption of vehicles and fleets.

GVWR (lbs.)	Block Size (# Veh)	Block Decline Rate (%)	Value: Block 1	Value: Block 2	Value: Block 3
8,501 – 10,000	200	15%	$7,500	$6,375	$5,419
10,001 – 14,000			$15,000	$12,750	$10,838
14,001 – 16,000	100	15%	$30,000	$25,500	$21,675
16,001 – 19,500			$45,000	$38,250	$32,513
19,501 – 26,000			$60,000	$51,000	$43,350
26,001 – 33,000	50	15%	$75,000	$63,750	$54,188
33,001 +			$90,000	$76,500	$65,025

Figure 7: Rebate values for different blocks. Source: MOR-EV Rebate Program | Mass.Gov, 2021

8.2.1.1. Vouchers

Since some medium-and heavy-duty vehicles are not as readily available as passenger EVs, vehicles over 6.3 tons will be allowed to place applications for vouchers instead. Until they possess control of the vehicle, the voucher allows them to reserve a rebate(which should be within 9 to 12 months, depending on the vehicle class.)

8.2.1.2. Environmental Justice

Registered vehicle drivers or those who can show that they operate for more than 50% of the time in communities which meet the Environmental Justice (EJ) Income Criteria of the state will be deemed eligible for a rebate. This rebate would be 10% higher than the current value of the block.

The 'adder' has been added in recognition of the fact that the communities marked EJ suffer disproportionately due to air pollution & medium-and heavy-duty vehicles are the worst offenders when it comes to local air pollution (Vanderspek, 2021).

8.2.2. Vehicle Emissions Reduction Grants

The Massachusetts Department of Environmental Protection's (MassDEP) Volkswagen Open Solicitation Grant Program (Program) provides an incentive of upto 80% of the cost of alternative fuel or newer diesel replacements and repowers (re-fitting with a more efficient diesel engine or converting to sustainable alternative-powered drivetrain) for eligible government entities. For eligible non-government entities, the program provides an incentive of up to 40% of the cost of an alternative fuel repower or newer diesel repower, up to 25% of the cost of a new diesel or alternative fuel vehicle, and up to 75% of the cost of an all-electric repower or replacement, including charging infrastructure necessary for the truck. The alternative fuels that qualify include, but are not limited to, natural gas, propane, hydrogen, electricity, and diesel electric hybrid (*Apply for a VW Open Solicitation Grant,* Mass.gov, 2021). Vehicles that qualify for replacement or repower are shown in figure 8 below.

Model Year	Vehicle Type
1992-2009	Class 8 Local Freight Trucks and Port Drayage Trucks
1992-2009	Class 4-7 Local Freight Trucks
2009 or older	Class 4-8 School Buses, Shuttle Buses, and Transit Buses

Figure 8: Vehicles eligible for Emission Reduction Grants. Source: Alternative Fuels Data Center: Massachusetts Laws and Incentives, 2021

8.2.3. Alternative Fuel Vehicle and Infrastructure Grants

The Massachusetts Department of Energy Resources' Clean Vehicle Project offers grants for private as well as public fleets for purchase of alternative fuel powered vehicles and the necessary infrastructure. Eligible vehicles include those fueled by natural gas, propane, and electricity, including hybrid electric and hydraulic hybrid vehicles. Eligible infrastructure includes electric vehicle power supply and charging equipment and natural gas fueling stations and equipment (*State and Federal Electric Vehicle Funding Programs*, Mass.gov, 2021).

Public Access Electric Vehicle Supply Equipment (EVSE) Grant provides grants to non-residential entities for 80% of the cost of installation of Level 2 EVSE for cars, and a maximum of $50,000 for purchase of hardware and installation costs per street address. Similar installations at government property also qualify for 100% of the cost, up to $50,000. The grant also regulates that the qualified EVSE must be available to the public for at least 12 hours per day. This program is part of Massachusetts Electric Vehicle Incentive Program (MassEVIP). It is funded by Massachusetts' portion of the Volkswagen Environmental Mitigation Trust (*Apply for MassEVIP Public Access Charging Incentives*, Mass.gov, 2021).

8.2.4. Voluntary Biofuels Program

The Massachusetts Department of Energy Resources (DOER) is planning to launch a voluntary biofuels program. Through this program, it plans to work with suppliers to certify biofuels. Data gathered and lessons learned through this certification program will provide useful basis for future expansion of biofuels certification and potential full implementation of a state biofuels mandate (*Advanced Biofuels,* Mass.gov, 2020).

8.2.5. Notable Mandates - State Agency Alternative Fuel Use Requirement

All Massachusetts agencies are required to use a minimum of 15% biodiesel (B15) in all on-and off-road diesel engines. This is applicable, provided that it is declared that the B15 goal is relevant and appropriate, by the Commonwealth Office of Vehicle Management and other appropriate agencies. Every year, the Executive Office for Administration and Finance and the Massachusetts Department of Energy Resources (DOER) are mandated to set required minimum percentage of E85 for use in flexible fuel vehicles of the state. This depends majorly on the availability of E85 fuel in the state. Agencies may apply for exemptions from the use of E85 and biodiesel if they can demonstrate that the alternative fuel is not available for purchase and sourcing within a reasonable distance, cannot be procured by the state and thereby cannot be purchased by operators, or the price of the alternative fuel is cost prohibitive, as determined by DOER (*Alternative Fuels Data Center: Biodiesel Laws and Incentives in Massachusetts*, 2020).

8.3. Policies in New York

The state of New York is planning to phase-out gas-fueled vehicles by 2035. With this, the state plans to join California by means of their own decarbonization goal. The state senator Pete Harckham hopes to achieve this by amending the state's Environmental Conservation Law with the legislation S.9008. This gas phase-out by 2035 is supposed to include all types of vehicles like cars, trucks, off-road vehicles and other equipment. However, in order to make the transition easier for medium-duty and heavy-duty vehicles, an additional deadline will be set, where the sale of gas-powered vehicles is to be banned by 2045 (*New York State Considers Combustion Vehicle Ban in 2035*, 2020).

New York has developed a new and modified act to reach its goals of climate targets. To achieve the climate and clean energy goals mentioned in the Climate Leadership and Community Protection Act (CLCPA), the state has to reduce GHG emissions from the transportation sector aggressively. This is because the transportation sector is the largest source of emissions in the state. So far, majority of the emission reductions achieved are from passenger vehicles. However, to achieve deeper decarbonization in the transport sector, the state must find ways to electrify buses and trucks. New York has already taken important steps in this direction, towards electrification of buses and trucks by signing onto a 15-state Memorandum of Understanding (MOU). This MOU sets a goal for sale of 100 percent electric truck and bus sales by 2050 and for 30 percent of the road fleet to be electric by 2030 (NRDC, 2020).

However, for the state to achieve its climate and zero-emission vehicle goals, there is more to do. The cost of electrify buses and trucks as well as charging infrastructure to support these vehicles is quite high. It is important to bring these prices down. Policy incentives and pathways aid in reducing these costs and support the adoption and expansion of electric buses and trucks in New York (*3 Ways New York Can Speed up Progress on Its Ambitious Clean Transportation Goals*, Greenbiz, 2020).

The state began taking necessary steps for electrifying the truck and bus fleets and the policies can be modelled based on policies from other states. A good example for this is the California Air Resources Board (CARB) adopted the Advanced Clean Truck Rule (ACT). This was a policy that requires truck and bus manufacturers to sell electric versions of their existing models or newer model trucks as an increasing percentage of sales. Adoption of policies such as ACT in New York could mean a promising step towards reaching the goal of 100 percent electric bus and truck sales by the year 2050. It is to be noted that no single policy is perfect enough to tackle the entire scale of the issue. Multiple policy pathways and financial incentives are necessary to support truck and bus electrification. To support the state's goals for electrification, the price gap between purchase price of electric and diesel trucks should be reduced. Incentives can be strategically implemented to help close the gap between the upfront costs of electric and diesel vehicles (*3 Ways New York Can Speed up Progress on Its Ambitious Clean Transportation Goals*, Greenbiz, 2020).

New York can make use of programs such as a Low Carbon Fuel Standard, the Transportation Climate Initiative to fund and support incentives. It can also look to expanding existing programs like the Clean Truck Voucher Program. Utilities can help support the expansion of a statewide network of charging stations. A good example of this is the state's Make-Ready Program. This program is funded by investor-owned utilities and supports electrification throughout the state by providing essential charging infrastructure. Through this program, New York is committing $15 million in Make-Ready funds for electrifying trucks and buses (*3 Ways New York Can Speed up Progress on Its Ambitious Clean Transportation Goals*, Greenbiz, 2020).

8.3.1. Incentives for Vehicular purchase

The New York Truck Voucher Incentive Program (NYTVIP), introduced by the New York State Energy Research and Development Authority (NYSERDA) makes it easier for truck fleets to adopt cleaner and sustainable fuel powered vehicle technologies while scrapping the old polluting diesel engines from the roads of New York. NYTVIP provides vouchers or discounts to fleets across the state, for the purchase or leasing of Battery Electric Trucks (BETs), Hydrogen Fuel Cell Electric Trucks (FCETs), Plug-in Hybrid Electric Trucks (PHEVs), Compressed Natural Gas (CNG) or propane trucks, for both medium and heavy-duty category (weight class 3 through 8) and scrap a similar older and polluting diesel vehicle that is part of their fleet. Voucher amounts are based on percentage of the incremental cost of the vehicle, up to a per-vehicle cap. This is the difference in cost between the diesel truck and alternative fuel powered truck. Voucher incentive amounts may differ based on the vehicle technology, weight class, and the domicile status of the vehicle. Voucher amounts are subject to funding availability and applicable per-project caps (*New York Truck Voucher Incentive Program (NYTVIP)*, 2020). The caps and voucher amounts can be found in figure 9.

		Vehicle Weight Class (GVWR)				
Vehicle Technology	Incremental Cost %	4	5	6	7	8
BEV	95%	$100,000	$110,000	$125,000	$150,000	$185,000
FCEV	95%	$100,000	$110,000	$125,000	$150,000	$185,000
PHEV	90%	$55,000	$60,000	$70,000	$100,000	$120,000
HEV	90%	$25,000	$35,000	$45,000	$50,000	$55,000
CNG	90%	$30,000	$40,000	$50,000	$55,000	$60,000
Propane	90%	$30,000	$40,000	$50,000	$55,000	$60,000

Note: Vehicles domiciled or operating in NYC Industrial Business Zones may qualify for incentives at these levels through the New York City Clean Trucks Program instead of through NYTVIP. For more information, go to https://nycctp.com/.

Figure 9: Voucher amounts and caps for Trucks under the NYTVIP. Source: (New York Truck Voucher Incentive Program (NYTVIP), 2020)

Other incentives to support the transition to sustainable alternatives include rebates and incentives for establishing the supply and demand of products, services and refueling of the sustainable alternatives. Some of them that impact the TCO of the user directly, are mentioned below.

8.3.2. Emission Reduction Grants

8.3.2.1. EVSE - NYSDEC

Vehicle Emissions Reduction and Electric Vehicle Supply Equipment (EVSE) project, funding the New York State Department of Environmental Conservation (NYSDEC), provides funding for projects to replace diesel vehicles and is detailed in the Clean Transportation NY Beneficiary Mitigation Plan. The projects are funded by New York's portion of the Volkswagen (VW) Environmental Mitigation Trust. The plan provides funding for the repower or replacement of diesel-powered medium-and heavy-duty vehicles, including Class 8 local freight or port drayage trucks, Class 4-8 school, shuttle, or transit buses, and Class 4-7 local freight trucks. The Plan also provides funding for the all-electric repower or replacement of light-duty EVSE, airport ground support equipment, forklifts, and port cargo handling equipment (*Alternative Fuels Data Center: Vehicle Emissions Reduction and Electric Vehicle Supply Equipment (EVSE) Project Funding*, 2020).

8.3.2.2. Clean Truck Replacement Program

The Port Authority of New York & New Jersey's Truck Replacement Program (Program) provides funding for up to 50% (up to $25,000) of the cost towards replacing a heavily emitting diesel truck. Eligible recipients of the funding include independent owner operators and licensed motor carriers, servicing the port with drayage trucks equipped with Model Year 1996 to 2003 engines. The funding, however, is limited to two truck replacements per eligible applicant. (*Truck Replacement Program Information*, Port Authority of New York and New Jersey, 2020).

8.3.3. Alternative Fueling Infrastructure Tax Credit

An income tax credit of 50% (up to $5,000) of the cost of alternative fueling infrastructure is available for qualifying infrastructure. These include electric vehicle charging equipment and equipment to dispense fuel which is 85% or more natural gas, propane, or hydrogen. Unused credits may be carried over into future tax years. The credit expires on December 31, 2022 (*Alternative Fuels and Electric Vehicle Recharging Property Credit (for Tax Years Beginning on or after January 1, 2013)*, 2020).

8.3.4. Alternative Fuel Vehicle Research and Development Funding

The New York State Energy Research and Development Authority (NYSERDA) implemented a program called Clean Transportation Program, which provides funding for projects that perform research on developing newer technologies that improve the efficiency of fuels, reduce emissions and bring newer sustainable alternatives to the market. NYSERDA also offers annual solicitations that assist research on new policies and strategies to improve the transportation sector and aid in its decarbonization. NYSERDA also supports projects which prove and demonstrate the benefits of underutilized but commercially available products, in the state. The authority provides incentives to accelerate the market introduction of these demonstrated emerging technologies by means of its ChargeNY Program (*Alternative Fuels Data Center: Alternative Fuel Vehicle Research and Development Funding*, 2020).

