A SOCIO-TECHNICAL APPROACH TO GREENHOUSE GAS REDUCTION OF EUROPEAN MAINTENANCE MOBILITY IN A LARGE ENGINEERING AND SERVICE COMPANY

Case: KONE Oyj

Lappeenranta–Lahti University of Technology LUT

Master’s Programme in Circular Economy, Master’s thesis

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ABSTRACT

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A Socio-technical Approach to Greenhouse Gas Reduction of European Maintenance Mobility in a Large Engineering and Service Company.

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Keywords: Scenario analysis, greenhouse gas emissions reduction, sustainable mobility, socio-technical transition, direct and indirect emissions

The client of this master thesis is KONE Oyj. The aim is to research the potential to reduce greenhouse gas emissions in European maintenance mobility and provide insights into the sector of mobility in Europe by 2030. A mixed approach is used in the thesis, where the qualitative methodology is used to understand the actual mobility requirements and the quantitative methodology is used to quantify the emissions reduction potential of the created scenarios. This thesis includes a theoretical part and a case study. The theoretical part focuses on the policy developments in the sector of mobility in Europe by 2030. The theoretical part and case study is used as basis for the three different mobility scenarios created in this thesis. The greenhouse gas reduction potential is calculated based on the created scenarios to provide insights into the impact of a possible transition to low-emission modes of mobility in maintenance services. In addition, the social aspects of the possible transition to low-emission modes of mobility are studied.

The results of this thesis indicate that a transition to low-emission modes of mobility enables a major potential for greenhouse gas emissions reduction. In addition, a transition to low-emission modes of mobility enables also potential savings in energy costs and used time. The transition is possible with already existing technologies. The results of the thesis can be utilized in the development of the European maintenance services.

TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT

LUT Energiajärjestelmät

Ympäristötekniikka

Martin Excell

Sosiotekninen lähestyminen kasvihuonekaasupäästöjen vähentämiseen eurooppalaisessa kunnossapidon liikkumisessa suuressa suunnittelu- ja huoltoyrityksessä.

Tapaustutkimus: KONE Oyj.

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Tämän diplomityön toimeksiantaja on KONE Oyj. Työn tarkoituksena on tutkia potentiaalia kasvihuonekaasupäästöjen vähentämiseen eurooppalaisessa kunnossapidon liikkumisessa ja tarjota tietoa liikenteen sektorin muutoksista vuoteen 2030 asti. Työssä käytetään sekä laadullisia että kvantitatiivisia menetelmiä, joista laadullista menetelmää hyödynnetään kunnossapidon todellisten tarpeiden ymmärtämiseen ja kvantitatiivisia menetelmiä päästövähennys potentiaalin määrittämisessä. Tämä työ sisältää teoreettisen osuuden ja tapaustutkimuksen. Teoreettinen osuus käsittelee pääosin liikenteen sektorin muutoksia Euroopassa vuoteen 2030 asti. Teoreettinen osuus ja tapaustutkimus toimivat pohjana kolmelle työssä luodulle skenaariolle. Skenaarioiden pohjalta lasketaan päästövähennys potentiaali, joka tarjoaa tietoa vähäpäästöiseen liikkumiseen siirtymisen vaikutuksista kunnossapidossa. Työssä tutkitaan myös vähäpäästöiseen liikkumiseen siirtymisen sosiaalisia vaikutuksia.

Tämän työn tulokset osoittavat, että siirtyminen vähäpäästöisiin liikkumismuotoihin mahdollistavat huomattavan kasvihuonekaasupäästöjen vähentämisen. Lisäksi siirtymä mahdollistaa säästöjä energiakustannuksissa ja käytetyssä ajassa. Siirtyminen vähäpäästöisiin liikkumismuotoihin on mahdollinen jo olemassa olevilla teknologioilla. Tämän työn tuloksia voidaan hyödyntää kunnossapitopalveluiden kehityksessä Euroopassa.

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Helsinki, August 24th 2022

Martin Excell

ABBREVIATIONS

AC	Alternative Current
BEV	Battery-electric vehicle
CCS	Combined Charging System
CEN	European Committee for Standardization
CFC	Chlorofluorocarbon
CH_4	Methane
CNG	Compressed Natural Gas
CO	Carbon monoxide
CO_2	Carbon dioxide
ETS	Emissions trading system
gCO_2e	grams CO_2 equivalent
GHG	Greenhouse gas
GWP	Greenhouse warming impact
HC	Hydrocarbons
HEV	Hybrid-electric vehicle
HFC	Hydrofluorocarbon
ICE	Internal Combustion Engine
ISO	International Organisation for Standardization
$kgCO_2e$	kilograms CO_2 equivalent
kWh	Kilowatt-hour
LCA	Life cycle assessment
LEFV	Light electric freight vehicle
LEZ	Low Emission Zone

MaaS	Mobility-as-a-Service
MLP	Multi-level perspective
N_2O	Nitrous oxide
NO_x	Oxides of nitrogen
OEM	Original Equipment Manufacturer
PFC	Perfluorinated hydrocarbons
PHEV	Plug-in hybrid electric vehicle
PM	Particulate matter
SF_6	Sulphur hexafluoride
SULP	Sustainable Urban Logistics Plan
SUMP	Sustainable Urban Mobility Plan
TCO	Total Costs of Ownership
TEN-T	Trans-European Transport Network
TIC	Techno-institutional complex
TTW	Tank-to-Wheel
WLTP	World harmonized Light-duty vehicles Test Procedure
WTT	Well-to-tank
WTW	Well-to-Wheel
ZEZ	Zero Emission Zone

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1. Introduction

“Climate change refers to long-term changes in temperatures and weather patterns” (United Nations 2022). Human activities have been the main driver of climate change since the 1800s, primarily through the burning of fossil fuels (United Nations 2022). The climate change is a major challenge for everyone on the planet as it impacts everything. The climate change requires actions on individual, corporate and governmental levels.

Anthropogenic emissions are for example greenhouse gases (GHG), precursors of greenhouse gases, and aerosols, resulting from human activities. GHG includes e.g., carbon dioxide (CO_2), chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), nitrous oxide (N_2O), methane (CH_4), perfluorinated hydrocarbons (PFCs), and sulphur hexafluoride (SF_6). These are the major GHGs in focus in international agreements, such as the Montreal Protocol and Kyoto Protocol. (National Research Council 2010)

The Intergovernmental Panel on Climate Change (IPCC) have identified that all pathways to limit the global warming to 1.5 degrees Celsius require limiting emissions of long-lived GHGs such as CO_2 and N_2O (IPCC 2018a). IPCC identified however in the most recent sixth assessment report (AR6) that the likelihood of limiting global warming to 1.5 degrees with no or limited overshoot has dropped as the global GHG emissions have continued to rise since 2017 (IPCC 2022: TS-39). The GHG reduction from the transport sector is important as the sector represents 23 per cent of the global energy-related CO_2 emissions and evidence suggest that emissions should be restricted to 70 to 80 per cent below the 2015 level to meet goals set in the Paris Agreement (IPCC 2022). Other actions for mitigation of climate change include e.g., improving resource efficiency in buildings, adoption of low-emission innovations, adoption of energy efficient appliances, promoting energy-saving behaviour, promoting buying products and materials with low GHG emissions during production and transport, and through changed organisational behaviour (IPCC 2018b).

Transport represents approximately a quarter of the GHG emissions in Europe, and road transport accounts for more than 70% of total GHG emissions caused by transport in Europe (European Commission 2016). The GHG emissions of road transport are a result of burning fuel in internal combustion engine (ICE) of a vehicle (Ligterink et al. 2016). IPCC stated in the most recent AR6 that "meeting climate mitigation goals would require transformative changes in the transport sector" (IPCC 2022: TS-67). The COVID-19 pandemic has already transformed the work-life as telecommunication services have replaced large numbers of work and personal trips (IPCC 2022). "Changes in urban form, behaviour programs, the circular economy, the shared economy, and digitalisation trends can support systemic changes that lead to reductions in demand for transport services and expands the use of more efficient transport modes" (IPCC 2022 TS-67).

The need for mobility is expected to increase for people and goods, which is why the European Commission has adopted, in 2016, a low-emission mobility strategy with three key areas: increasing the efficiency of the transport system, speeding up the deployment of low-emission alternative energy for transport, and moving towards zero-emission vehicles (European Commission 2016). As part of the "Fit for 55" legislative package by the European Commission, new regulation on the CO_2 emissions of cars and vans have been proposed from 2030 onward. The European Commission has proposed a new CO_2 reduction target for new cars and vans as compared to the 2021 target. The CO_2 reduction target for new cars from 2030 onward is 55% and for new vans 50%. (European Commission 2019; 2021a)

The green mobility transition supports cities, businesses, and individuals e.g., in reducing their GHG emissions. The transition enables also e.g., the creation of more liveable urban space, improved quality of life, and accommodation of urban growth. At the core of the green mobility transition is the uptake of clean, more efficient, and shared mobility options. (Tsavachidis et al. 2022)

1.1. Objective

The client of this master's thesis is KONE Oyj (further referred to as KONE). KONE published in 2020 a climate pledge by which the company set its GHG emissions reduction targets in line with the target to limit increase in global temperature to 1.5 degrees Celsius. KONE has pledged to have carbon neutral operations by 2030 with manufacturing units reaching the target in 2024. KONE's targets have been validated against the latest climate science by the Science Based Targets initiative (SBTi). The climate pledge includes a company-wide target and commitment to reduce scope 1 and 2 carbon footprint with 50 per cent from 2018-level by 2030. KONE targets also a 40 per cent reduction in the emissions related to its products' materials and lifetime energy use, which are scope 3 emissions, over the same target period, relative to orders received. (KONE Oyj 2022)

GHG emissions are classified as direct or indirect emissions. Scope 1 emissions are direct GHG emissions that occur from sources owned or controlled by an organization. These are e.g., company vehicles and company facilities. Scope 2 emissions are indirect GHG emissions associated with the purchase of electricity, steam, heat, or cooling. The scope 2 emissions are accounted for in the organization's GHG inventory as they are a result of the organization's energy use, even though the emissions would be generated elsewhere. Scope 3 emissions include other indirect GHG emissions. The scope 3 emissions are a result of the actions of the company but occur from sources not controlled or owned by the company. These emissions include e.g., transportation of used fuels and energy consumption of sold products. (GHG Protocol Initiative 2004; Environmental Protection Agency 2021)

The majority of KONE's total GHG emissions are scope 3 emissions. The scope 1 and 2 emissions represent approximately 1% and scope 3 emissions represent 99% of KONE's total GHG emissions. KONE has globally a vehicle fleet consisting of approximately 18 000 vehicles and the vehicle fleet accounts for 84% of the total scope 1 and 2 greenhouse gas emissions in 2021. Transition to a low-emission vehicle fleet has been identified to be one of the most important actions to reach the company's carbon footprint reduction target. Two thirds of the company vehicles are maintenance vehicles, used by maintenance to move technicians and e.g., spare parts to needed locations. The rest of the company vehicles are so called benefit cars for other employees. (KONE Oyj 2022)

KONE has taken actions to reduce the GHG emissions of their vehicle fleet e.g., through encouraging the employees to select low emission vehicles, and providing charging stations. Nearly 30% of the KONE's car fleet in Norway and over 10% of fleets in Israel, the Netherlands, and Sweden consists of electric vehicles. KONE has also started piloting e-cargo bikes and e-scooters in their maintenance operations in Austria and are replacing old motorcycles with electric ones in Hong Kong. (KONE Oyj 2022)

KONE wants to research the use of different modes of mobility in the maintenance operations in Europe. The company wants to understand the impact of the implementation of battery electric vehicles (BEV) and other alternative modes of mobility on the company's carbon footprint, and the barriers and requirements of the implementation of new modes of mobility. KONE is interested in finding useful actions to reduce the GHG emissions in maintenance mobility. KONE aspires to be a wanted employer now and in the future which requires that the social perspective of low-emission mobility transition is also covered.