Apart from these state level incentives, the state of New York has joined hands with other states that include California, Pennsylvania, Massachusetts and others to sign a Memorandum of understanding (MOU) to support the deployment of medium and heavy-duty Zero Emission Vehicles (ZEVs) through involving in a Multi-State ZEV Task Force (*Alternative Fuels Data Center: New York Laws and Incentives*, 2021).

8.4. Policies in Pennsylvania

Pennsylvania joined 16 other states in Multi-State ZEV Task Force in July 2020 to support the development and deployment of zero-emission MDVs and HDVs. The state has also joined hands with 8 north-eastern states to form a regional pact to cut CO2 emissions and other air pollutants from cars and trucks. However, the state did not sign the pact at the end along with 7 other states who say the proposal is still being evaluated over concerns on increase in fuel price. Although, Pennsylvania was key in shaping the program, it did not sign the pact but said it will continue to support the Transport and Climate Initiative (TCI). The states have estimated that this program would rise the fuel price by 5 to 9 cents a gallon, assuming the carbon credits are passed on to the driver (*Pennsylvania Opts out of Carbon-Cutting Pact for Cars, for Now*, 2020).

8.4.1. Incentives for Vehicular Purchase

According to the Truck and bus Fleet Grant Program, approximately $ 16 million is allocated over a period of 5 years to fund the replacement or repowering the fleets which contain 6 or more class 4-8 trucks, buses and other medium and heavy-duty vehicles.

8.4.1.1. Rebates for Non-Electric Alternative Fuel & Diesel-powered Trucks

According to the chart in figure 10 below, the maximum reimbursement amount for Class 8 trucks, which are heavy duty trucks used for hauling weights over 14 tons, is $ 225,000 (min of 30% and maximum of 70% of purchase price) for trucks powered by alternative fuels or a maximum of $ 175,000 (min of 30% and maximum of 60% of purchase price) for newer diesel-powered trucks that emit less CO2 and nitrogen oxides than the one they replace (DEP, 2020). All the above is for trucks run by government owned entities. For non-government owned companies, the percentages vary from 25% to 75%. However, the maximum rebate that can be obtained is only $ 56,250 for alternate fuel replacement or repower and $ 43,750 for diesel repower or replacement.

GOVERNMENT OWNED				
Project Category	Max DEP Fund %	Min Applicant Match %	Max Reimbursement per Vehicle	Max Reimbursement per Vehicle for Act 47 Municipalities (or 100%)
Class 4-5 Truck Alt Fuel Repower or Replacement	70%	30%	$70,000.00	$100,000.00
Class 4-5 Truck Diesel Repower or Replacement	70%	30%	$56,000.00	$80,000.00
Class 6-7 Truck Alt Fuel Repower or Replacement	70%	30%	$105,000.00	$150,000.00
Class 6-7 Truck Diesel Repower or Replacement	70%	30%	$70,000.00	$100,000.00
Class 8 Truck Alt Fuel Repower or Replacement	70%	30%	$157,500.00	$225,000.00
Class 8 Truck Diesel Repower or Replacement	70%	30%	$122,500.00	$175,000.00
Drayage Truck Alt Fuel or Diesel Repower	40%	60%	$70,000.00	$175,000.00
Drayage Truck Alt Fuel or Diesel Replacement	50%	50%	$112,500.00	$225,000.00
School Bus Alt Fuel Repower or Replacement	30%	70%	$33,000.00	$110,000.00
School Bus Diesel Repower or Replacement	30%	70%	$27,000.00	$90,000.00
Shuttle Bus Alt Fuel Repower or Replacement	50%	50%	$75,000.00	$150,000.00
Shuttle Bus Diesel Repower or Replacement	50%	50%	$65,000.00	$130,000.00
Transit Bus Alt Fuel Repower or Replacement	100%	0%	$100,000.00	$100,000.00

* Note: Preference will be given to applicants that are approved distressed municipalities under Act 47, Financially Distressed Municipalities Act of 1987, by allowing up to 100 percent reimbursement for eligible projects. Such municipality must be identified on DCED's website to be eligible.

Figure 10: Reimbursement amounts for various classes of medium and heavy-duty vehicles. Source: DEP, 2020

8.4.1.2. Rebates for Electric powertrain Trucks

This reimbursement and funding for electric trucks is different to that of non-electric sustainable options. Figure 11 states that the maximum funding/reimbursement that can be received per truck is $ 180,000 or $ 300,000 (or 100%) per vehicle with electric drivetrain, if the applicant is from a financially distressed municipality under Act 47 (DEP, 2020).

ELECTRIC

GOVERNMENT AND NON-GOVERNMENT OWNED			
Project Category	Max Percentages	Max Reimbursement per Vehicle	Max Reimbursement per Vehicle for Act 47 Municipalities (or 100%)
Class 4-5 Truck Electric Repower or Replacement	60%	$108,000.00	$180,000.00
Class 6-7 Truck Electric Repower or Replacement	60%	$126,000.00	$210,000.00
Class 8 Truck Electric Repower or Replacement	60%	$180,000.00	$300,000.00
Drayage Truck Electric Repower or Replacement	60%	$180,000.00	$300,000.00
School Bus Electric Repower or Replacement	60%	$150,000.00	$250,000.00
Shuttle Bus Electric Repower or Replacement	60%	$121,200.00	$202,000.00
Short Range Transit Bus Electric Repower or Replacement	100%	$100,000.00	$100,000.00
Long Range Transit Bus Electric Repower or Replacement	50%	$250,000.00	$500,000.00

* Note: Preference will be given to applicants that are approved distressed municipalities under Act 47, Financially Distressed Municipalities Act of 1987, by allowing up to 100 percent reimbursement for eligible projects. Such municipality must be identified on DCED's website to be eligible.

Figure 11: Reimbursement for various classes of electric medium and heavy-duty vehicles. Source: DEP, 2020

This reimbursement amounts increase slightly by $ 6000 to $ 10,000 if there is a need to fund the infrastructure as well, along with the vehicle.

8.4.2. Grants for Infrastructure Development

The Pennsylvania Department of Environmental Protection (DEP) also provides grants for acquiring, installing, operating and maintaining public DC fast chargers and hydrogen fueling infrastructure. The grants are awarded after the project completion and the grant amounts for different fueling station can be seen in figure 12 below.

Project Type	Maximum Reimbursement	Maximum per Award
DC Fast EVSE	Up to 70% reimbursement	$250,000
Hydrogen Fueling - at least 250 kg/day	Up to 33% reimbursement	$500,000
Hydrogen Fueling - at least 100 kg/day	Up to 25% reimbursement	$500,000

Figure 12: Grant amounts for the infrastructure development of Electric and Hydrogen fuel cell vehicles. Source: Alternative Fuels Data Center: Pennsylvania Laws and Incentives, 2020

The Alternative Fuels Incentive Grant (AFIG) program provides grants in the form of reimbursement of costs for installing refueling infrastructure for new or existing alternative fuels. This infrastructure can be used at workplace, residential, or public and fleet refueling sites. Grants are available for reimbursement of 50% of the cost (up to $600,000), to install CNG, Hydrogen, Propane refueling infrastructure as well as electric charging infrastructure. Eligible applicants for this grant include municipal authorities in Pennsylvania, political subdivisions, non-profit entities, corporations, and limited liability companies (LLCs) or partnerships incorporated or registered in the Commonwealth (*Alternative Fuels Incentive Grant*, 2020).

8.4.3. Renewable Fuels Mandate

This mandate states that, for cellulosic ethanol, after one year of in-state production has reached 350 million gallons and after this production volume is sustained for three months, all gasoline sold in Pennsylvania must contain a blend of atleast 10% cellulosic ethanol. Similarly, all diesel fuel sold, must contain at least 2% biodiesel (B2) blend, one year after in-state production of biodiesel reaches 40 million gallons. The mandated biodiesel blend level will supposedly continue to increase, according to the following schedule (*Alternative Fuels Data Center: Biodiesel Laws and Incentives in Pennsylvania*, 2020):

- 5% biodiesel (B5), one year after in-state production of biodiesel reaches 100 million gallons and sustains it for three months
- 10% biodiesel (B10), one year after in-state production of biodiesel reaches 200 million gallons and sustains it for three months
- and 20% biodiesel (B20), one year after in-state production of biodiesel reaches 400 million gallons and sustains it for three months.

9. Categorizing the incentives and deterrents

All the incentives and deterrents introduced by different countries are gathered and compiled in the report. However, for easy comprehension, they are tabulated based on the country, type of incentive, its impact in the supply chain and the drive for the incentive.

The impact in supply chain determines at what level in the supply chain the incentive/deterrent is aimed at. It could be at the policy-making level, OEM R&D level, manufacturing level, consumer level or even the infrastructure level. Knowing which level the policy impacts, better helps in understanding how easy it is to use while modeling TCO. Policies closer to consumer level are in general, easier to work with for the level of this study. Policies at the R&D level or infrastructure do have an impact on the industry and technology development, but do not directly impact the TCO or are harder to use while modeling.

Drive of the incentive or deterrent is to determine if that particular policy is driven to aid any specific technology or if it is technology neutral. This helps in understanding which technology is being preferred by the different countries and regions.

The table can be found below.

Table 1: Comparison of incentives and deterrents based on multiple factors

Country	Incentive/Deterrent	Type of Incentive	Impact – Level of Supply Chain	Drive
Germany	• Distance-based toll • Funding guidelines • Purchase Incentives • Funding for innovation in electric mobility, H2 fuel cells • Funding for Infrastructure Development	• Tax-based deterrents • Supporting regulatory framework • Rebates, funding for R&D	• OEM R&D level • Consumer level • Infrastructure level • Policy level	Not technology specific
Sweden	• Annual Toll – based on emission class and size/axles • Mandatory sale of renewable fuel in filling stations • Reduktionsplikt • Carbon Tax on fuels • Eurovignette • FFI-Vinnova Funding for research	• Tax-based deterrents • Toll-based deterrents (Highway tolls) • Regulation for infrastructure development	• Consumer level • Infrastructure level • OEM R&D level	Not technology specific but some policies inadvertently drove the growth of E85 biofuel

France	• French mobility Conference Objective - 30% commercial fleet to run on natural gas • Loi Mobilites – Law to decarbonize road-freight industry by 2050 • Exemptions on ownership tax, registration fee • Rebate for purchase of sustainable alternative vehicle • Deduction in taxable income earned by sustainable truck • PREDIT & FSI Investment in R&D • Increase in price of conventional fuel • 30% subsidy for infrastructure development by government companies	• Regulation forming and implementation • Tax exemptions • Rebates • R&D funding • Subsidies for infrastructure development	• OEM R&D level • Consumer level • Infrastructure level • Policy level	Some policy aided Natural Gas and Biofuels. Rest are not technology specific
UK	• ULEV Strategy & Automated and Electric Vehicles bill • Plug-in Van Grant • Alternative Fuel Infrastructure Directive • Government investment in R&D of electric and Hydrogen trucks and buses • Grant schemes for EV charging Infrastructure • UKEMS development program	• Policy and directives • Vehicle purchase grants • Infrastructure development grants • Government-led infrastructure development • Funding for R&D	• Policy Level • Infrastructure level • OEM R&D level • Consumer level	Not technology specific but most policy designed for electric and hydrogen powertrains
USA - California	• Advanced Clean Trucks Mandate • Funding to improve market presence of Fuel cell trucks • NOPA funding for H2 filling stations development	• Mandatory policies • Purchase grants • Infrastructure development grants and funding • R&D funding	• Policy level • Infrastructure level • OEM R&D level • OEM manufacture level	Policy encouraging every sustainable alternative. More focus on electrification and H2 fuel cells

	• CARB mandate to transition to sustainable alternatives starting 2024 • ZEV purchase grants • VIP funding for charging and refuelling equipment • LIGHTS project funding for charging stations based on solar power • Private and Public owned companies' investment in infrastructure development		• Consumer level • OEM sales mandates	
USA - Massachusetts	• Cap -and-trade for gasoline and diesel trucks operators • MOR-EV purchase grants • MassDEP VOGP funding for repowering or replacing with sustainable alternatives for eligible government entities • Clean Vehicle Project grants for alternative fuel infrastructure • Voluntary Biofuels Program • Mandated alternative fuel use	• Mandatory policies • Purchase grants • Infrastructure development grants • Voluntary certification programs	• Consumer level • Policy level • Infrastructure level	Not technology specific
USA – New York	• Mandatory phase-out of conventional fuel trucks by 2045 • Make-Ready program to fund electric infrastructure development • NYTVIP vouchers/discounts for sustainable truck purchase • EVSE-NYSEDEC grant for diesel vehicle replacement • Port Authority of New York – Clean Truck Replacement Program • Alternative fuel infra tax credit	• Mandatory legislations • Purchase rebates and grants • Infrastructure development funding and grants • R&D funding, tax credits	• Consumer level • Policy level • Infrastructure level • OEM R&D level • OEM sales mandates	Not technology specific. More focus on electrification.

	• Alternative fuel vehicle R&D fund			
USA – Pennsylvania	• Truck and bus Fleet Grant program • DEP - Rebates for non-electric sustainable alternatives • DEP - Rebates for electric trucks • DEP – Infrastructure development grants • Renewable Fuels Mandate (for biofuel use)	• Purchase grants and rebates • Infrastructure development grants • Policy regulations and mandates	• Consumer level • Infrastructure level • Policy level	Not technology specific, however some rebates are higher for electric trucks

10. TCO Calculations

In this section, we provide a comparison of the TCO for the different trucks powered by the different powertrains. To perform the comparison, we assume close to real-life scenarios for use cases as well as costs. In order to make a fair comparison, it is necessary to choose trucks that are of similar capacity and that can be used for similar purposes.

A simplified version of the below formula is used in this study.

$$\mathrm{TCO} = (\mathrm{I} - \mathrm{RP}) + \mathrm{FC} + \left(\frac{\mathrm{np}}{1 - (1 + \mathrm{p})^{-\mathrm{y}}} * \mathrm{y} - \mathrm{n}\right) + \mathrm{z} + \mathrm{u} + \mathrm{x} + \mathrm{t} - \mathrm{s}$$

The simplified formula used is:

$$\mathrm{TCO} = (\mathrm{I} - \mathrm{RP}) + \mathrm{FC} + \mathrm{z} + \mathrm{u} + \mathrm{x} + \mathrm{t} - \mathrm{s}$$

Once again, the variables in the equation are as follows:

I – Initial price of the truck
RP – Resale price of the truck at the end of useful life
FC – Fuel and energy costs along the driven kilometers
z – Insurance
u – Maintenance
x – Repair
t – Tax
s – Subsidies

The difference between initial price and the resale price gives the depreciation. The largest cost incurred during the purchase and running a vehicle is typically the value of depreciation, during the initial 6-year period (Analysis of Fleet Replacement Lifecycle, 2012). The resale value is taken as 20% of the initial cost of the vehicle. For well-maintained fleets, this value is comfortably higher than 20%.

The fuel and energy costs form an important aspect while comparing the different powertrain options. The costs can be calculated by simply multiplying the price of fuel with the amount required for the estimated driving distance. However, with the variations in price for different countries and continuous change in fuel prices, the variables in the analysis can always be changed to obtain results that are relevant to any particular scenario. For this study however, we stick to the market price which is the average price for 2020 and 2021, when the modelling was performed. Taking the average price for hydrogen, and especially green-hydrogen for the past year proved to be difficult owing to the lack of available data, which is why the current price of grey-hydrogen fuel is taken. Sources like Statista, globalpetrolprices.com, gasprices.aaa.com, etc are used to obtain the real-world prices for different fuels and these websites are cited wherever appropriate.

The cost of insurance is taken from an industry research report by eurotransport.de. It is a fixed rate of € 22,000 over the lifetime and is taken the same for all the trucks.

Maintenance and repair costs are taken from GREET model, which is developed by Argonne National Laboratory. It considers that electric vehicles have reduced maintenance costs per km, which was set to € 0.095 for electric vehicles and € 0.10 for diesel vehicles (*Transitioning to Zero-Emission Heavy-Duty Freight Vehicles*, ICCT, 2017). This maintenance cost also includes the initial registration fees, which in some cases can be waved off by different incentives. Even when not waved off, these costs usually amount to a maximum of 1-2% of the initial cost price.

Taxes and subsidies introduced by different countries have been compiled in the report and the taxes are to be added to the overall costs and the subsidies are subtracted.

To begin with the calculations, a few value assumptions made are stated. The estimates are made assuming the truck capacity is 40 tonnes and the prices for them are obtained from internet sources, which are cited wherever the values are mentioned in the report. The price of conventional diesel fuel truck is taken as € 110,000 (Earl et al., 2018) in all the countries and states. This is assumed by considering the average value of the price for such trucks and using it for every region. For various trucks, however, a lot of other factors like import charges and price fluctuations apply. As for the price of biofuel based truck, we assume it is the same as conventional diesel truck. This assumption stems from the fact that Scania's trucks can run on Hydrogenated Vegetable Oil by not having any modifications to its current ICE design.

The price of H2 fuel cell truck is estimated by using the data from a report by Roland Berger (Ruf et al., 2020). The price of Battery Electric truck is taken from the quote from Tesla's website. There are no H2 fuel cell trucks currently being manufactured for mass-market usage. Iveco, Daimler, Volvo and Hyundai are on track to building a limited number of these trucks for trail runs in different countries in Europe. Owing to the high cost of manufacturing the components and assembly, the estimate of cost for Hydrogen fuel cell electric trucks could be around \$ 268,000 (Field, 2020) or € 220,000. This price could be cost competitive and reach a value of 22% premium over diesel trucks overtime. But let us stick to the current values for our assumptions. We have taken this exact value without correcting for import tariffs and inflation. The price of the electric truck is taken as € 164,000 which is the price of a Tesla Semi with some potential optional extras that match it to European usage standards (Earl et al., 2018).

While calculating the fuel costs, it is assumed that the average distance travelled by each truck is 150,000 km per year. It is also assumed that the lifetime or retention period of the truck is 7 years. In order to calculate the fuel price in this lifetime, we need some average estimates for the mileage (fuel consumption) of the trucks for different fuels. The mpg or km/lit value is taken as 8 mpg or about 3.4km/lit (Smarter Driver Behaviour Improves Fuel Economy for Trucks, 2011) as an average. This is the best-case scenario which encompasses all kinds of driving conditions like up-hill driving, flat and straight-line driving, stop-start situations in traffic and also the weight of the freight hauled, including empty runs. This translates to about 44,000 litres for 150,000 km. We rounded this off to 45,000 litres per year.

In order to obtain the price of fuel for the lifetime, we multiply the 45,000 litres by 7 and then by the price of fuel (*Diesel Prices around the World*, globalpetrolprices.com, 2021; *AAA Gas Prices*, 2021) in euros/litre. When considering biofuels, we assumed the same mileage as diesel trucks but changes in price for biofuels. Also, regarding the pricing for biofuels, in order to have uniformity on the type of biofuel, this study has considered Hydrogenated Vegetable Oil (HVO) as the kind used and the national average price of this fuel is taken from sources like *Alternative Fuels Data Center: Fuel Prices,* (2020) for the states in USA and from *Ethanol Prices around the World,* globalpetrolprices.com, (2021) for countries in Europe.

It is known that the fuel prices have been going up and down over the past decade, which is why obtaining a number for this increase or decrease became complex. For this reason, for the initial case, it is assumed that the price of all fuels remains the same throughout the lifetime of operation.

In the case of H2 fuel cell trucks, there are no real-world usage statistics. So, we had to rely on estimates from manufacturers. According to Bosch, who are working on the hydrogen fuel cell truck with Iveco, their trucks can get a mileage of 16.093km per Kg of hydrogen (Driving Transportation to an Emission less Future - IEEE Spectrum, 2017). Although this hasn't been tested on roads and real-life scenarios yet, we take this value as is. According to Nikola (minority business-holder), Iveco and their partner Bosch, who are developing their 40-tonn truck, the truck consists of 9 high-pressure hydrogen tanks, each with a capacity of 9kg (Truck Yeah, 2021). So, considering 16km per kg, we need 9375kg of hydrogen to drive 150,000km. Multiplying this with average market price for green-hydrogen, which is € 4.25 (The Formation of a Market for Green Hydrogen in the EU, 2019) and € 3.80 in USA (Collins, 2020) over a period of 7 years gives the cost of hydrogen for the operating lifetime.

For electric trucks, the estimations are made by taking Tesla Semi into consideration. Tesla quote 2kWh/mile (*Tesla Semi*, 2021) which is not yet tested in real-world scenario. The truck is on the line for mass-market manufacturing by beginning of 2022. Hence, the values are taken as is. If we assume 2kWh/mile, it amounts to 1.243kWh per km. Multiplying it with 150,000km, we get 186,450kWh of electricity usage per year. Multiplying this by 7 and the cost of electricity in the different regions, we get the usage for the entire operational lifetime. The cost of 1kWh is € 0.1718 in Sweden, € 0.1825 in Germany, € 0.130 in France, € 0.08 on average in USA and € 0.16 in UK (*Global Energy Prices*, Statista, 2020). These are the prices for generating 1 unit before differentiating the purpose, like household or business. We consider these values for the analysis, as the cost for electricity to be used as commercial transport fuel have not been defined in many countries.

11. Results

For the initial analysis, we do not assume any future scenarios or changes. This essentially is the original base case analysis for the data collected. The results here pertain to the present and not to any future setting. Included in this analysis are all the incentives that could be added to modelling like the purchase grants and incentives, levying, reduction or exemption from tolls for relevant technologies. Other incentives and policies like R&D funds, fuel mandates, etc. could not be added to the analysis as their impact on monetary value is hard to model for this study. Putting the data together into excel and graphing out the TCO by including the different incentives and deterrents, we get the graph presented in figure 13:

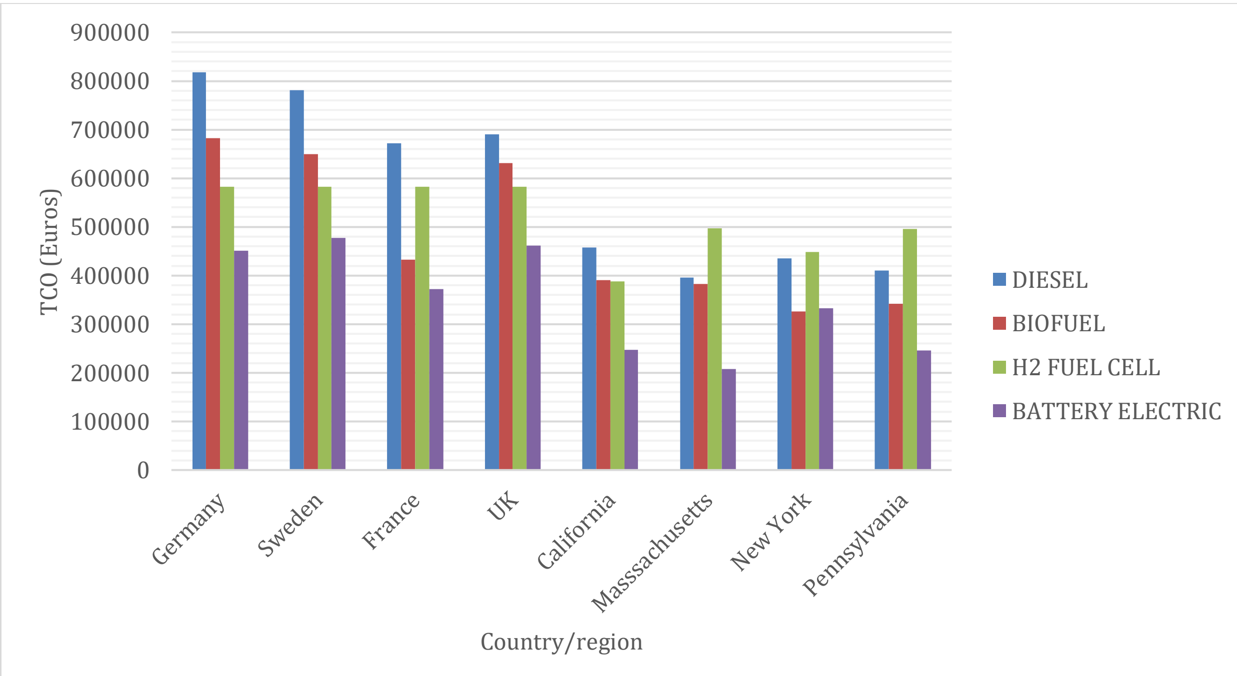

Figure 13: TCO Comparison – Base Case

In figure 13 above, on x-axis, we take the different countries and states in our modelling and the different technologies included in our study. The y-axis is the value of TCO over a period of 7 years for individual technology in each country. When the graph is observed, the cost of transport is higher in European countries when compared to states in America. Part and majority of this difference is owed to the cost of fuel in these regions. The price for diesel, biofuel and electricity is substantially cheaper in USA compared to Europe. Although it looks like battery electric is the cheapest to run, an interesting aspect to note here is the cost of running a diesel or biofuel truck in USA is similar or sometimes cheaper than running electric in Europe. Such is the difference in price of fuels in both regions. Also, USA has more customer focussed incentives for the purchase of multiple sustainable powertrain options. These incentives also contribute to reduction in total costs.

Trucks make up only 7.5% of the entire road traffic in the United States, while they account for 16.5% in Europe ("America and Europe — Keep on Trucking," 2005). USA relies on freight haulage by trains for most parts. Europe however, is quite dense and more urban, which makes rail transport quite ineffective and road freight transport more prominent. Despite this, the cost of operating commercial trucks is cheaper in USA compared to Europe, majorly due to the previously stated reason: fuel prices.

As we look at the results from the different countries and different technologies, it can be observed that although the BETs and FCETs have a higher initial price, the cost of fuels and incentives to some extent help in reducing the overall costs during the lifetime. Countries in Europe are yet to introduce and materialize policy incentives for more mainstream adoption of sustainable alternatives. However, the policies currently in practice, in each country, are discussed and included in the analysis. Once the technology is ready for mass-production and the policies begin to take effect, it can only be said that the cost of operation is going to decrease further. The major deterrent in most of the European countries is the price of diesel itself. As long as the price of diesel remains high, the cost of operation also remains high.