1.2. Scope and research questions

The maintenance vehicles make up for two thirds of the total vehicle fleet in the company (KONE Oyj 2022). The maintenance vehicle fleet consists of a mixed set of vehicles ranging from small cars to large vans. The utility vans currently in use are mainly ICE-driven. A long-term objective is to reduce the emissions of the vehicle fleet. A transition to EVs is currently identified as the mean with highest potential for emissions reduction, but currently the availability of suitable models is hindering the transition. The major questions revolving around the suitability of an electrified fleet regards the cost of vehicles, total cost of ownership (TCO), range of the BEVs, load capacity and the charging of the vehicles.

There is also an interest towards research of alternative modes of mobility for vehicles. This includes alternative modes such as electric cargo bikes or usage of public transport if these have been tested or piloted in the focus regions prior to this research. The use of renewable fuels, such as HVO (Hydrotreated Vegetable Oil) diesel and biomethane in the maintenance vehicle fleet is ruled out of the scope for this research, as they are not seen in the big picture as a useful method to reduce the carbon footprint, mainly due to their higher cost and limited availability compared to fossil fuels (Neste 2022; SGS INSPIRE 2021). A purpose of this research is to collect information, data, and experiences from the focus regions on successful and non-successful tests and pilots on new technologies and alternative modes of mobility. Country units are operating in focus regions, and they have the freedom to test suitable modes of mobility. This research aims to identify possible barriers and enablers identified in these tests.

A future transition towards low-emission maintenance mobility will certainly have an impact on the maintenance technicians of KONE, which is why the social impact of the transition will be included in the research. The social impact will be studied from the perspective of the employee as of how they will be impacted by the change, what is required from them, and how their perspective can be taken into consideration in planning the transition. As has been identified prior to this research, maintenance technicians have shown interest towards use of electric vehicles in their daily commute, but challenges related to charging, load capacity and range-anxiety are questions to solve prior to the transition.

This research will be limited to maintenance vehicles and technicians located in specified European countries, namely Finland, France, and the Netherlands, as these markets have a high number of utility vans in the vehicle fleet and/or alternative modes of mobility have been tested in the markets. European markets are in focus in this research as the services in the region are strongly dependent on vehicles and the region has seen increased regulation for emissions of road transport. The maintenance services are provided globally by a variety of means ranging from walking with backpacks to vehicle use. The aim of this research is to focus on the emission generating vehicle use, and what the modes of maintenance mobility could be by 2030.

The main research question and sub-questions of this Master thesis are:

- What are the different modes of low-emission mobility and their impact on the daily work of technicians in maintenance services by 2030?
    - What is the carbon footprint reduction potential of different low-emission mobility scenarios by 2030?
    - What are the barriers, enablers, and estimated cost impact of different mobility scenarios by 2030?

1.3. Structure

The structure of the thesis is following. In the beginning the valid theoretical concepts are introduced. The following chapter introduces the relevant definitions and an overview of the trends of the transport system in the EU (European Union), the recent and future trends of mobility in general, and the possible mobility modes and services by 2030. The overview includes insights to the development and trends of BEVs, FCEVs, electric cargo bikes, and public transport as modes of mobility.

Next, the social aspects of mobility will be reviewed. The focus is on examining the social aspects that could impact the low-emission mobility transition. The purpose is to highlight the user perspective and understand the impact of mobility on daily commute.

The following chapters introduces the deeper insights to the regulation and policies on emissions of road transport in the EU and the methodology used in the research. These combined create a structure for the scenario creation in the following chapter.

Based on the analysis three scenarios for the future will be created. These scenarios will include a baseline scenario and two alternative scenarios. These scenarios include the current state of mobility, an alternative scenario including new technology implementation and a third more challenging yet realistic alternative for mobility solutions which includes multi-modality. Based on the scenarios the potential for carbon footprint reduction (tank-to-wheel) and other identified important parameters will be calculated. The calculations will be compared primarily to the baseline scenario. The conclusions and summary will be discussed in the final chapter.

2. Socio-technical approach to GHG reduction

“A socio-technical approach to transition highlights the co-evolution and multi-dimensional interactions between industry, technology, markets, policy, culture and civil society” (Geels 2012). A socio-technical approach is used in this research to understand the impacts of alternative modes of mobility on maintenance service from the technical perspective and social perspective. The technical perspective will later focus on technological development of alternative modes of mobility such as BEVs by 2030 and the social perspective will focus on mapping the impacts these modes have on the maintenance technicians who will be directly impacted by the change in mobility.

The multi-level perspective framework introduced in sub-chapter 2.1 is used as structure to create understanding on the complexity related to the current state and future transition of maintenance mobility.

2.1. Multi-level perspective framework

Geels introduced the multi-level perspective (MLP) framework (Figure 1) to as a tool to address the core of complex transitions, namely stability and change. Existing systems are characterized by stability, lock-in and path-dependence which supports incremental change along predictable trajectories. Competing alternative systems are proposed, developed, and tried by individuals working outside the current regime. These alternative systems, also referred to as niche and radical innovations, struggle to survive as they usually compete against a set of rules, policies and markets created for the current regime. The usage of alternative systems or radical innovations often require are higher amount of investment, a change in user practices, update to infrastructure and to regulation. The MLP framework provides a way to investigate the core of transition, stability, and change. (Geels 2012)

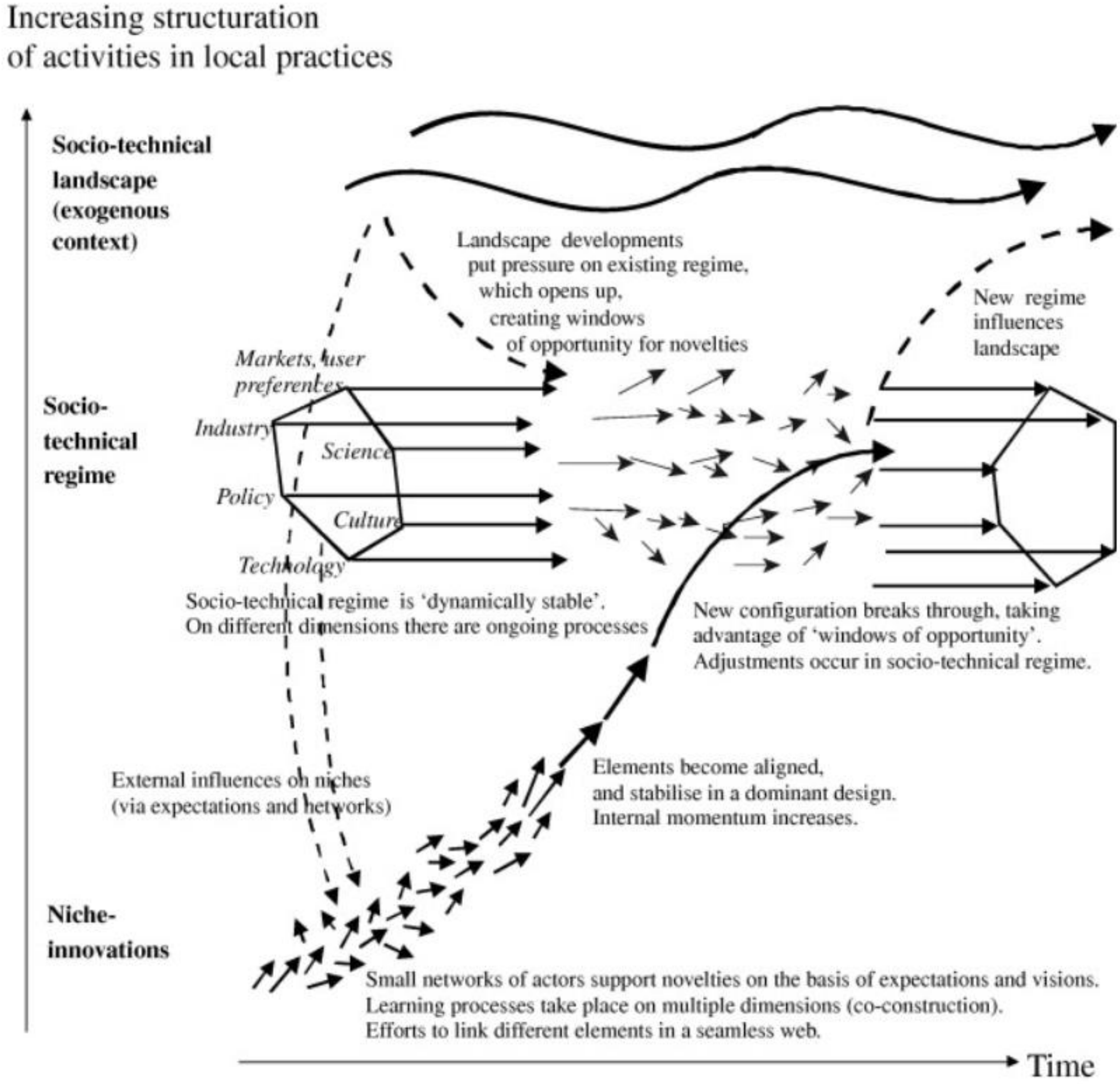

Figure 1. Multi-level perspective (MLP) on transitions (Geels 2012)

The MLP framework consists of three analytical levels, niche, regime, and landscape. The niche-level in the framework describes the location where radical innovations are nested. An example of niche-level innovations in the transport system is the battery-powered vehicles that used to compete against ICE-powered vehicles. The actors on the niche-level work on innovations which compete against the existing regime and will possibly even replace the regime. Replacing a regime is however not easy, as the regime is stabilized by lock-in mechanisms. (Geels 2012)

A socio-technical regime describes the second level of the MLP framework, where existing technologies, regulations, user patterns, infrastructures, and cultural discourses are aligned. The system elements are adapted, maintained, and changed by various social groups and actors. Innovation in existing regimes is usually incremental due to the lock-in mechanisms and path-dependence. An example of a socio-technical regime is the car-dominant mobility system. In a socio-technical regime the actors are supported by cultural beliefs and regulation which helps to withstand the potential threats from niches to the regime. (Geels 2012)

A socio-technical landscape is the third level of the MLP framework and simultaneously a landscape which influences both regime and niche levels. The actions in the landscape can cause changes to the regime and open opportunities to niche innovations. The landscape includes e.g., political ideologies, societal values and macro-economic trends and it represents the greatest of structuration in the MLP framework. An example of a recent landscape development is the discussion around climate change which has led to policy action in the European Union. (Geels 2012)

2.1.1. Lock-in

Existing systems tend to be characterized by so called lock-ins. Lock-ins can have different sources, which can be categorized as industrial, institutional, organizational, societal, and technological. E.g., the use of standardized solutions, standardized operating procedures and emphasis on incremental development programs tend to create and reinforce lock-in in firms. A lock-in can be important at firm level, as technological lock-in can e.g., reduce required investments and improve performance on specialized skills. Lock-ins can also be negative as it can lock firms to use sub-optimal solutions. (Unruh 2000; 2002)

On systems level government policies tend to create institutional lock-in through e.g., policy intervention and legal frameworks. Institutional lock-in tends to persist in their initial form over a long period of time, and governmental and legal institutions can exacerbate lock-in conditions. Radical change to institutions tends to require major crisis or external shocks. (Unruh 2000; 2002)