Biofuels might seem a better option when compared to diesel or petrol. However, it should also be noted that they are not entirely zero-emission fuels. They are definitely prone to be taxed and phased-out for the future. As diesel gets phased-out and the transition to decarbonization reaches higher levels, it is only logical to run completely zero-emission trucks and vehicles. If this is the case, then biofuels will definitely become the next big polluting fuel after diesel. So, the logical explanation would be to not entirely rely on biofuels to reduce emissions. It would be suggestible to develop the ZEV alternatives more and use biofuels as a supplementary alternative meanwhile. Also, interesting would be to discuss on the time-span required for phasing-out biofuels from road-freight. This helps in the quicker transition towards ZEVs and makes the phase-out of polluting fuels easier.

Another important aspect that we cannot model while calculating TCO is the incentives given to develop the infrastructure for manufacture, service and refuelling. These incentives go out at OEM levels and help in creating the market for more practical use of these sustainable powertrains. Almost all the countries and states give out hundreds of millions of euros in incentives to accelerate the development of the sustainable trucks, to establish production lines and also for public, high-capacity fast charging and refuelling infrastructure.

12. Sensitivity Analysis

In order to understand the sensitivity of TCO to various factors like changing incentives and fuel prices, we shall consider different cases and observe how the graphs turn out.

12.1. Scenario 1 – Cheaper BETs & FCETs

Here, let us consider that in a few years, hydrogen fuel stations and trucks become mainstream, reducing the price for truck ad fuel. Similarly, let us also assume that owing to advancements in battery density and design, electric truck prices have also reduced. This makes for an interesting case on how the price fluctuates.

In 10 years from now, in the year 2030, it is possible that electric and fuel cell trucks are in mainstream use, in order for the countries to transition towards decarbonizing road transport. Let us consider the above assumptions and assume that truck prices for both technologies come down by 20%. It would leave them at € 176,000 for Fuel-cell Electric Trucks (FCET) and € 131,200 for Battery Electric Trucks (BET).

As we already know that the price of electricity is substantially less, we might consider the new normalized costs based on the data from IEA (Projected Costs of Generating Electricity 2020 – Analysis, 2020). This normalization calculator assumes all default values and central cases, with no modifications. The costs for 1kWh are € 0.028 in Sweden, € 0.057 in Germany, € 0.030 in France, € 0.033 in USA and € 0.038 in UK. These electricity costs are normalized prices for low-carbon generation techniques in the year 2020 and let us assume that they remain the same even in a futuristic scenario, such as this. The assumption also holds for biofuels and diesel.

Hydrogen too, is projected to fall drastically in price, once mass-production starts. Many industry experts have claimed that it is possible to bring the price of green hydrogen down to less than € 2 (*Can Renewable Hydrogen Beat Grey Hydrogen on Price?*, 2021). Based on this, let us assume that the price of hydrogen has reached € 2. This reduces the price by more than half. Modelling these values gives an interesting result as shown below:

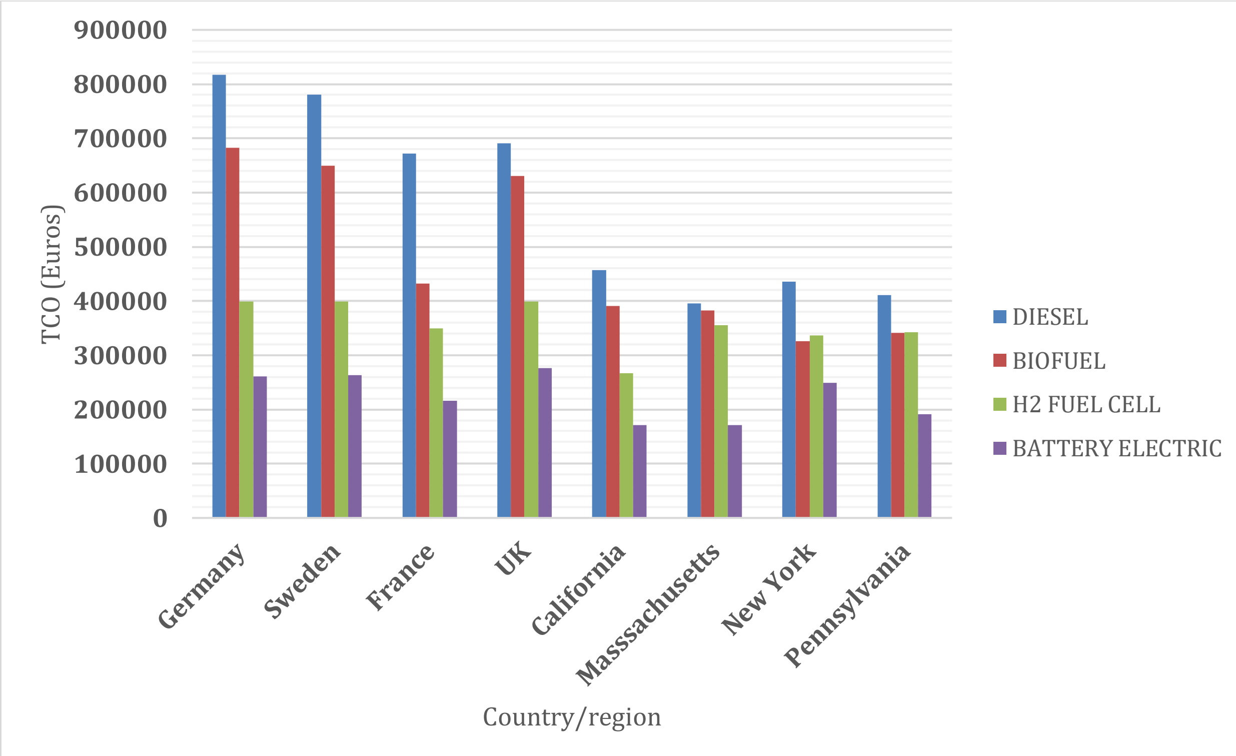

Figure 14: Scenario 1, Cheaper BETs and FCETs

Under this scenario shown by figure 14, the cost of operation for electric powertrains is substantially less, when compared to diesel and biofuels. Another notable change here, is the fall in operation costs for FCETs. They are now less expensive to operate in Europe and are similar to that of biofuel in France and USA, but definitely less than diesel in most regions.

In order to achieve deep decarbonization, diesel must be entirely phased out. So far, the measures like purchase grants and subsidies for sustainable alternatives point towards the right direction as their TCO is proving to be cheaper than diesel. Thus, it can be said that these incentives are aiding in creating the market and technology that can replace Internal Combustion Engines (ICE) with sustainable alternatives. It is hard to project the changes that might happen beyond the coming decade.

A major factor in this shift are the incentives provided by different governments to bring sustainable alternatives into more mainstream usage. However, we cannot expect these incentives to last forever and a decade definitely seems like long enough time to bring the market transition. Ultimately, we need a scenario where the sustainable alternatives are cheaper and more lucrative than ICE, even without any kind of incentives.

12.2. Scenario 2 – No Incentives

In this case, let us keep the previous case values and assumptions as is. However, let us see what happens if we assume that the incentives for sustainable alternatives are phased out. We can assume this to happen sometime after the year 2030. A decade from now, the new technologies are more mature and are in mass-production. In order for them to be a better choice compared to ICE trucks, the TCO must be less even when these incentives are no longer applicable. Assuming the prices of all kinds are similar to the assumptions in case 1 and no new taxes are levied other than the ones already present, the resulting graph looks like below.

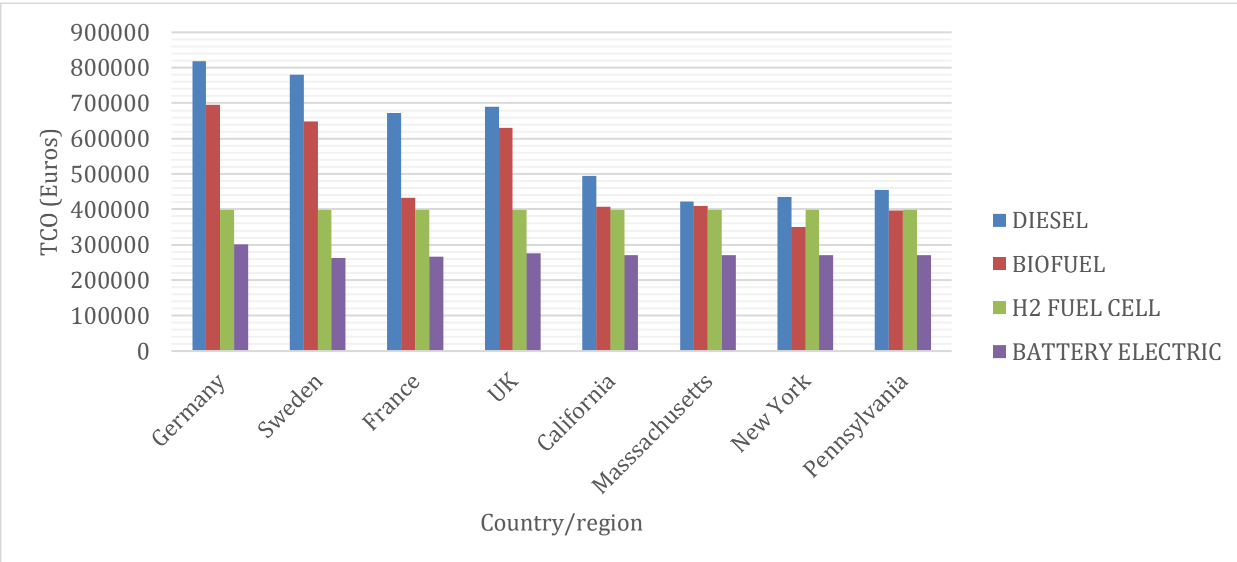

Figure 15: Scenario 2 – TCO calculation without incentives

In this scenario, from figure 15, it can be observed that, although the incentives are removed, owing to reduction in costs for manufacturing, less cost of maintenance and lower prices for electricity, the electric trucks are still a relatively more lucrative option, compared to diesel trucks. Hydrogen fuel cell technology has improved quite well and owing to those improvements, as in previous case, it remains an equivalent and zero-emission option to diesel and biofuel.

But the glaring factor that can be observed here, just like in the previous cases, is the price of diesel and biofuels in Europe. It is relatively higher in Europe, which makes hydrogen a compelling sustainable alternative. This is quite important in Europe, as trucks make up 16.5% of road traffic as previous stated. These sustainable options being substantially cheaper to ICE, makes it more likely to be adopted in Europe. This also shows that the incentives that are currently present and those that would be introduced in the future, would be more important for biofuels and FCETs than BETs. Also, in the case of FCETs, these incentives are necessary to create a market, manufacturing and service, which in-turn aid in reducing the price of not just the trucks but also the H2 fuel.

12.3. Scenario 3 – Change in Diesel and Biofuel Prices

Another important aspect to consider here is the price of diesel. As long as the price of diesel is low, it will always be an easy option to choose. In order to support the transition to sustainable alternatives, a good deterrent would be to increase the price of diesel and other carbon-emitting fuels. Although biofuels are a more sustainable alternative to diesel, they are not entirely emission-free. But let us consider that biofuel still exists and with improved sustainability in manufacturing and regulations, the price has become less by 10%. Diesel however, in leu of being a polluter, is more expensive by 30%. All the other costs remain same as assumed in Case 2. Let us see how these changes impact the TCO graph.

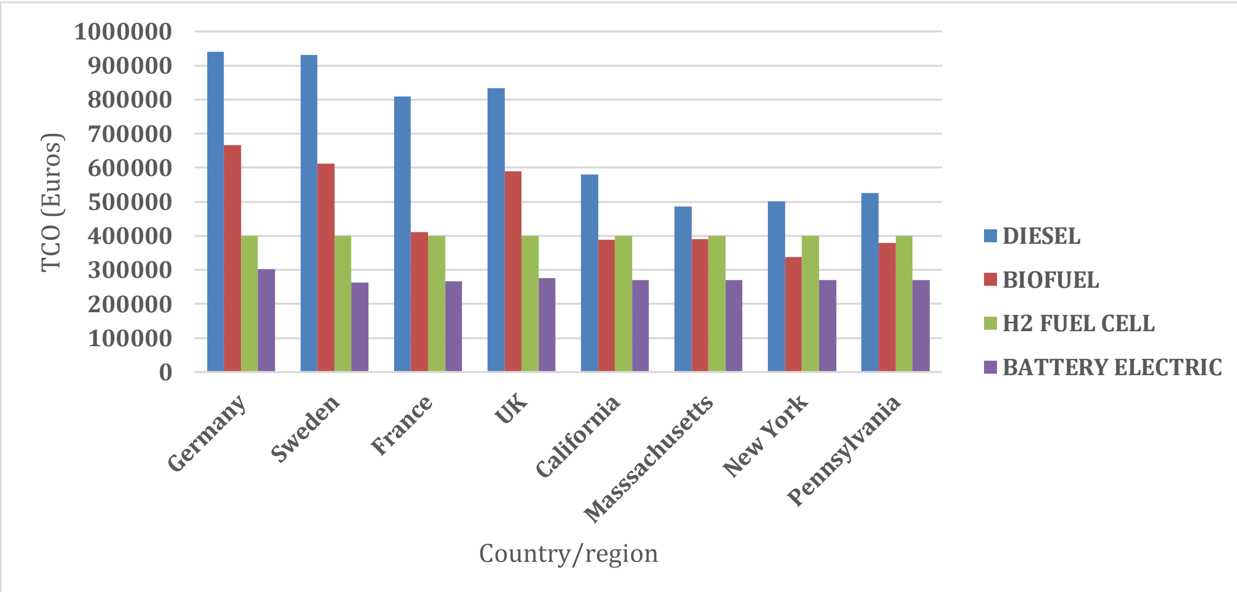

Figure 16: Scenario 3 – Increase in diesel prices

Here, from figure 16, the decrease in cost of biofuel makes it competitive and slightly less expensive than FCET but is still expensive, when compared to BET in USA. France, owing to its commitment to biofuel industry, also has less prices for the fuel and creates a compelling market. In other countries however, not much of the gap is bridged between biofuels and zero emission alternatives.