2.1.2. Carbon lock-in

A carbon lock-in describes a situation where a carbon intensive solution is preferred over low-carbon alternatives due to several different barriers in the implementation of the technology. A lock-in can be diminished, but an understanding of the barriers is needed to be able to focus on the right things. The barriers can be split into micro and macro-levels, where the micro-level depends on the local decision-making and macro-level depends on larger e.g., societal preferences. (Unruh 2000)

An example of a technological carbon lock-in is the use of ICEs in vehicles. The development of the ICE and the mass production of vehicles during the last century has led to the rise of the ICE to become the dominant propulsion design in the automotive industry. The lock-in is enforced by actions by several other societal institutions. (Unruh 2000)

A technological lock-in has also been identified in research to lead to focus on incremental development in companies. Standardized operating procedures have also been identified as a source of barriers to adoption of low-carbon alternatives. (Unruh 2000)

Interdependent technological systems depend on the effort of multiple separate institutions, which can create a lock-in around a technology. The use of vehicles requires e.g., building infrastructure and maintaining it, manufacturing of tyres and production of fuels. This inter-relatedness of institutions can stabilize a lock-in around the car-based transport system. A lock-in is often also supported by externalities such as financial institutions, as funding for development using a new technology often requires applying for funds from venture capitals, or governmental institutions which have stricter requirements or higher costs for the funding. "Financial tendencies create incentives that can further enhance a lock-in conditions". (Unruh 2000)

2.1.3. Path-dependence

Path-dependence is one characteristic of technological systems change. It presents a challenge to the development of new solutions, pathways, and scenarios for the future transition towards e.g., low-emission solutions. Underplaying path-dependence in transition planning can give a misleading picture of how change might occur and what the result of different decisions are. Path-dependence can favour less optimal solutions due to decisions and events that have been made along the way. (Foxon et al. 2012)

The theory of path-dependence has its roots in evolutionary and institutional economics. Path-dependence explains situations where historical decisions and events has an impact on potential beginnings by narrowing down options overtime. Path dependency can be driven by increasing returns to scale, which can reduce costs in the short term (Unruh 2002). Path-dependency and its reinforcing tendency will most likely lead over time to institutional, organizational, or technological lock-in. (Sydow et al. 2012)

2.1.4. Techno-institutional complex

The techno-institutional complex (TIC) is a term used by Unruh (2000) to describe the interdependency of technological systems and institutions at macroeconomic scale. The TIC consists of large technological systems and public and private institutions who govern their diffusion and use. The technological system and the institutions are feeding-off one another in the TIC, which reinforces the systemic lock-in. At an early stage a TIC can play an important role in the adoption of useful technological systems, but in the long-term the TIC can slowdown the adoption of alternative technological solutions. The TIC has a role e.g., in the creation of fossil-fuel dependency in industrialized countries which has resulted in a carbon lock-in. An example of a simplified TIC is the car-centric transportation network where the institutions collect taxes from vehicle owners, to construct and expand the road network, which increases the individual’s urge to drive. The TIC becomes a circle that feeds itself and reinforces a lock-in. (Unruh 2000; 2002)

3. Urban Mobility 2030

The following sub-chapters introduce the key concepts which are important for the target of this research. The sub-chapters introduce the future development of the transport system in the EU, mobility in a circular economy, total cost of ownership and trends in sustainable mobility. The trend of sustainable mobility provides insights to the development paths and policies related to electric vehicles, fuel cell electric vehicles, bicycles, and public transport in the European Union.

3.1. Future development of the transport system in the EU

A transport system in the socio-technical approach is conceptualized as a configuration of elements that include technology, policy, markets, consumer practices, infrastructure, cultural meaning, and scientific knowledge. Major shifts to socio-technical systems are indicated as socio-technical transitions. (Geels 2012)

According to Geels (2012) the future of the transport system is likely to stay as car-dominant for the time being and that public transport modes such as bus, train and light rail likely experience some further growth, and that the technological evolution will result in gradual greening of technology. Since the conclusion by Geels (2012), several policy developments regarding sustainable transport system have taken place in Europe. The European Commission adopted, in 2016, a low-emission mobility strategy and in 2019 the Commission proposed a new CO_2 reduction target for new cars and vans in the market from 2030 onward. The European Council reached an agreement in June 2022 to set a target of 100% CO_2 emissions reduction for new cars and vans by 2035. (European Commission 2016; 2019; European Council 2022)

As part of the “Fit for 55” legislative package, for cleaner road transport the Commission has proposed a target to reduce CO_2 emissions for new cars with 55% by 2030 and for new vans with 50% by 2030. The old targets are 37.5% and 31% respectively. It is also proposed that incentives for new zero- and low-emission vehicles would be removed by 2030 (European Commission 2022a). The cleaner road transport plan includes also public charging stations for cars and vans, and hydrogen refuelling stations for heavy duty vehicles. Public charging stations are planned to be located along the core Trans-European Transport Network (TEN-T) with at least 300 kW power output every 60 kilometres by 2025 and at least 600 kW power output every 60 kilometres by 2030. The charging network is planned to be expanded to the comprehensive TEN-T network with at least 300 kW power output every 60 kilometres by 2030 and at least 600 kW power output every 60 kilometres by 2035. (European Commission 2021a)

The *core* network and *comprehensive* network have been described in the European Union regulation No 1315/2013. The core network includes the identified most important transport corridors, which are important for the development of the sustainable multimodal transport network in the Union. The comprehensive network will ensure the accessibility and connectivity of all regions in the Union. (European Commission 2013)

3.2. Mobility in a circular economy

Mobility is a key priority in the urban environment. Mobility has a significant impact on the quality of life, the local environment, and resource consumption. 13% of the global resource consumption is related to mobility. Vehicle emissions causes 90% of the air pollution in cities and 60% of the air pollution is caused by freight movement. The current urban mobility system experiences inefficiencies also e.g., through congestion, which causes additional fuel consumption and lost time, and lack on loading spaces for delivery vehicles, which results in e.g., illegal parking. (Ellen MacArthur Foundation 2019)

The mobility in a circular economy system focuses on effectively providing solutions for the user's mobility needs by diversifying modes of transport. The advantages of a circular economy development path are the maximized vehicle and infrastructure utilization, lower operating costs, eliminating waste and pollution, and reducing the virgin material consumption. (Ellen MacArthur Foundation 2019)

The European Commission supports the transition to cleaner, greener, and smarter mobility which are in line with the objectives of the European Green Deal. The proposed development goals for a sustainable transport system target improvement in rail connections, public transport, and development in infrastructure for walking and cycling. The Commission targets also development in Smart Mobility solutions, such as connected and automated mobility, and new mobility options and services. (European Commission 2021b)

The urban mobility consists of different actors, services, and modes of mobility. Urban mobility is seen to include e.g., cars, public transport, bicycles, and walking. In the recent years, mainly due to the evolution of the internet, alternative mobility solutions, such as different sharing schemes and mobility-as-a-service (MaaS) have grown in popularity. These sharing schemes consist e.g., of bike-sharing, car-sharing, and scooters. The popularity of sharing schemes builds on the short-term need for mobility, but simultaneously joining a sharing scheme does not require the same amount of capital at the start than owning a vehicle. MaaS, which are complex sociotechnical systems, provide different mobility solutions for users, through a digital platform (Hesselgren et al. 2020). The ongoing pandemic has not led to decrease in interest towards MaaS. (Tomaino et al 2020; Hensher et al 2021)

The integration of MaaS and freight transport has been studied recently by Le Pira et al. (2021). “Public transport is often considered as the backbone of MaaS, complemented by shared and mobility on demand services that should serve a first- or last-mile connection to other modes” (Le Pira et al 2021). The focus in MaaS has so far been on the passenger transport services, and freight transport has mainly been overlooked. The potential for integration of MaaS and freight transport is related to parcel sized packages rather than to larger freight, as shipping of smaller packages are relatively expensive. (Le Pira et al 2021)

A limited number of studies have also focused on the implementation of MaaS in corporate environments. This type of MaaS is usually called CMaaS or corporate MaaS and the research have focused on e.g., understanding user practices and attitudes in MaaS (Hesselgren et al. 2020; Günther el al. 2020), key barriers in MaaS development and implementation (Zhao et al. 2020) and measuring system-level impacts of CMaaS (Vaddadi et al. 2020). In CMaaS the organisation can be the service provider and/or the operator or the organisation could have a third-party as a service provider (Vaddadi et al 2020). The organisation is usually able to control variables related to the service such as available transportation modes and pricing of the transportation (Hesselgren et al. 2020). It is identified that the true economic potential of CMaaS is currently insufficiently studied and requires more research (Günther et al. 2020).

3.3. Total Cost of Ownership

In saturated markets urban mobility trends are towards ecological sustainability and demotorization, and these are to replace the traditional values such as, individual status and personal mobility guarantor, associated with private vehicle ownership. Private vehicles are also increasingly linked to high Total Costs of Ownership (TCO) which decreases the desirability of private vehicles as mode of mobility. (Lempp & Siegfried 2022)

The TCO takes into consideration the purchase price of an asset and the costs of the operation of the asset over throughout its life cycle. The TCO is a way of accessing the long-term value of a purchase to a company or an individual. A TCO analysis is usable when comparing alternative drive-technologies that decreases carbon emissions as these usually come with a cost. A TCO analysis offers a way to assess the cost effectiveness of alternative modes of mobility as the costs of the complete lifetime are considered. (Twin 2021; Noll et al 2022)

3.4. Trends in Sustainable Mobility

This chapter introduces technological trends in sustainable urban mobility. As the vehicles used in maintenance are currently mainly ICE vehicles, the focus in this chapter is on competing more sustainable technologies for use in maintenance mobility. The focus is on technological solution and the requirements for use and potential barriers to the transition.

3.4.1. Electric Vehicles

The upfront costs or purchase price of vehicles make up just a portion of the TCO. The upfront cost of a BEV van is forecasted by Bloomberg to match the upfront cost of an ICE van by 2024 – 2025 (Figure 2). The most important factor of the price of electric vehicles is the cost of battery packs. The price of battery packs has decreased rapidly and is estimated to continue decreasing as the use technology expands and technology matures. The TCO parity for medium and heavy BEV vans is estimated to be reached in 2022 – 2023. The lack of adequate supply of BEV vans remains however as the key barrier for the utilization. (Transport & Environment 2021)

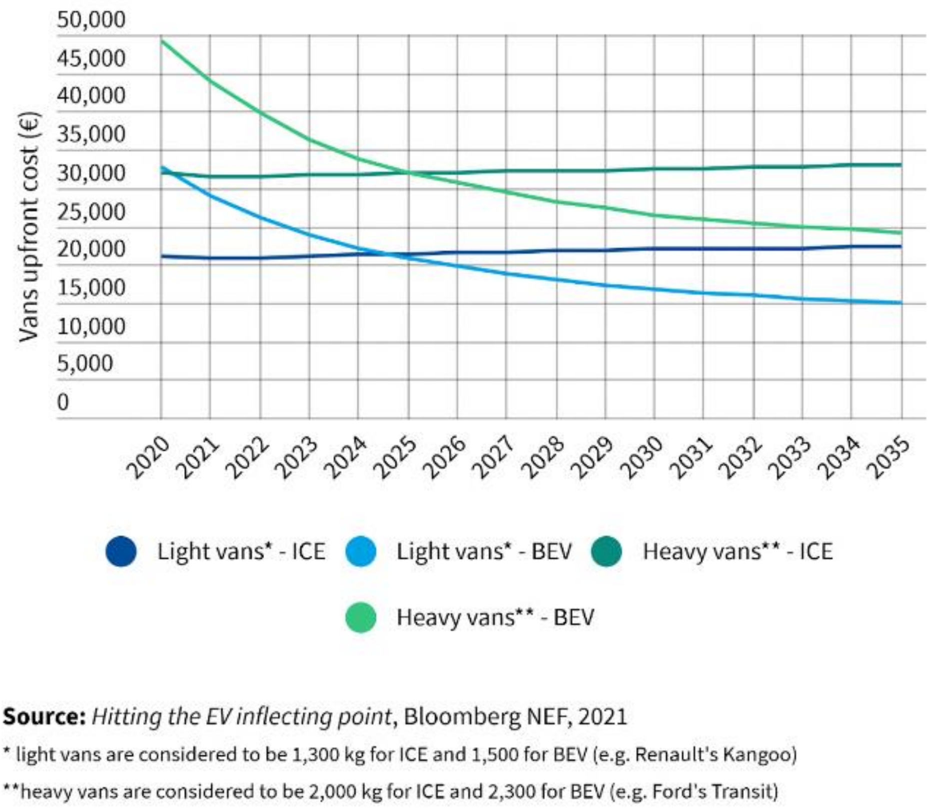

Figure 2. Forecast of upfront costs for light and heavy vans (Transport & Environment 2021).