A good aspect of this scenario is that diesel and ICE are no longer a compelling choice and will be on the trend towards being phased-out. Although it might take more time to phase-out the running trucks, it can be assured that majority of the newer vehicle would be substantially less or even non-polluting.

12.4. Overhead Catenary Trucks

When it comes to BETs, long-haul freight transport with electric vehicles is quite challenging to achieve, owing to the energy constraints due to heavy loads and longer distances (Mareev et al., 2018). The cost of battery constitutes the majority of price and recharging takes much longer than simply refuelling with liquid fuels. This hurdle led to the development and testing of Overhead-Catenary Trucks. Pilot tests for overhead catenary trucks are being conducted in Sweden and Germany. For this study, only the tests done in Germany are only considered for analysis.

Before actually calculating the costs, the report by Mareev et al. (2018) considers various truck parameters and external conditions along with modeling the route scenario. From the report, it is known that this system has a traction battery present that can power the movement of the truck whenever the catenaries are not available or when the power through the catenaries is not enough to power the truck. The efficiency of this battery is assumed close to 95% and the efficiency of the pantograph is assumed to be 99% as these are the values from ENUBA 2 (Lehmann et al., 2016). The gearbox efficiency is taken at 94% (Schmalstieg et al., 2014) and the power of the two electric motors present is a combined 376kW, which is suitable for a long-distance heavy-duty truck.

For transmission of the power from the catenaries to the battery and to the electric motors, a battery management system is used, which also ensures optimum power delivery towards all auxiliaries. The power from the catenary is used to drive the electric motors and the excess power is used to charge the traction battery. The regenerative braking generated, is used to recharge the batteries and if the batteries are full, send it back into the grid through the pantograph. Mareev et al. (2018) assumes that the catenaries are always available to receive power from trucks.

The life cycle costs calculation from Mareev & Sauer (2018) assumes that the total price of the vehicle is paid upfront and includes all the equipment necessary for the truck to charge from the overhead catenaries. There are fixed costs and variable costs during the operation. The fixed costs can include insurance and annually paid taxes, which are independent of the driven mileage. The variable costs depend on the driven mileage and include tolls and other service charges. The infrastructure costs include the building of catenaries and sub-stations either in the continuous configuration or sectional configuration.

Other conditions to consider are that the diesel trucks are taxed with an emission standard and upto a maximum weight of 40 tonnes. The electric trucks are currently excluded from any kind of taxes. The costs for insuring are assumed to be the same for both kinds. However, the service costs for electric trucks are lesser when compared to ICE trucks as they do not have an engine and less mechanical-moving parts. Since there is an overhead catenary powering the electric motors and charging the battery, the traction battery present is assumed to be of a lower capacity compared to battery electric trucks. Assuming the values from (Mareev & Sauer, 2018), the weight of the diesel truck's traction components is assumed to be 1700kg. Considering that these components are not necessary for electric trucks, this weight could be used for electric components and additionally, the battery. The battery is assumed to have a density of 0.125kWh/kg for high energy cells and 0.90kWh/kg for high power cells. The weight of components powering the electric drivetrain, including the pantograph is assumed to be 550kg. the gearbox is assumed to be of same weight for both varieties. The weight breakdown is depicted further, in figure 17.

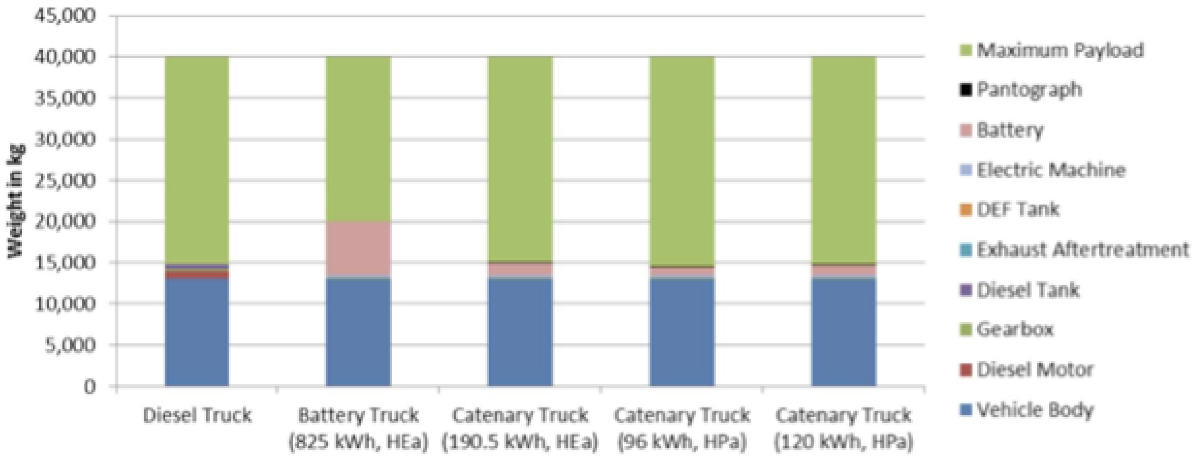

Figure 17: Net Weight of different trucks. Source: (Mareev & Sauer, 2018)

As seen from figure 17, the battery weight is substantially less in a catenary electric truck, when compared to a battery electric truck. This, as we recall, is one of the main disadvantages of the battery electric truck. This results in the catenary trucks to have a payload capacity similar to that of ICE trucks.

It is important to define a practical scenario where this technology could be put in use, to calculate the costs. The legislative regulations (EUR-Lex - 32006R0561 - EN - EUR-Lex, 2020) specify that a daily operation sequence must under no circumstance, have less than 9 hours of continuous rest. So, a good social condition of 4.5hr of driving followed by a rest period of min 45min and another session of 4.5hr driving would conclude the day's driving (Mareev & Sauer, 2018). This sequence follows for 5 days a week and 52 weeks per year. The route is assumed to be similar to that from (Mareev et al., 2018). This route is 723km long and the payload is assumed to be 18 tonnes. This is the 70% average payload capacity of ICE truck and the current threshold under which this technology is being tested.

The catenary trucks charge only through the catenaries and not by any other means. The cost of charging stations is considered, and, in the next step, the report compares the battery electric trucks to catenary trucks for entire Life Cycle Costs. In the figure 18 below, we find the result of the comparison of costs for infrastructure for catenary trucks, both in sectional and continuous configurations, along with the cost of infrastructure for charging stations. These costs pertain to 1 truck in the specified transport scenario with 5-year duration (Mareev & Sauer, 2018).

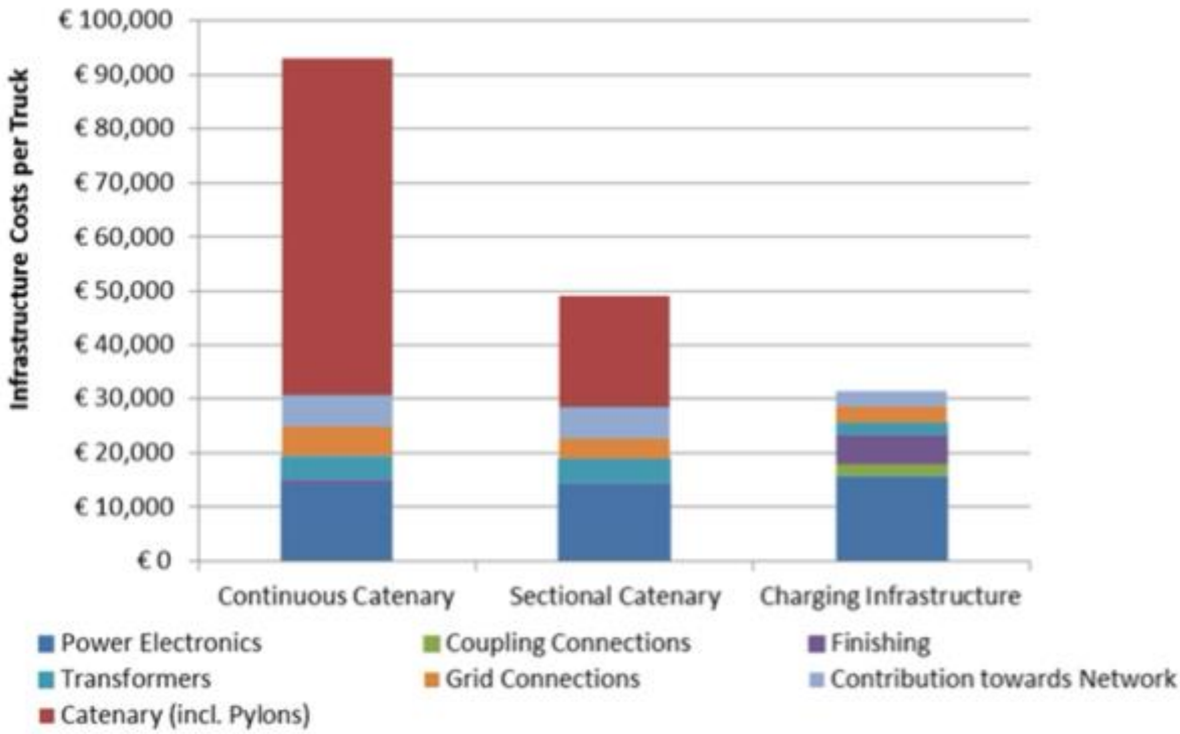

Figure 18: Infrastructure costs for Catenary and Charging trucks. Source: (Mareev & Sauer, 2018)

The depiction here may be disheartening, as the costs for building catenaries and supporting infrastructure is higher and in some cases, double to that of common charging infrastructure. But, if we include the life cycle costs and distribute the cost of infrastructure to the trucks utilizing the technology over a long period of time, the results are surprising.

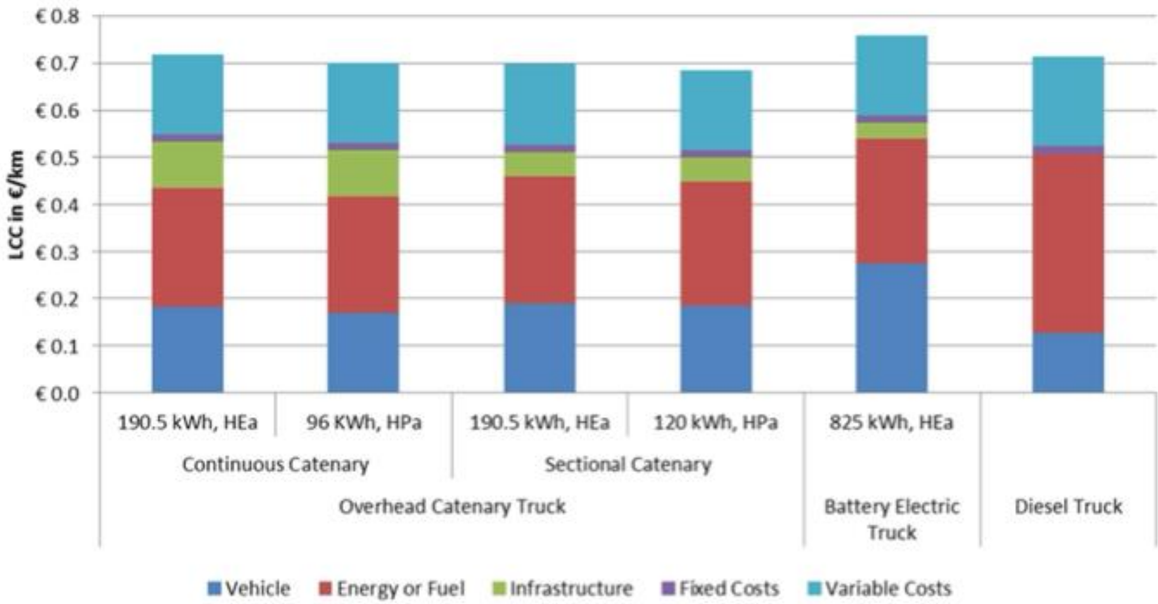

Figure 19: Life Cycle Costs (LCC) for different trucks. Source: (Mareev & Sauer, 2018)

As can be seen in Figure 19, if additional costs are included and the cost of infrastructure distributed over a period of 5 years, the total Life Cycle Costs for catenary trucks is lesser than battery electric trucks and extremely similar to that of ICE trucks. The total scenario mileage of 939,600km is considered over the said period of time in the specified scenario, which is not far from the 1,050,000km over a lifetime of 7 years, that we assumed for our scenario.

This research shows that the sectional catenary truck with 120kWh capacity has the lowest Life Cycle Costs of the lot. Another interesting note here, is the cost of vehicle. It can be clearly seen that battery electric truck costs way more than catenary and diesel trucks. Majority of this cost is owed to the battery present in it. If the capacity of battery is reduced, the price is reduced substantially. Trying to relate this TCO analysis done for catenary trucks to the TCO analysis done in this research study, it can be observed that the base assumptions are not very far off. The total lifetime assumed in Mareev et al. (2018) while calculating TCO for catenary trucks is 5 years. All the technical aspects of the battery and efficiency of the trucks assumed pertain to real-world values as stated by them. This implies that the results obtained, and the costs inferred for this technology are also close to real-life situations. The study even included the cost of infrastructure in the overall TCO of each truck for the 5-year period. Even still, the cost of catenary trucks is less than conventional BETs. A suggestion from this derivation is that investing in better infrastructure rather than batteries proves to be beneficial for long-haul heavy-duty transport.

13. Discussion

The results in figure 13 show very clearly that no matter what technology, the cost of operating in the US is considerably lower than in Europe. A major reason for this is the substantially lower prices for fuels and electricity in the US compared to Europe. The lower prices are due to the lower taxes on fuels. Since the majority of costs during lifetime of operation, apart from initial purchase price, are the cost of fuels, this lower taxes and eventually lower price for fuels has gone a long way in reducing the TCO for trucks running in USA compared to Europe.

As the newer technologies like BETs and FCETs become more mainstream, their manufacturing costs go lower. The purchase price reduction is essential for these technologies to become a lucrative option compared to conventional trucks. Which is why, in order to stimulate the transition, incentives that lower the price of these alternatives is of high importance. It is also noteworthy that a reduction in the fuel prices is also a stimulating factor for the sustainable alternatives. The cost of electricity and hydrogen fuel also fall in case 1, shown in figure 14. This led to further lowering in the TCO for these sustainable alternatives.

Eventually, there has to come a day when the alternatives are a better and cheaper option that conventional trucks, even when no incentives are present. This is what discussed in case 2 and shown in figure 15. Taking values as close to real-world as possible, it looked positive during the analysis that, in the future, these alternatives are on-track to become a better and cheaper option for the trucking industry.

Although the sustainable alternatives become a cheaper option, it is of high importance that there need to be a well-established service and refuelling infrastructure. This development has to happen in accordance to the development and adoption of the technology. During this research study, it was mentioned at several points about the many incentives created by different countries to encourage the development of refuelling infrastructure for the sustainable alternatives. On that aspect, it is also important for the industry that in order to reach net zero emissions, the sourcing and manufacture of these sustainable fuels should also happen in a sustainable way. Modelling the impact of incentives for infrastructure on the TCO of a user is harder for the scope of this study. But it can be said that there will definitely be an impact on the adoption of the sustainable alternative trucks.

A very interesting alternative among the sustainable alternatives are the overhead catenary trucks. Although they could not be directly modelled in this study, we looked at a similar TCO analysis that was performed, especially comparing the catenary trucks to conventional BETs and diesel trucks. The results were surprising and promising. It turns out, that having a smaller battery in the truck and a sectional catenary on the highway is a much cheaper option, compared to conventional BETs and is closer in price to diesel trucks. This is done when the technology is during the pilot stage and by including the cost of infrastructure over a period of 5 years. So, it can be said that, as the technology and manufacturing gets more mainstream and as the infrastructure gets concrete, the prices are bound to come down. This technology, in particular, reduces the negative aspects of range-anxiety and longer-charging hours.

14. Conclusion

This study has provided a comprehensive tabulation and analysis of the incentives in different countries and their impact on the TCO. All the scenario analysis performed were done so, by assuming close-to-real-world values. It is understandable that multiple assumptions can be made and several inferences made. But it is to be noted that the results of this analysis pertain to the scope and limitations of this study.

The analysis results clearly show that sustainable alternatives can be a cheaper alternative to conventional trucks with appropriate price incentives. The stimulating growth in adoption of these alternatives leads to development of infrastructure and lowers manufacturing costs, making them cheaper. This points out that the industry is headed in the right direction, in its goal of decarbonizing the commercial transport sector. It also shows that states in USA provide more monetary incentives for the purchase of sustainable alternative trucks, when compared to countries in Europe. They also provide more incentives for development of refuelling infrastructure. The reason countries in Europe are not currently providing such incentives is because these countries are either piloting the technologies and will implement the incentives at a later stage, based on more precise data or they are creating regulations for the market and looking for a more steady transition.

Regarding the limitations of this study, it would have been interesting to analyze TCO of overhead catenary trucks as part of the analysis and not as a separate comparison study. However, it couldn't be possible in the limited time available. Also, there could be a possibility of performing the analysis by including incentives for manufacturing and infrastructure development, in order to get a more comprehensive and overall idea of the industry development.

Another limitation of the study is regarding the insecurities like fuel prices and future costs, which can only be predicted now but cannot be determine how they might turn out in the future. The price of fuels has been going up and down over the last decade. It is possible that it can keep increasing through this decade. Modelling the price increase over the years is more complex than simply assuming a percentage increase year-on-year. Interestingly, during the analysis of this study, the TCO of diesel trucks is more than sustainable alternatives even when all fuel prices are assumed constant over the lifetime. Even if there is an increase in prices for all fuels, the corresponding TCO might increase, but would still show that TCO of diesel trucks is higher than sustainable alternatives, thereby corroborating with current assumptions.

As much as the study shows the future prominence of sustainable alternatives, it is important to know that the net zero emissions of the industry are reached if the entire supply chain is sustainable. This includes the manufacture and sourcing of the fuels, and also the manufacture, service and recycling of the trucks. Although, this cradled-to-grave analysis of the trucks and the industry is outside the scope of the study, it could be an option for potential future research.

These interesting alternatives are to be tested out further, in order to understand the feasibility and practicality for implementation. But they do provide an interesting premise for sustainable alternatives and their market domination. It remains fascinating on how technology evolves and paves the way for quicker and easier decarbonization. According to the analysis performed in this study, every measure being undertaken now, is definitely a step towards the end goal of decarbonizing the transport industry.

BETs and FCETs prove to be long-term reliable technologies that help us in achieving net zero emissions and further our goal in building a sustainable transport industry. The catenary trucks, although initially thought of as an expensive idea, prove to be an effective and reliable solution for long-haul trucking, owing to the lesser cost of batteries and longer lifetime of the infrastructure. This technology can be further complemented with fuel-cell technology to find out which permutation actually yields the lowest Life Cycle Costs, and which proves to be more reliable over longer distances.

15. References

AAA Gas Prices. (2021). AAA Gas Prices. Retrieved May 28, 2021, from https://gasprices.aaa.com/

Administration française. Bonus écologique pour un véhicule électrique. 2018. URL: https://www.servicepublic.fr/particuliers/vosdroits/F34014.

Air and climate pollution from freight traffic. (2021). Retrieved May 29, 2021, from https://www.forschungsinformationssystem.de/servlet/is/39787/

Alternative fuels and electric vehicle recharging property credit (for tax years beginning on or after January 1, 2013). (2020). Retrieved April 28, 2021, from https://www.tax.ny.gov/pit/credits/alt_fuels_elec_vehicles.htm

Alternative Fuels Data Center: Alternative Fuel Vehicle Research and Development Funding. (2020). Retrieved June 9, 2021, from https://afdc.energy.gov/laws/5325

Alternative Fuels Data Center: Biodiesel Laws and Incentives in California. (2020). Retrieved June 8, 2021, from https://afdc.energy.gov/fuels/laws/BIOD?state=CA

Alternative Fuels Data Center: Biodiesel Laws and Incentives in Massachusetts. (2020). Retrieved April 30, 2021, from https://afdc.energy.gov/fuels/laws/BIOD?state=MA

Alternative Fuels Data Center: Biodiesel Laws and Incentives in Pennsylvania. (2020). Retrieved April 29, 2021, from https://afdc.energy.gov/fuels/laws/BIOD?state=PA

Alternative Fuels Data Center: Fuel Prices. (2020). Retrieved June 9, 2021, from https://afdc.energy.gov/fuels/prices.html

Alternative Fuels Data Center: Hydrogen Laws and Incentives in California. (2020). Retrieved April 27, 2021, from https://afdc.energy.gov/fuels/laws/HY?state=CA

Alternative Fuels Data Center: Massachusetts Laws and Incentives. (2021). Retrieved April 30, 2021, from https://afdc.energy.gov/laws/all?state=MA

Alternative Fuels Data Center: New York Laws and Incentives. (2021). Retrieved April 28, 2021, from https://afdc.energy.gov/laws/all?state=NY

Alternative Fuels Data Center: Pennsylvania Laws and Incentives. (2020). Retrieved April 29, 2021, from https://afdc.energy.gov/laws/all?state=PA

Alternative Fuels Data Center: Vehicle Emissions Reduction and Electric Vehicle Supply Equipment (EVSE) Project Funding. (2020). Retrieved June 9, 2021, from https://afdc.energy.gov/laws/12419

Alternative Fuels Incentive Grant. (2020). Department of Environmental Protection. Retrieved April 29, 2021, from https://www.dep.pa.gov:443/Citizens/GrantsLoansRebates/Alternative-Fuels-Incentive-Grant/Pages/default.aspx

America and Europe—Keep on Trucking. (2005, June 15). The Globalist. https://www.theglobalist.com/america-and-europe-keep-on-trucking/

Analysis of Fleet Replacement Lifecycle (2012). Retrieved May 18, 2021, from https://docplayer.net/11374526-Analysis-of-fleet-replacement-lifecycle.html

BAG – Home. (2018). *New support programme for more energy efficiency and CO2 savings in road freight transport*. Retrieved May 29, 2021, from https://www.bag.bund.de/SharedDocs/Kurzmeldungen/DE/2018/foerderprogramm_%20mehr_%20energieeffizienz.html

Baudry, G., Macharis, C., & Vallée, T. (2018). Can microalgae biodiesel contribute to achieve the sustainability objectives in the transport sector in France by 2030? A comparison between first, second and third generation biofuels though a range-based Multi-Actor Multi-Criteria Analysis. *Energy*, *155*, 1032–1046. https://doi.org/10.1016/j.energy.2018.05.038

Bicer. (2018). Life cycle environmental impact assessments and comparisons of alternative fuels for clean vehicles. Resour. Conserv. Recycl. 132, 141-157. URL: Life cycle environmental impact assessments and comparisons of alternative fuels for clean vehicles | Request PDF (researchgate.net)

Börjesson, M., Eliasson, J., Hugosson, M. B., & Brundell-Freij, K. (2012). The Stockholm congestion charges—5 years on. Effects, acceptability and lessons learnt. *Transport Policy*, *20*, 1–12. https://doi.org/10.1016/j.tranpol.2011.11.001

Bosch Global. (2021). Truck Yeah: How to get a fuel-cell truck on the road. Retrieved May 25, 2021, from https://www.bosch.com/stories/fuel-cell-truck-nikola-two/

Bryman, A., Bell, E. (2003) Business research methods. New York: Oxford University Press.

California Air Resources Board. (2015). Retrieved May 5, 2021, from https://ww2.arb.ca.gov/

Cansino, J. M., Sánchez-Braza, A., & Sanz-Díaz, T. (2018). Policy Instruments to Promote Electro-Mobility in the EU28: A Comprehensive Review. *Sustainability*, *10*(7), 2507. https://doi.org/10.3390/su10072507

CDGG. (2019). Chittres clés du transport -edition 2019. Commissariat General au Developpement Durable. Report. URL: https://www.statistiques.developpem ent-durable.gouv.fr/chiffres-cles du transport edition-2019.

Clean Transportation Program. (2021). NYSERDA. Retrieved April 28, 2021, from https://www.nyserda.ny.gov/All-Programs/Programs/Clean-Transportation-Program

Collins , L. (2020, March 19). A wake-up call on green hydrogen: The amount of wind and solar needed is immense | Recharge. Recharge | Latest Renewable Energy News. https://www.rechargenews.com/transition/a-wake-up-call-on-green-hydrogen-the-amount-of-wind-and-solar-needed-is-immense/2-1-776481

Cost to refill | California Fuel Cell Partnership. (2019). Retrieved May 25, 2021, from https://cafcp.org/content/cost-refill

Council, N. R., Board, T. R., Sciences, D. on E. and P., Systems, B. on E. and E., & Vehicles, C. to A. F. E. T. for M. H.-D. (2010). *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles*. National Academies Press.

Council of the European Union. Transport, Telecommunications and Energy. Press release. 13 June, 2014.

Déduction exceptionnelle: Véhicules lourds utilisant des énergies propres - les-aides.fr. (2021). Retrieved May 4, 2021, from https://les-aides.fr/aide/QScvGSwMDA4v/ddfip/deduction-exceptionnelle-vehicules-lourds-utilisant-des-energies-propres.html

Department for Transport, "Automated and electric vehicles bill 201719," 2017.

Department for Transport, "Consultation on proposed transposition of alternative fuels infrastructure directive government response, 2017.