PHEV and HEV usually referred to as *hybrid* vans may not be seen as a long-term solution for CO_2 emissions reduction. In 2020, average hybrid vans emit approximately 14% lower CO_2 emissions compared to average ICE vans. The availability of hybrid vans is lacking as only two main OEMs (Original Equipment Manufacturer) Ford and Fiat are selling hybrid vans. It is estimated that in 2030 hybrid van sales make up for approximately 2,5% of the total van sales. The availability of hybrid vans and the questionable actual CO_2 emissions reduction potential, compared to ICE vans, remains as barriers for their utilization. (Transport & Environment 2021)

The charging network for EVs must expand as the number of electric vehicles on the roads increase. Charging at home and at the workplace is a priority as most charging will take place at these locations (Transport & Environment 2022a). Transport & Environment have proposed the implementation of "right to plug" legislation, which would give individuals the right to install charging infrastructure at home regardless of a permission from the building owners (Transport & Environment 2022b). Charging of EVs require also behavioural adaption from the users when compared to the current state of dominant ICE vehicles in the transport system (Marletto 2014). The European Union has addressed this in the proposed European Green Deal which proposes to increase the availability of charging stations in the Union area (European Commission 2021a). Charging stations are also built with momentum for low-emission mobility, which supports the penetration of electric vehicles (Schwanen 2015). EVs are also an important part of the future smart grids when EVs can be utilized to stabilize the electric grid and reduce supply and demand unbalances (Marletto 2014).

Life cycle assessments (LCA) on BEVs have been increasing recently. Car manufacturer Polestar published a LCA for the carbon footprint of their Polestar 2 model in 2021. In the report Polestar has compared the LCA of the Polestar 2 with the LCA of a Volvo XC40 with a petrol ICE. The comparison has been made between these two models as they represent a relatively similar size and both companies are sub-brands of Chinese car manufacturer Geely. The LCA was conducted according to ISO LCA standards, ISO 14044:2006 LCA requirements and guidelines and ISO 14040:2006 LCA principles and framework. (Polestar 2021)

The results of the LCA concludes that the major differences in the carbon footprint of the vehicles comes from the material production and the use phase of the vehicle. A BEV has a higher carbon footprint in the materials production phase than the vehicle with an ICE. The difference in the material production phase comes mainly from the production of the 78 kilowatt-hour lithium-ion battery pack of the vehicle and when the battery pack is included in the calculations it increases the BEVs production phase carbon footprint with approximately 70% compared to the ICE vehicle. (Polestar 2021)

The use phase of the BEV is critical for the impact on carbon footprint reduction over the lifetime of the vehicle. Polestar calculated the LCA for the Polestar 2 with an estimated lifetime range of 200 000 kilometres. During this lifetime the carbon footprint of the Polestar 2 is in all scenarios lower than the one of the Volvo XC40 ICE. Scenarios were calculated with different electricity mixes: the global electricity mix, European electricity mix and pure wind power. The use phase carbon footprint of the Volvo XC40 ICE was 41 tonnes CO_2-equivalent, when the use phase carbon footprint of the Polestar 2 was 23 tonnes CO_2-

equivalent with global electricity mix, 15 tonnes CO_2-equivalent with European electricity mix and 0,4 tonnes CO_2-equivalent with wind power. (Polestar 2021)

When using wind power, the Polestar 2 meets the break-even with the Volvo XC40 ICE after 50 thousand driven kilometres. With the European electricity mix the driven range for break-even is 78 thousand kilometres and with the global electricity mix the driven range is 112 thousand kilometres. The break-even point is used to describe the number of driven kilometres after which the BEV has lower lifetime carbon footprint than the ICE vehicle. (Polestar 2021)

Another LCA study concludes that BEVs in Europe have 63 to 69 per cent lower life cycle emissions than comparable ICE cars. The LCA study took into consideration the life cycle GHG emissions of the vehicles including the vehicle manufacturing, battery manufacturing, maintenance, fuel consumption and energy production. The life cycle GHG emissions of BEVs compared to ICE cars were estimated also for year 2030 and the assumed technological advancements and reduction in GHG emissions of battery manufacturing is estimated to result in 71 to 77 per cent lower life cycle emissions compared to the ICE counterparts. (Bieker 2021)

The phenomenon of range anxiety is a challenge that has been identified in relation to adoption of EVs, and it has been studied e.g., from the perspective of the impact of the driving experience (Rauh et al 2014), the charging station location problem (Guo et al 2018) and charging infrastructure (Neubauer et al 2014). The range of EVs is common concern for individuals and companies who might be planning to purchase a new vehicle (Virta 2022a). The real-world range of the EV is influenced by several parameters such as e.g., the weight of the vehicle, size of the battery pack, infrastructure design and driving style (Szumska et al. 2021).

A typical medium-sized van e.g., Opel Vivaro-e with 75 kWh battery pack has an advertised range of approximately 330 kilometres and the small-sized van Opel Combo-e with 50 kWh battery pack has an advertised range of approximately 275 kilometres (Opel 2022a; Opel 2022b). EVs can be charged with either AC-speeds (e.g., home charging) ranging from 3 – 43 kW or CCS-speeds (Combined Charging System) (e.g., fast charging) ranging from 50 kW up to 350 kW (Virta 2022b; 2022c). The charging times in the Opel Vivaro-e AC-speeds, which is supported up to 11 kW are from 7-42 hours and on CCS-speed which is supported up to 100 kW is 48 minutes (Opel 2022a). It is estimated that the efficiency and range of EVs will continue to increase in future (Mercedes-Benz 2022).

3.4.2. Fuel Cell Electric Vehicles

Fuel cell electric vehicles (FCEV) use hydrogen as energy source. FCEVs are in practice electric vehicles, where the energy is generated internally in fuel cells from hydrogen. Hydrogen production requires electricity which results in additional losses of energy as hydrogen is converted in the FCEVs back to electricity. Wider utilization of hydrogen is however an important part of the plan for decarbonisation of mobility in the EU. EU adopted in 2020 a dedicated strategy on hydrogen, where the target is to bring together different actors in research and innovation on the technology. Hydrogen, produced with renewable electricity, plays also a key role in the European Green Deal. Hydrogen can provide a partial solution in the Union to reach emissions reduction targets by 2030 and by 2035, especially in heavy-duty vehicles if the industry decides to invest in the development of the technology. (European Commission 2021c; 2022b)

The emissions reduction potential of FCEVs is 86 to 89 per cent as compared to ICEs using diesel or gasoline as fuel (Burkhardt et al. 2016). Another study has concluded that the emissions reduction potential depends heavily on the production of hydrogen, as the use of natural gas-based grey hydrogen results in 21 to 26 per cent lower life cycle GHG emissions than comparable ICE cars. The use of blue hydrogen, which combines natural gas and carbon capture and storage could result in 68 per cent lower life cycle GHG emissions. The use of green hydrogen which is produced on energy sources solely from renewable sources could according to the study result in 76 to 79 per cent lower life cycle GHG emissions when compared to similar ICE cars. (Bieker 2021)

There are currently approximately 150 hydrogen refuelling stations (HRS) with 700 bar refuelling capability and 30 HRS with 350 bar refuelling capability in operation in Europe with approximately 40, and 18 respectively, more under construction (H2 Initiative 2022). Extensive utilization of FCEVs requires a substantial increase in the number of refuelling stations in the Union. Currently the refuelling infrastructure is focused on Central Europe with most of the refuelling stations located in Germany, as seen in figure 3. As part of the

European Green Deal the European Commission has set a target to improve the alternative fuel infrastructure, including hydrogen refuelling stations and to have one alternative fuels station available every 150 km along the *core* TEN-T network and in every urban node (European Commission 2021c). An urban node is defined in the EU Regulation No. 1315/2013 as “an urban area where the transport infrastructure of the TEN-T network, such as ports including passenger terminals, airports railway stations, logistic platforms and freight terminals located in and around an urban area, is connected with other parts of that infrastructure and with the infrastructure for regional and local traffic” (Regulation 1315/2013).

FCEV are expected to play a minor role in the van, or light-duty vehicle, market segment during this decade as assumed by Transport & Environment (2021). FCEVs would represent only 20 000 vehicles of the two million vans annual production in Europe in 2030. It is projected that vehicle manufacturers have 7 FCEV models available in 2030, in comparison to the 40-50 ICE models to be produced in Europe. (Transport & Environment 2021)

Figure 3. Hydrogen refuelling stations in Europe on 31.03.2022 (H2-Map 2022)

The advantages of the utilization of FCEVs are the substantial emissions reduction potential of the technology compared to ICEs (Burkhardt et al. 2016; Bieker 2021). FCEVs have also advantages compared to similar sized BEVs such as e.g., longer estimated 400-kilometre WLTP (World harmonized Light-duty vehicles Test Procedure) range and faster, few minutes refuelling of FCEVs (Stellantis 2021; Peugeot 2022).

Currently, the main challenges of the utilization of FCEVs are related to the limited hydrogen refuelling network (H2 Initiative 2022) and availability of models by vehicle manufacturers (Transport & Environment 2021). From the emissions reduction perspective the main challenge is the supply of green hydrogen. Hydrogen has been produced with biomethane as replacement for fossil natural gas in small test quantities e.g., by Repsol (Repsol 2021). Hydrogen is currently mainly produced from fossil fuels and when examining the current and estimated projects related to the production of green hydrogen, the supply of green hydrogen by 2030 will represent approximately 10% of the current total need of hydrogen. (IEA 2021)

3.4.3. Bicycles

A CityChangerCargoBike (CCCB) -project was launched as part of the EU's research and innovation funding programme Horizon 2020. The aim of the programme is to identify the potential use cases for cargo bikes in urban mobility and introduce the possibilities of using cargo bikes for private and commercial users. (Innovation and Networks Executive Agency 2022)

The European Committee for Standardization (CEN) established in 2020 a working group to develop an EN standard for cargo bikes. The current regulation in Europe related to cargo bikes rely mainly on local regulation in Germany and France as these countries have established industry standards for cargo bikes. The standards for cargo bikes in Germany (DIN 79010:2020-02) and France (NF-R30-050-1) serve as basis for the EN standard in development. The standardization on Union-level is currently under approval and it is estimated that a standard could be ready for voting by 2023 (CEN 2022). (CityChangerCargoBike 2022)

The expected product life cycle of electric bikes varies depending on the source. The expected life span of an e-bike is from 3-20 years if it has been maintained properly. The shorter life span expectancy takes into consideration the life span of the battery packs and motor. The longer life span expectancy takes into consideration the life span of the frame including e.g., the battery pack and motor changes during the life cycle. In postal service the battery packs of e-bikes have lasted for 2-4 years. The estimated life span of e-bikes in kilometres is 15 000 km. (Fraselle et al. 2021; Machedon-Pisu et al. 2020; Motiva 2022; Schünemann et al. 2022)

The suitability of cargo bikes in e.g., construction logistics and service logistics have been studied in a two-year research programme which focused on the use of light electric freight vehicles (LEFV) in city logistics in The Netherlands. The term LEFV includes cargo bikes, cargo mopeds and small electric distribution vehicles. The study was conducted in a partnership between universities, public organisations, mobility solutions providers and industry actors. (Ploos van Amstel et al. 2018)

It is identified that the use of LEFVs in construction logistics can be limited. LEFVs are not suitable for transportation of heavy and large sized shipments, but LEFVs can be utilized in e.g., smaller time-critical shipments. LEFVs can also be utilized in transport of materials from a hub or wholesaler to the construction site. (Ploos van Amstel et al. 2018)

In service logistics the activities include e.g., maintenance, installation, and reparation. Delivery of a service is the key activity, and it can require the transport of materials and tools. Advantages of using LEFVs in service logistics is the lower space requirement of the vehicle which supports finding a parking place easier. The unpredictability of routes was regarded as a possible disadvantage for the use of LEFVs in service logistics. (Ploos van Amstel et al. 2018)

It is estimated that approximately 10 to 15 per cent of city logistics shipments could be covered with LEFVs. In another study it was estimated that 51 per cent of the motorized trips related to goods transport could be replaced by transport with a bicycle or cargo bike, with a 50 per cent potential in service and business logistics (Wrighton et al. 2016). The potential for higher use of LEFVs in urban areas in the future depend on possible area restrictions on delivery vans from city administrations. (Ploos van Amstel et al. 2018)

3.4.4. Public transport from logistics perspective

The urban public transport system has a significant role in providing alternative modes of transportation in the urban environment. The urban public transport system has also a major role in reducing congestion in urban areas and contributing to increased quality of urban life.

The public transport system is a complex structure which includes social, economic, political, technological, and organizational aspects. The main modes of public transport are e.g., buses, trams, rail transport and water transport. (Canitez 2019)

Research related to the use of public transport in logistics has e.g., focused on crowd-shipping (Gatta et al 2018; Galkin et al 2021), utilization of the urban public transport network in freight deliveries (Galkin et al 2019), creating an urban logistics transport system on the public transit service (Azcuy et al 2021) and integration of MaaS and freight transport (Le Pira et al 2021). Galkin et al (2019) concluded that the requirements for transportation of goods in the public transport system has been insufficiently studied.

The main barriers of utilization of public transport from logistics perspective are currently the regulatory and infrastructure barriers. Urban public transport is currently mainly human-centred, and it serves the purpose of individual mobility. The lack of dedicated space for freight in urban public transport creates a barrier for the use of it in urban logistics. The use of public transport could help in reducing the negative externalities of urban delivery operations (Azcuy 2021). Public transport has also the possibility to be used as method for a specific leg on the shipping route. This would require it to be connected to other delivery methods through e.g., MaaS. (Le Pira et al 2021)

The development of the public transport network is a crucial part of the European Commission’s new Urban Mobility Framework. The Commission states that clear priority should be placed on national and local level on the development of the public transport network, walking, cycling and connected services, such as shared mobility services. As an action the Commission suggests the adoption of Sustainable Urban Mobility Plans (SUMP), for which the framework was created back in 2013. The sustainable urban logistics plan (SULP) was later embedded into the SUMP framework. The purpose of the SUMP is to help address challenges related to mobility in entire urban areas including synergies with climate, energy, and spatial plans. The integration of SULP into the SUMP framework supports the actions to reach the Commissions set target of zero-emission city freight logistics by 2030. (European Commission 2021d & 2021e)

3.5. Social aspects of mobility

The social aspects of mobility are a broad topic. This chapter focuses on the daily decisions made by individuals, what impacts the decisions of individuals, what are the social impacts of mobility and how sustainable transition can be achieved from the social perspective.

The Figure 4 displays the average daily distance covered for individuals in 13 European member states. The distances range from 5.6 kilometres covered in Greece to 19.0 kilometres covered in Germany. Commuting to work is the main reason for daily distance covered in most countries. (Eurostat 2021)

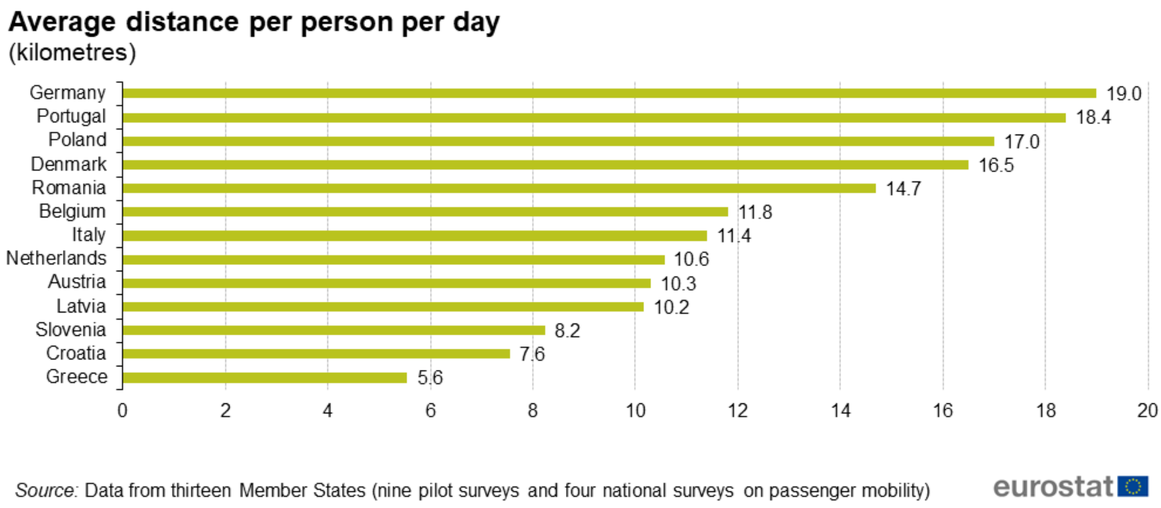

Figure 4. Average distance per person per day (Kilometres) (Eurostat 2021)

The daily travel distance for each Finn on average totals to 41 kilometres, of which 31.1 kilometres were travelled using cars. Sustainable travel modes which include walking, cycling and public transport accounted for 31% of all work-related trips. The megatrend of urbanization is present also in Finland, as the population is concentrating in urban areas and a gradual shift from car use towards sustainable travel modes is expected. (Traficom 2020)

Private car is the most used method for mobility in all member states ranging from 57 to 81 per cent of travelled distance. National differences can be found e.g., in the use of cycling (16 per cent of travel distance) in The Netherlands, and the use of bus, coach and urban rail in Romania and Poland (around 30 per cent of travel distance). (Eurostat 2021)

The private motorised transport is one of the greatest obstacles slowing the transition towards sustainable mobility. The automobility paradigm includes the car, truck and bus, their complete supply chain, the usage of these vehicles and the social and cultural changes it has brought with it. The transition towards sustainable mobility requires a change to the elements of the automobility paradigm, which also require preparation for the possibly dramatic social and economic impacts. (Nieuwenhuis et al 2017)

The climate affecting emissions are not the only impacts arising from mobility. The environmental impacts and social impacts of mobility are interrelated. The social impacts of mobility are also not equally distributed across social classes and societies. E.g., noise pollution and visual impacts of mobility tend to affect all, but they tend to affect poorer parts of the population more than the richer people. (Geerken 2017)

The social aspects of mobility have also been researched e.g., from the perspective of mobility habits of young adults (Delclòs-Alió et al. 2019), information as contributors to the shape of individuals mobility choices (Vecchio et al. 2019; Blayac 2022), and the impact of COVID-19 pandemic on the transportation planning, mobility habits and sustainable development (Cartenì et al. 2022). Young adults have been identified to have e.g., higher environmental consciousness when compared with older adults. There is also evidence that the possession of a drivers' license is declining among the present generation of youths. Rural areas are also usually associated with higher car dependence as these areas have difficulties in providing quality public transportation options. (Delclòs-Alió et al. 2019)

Information is a product and a key factor of the sharing economy. Sharing economy companies (e.g., MaaS companies) are based on data collection and the use of mobility-related data. Information is crucial as it can shape the mobility preferences of individuals. It has e.g., been identified that travel distance has an impact on the mobility behaviour of individuals as the longer the travel distance, the more the user will try to optimize the travel by using information available and by changing behaviour (Blayac et al. 2022). Wide use of information for analytical purposes raises however also concerns regarding privacy and effectiveness. If data is collected from portable digital devices, it creates a scenario where the actor can easily be tracked and has 'nowhere to hide' (Vecchio et al. 2019).

The COVID-19 pandemic also caused a setback in the sustainable mobility transition. The pandemic caused a spike in the sales of used private vehicles in Finland as many individuals who had been using public transportation prior to the pandemic purchased a private vehicle during the pandemic e.g., due to health risks related to use of public transport and the decreased service level of public transport during the prolonged pandemic. During the pandemic the use of public transport decreased significantly as research had found correlation between public transport use and the COVID-19 contagion. How the new measures of hybrid-working and stay-at-home policies will impact the demand for public transport post-pandemic remains to be seen, but the achievements of climate targets rely on the increased usage of public transport (Salomaa 2020; Cartenì et al. 2022)

The IPCC identified in the recent sixth assessment report the need for a behaviour change as part of decarbonization of transport. Time, cost, and income dominate people’s travel choices. There is however also evidence that personal values and environmental values shape choices within the same time, cost, and income limitations. “Individuals are more likely to drive less when they care about the environment.”. (IPCC 2022)

4. Regulation and policies on emissions of road transport

This chapter introduces the recent trends of regulation and policies on emissions of road transport. The focus is on the trends of this decade in the EU and especially in two of the interest countries, namely France and the Netherlands. The trends in this chapter are visualized in figure 6, according to the expected timeline of the events.