DEP, P. (2020). *Driving PA Foward*. Retrieved April 29, 2021, from https://gis.dep.pa.gov/DrivingPAForward/#projects

Doumax, V., Philip, J.-M., & Sarasa, C. (2014). Biofuels, tax policies and oil prices in France: Insights from a dynamic CGE model. *Energy Policy*, *66*, 603–614. https://doi.org/10.1016/j.enpol.2013.11.027

Driving Transportation to an Emissionless Future—IEEE Spectrum. (2017). IEEE Spectrum: Technology, Engineering, and Science News. Retrieved May 25, 2021, from https://spectrum.ieee.org/transportation/efficiency/driving-transportation-to-an-emissionless-future

Earl, T., Mathieu, L., Cornelis, S., Kenny, S., Ambel, C. C., & Nix, J. C. (2018). Analysis of long haul battery electric trucks in EU Marketplace and technology , economic , environmental , and policy perspectives. Retrieved May 25, 2021, from /paper/Analysis-of-long-haul-battery-electric-trucks-in-EU-Earl-Mathieu/21e0357feec21a0f6a4023b739e78855a8140bfe

Easterby-Smith, M., Thorpe, R., & Jackson, P. R. (2015) Management and business research. Los Angeles: Sage Publications LTD. (5th edition)

Electric vehicles [Text]. Mobility and Transport - European Commission. (2016, September 22). https://ec.europa.eu/transport/themes/urban/vehicles/road/electric_en

EC, 2003, Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport Official Journal of the European Union L123 42-46, 17 May

EC, 2009, Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC Renewable Energy Directive Official Journal of the European Union L140 16-62, 5 June

EHighway – Solutions for electrified road freight transport. (2017). Retrieved April 1, 2021, from https://press.siemens.com/global/en/feature/ehighway-solutions-electrified-road-freight-transport

E. I. Department for Business. "2017 UK greenhouse gas emissions, provisional figures," 2018.

Electric truck rebates expanded in Massachusetts. (2021, February 19). *Land Line*. https://landline.media/massachusetts-and-new-jersey-invest-millions-of-dollars-in-electric-trucks/

European alternative fuels observatory, France. 2018. URL: http://www.eafo.eu/content/France.

European Commission. (2020). *State aid: Commission approves one-year prolongation of tax exemption for biofuels in Sweden*. Retrieved April 13, 2021, from https://ec.europa.eu/info/news/state-aid-commission-approves-one-year-prolongation-tax-exemption-biofuels-sweden-2020-oct-08_en

European Parliament, "Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure," 2014.

Europe changes the Eurovignette, extending it to all kinds of vehicles - Bilogistik. (2018). Retrieved March 31, 2021, from https://www.bilogistik.com/en/blog/europe-changes-the-eurovignette-extending-it-to-all-kinds-of-vehicles/

EUR-Lex—32006R0561—EN - EUR-Lex. (2020). Retrieved April 1, 2021, from https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32006R0561

European Parliament and Council, Directive 2009/28/EC of 23 April on the Promotion of the Use of Energy from Renewable Sources: 2009

EV City Casebook – Urban Foresight. (2014). Retrieved February 26, 2021, from https://urbanforesight.org/projects/ev-city-casebook/

Fagerström, A., & Anderson, S. (2019). *The contribution of Advanced Renewable Transport Fuels to transport decarbonization in Sweden—2030 and beyond*. 44.

Forbes. (2020). *California Accelerates Clean Transportation Policy, Targeting 500,000 Electric Trucks By 2040*. Retrieved April 27, 2021, from https://www.forbes.com/sites/energyinnovation/2020/06/24/california-accelerates-clean-transportation-policy-targeting-500000-electric-trucks-by-2040/

Fuel Cell & Hydrogen Energy Association. (2020). *California Policy Update*. Retrieved April 27, 2021, from https://www.fchea.org/in-transition/2020/12/7/california-policy-update

F3 centre | ett nationellt centrum för samverkan. (2021). f3 centre. Retrieved April 13, 2021, from https://f3centre.se/sv/

Germany's greenhouse gas emissions and energy transition targets. (2014, October 23). Clean Energy Wire. https://www.cleanenergywire.org/factsheets/germanys-greenhouse-gas-emissions-and-climate-targets

Gibbert, M., Ruigrok, W. and Wicki, B. (2008) What passes as a rigorous case study? Strategic Management Journal, vol. 29, nr 13, pp. 1465-1474.

GlobalPetrolPrices.Com. (2021). *Diesel prices around the world.* Retrieved May 28, 2021, from https://www.globalpetrolprices.com/diesel_prices/

GlobalPetrolPrices.Com. (2020). *Ethanol prices around the world.* Retrieved June 9, 2021, from https://www.globalpetrolprices.com/ethanol_prices/

GOV.UK. (2021). *Low-emission vehicles eligible for a plug-in grant*. Retrieved April 22, 2021, from https://www.gov.uk/plug-in-car-van-grants

GOV.UK. (2017). *Provisional UK greenhouse gas emissions national statistics 2017*. Retrieved April 22, 2021, from https://www.gov.uk/government/statistics/provisional-uk-greenhouse-gas-emissions-national-statistics-2017

Grant and Incentive Programs. (2020). Retrieved April 27, 2021, from http://valleyair.org/grants/truck-replacement.htm

Greenbiz. (2020).*3 ways New York can speed up progress on its ambitious clean transportation goals*. Retrieved April 28, 2021, from https://www.greenbiz.com/article/3-ways-new-york-can-speed-progress-its-ambitious-clean-transportation-goals

Güldas, Y. (2019). *Adoption and diffusion of electric trucks in urban freight transport*. Institut für Volkswirtschaftslehre und Recht der Universität Stuttgart. Retrieved September 15, 2021 from Adoption and Diffusion of Electric Trucks in Urban Freight Transport.pdf (uni-stuttgart.de)

Hall, D., & Lutsey, N. (2017). Emerging best practices for electric vehicle charging infrastructure. *Washington, DC: The International Council on Clean Transportation (ICCT)*.

Hao, H.. Liu, Z., Zhao. F., Li, W. (2016). Natural gas vehicle fuel in China: review. Renew. Sustain. Energy Rev. 62, 521-533. URL: http://www.sciencedirect.com/science/article/pii/ S1364032116301253.

Heimer, B.W., Levinson, R.S., West, T.H. (2017). ParaChoice model. Technical Report SAND-2017-13263R. 1413415. URL: http://www.osti.gov/servlets/purl/1413415/.

Helby, P., Holmberg, D., & Åhman, M. (1999). *Nya styrmedel för begränsad klimatpåverkan*. Naturvårdsverket.

HM Government. (2009). Ultra-low carbon vehicles in the UK. [Online]. Available: http://www.dft. gov. uk/adobepdf/187604/ultralowcarbonvehicle.pdf

HM Government. (2011). Carbon plan. [Online]. Available: https://assets. publishing. service. gov. uk/government/uploads/system/uploads/attachment_data/file/47621/1358-the-carbon-plan.pdf

Hosseinzadeh-Bandbafha, H., Tabatabeei, M., Aghbashlo, M., Khanali, M., Demirbas, A. (2018). A comprehensive review on the environmental impacts of diesel/biodiesel additives. Energy Convers. Mana. 174, 579-614. URL: http://www.sciencedirect.cr cience/article/pil/SO 196890418308999

Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project, California HVIP. (2021). *Straight Truck*. Retrieved April 27, 2021, from https://californiahvip.org/vehicle-category/straight-truck/

ICCT. (2013). *Zero-emission trucks: An overview of the state-of-the-art*. Retrieved February 26, 2021, from https://theicct.org/publications/zero-emission-trucks-overview-state-art

ICCT. (2017). *Lessons learned from Sweden's electric vehicle rollercoaster*. Retrieved May 4, 2021, from https://theicct.org/blog/staff/lessons-learned-sweden-EV-rollercoaster

ICCT. (2019). *Estimating the infrastructure needs and costs for the launch of zero-emission trucks*. Retrieved April 27, 2021, from https://theicct.org/publications/zero-emission-truck-infrastructure

ICCT. (2017). Transitioning to zero-emission heavy-duty freight vehicles. Retrieved February 26, 2021, from https://theicct.org/publications/transitioning-zero-emission-heavy-duty-freight-vehicles

IEA. (2018). World Energy Balance Overview.

Jaffe, A.M., Dominguez-Faus, R., Parker, N., Scheitrum, D., Wilcock, J., Miller, M. (2016). The feasibility of renewable natural gas as a large-scale, low carbon substitute. California Air Resources Board Final Draft Report Contract (13-307).

Janssen, A., Lienin, S.F., Gassmann, F., Wokaun, A. (2006). Model aided policy development for the market penetration of natural gas vehicles in Switzerland. In: Transportation Research Part A: Policy and Practice, vol. 40, pp. 316-333. URL: http://linkinghub.elsevier.com/retrieve /pii/S0965856405001023.

Johansson, H. (2004). *Klimatstrategi för vägtransportsektorn*. Vägverket.

Kampker, A., Krcisköther, K., Büning, M. K., & Dorantes Gómez, J. G. (2018). Technological and Total Cost of Ownership Analysis of Electric Powertrain Concepts for Long-Haul Transport in Comparison to Traditional Powertrain Concepts. 2018 8th International Electric Drives Production Conference (EDPC), 1–7. https://doi.org/10.1109/EDPC.2018.8658298

Kast, J., Morrison, G., Gangloff Jr, J. J., Vijayagopal, R., & Marcinkoski, J. (2018). Designing hydrogen fuel cell electric trucks in a diverse medium and heavy duty market. *Research in Transportation Economics*, *70*, 139–147.

Khan, M.I., Yasmin, T., Shakoor, A. (2015). Technical overview of compressed natural gas (CNG) as a transportation fuel. Renew. Sustain. Energy Rev. 51, 785-797. URL: http://www.sciencedirect.com/science/article/pii/S1364032115006255.

Krupnick, A. (2010). Energy, Greenhouse Gas, and Economic Implications of Natural Gas Trucks. Backgrounder, vol. 44. Resources for the Future, Washington, DC.

Lehmann, M., Aktiengesellschaft, M., Stephan, A., & Mazzega, J. (2016). *ENUBA 2: Elektromobilität bei schweren Nutzfahrzeugen zur Umweltentlastung von Ballungsräumen : FuE-Programm "Förderung von Forschung und Entwicklung im Bereich der Elektromobilität" : gemeinsamer Abschlussbericht : Laufzeit des Vorhabens: vom: 01.05.2012 bis: 31.12.2015*. https://doi.org/10.2314/GBV:872400697

Lévay, P. Z., Drossinos, Y., & Thiel, C. (2017). The effect of fiscal incentives on market penetration of electric vehicles: A pairwise comparison of total cost of ownership. *Energy Policy*, *105*, 524–533. https://doi.org/10.1016/j.enpol.2017.02.054

Lin, D.-Y., & Ng, K. H. (2012). The impact of collaborative backhaul routing on carbon reduction in the freight industry. *Transportation Research Part D: Transport and Environment*, *17*(8), 626–628. https://doi.org/10.1016/j.trd.2012.08.002

Link, H. (2008). Acceptability of the German Charging Scheme for Heavy Goods Vehicles: Empirical Evidence from a Freight Company Survey. *Transport Reviews*, *28*(2), 141–158. https://doi.org/10.1080/01441640701474809

Mareev, I., Becker, J., & Sauer, D. U. (2018). Battery Dimensioning and Life Cycle Costs Analysis for a Heavy-Duty Truck Considering the Requirements of Long-Haul Transportation. *Energies*, *11*(1), 55. https://doi.org/10.3390/en11010055

Mareev, I., & Sauer, D. U. (2018). Energy Consumption and Life Cycle Costs of Overhead Catenary Heavy-Duty Trucks for Long-Haul Transportation. *Energies*, *11*(12), 3446. https://doi.org/10.3390/en11123446

Mass.gov. (2020). *Advanced Biofuels*. Retrieved April 30, 2021, from https://www.mass.gov/service-details/advanced-biofuels

Mass.gov. (2021). *Apply for MassEVIP Public Access Charging Incentives*. Retrieved April 30, 2021, from https://www.mass.gov/how-to/apply-for-massevip-public-access-charging-incentives

Mass.gov. (2021). *Apply for a VW Open Solicitation Grant*. Retrieved April 30, 2021, from https://www.mass.gov/how-to/apply-for-a-vw-open-solicitation-grant

Mass.gov. (2021). *MOR-EV Rebate Program*. Retrieved April 30, 2021, from https://www.mass.gov/service-details/mor-ev-rebate-program

Mass.gov. (2021). *State and Federal Electric Vehicle Funding Programs*. Retrieved April 30, 2021, from https://www.mass.gov/service-details/state-and-federal-electric-vehicle-funding-programs

Massachusetts Joins Multistate Pledge for Zero-Emission Trucks, Buses. (2020, July 15). CAI. https://www.capeandislands.org/science-environment/2020-07-15/massachusetts-joins-multistate-pledge-for-zero-emission-trucks-buses

Mazur, C., Contestabile, M., Offer, G. J., & Brandon, N. P. (2015). Assessing and comparing German and UK transition policies for electric mobility. *Environmental Innovation and Societal Transitions*, *14*, 84–100. https://doi.org/10.1016/j.eist.2014.04.005

Morrison, G., Stevens, J., Joseck, F. (2018). Relative economic competitiveness of light duty battery electric and fuel cell electric vehicles. Transport. Res. C Emerg. Technol. 87, 183-196. URL: http://www.sciencedirect.com/science/article/pii/S0968090X18300056.