Functional low-emission zones (LEZ) are mostly focused on regions in western Europe. The city administrations in several European cities such as e.g., Paris in France and Amsterdam in the Netherlands have established LEZs in the city. The purpose of these LEZs is to improve the air quality in the city through reduction of emission caused by vehicles. The LEZs usually have restrictions for different vehicles categories such as mopeds, cars, vans, trucks, and buses. Zero-emission zones (ZEZ) are planned to be implemented in e.g., Paris, France in 2030, around the Netherlands in 2025, in Bergen, Norway in 2023, and United Kingdom where e.g., a ZEZ has been active in the city of Oxford since February 2022. (Sadler Consultants Europe 2022a; 2022b)

4.1. European Union

The most recent emission standard for cars, vans and trucks in the EU is called Euro 6. The current emission standard Euro 6 was implemented by the EC in 2014, as the successor to the Euro 5 emission standard. By setting emission standards the EC aims to protect the public from particles emitted by vehicles, as particles can lead to respiratory and cardiovascular illnesses, and increased mortality. The Euro 6 emissions standard sets emission limits for e.g., carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_x), particulate matter (PM), and particles. (Regulation 459/2012)

The EC is developing the next generation of emission standard which is expected to include stricter pollutant emission limits for cars, vans, and trucks, and it will be called Euro 7. The Euro 7 standard is expected to be implemented in 2025. With the new Euro 7 standard the Commission aims to improve the air quality across Europe. (Transport & Environment 2022c)

The EC is planning to extend the EU emission trading system (ETS) to also cover road transport, shipping, and larger share of aviation. The current plan is to include emissions of shipping in the existing EU ETS and to create a separate emissions trading system for emissions of road transport and buildings. Including the road transport emissions into the new ETS is expected to increase the cost of fuels used in road transport, even though the direct impact is targeted on the fuel producers. The new ETS for road transport and buildings is expected to become operational in 2025, with a cap for emissions set from 2026. (European Commission 2021f)

4.2. France

The French Ministry of Ecological Transition has established a so called "Crit'Air Sticker" which as an air quality certificate for vehicles in France (Figure 5). The sticker can be required anywhere in the country and local authorities can have additional restrictions for vehicles in specific areas. E.g., in Paris the local authorities are adding requirements for vehicles entering the city's LEZ during this decade. In 2022 the city authorities added a requirement of Crit'Air Sticker 2 for entering the city's LEZ. This requirement requires e.g., diesel vehicles and light duty vans to have in minimum Euro 5 certificates. In 2024 the requirement will tighten to require Crit'Air Sticker 1, which means e.g., that no diesel vehicles may enter the LEZ from Monday to Friday between 08 in the morning and 20 in the evening, light duty vans are still required to be in minimum Euro 5 certified. The Paris city administration are implementing in 2030 requirements in the LEZ where no ICE-vehicles are allowed to circulate in the area, which supports the transition to electric and hydrogen fuel cell vehicles. The aim of these developments is to improve the air quality in the city. (Ministry of Ecological Transition 2022a; Sadler Consultants Europe 2022c)

Figure 5. French Crit'air sticker classification. (Ministry of Ecological Transition 2022b)

4.3. The Netherlands

The Netherlands has a national framework for LEZs and several cities such as e.g., Amsterdam, Eindhoven and Rotterdam have implemented LEZs in their city centres. Municipalities have created LEZs to improve the air quality in the cities. The LEZs apply only to diesel vehicles in the Netherlands and the access is regulated based on the Euro emissions certificate of the vehicles. (Sadler Consultants Europe 2022d; Milieuzones 2022a & 2022b; City of Amsterdam 2022)

The Netherlands have decided on tightening the regulation through implementation of zero emission zones (ZEZ) for logistics from 2025 onward. The logistics include delivery and service vehicles. All new delivery vans and lorries are required to be zero emission in order to be allowed into the ZEZs. This scheme includes a transitional arrangement where the minimum emission standard for delivery vans is Euro 5 from 2025, Euro 6 from 2027 and zero emission from 2028. The municipality of Amsterdam will ban all petrol and diesel vehicles from the LEZ from 2030 onward. (Sadler Consultants Europe 2022d & 2022e)

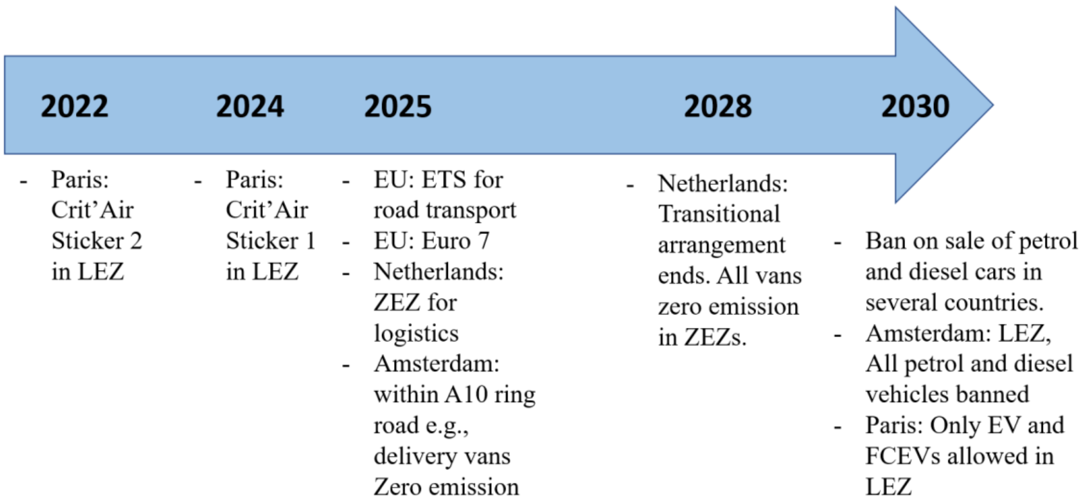

Figure 6. Actions in focus regions until 2030. (Combined from Transport & Environment 2022c; European Commission 2021f; Ministry of Ecological Transition 2022a; Sadler Consultants Europe 2022c & 2022d & 2022e)

5. Methodology

This chapter presents the methodology used in this research. The following sections present the choosing of the suitable research methodology, the data collection methods, methods for analysis and how validity and reliability of the research is ensured.

This research is conducted as mixed approach research to both deepen the understanding of the requirements of maintenance mobility for creation of different future scenarios and modelling the future emissions reduction potential of different scenarios. The mixed methodology approach was chosen for this research as the purpose is to understand the potential of using different modes of mobility in maintenance and modelling the impact of using different modes of mobility on the GHG reduction potential.

Different areas and regions have different requirements for mobility, which led to the decision to choose the qualitative approach as it is possible to gather through interviews deep understanding of the requirements for and experiences of mobility. A user perspective is provided by maintenance technicians through responses to employee surveys conducted prior to this research. The information collected through personnel surveys are analysed to create a comprehensive understanding of the social aspects, such as opinions and possible concerns of maintenance technicians related to the transition towards low-emission maintenance mobility. In addition, personnel whose work is related to the environmental aspects of mobility in the focus regions were interviewed during spring 2022 about the perceptions and existing knowledge related to low-emission mobility and alternative modes of mobility.

The modelling of GHG emissions reduction potential also requires the use of quantitative methodologies as one aim is to quantify the emissions of vehicles and other modes of mobility and model the reduction potential in different scenarios. The GHG reduction potential calculations will utilize information from the vehicle fleet and generic information on emissions of different transport modes, and energy sources.

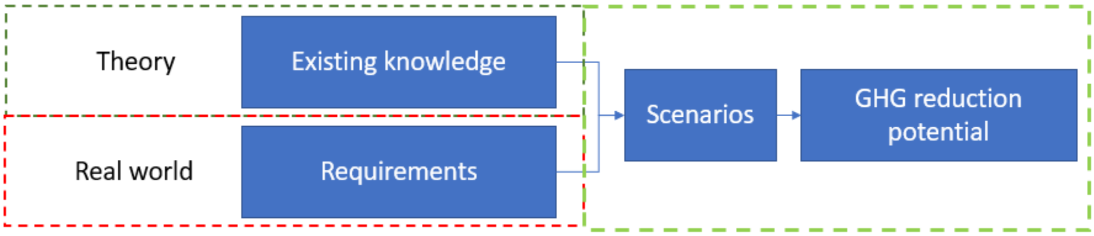

Figure 7. Description of thesis process

The theory of socio-technical approach creates a structure to the understanding of the current operating environment. This theory is combined with observations from the interviews to create future scenarios through scenario analysis. The scenario analysis is used as basis for the calculating estimates of GHG reduction potential in maintenance mobility. The process is visualized in figure 7. The aim of this thesis is to understand the enablers and barriers for transition to low-emission mobility, the estimated cost impact of the transition, the GHG reduction potential and the social impact on personnel.

5.1. Scenario Analysis

Scenarios supply a hypothetical construct of possible future which builds on knowledge gained in the present and past. “Scenarios are holistic pictures of the future, setting out alternative ways in which the world could evolve” (Khong 2019). Scenarios are not an illustration of the reality as they do not provide knowledge of the future. “Scenarios are descriptions of journeys to possible futures. They reflect different assumptions about how current trends will unfold, how critical uncertainties will play out and what new factors will come into play” (UNEP 2002 from Kosow et al. 2008). (Kosow et al. 2008)

“Scenarios are used to attain different goals and thus meet the need for different functions” (Kosow et al. 2008). These functions can be laid out in ideal-typical manner in four dimensions. The first dimension is the explorative and/or scientific function, second is the communicative function, third is the function of target concretization and the fourth is the decision-making and strategy formation function. (Kosow et al. 2008)

In the explorative and/or scientific function the purpose is to deepen the understanding of future relevant factors and possible future development paths. The scenarios of the process not only deepen the knowledge, but also reveals the limits to the knowledge e.g., the dilemmas, gaps, uncertainties, and unpredictability's. "Scenarios are perhaps most effective when seen as a powerful tool to broaden perspectives, raise questions and challenge conventional thinking". (Kosow et al. 2008)

In the communicative function scenarios can be utilized in two ways. Firstly, the scenarios can be generated as part of the communicative process to promote the shared understanding of a problem and to promote the exchange of ideas and perspectives on the topic. Secondly, the scenarios can be used to generate communication and inform about topics and priorities. Usage of scenarios in communication expands the understanding of the topic and enriches the debates on the topic. (Kosow et al. 2008)

In the function of target concretization, the scenarios can be utilized in the development and concretization of goals. The scenarios create possibilities to answer the questions about wanted targets and hoped achievements. Scenarios can be utilized to create images of the future and reflect on the desired future developments. (Kosow et al. 2008)

In the decision-making and strategy formation function the scenarios are used in processes of arriving at decisions and carrying out strategic planning. The scenarios can be used as basis to options and indicators for taking action. In addition, scenarios make it possible to evaluate decision-making processes, actions to be taken and strategies. This is usually done with several different alternative scenarios which are compared with one another to illustrate different future development paths. (Kosow et al. 2008)

5.1.1. Scenario construction process

The scenario construction process has been described by Chermack (2011) and is displayed in the figure 8. The process consists of five phases which are project preparation, scenario exploration, scenario development, scenario implementation, and project assessment.

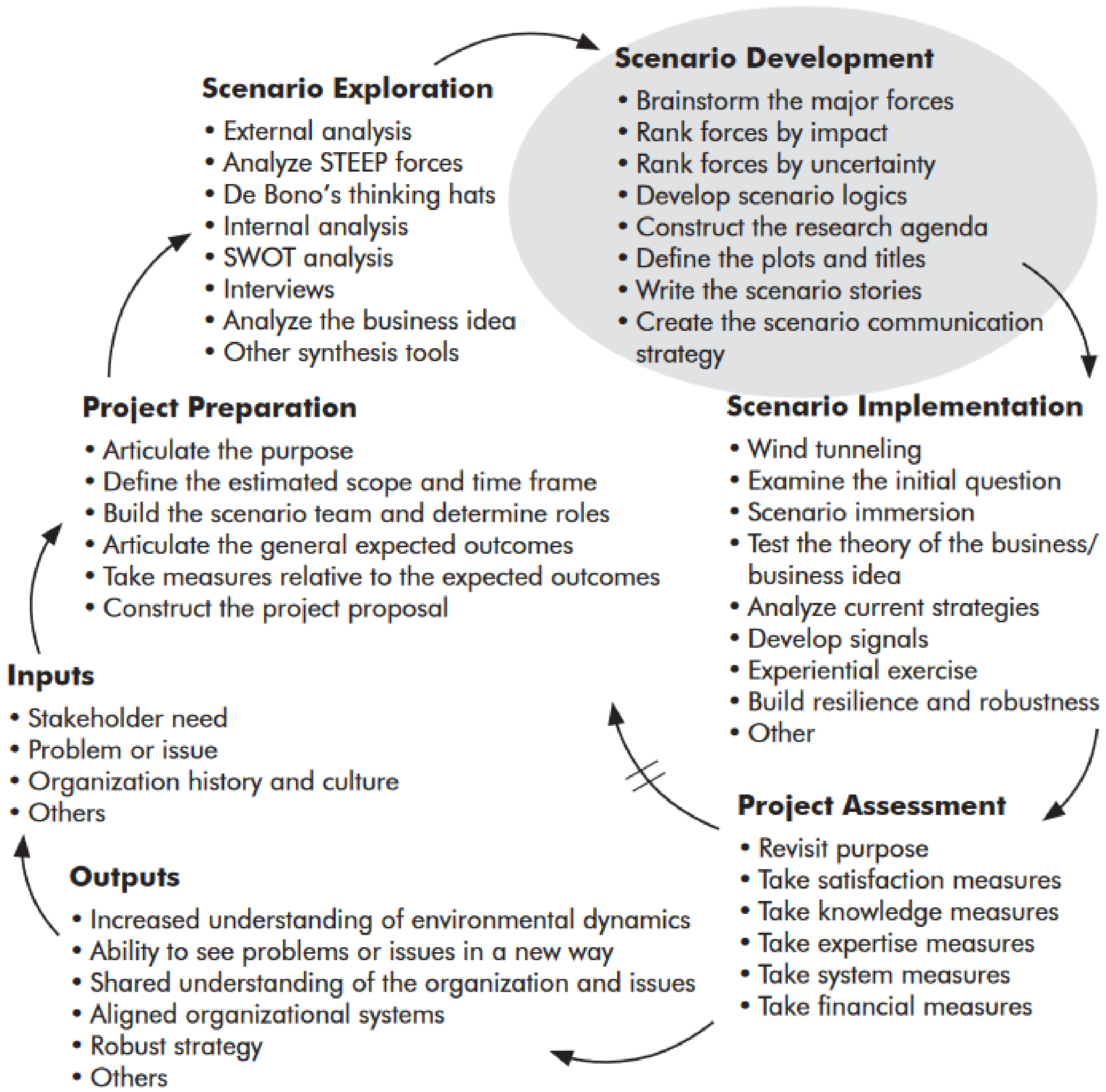

Figure 8. Overview of the Performance-Based Scenario System (Chermack 2011)

In the scenario exploration -phase the focus is on analysis of the internal and external environments of the organization. In the external analysis the goal is to expand the knowledge of relevant external factors such as the social and economic factors, and to gather other information relevant to the objective in focus. In the internal analysis the goal is to understand the forces in the organization, which can be achieved e.g., through interviews with key stakeholders. (Chermack 2011)

The scenario development -phase builds e.g., on workshops used to create scenarios. The outcome of the scenario development is two to four scenarios which are relevant, plausible, and challenging. A suggested approach to the number of scenarios is to have one status quo scenario and two alternatives. The two alternative scenarios can be used to provide compelling stories of fundamentally different futures. The use of three scenarios creates the tendency to fall into the thinking of best case, worst case, and the status quo. Another suggested approach is to use four scenarios, which can be used in e.g., a 2 by 2 matrix and which helps in avoiding common thinking traps related to the use of two or three scenarios. (Chermack 2011)

The scenario implementation -phase focuses on actions how to get the most out of built scenarios and methods to impact the thinking inside the organization. For the implementation of scenarios, it is vital to activate and engage decision makers already in the scenario building phase. (Chermack 2011; Khong 2019)

5.2. Life cycle analysis and GHG emissions calculation

The GHGs are important due to their global warming potential GWP) and the most common GHGs that result from combustion are carbon dioxide (CO_2), methane (CH_4) and nitrous oxides (N_2O). CO_2-equivalent (gCO_2e) is used as unit in GHG calculation to simplify calculations, as CH_4 has 21 times greater GWP than CO_2 and N_2O has 310 times greater GWP than that of CO_2. Fossil fuels contain also other pollutants such as hydrocarbons, nitric oxides and particles which have direct impact on the human health. Life cycle analysis calculations can be done with commercially available software such as GaBi. (Silva et al. 2006; Stanojevic et al. 2021)

The life cycle analysis assessments of GHG emissions can be divided into at least three different categories. These are tank-to-wheel (TTW), well-to-tank (WTT) and well-to-wheel (WTW) contributions. TTW contribution describes the GHG emissions generated through fuel use by a vehicle also referred to as tailpipe emissions. WTT contribution covers the GHG emissions generated in the processes of fuel extraction to the refuelling station. WTW considers the life cycle of the fuel from fuel extraction to the use in vehicles. (Silva et al. 2006; Saniul Alam et al. 2016)

The GHG Protocol Initiative was launched in 1998 with mission to develop internationally accepted GHG accounting and reporting standards. The GHG Protocol Initiative have later published guidance's to e.g., scope 2 and 3 emissions reporting. Well-designed and maintained corporate GHG inventories, which reflects the GHG emissions of the company, can serve several business goals, such as managing risks, identifying reduction opportunities, and participation in mandatory and voluntary programs and actions. (GHG Protocol Initiative 2004; 2022)

The scope 1 emissions are direct emissions from sources that are owned or controlled by the company. GHG emissions such as e.g., CFCs and NO_x, which are not covered by the Kyoto Protocol are excluded from Scope 1 but can be reported separately. The scope 2 emissions are indirect GHG emissions from the generation of purchased electricity, steam, heat or cooling. The scope 2 reporting guidance includes instructions for reporting the GHG emissions of electricity if the purchased electricity do not have known emission factors. In this case the residual mix emission factor should be used, if it is available, for the unknown share of electricity. (GHG Protocol Initiative 2004; 2015)

The emissions of leased assets such as e.g., cars and vans may be categorized as scope 1, scope 2, scope 3 emissions in category 8 or scope 3 emissions in category 13. Scope 3 category 8 emissions are so called upstream leased assets and scope 3 category 13 are downstream leased assets. Upstream leased assets describe assets that are leased and operated by the company. Downstream leased assets describe assets that are owned and leased to others by the company. The type of leasing agreement and organizational boundary approach determines whether the emissions from assets are categorized as scope 1, 2 or 3. (GHG Protocol Initiative 2011)

GHG emission calculations can be used e.g., to determine the carbon footprint of a company, organization, or country. “Companies shall choose and report a base year for which verifiable emissions data are available and specify their reasons for choosing that particular year” (GHG Protocol Initiative 2004). Structural changes such as e.g., mergers, acquisitions, and divestments have also an impact on the company’s GHG emissions calculation, as these events require a recalculation of the base year emissions. GHG emissions must be calculated according to a company policy, in a consistent manner, in order to track emissions over time. (Scrucca et al 2020; GHG Protocol Initiative 2004)

However, the solely use of GHG emissions or carbon footprint as measure in development of company or government policies can be misleading as environmental problems include also other important issues such as e.g., eutrophication and toxicity impacts. The use of only one measure can lead to reduction in GHG emissions and simultaneously to the increase of other environmental impacts. (Scrucca et al 2020)

6. Case Study

This chapter introduces key findings from interviews with personnel, which will be used as background information for scenario creation. The findings are related to the current state of the work of maintenance technicians.

The current working model in the European markets is constructed around the combination of a maintenance technician and a vehicle. As of today, the main transportation method for maintenance technicians in this region are ICE vehicles with marginal shares for HEVs, CNG vehicles and BEVs. The maintenance vehicle fleet consists mainly of leased vehicles with a five-year leasing plans. The size of the vehicles varies depending on the country, as technicians in some countries prefer vans and other make use of smaller cars. Other factors impacting the vehicle size are e.g., the role of the technician and the area they operate in. It has been brought up during interviews that vehicles are also “safe spaces” for technicians during workdays and the possible transition to other modes of mobility require solving this challenge.

As technological advancements in the recent years have enabled the introduction of EVs in the maintenance vehicle fleet, simultaneously several challenges related to their social acceptance have been brought up. The transition away from ICE vehicles require adaptation to new technologies. From the social requirements perspective, the main questions related to the transition concerns range, charging and right sizing of the vehicle.

Traffic related aspects cause increasingly challenges to maintenance technicians especially in old European city centres such as e.g., Amsterdam. Urban areas and city cores are e.g., identified by narrow streets and limited space for vehicles, which leads to few parking options and traffic congestion. Municipalities are battling these challenges with increased parking fees and road tolls which increase the total cost of operations in these areas. These adds challenges for the operations in these areas as costs are only expected to increase in the coming years.

The required carrying capacity of vehicles have been discussed during interviews, but no certain answer to the question was given. In the case of downsizing however the usual response was that solutions were to be found through discussion with personnel and the right sizing were not seen as a major challenge. The vans that are currently in use are fitted with trailer hitches for the possibility to move more parts to the needed location.

The range of currently available EVs have raised questions in the organization. Vehicles such as the Opel Vivaro-e, which is a typical medium-sized electric van have an advertised range of 330 kilometres. The range is 1/3 of the estimated 900–1000-kilometre range for a Renault Trafic, which is a typical medium-sized ICE van. Smaller cars such as the Volkswagen ID.3, which has been taken up by the organization in the Netherlands have an advertised range of 413 kilometres. The Volkswagen ID.3 are seen as a replacement to Toyota Corolla HEVs. The range of the vehicle is typically a question in the use of vehicles in rural areas and during on-call duties.

The emissions of maintenance vehicles are mainly related to the burning of fossil fuels. The GHG emissions of a typical Renault Trafic ICE van is 186 g/km. The consumption of the vehicles is however monitored by following the amounts of purchased fuels, which provides a representation of the true consumption, rather than the advertised theoretical consumption of the vehicles. The tailpipe emissions of EVs are 0 g/km.

Available information on daily travel distance varies depending on the country in question. Telematics information is becoming more valuable e.g., due to reporting requirements on vehicle emissions, but also for possible implementation of alternative modes of mobility. These factors support the further examination of possibilities for telematics collection and utilization.

6.1. Technical analysis

A technical comparison of the different transport modes is presented in tables 1 and 2. The key parameters chosen for the comparison are model, range (WLTP), load capacity, battery capacity, drag capacity, emission level, and CO_2 emissions per kilometre. The models for this comparison were chosen based on typical vehicles currently existing in the vehicle fleet. These typical vehicles are the Renault Trafic van, Ford Transit Connect van, Toyota Corolla Hybrid, Volkswagen Caddy CNG van and in addition to these the potential alternative EVs Opel Vivaro-e and Volkswagen ID.3 was chosen to the comparison. In addition to the vehicle comparison a cargo bike and an e-scooter were also included in the comparison to give an understanding of their technical capabilities.

The range of the vehicle is important as a technician must be able to get through a workday without the need to spend time refuelling or charging the vehicle. The range of the ICE, HEV and CNG vehicles are estimated based on the estimated consumption and fuel tank size, as no specific range estimate were provided in the manufacturer's materials. The range of the EVs, cargo bike and e-scooter are based on estimates provided by manufacturers or retailers. The life span estimate of a vehicle, cargo bike or e-scooter indicates for how it can be used before it must be replaced. The life span is impacted by e.g., durability, repairability, driving profile, and daily travel distance (Machedon-Pisu et al. 2020). The life span impacts also the cost of use for the type of mobility.

The load capacity and dimensions of the vehicle or cargo bike is an important factor as technicians need to carry e.g., tools and parts with them through the working day. The load capacity data is based on information provided in the manufacturers' materials. The load capacity includes the weight of the driver. The battery capacity of the vehicle or cargo bike is an important factor as the battery pack manufacturing causes major environmental impact of a new EV. The comparison also displays the difference between EVs and cargo bikes in terms of battery capacity in relation to load capacity and range.