Muncrief, R., & Sharpe, B. (2015). *Overview of the heavy-duty vehicle market and CO2 emissions in the European Union.*

Muñoz, M., Heeb, N. V., Haag, R., Honegger, P., Zeyer, K., Mohn, J., Comte, P., & Czerwinski, J. (2016). Bioethanol Blending Reduces Nanoparticle, PAH, and Alkyl- and Nitro-PAH Emissions and the Genotoxic Potential of Exhaust from a Gasoline Direct Injection Flex-Fuel Vehicle. *Environmental Science & Technology*, *50*(21), 11853–11861. https://doi.org/10.1021/acs.est.6b02606

National Geographic. 2011. *Smarter Driver Behaviour Improves Fuel Economy for Trucks*. https://www.nationalgeographic.com/science/article/110923-fuel-economy-for-trucks

New York state considers combustion vehicle ban in 2035. (2020, October 12). Electrive.Com. https://www.electrive.com/2020/10/12/new-york-state-considers-combustion-vehicle-ban-in-2035/

NRDC. (2020, October 10). *New York Pathways To Bus & Truck Electrification*. CleanTechnica. https://cleantechnica.com/2020/10/10/new-york-pathways-to-bus-truck-electrification/

NYSERDA. (2020). *New York Truck Voucher Incentive Program (NYTVIP)*. Retrieved April 28, 2021, from https://www.nyserda.ny.gov/All-Programs/Programs/Truck-Voucher-Program

Office for Low Emission Vehicles. (2013). *Driving the future today strategy for ultra low emission vehicles in the UK*. [Online]. Available: https://assets. publishing. service. gov. uk/government/uploads/system/uploads/attachment_data/file/236811/ultra-low-emission-vehiclestrategy-summary.pdf

Office for Low Emission Vehicles. (2013). *Lessons learnt from the plugged-in places projects.* Available: https://assets.publishing. service.gov.uk/government/uploads/system/uploads/attachment_data/file/ 236750/plugged-in-places-lessons-learnt.pdf

Office for Low Emission Vehicles. (2014). "Investing in ultra low emission vehicles in the UK, 2015 to 2020" .

Office for Low Emission Vehicles. (2015). Take-up of plug-in car grant continues to rise. [Online]. Available: https://www.gov.uk/government/news/take-up-of-plug-in-car-grant-continues-to-rise

Office for Low Emission Vehicles. (2016). Government pledges €290 million boost for low emission vehicles. [Online]. Available: https:// www. gov. uk/government/news/government-pledges-290-million-boostfor-low-emission-vehicles

Office for Low Emission Vehicles, "Grant schemes for electric vehicle charging infrastructure," 2016.

Office for Low Emission Vehicles. (2016). New plug-in car grant levels from March 2016. [Online]. Available: https://assets.publishing. service. gov. uk/government/uploads/system/uploads/attachment_data/file/ 502056/plug-in-grant-rate-changes-2016.pdf

Pittsburgh Post-Gazette. (2020). *Pennsylvania opts out of carbon-cutting pact for cars, for now*. Retrieved April 29, 2021, from https://www.post-gazette.com/business/powersource/2020/12/22/Pennsylvania-TCI-carbon-emissions-car-truck-air-pollution/stories/202012210116

Port Authority of New York and New Jersey. (2020). *Truck Replacement Program Information.* Retrieved April 28, 2021, from https://www.panynj.gov/port/en/our-port/sustainability/truck-replacement-program.html

Pressemitteilungen online (2011). Neue Regeln für Lkw-Maut in der EU. [Online] Available: http://www.pressemitteilungen-online.de/index.php/neue-regeln-fur-lkw-maut-in-der-eu/

Quere. (2019). Agir en cohérence ave les Ambitions, Rapport 2019. Haut Conseil pour le C 27-28. Technical Report. URl: https://www.hautconseilclimat. fr/rapport-2019/pdf/

Regeringen.se. (2020). *Ökade krav i reduktionsplikten ska minska klimatutsläppen från bensin och diesel*. Retrieved June 8, 2021, from https://www.regeringen.se/pressmeddelanden/2020/12/okade-krav-i-reduktionsplikten-ska-minska-klimatutslappen-fran-bensin-och-diesel/

RENMAD Hydrogen. (2021). *Can Renewable Hydrogen Beat Grey Hydrogen on Price?* Retrieved August 31, 2021, from https://atainsights.com/hydrogen/2021/07/09/can-renewable-hydrogen-beat-grey-hydrogen-on-price/

Riksdagsförvaltningen. (2021). *Förordning (2006:1591) om statligt stöd till åtgärder för främjande av distribution av förnybara drivmedel Svensk författningssamling 2006:2006:1591 t.o.m. SFS 2011:177—Riksdagen*. Retrieved April 13, 2021, from https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/forordning-20061591-om-statligt-stod-till_sfs-2006-1591

Riksdagsförvaltningen. (2021). *Lag (2005:1248) om skyldighet att tillhandahålla förnybara drivmedel Svensk författningssamling 2005:2005:1248 t.o.m. SFS 2016:877—Riksdagen*. Retrieved April 13, 2021, from https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/lag-20051248-om-skyldighet-att-tillhandahalla_sfs-2005-1248

Riksrevisionen (2011). Biodrivmedel för bättre klimat?

Rose, L., Hussain, M., Ahmed, S., Malek, K., Costanzo, R., Kjeang, E. (2013). A comparative life cycle assessment of diesel and compressed natural gas powered refuse collection vehicles in a Canadian city. Energy Pol. 52, 453-461. URL: http://www.sciencedirect.com/science/ article/pii/S0301421512008464.

Ruf, Y., Baum, M., Zorn, T., Menzel, A. and Rehberger, J. (2020). *Fuel Cells Hydrogen Trucks - Heavy Duty's High Performance Green Solution*. [online] Roland Berger. Available at: https://www.fch.europa.eu/publications/study-fuel-cells-hydrogen-trucks [Accessed 8 July 2021].

Sangeeta, Moka, S ., Pande, M., Rani, M., Gakhar, R., Sharma, M., Rani, J., Bhaskarwar, N. (2014). Alternative fuels: an overview of current trends and scope for future. Renew. Sustain. Energy Rev. 32, 697-712. URL: http://linkinghub.elsevier.com/retrieve/pii/S1364032 114000343.

Sarasa, C., & Doumax, V. (2018). Looking towards policies supporting biofuels and technological change: Evidence from France. *Renewable and Sustainable Energy Reviews*, *94*. https://doi.org/10.1016/j.rser.2018.06.020

Scania Group. (2020). *Evolving our strategy to take on the future*. Retrieved March 8, 2021, from https://www.scania.com/group/en/home/investors/annual-review/evolving-our-strategy-to-take-on-the-future.html

Scania Group. (2021). *How does a hydrogen fuel cell electric truck work?* Retrieved May 29, 2021, from /group/en/home/newsroom/news/2020/how-does-a-hydrogen-fuel-cell-electric-truck-work.html

Scania Group. (2021). *Sustainable transport*. Retrieved March 8, 2021, from https://www.scania.com/group/en/home/sustainability/sustainable-transport.html

Scania Group. (2021). *Sustainability ambitions and targets*. Retrieved March 8, 2021, from https://www.scania.com/group/en/home/sustainability/sustainability-at-scania/sustainability-ambitions-and-targets.html

Schmalstieg, J., Käbitz, S., Ecker, M., & Sauer, D. U. (2014). A holistic aging model for Li(NiMnCo)O2 based 18650 lithium-ion batteries. *Journal of Power Sources*, *257*, 325–334. https://doi.org/10.1016/j.jpowsour.2014.02.012

Sharma, A., Strezov, V. (2017). Life cycle environmental and economic impact assessment of alternative transport fuels and power-train technologies. Energy 133, 1132-1141.

SIKA (2004). EFFEKTER AV PRISFÖRÄNDRINGAR PÅ DRIVMEDEL 2005 Beräkningar av CO_2-utsläpp från vägtrafiken2010 och 2020 – underlag Kontrollstation 2004. PM. SIKA.

skatteverket.se. (2021). *Vägavgift för svenska tunga fordon*. Retrieved April 13, 2021, from:https://www.skatteverket.se/foretagochorganisationer/skatter/bilochtrafik/vagavgiftforsvenskatungafordon.4.18e1b10334ebe8bc8000899.html

Skogsindustrierna. (2021). *Reduktionsplikt—Skogsindustrierna*. Retrieved June 14, 2021, from https://www.skogsindustrierna.se/vara-asikter/aktuella_fragor/reduktionsplikt/

SNBC. (2018). Projet de Statégie nationale bas carbone. Ministère de la Transition Ecologique t Solidaire 65-71. Technical Report. URL: https://www.ecologique-solidaire. gouv.fr/sites/default/files/Projet %20strategle/4.20nationale%420bas%20carbone.pdf.

Statista. (2020). *France: Number of electric vehicle charging stations 2020*. Retrieved April 20, 2021, from https://www.statista.com/statistics/932730/number-of-electric-vehicle-charging-stations-france/

Statista. (2021). *Topic: Global energy prices*. Retrieved June 8, 2021, from https://www.statista.com/topics/1323/energy-prices/

Statistics—Asecap Corporate. (2020). Retrieved May 29, 2021, from http://www.asecap.com/members-statistics.html

Stelling, P. (2014). Policy instruments for reducing CO2-emissions from the Swedish freight transport sector. *Research in Transportation Business & Management*, *12*, 47–54. https://doi.org/10.1016/j.rtbm.2014.08.004

S&P Global Platts. (2021). *UK government co-funds electric truck, hydrogen bus projects*. https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/032221-uk-government-co-funds-electric-truck-hydrogen-bus-projects

Tesla Semi. (2021). Tesla Semi. Retrieved May 29, 2021, from https://www.tesla.com/semi

Texts adopted—Promotion of the use of energy from renewable sources. (January, 2018). Retrieved April 20, 2021, from https://www.europarl.europa.eu/doceo/document/TA-8-2018-0009_EN.html

Tesla Semi. (2021). *Tesla Semi*. Retrieved May 29, 2021, from https://www.tesla.com/semi

The Centre for Sustainable Road Freight. (2020). *Decarbonising the UK's Long-Haul Road Freight at Minimum Economic Cost*.

The formation of a market for green hydrogen in the EU. (2019). CEPCONSULT. Retrieved May 25, 2021, from https://cepconsult.com/publications/the-formation-of-a-market-for-green-hydrogen-in-the-eu/

The path to zero emission trucks in California. (2019). The Climate Group. Retrieved April 27, 2021, from https://www.theclimategroup.org/our-work/publications/path-zero-emission-trucks-california

The Swedish Climate Policy Council. (2020). Retrieved May 29, 2021, from https://www.klimatpolitiskaradet.se/en/summary-in-english/

Tillväxtverket (2011). Transportbidrag. [Online]. Available: http://www.tillvaxtverket.se/ huvudmeny/insatserfortillvaxt/regionalutveckling/transportbidrag.4.21099e4211fdb a8c87b800016807.html

Toll Collect. (2021). *Toll rates*. Retrieved March 31, 2021, from https://www.toll-collect.de/de/toll_collect/bezahlen/maut_tarife/maut_tarife.html

Trafikverket (2012). Målbild för ett transportsystem som uppfyller klimatmål och vägen dit. Miljöavgiftskansliet (2006). Fakta och resultat från Stockholmsförsöket (2nd ed.). Stockholm: Stockholm Stad.

Trans.iNFO. (2020). *France to grant €50,000 for the purchase of electric and hydrogen trucks*. Retrieved May 4, 2021, from https://trans.info/en/france-to-grant-e50-000-for-the-purchase-of-electric-and-hydrogen-trucks-214072

Transport & Environment. (2020). *Electric trucks could be cheaper than fossil ones by 2024 in France*. Retrieved May 4, 2021, from https://www.transportenvironment.org/press/electric-trucks-could-be-cheaper-fossil-ones-2024-france

Transport for London, "An ultra-low emission vehicle delivery plan for London," 2015.

Tyson, K. S. (2005). *Biodiesel—Clean, Green Diesel Fuel: Great Fleet Fuel Gaining Popularity Rapidly*.

UNFCCC. (2021). *Key aspects of the Paris Agreement.* Retrieved August 30, 2021, from https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement/key-aspects-of-the-paris-agreement

Vanderspek, A. (2021). *New Electric Truck Incentives in Massachusetts*. Retrieved April 30, 2021, from https://blog.greenenergyconsumers.org/blog/new-electric-truck-incentives-in-massachusetts

Vierth, I. (2017). Road freight transport policies and their impact: A comparative study of Germany and Sweden. *Road Freight Transport Policies and Their Impact : A Comparative Study of Germany and Sweden*, 213–234. https://doi.org/10.19272/201706702003

Wallén, G. (1996) *Vetenskapsteori och forskningsmetodik.*

Wang-Helmreich, A., Lochner. (2012). The potential of natural: a bridging technology in low emission road transportation in Germany. Therm. Sei. 16, 729-746. URL: http://www.doiserbia. b.rs/Article. asox?ID: 0354-98361200125W

Williams: Pathways to deep decarbonization in the... - Google Scholar. (2014). Retrieved May 5, 2021, from https://scholar.google.com/scholar_lookup?title=Pathways%20to%20deep%20decarbonization%20in%20the%20United%20States&author=J.H.%20Williams&publication_year=2014

DEPARTMENT OF SPACE, EARTH AND ENVIRONMENT
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2021
www.chalmers.se

CHALMERS
UNIVERSITY OF TECHNOLOGY