Maintenance technicians have occasionally the need to attach a trailer to the vehicle to transport components to the required location. The drag capacity is an important factor as it displays how much mass the vehicle can drag.

The emission level of vehicles is an important factor as several municipalities are restricting the access to specified areas for vehicles depending on the emission level. The emission level information is provided in manufacturers' materials. Finally, the factor of CO_2 emissions per kilometre of different transport modes is included in the comparison. The CO_2 emissions is used as an indicator for the local emissions created by the transport mode. The local emissions have e.g., direct impact on the quality of life in the area.

Table 1. Technical comparison of transport modes.

Transport mode	**Diesel van (medium-size)**	**Diesel van (small)**	**BEV van**	**CNG van**
Model	Renault Trafic Blue dCI 150 EDC-aut. Nordic Edition. L1H1	Ford Transit Connect 1.5 TDCi 120hv A8 L2	Opel Vivaro-e	Volkswagen Caddy TGI
Range (WLTP)	1000-1100 km	1000 km	330 km	600 km
Life span	>160 000 km / 10-20 years	>160 000 km / 10-20 years	>160 000 km / 10-20 years	>160 000 km / 10-20 years
Load capacity	~1000 kg	853 kg	925 kg	750 kg
Battery capacity	N/A	N/A	75 kWh	N/A
Drag capacity (kg)	750/1800	1390	1000	N/A
Emission level	Euro 6 D-Full	Euro 6d	N/A	Euro 6
CO_2 emissions/ km (WLTP)	186 g/km	156 g/km	0 g/km	109 g/km
Source:	(Machedon-Pisu et al. 2020; Renault 2022a; 2022b)	(Machedon-Pisu et al. 2020; Ford 2022a)	(Machedon-Pisu et al. 2020; Opel 2022a)	(Machedon-Pisu et al. 2020; NGVA Europe 2019)

Table 2. Technical comparison of transport modes.

Transport mode	**HEV car**	**BEV car**	**Cargo bike**	**E-scooter**
Model	Toyota Corolla Hybrid 1.8	Volkswagen ID.3 150kW/58kWh	Urban Arrow Cargo e-bike	Segway Max Plus X
Range (WLTP)	950 km	413 km	40 km (one battery) / 80 km (two batteries) (not WLTP)	55 km (not WLTP)
Life span	>160 000 km / 10-20 years	>160 000 km / 10-20 years	15 000 km / 3-20 years	Up to 5 years
Load capacity (kg)	535	458	Up to 200 kg (incl. Driver)	100 kg (incl. Driver)
Battery capacity (kWh)	N/A	58 kWh	0.5 kWh	0.5 kWh
Drag capacity (kg)	750	0	0	0
Emission level	Euro 6d-TEMP	N/A	N/A	N/A
CO_2 emissions/ km (WLTP)	101 g/km	0 g/km	0 g/km	0 g/km
Source:	(Machedon-Pisu et al. 2020; Toyota 2022)	(Machedon-Pisu et al. 2020; Volkswagen 2022a; 2022b)	(Machedon-Pisu et al. 2020; Motiva 2022; Schünemann et al. 2022; Urban Arrow 2022a; 2022b)	(Segway 2022; Tier 2022)

In addition to above compared transport modes, the interest has been towards multimodal transportation and its efficiency. The emissions of public transport are challenging to calculate for individuals, as the service providers such as GVB in Amsterdam, HSL in Helsinki and RATP in Paris have not disclosed specific information on emissions per travelled kilometre. GVB has however published a target to provide zero emission bus transport by 2025, while the subway and trams already use 100% green electricity (VDL 2022). HSL requires the use of renewable electricity such as e.g., wind power, hydroelectricity and solar energy in metro and tram operations, and trains in the HSL region are operated with hydroelectricity (HSL 2022). The annual cost of a public transport travel pass, which allows unlimited travel in all zones in Paris region in France is 827,20€ in 2022 (RATP 2017). The annual cost of a travel pass in Amsterdam is 935,00€ in the 2-star area, which covers the Amsterdam centre and areas surrounding it (GVB 2022).

The possible use of rental cars and other vehicles such as Citroën Ami's have also been brought up during discussions. Rental car use can provide temporary solutions to mobility requirements when other mobility solutions are not optimal. The use of rental cars can increase the efficiency of vehicle use. The emissions of rental cars are accounted for in the scope 1, 2 or 3 depending on the type of lease agreements, however with a rental car the company might have less possibilities to impact the models of vehicles that are available for rent. The Citroën Ami is available as a cargo version, which could potentially be useful for use cases in maintenance mobility. The vehicle is a lightweight one-seat EV, which features a 5,5-kWh battery pack, a 75-kilometre range, 45 km/h top speed and a 140 kg load capacity (Citroën 2021). From the technical specifications the Ami is relatively similar to electric cargo bikes. The Ami provides weather protection, but it requires however the same infrastructure as cars and vans, which results in same limitations regarding e.g., charging.

6.2. Social Analysis

The table 3 introduces key parameters of transport modes, which allows the comparison of the transport modes from the social perspective. The parameters have been chosen based on responses to personnel questionnaires. The focus is on parameters that have been identified as possible challenges in transition towards low-emission mobility in maintenance services.

The chosen parameters are the weather protection included in mobility modes, temperature limitations impacting the usage, refuelling, and charging solutions required for use. The key aspects are compared depending on the transport modes which are ICE, HEV and CNG vehicles, BEV (incl. cars and vans), cargo bike and e-scooter.

The social impacts of mobility arise mainly from the daily travel distance covered with vehicles. The travel distances vary e.g., depending on the density of locations, and the region has also an impact on the travel distance. The travel distance from technicians' homes to job sites must also be considered as it might have an impact on the mobility alternatives on an individual level. An additional requirement comes from possible alert cases, where maintenance personnel are required to travel also outside normal working hours. In these cases, the vehicle used need to have enough range to reach the location.

The refuelling and charging solutions of vehicles are another potential barrier to the adoption of low-emission modes of mobility. The typical vehicle currently used is an ICE vehicle, which represents the socio-technical regime in vehicle technology, and the refuelling infrastructure for ICE vehicles and HEVs already exists. There are region dependent limitations on refuelling infrastructure of CNG vehicles. The possibly implemented BEV's require both public and private charging infrastructure. The private charging of EV's have been planned and it could be supported with means where the one who chooses the BEV could get a charging station to be installed at home if it is possible for the employee. The chargers could be e.g., smart chargers, which have software enabled identification if the vehicle is a company or private car, which enables also double use of the charging station. Charging stations are also planned to be implemented at major company locations. BEV's require charging infrastructure, which is still in development, but is expected to reach a wide implementation by 2030. The batteries of cargo bikes and similar light mobility solutions can be charged at home from a regular wall outlet, which enables charging without additional infrastructure. The charging should however be monitored somehow as the employees want to be compensated for home charging.

Different mobility modes have also different temperature limitations. It can be assumed that cars and vans can be used in any weather, mainly depending on the use range of energy source. Diesel fuels can be purchased in summer or winter quality, which sets the temperature limitations for use of diesel-powered ICE vehicles. The BEV's are not subject to specific temperature limitations. BEV's are however impacted by extreme weather conditions, where both cold and hot weather can impact the range of the BEV. The assumed reduction on the advertised WLTP range can be up to 30% depending on different factors. The cargo bikes have a technical temperature limitation where the usage of the bike is recommended in temperatures ranging from -5 to 40 C. E-scooters have relatively similar range limitation from 0 to 40 C.

Weather protection of the vehicle have been brought up in discussions as the currently used cars and vans enable weather protection for the maintenance personnel. All cars and vans regardless of the energy source provide similar weather protection. Cargo bikes and other light mobility solutions have no direct weather protection for personnel and might require e.g., weather resistant clothing. A possible MaaS solution might require similar clothing as personnel might not always have the possibility to use vehicles.

Table 3. Comparison of social aspects linked to mobility

Transport mode	**ICE/HEV/ CNG vehicle**	**BEV**	**Cargo bike**	**E-scooter**
Model	E.g., Renault Trafic or Ford Transit Connect or Volkswagen Caddy	E.g., Opel Vivaro-e or Volkswagen ID.3	E.g., Urban Arrow Cargo e-bike	E.g., Segway Max Plus X
Usage area	City Core / Urban / Rural	City Core / Urban / Rural	City Core / Urban	City Core / Urban
Weather protection	Yes	Yes	No	No
Temperature limitation	No	No	Yes (-5 – 40 C)	Yes (0 – 40 C)
Refuelling / Charging solutions	Infrastructure exists (limited gas refuelling infrastructure)	Requires charging infrastructure, both public and private	Can be charged from home wall outlets	Can be charged from home wall outlets

7. Scenarios

This chapter presents in the beginning the background information used for scenario generation and the process of generating scenarios. The potential for emissions reduction in scenarios is modelled after the scenario generation. The focus in the modelling is in TTW (Tank-to-Wheel) GHG emissions as the aim of the work is to identify the reduction potential for scope 1 and 2 emissions. The emissions of electricity production are included in the scenarios as they are classified as scope 2 emissions. The long-term aim is to reduce scope 1 and 2 emissions with 50% by 2030. The types of mobility and models utilized in the scenario creation are listed in table 4.

Table 4. Types of mobility and models

Type of mobility	Manufacturer and model	Source
ICE van, medium	Renault Trafic	(Renault 2022a; 2022b)
ICE van, small	Ford Transit Connect	(Ford 2022a; 2022b)
HEV car, medium	Toyota Corolla	(Toyota 2022)
BEV van, medium	Opel Vivaro-e	(Opel 2022a)
BEV car, medium	Volkswagen ID.3	(Volkswagen 2022a; 2022b)
CNG van, small	Volkswagen Caddy	(NGVA Europe 2019)
Cargo bike	Urban Arrow Cargo	(Urban Arrow 2022a; 2022b)
E-scooter	Segway Max Plus X	(Segway 2022a; 2022b)
Public transport	Helsinki (only travel time)	(Biazzo et al. 2019)

7.1. Background of scenarios

Three scenarios were prepared as possible development paths of maintenance mobility by 2030. The scenario 0 gives an overview of the current state of mobility and represents a baseline. The scenario 1 presents major changes to the current state, mainly through the electrification of the vehicle fleet. The scenario 2 presents a more hypothetical but still achievable scenario of multi-modality in maintenance mobility.

The scenarios are created with Europe as the context region and use of all scenarios in other regions require a separate work. The modal shares of scenario 0 which represents the current state of mobility provides an overview of the modal shares in Europe, where as e.g., public transportation is already today a significant part of mobility in some countries outside of Europe. The modal shares of the scenarios are summarized in table 5.

The modal shares are categorized in three areas: city core, urban, and rural. These areas represent an estimate of the use of vehicles by typical daily driving distance. The typical daily driving distance in areas are assumptions made for the example and the actual typical driving distance may differ from the assumptions. In the scenarios it is assumed that the typical daily driving distance, during a working day in city cores is 50 kilometres, in urban areas 150 kilometres and in rural areas 250 kilometres. The scenarios are generated based on the assumptions of the typical driving distance. The scenarios will include general aspects and try not to create solutions useable as such for specific regions.

The areas for the scenarios are defined based on the structure of Helsinki region (Figure 9). Helsinki region is used as an example in the scenarios however, the factors and parameters are only examples and do not represent the actual company specific values for the area. It is assumed that similar characteristics can also be identified from cities in other regions such as e.g., Paris and Amsterdam. An example of the assumed city core area is the city centre of Helsinki. City core areas are characterized by high likelihood for congestion, low average speeds of traffic and high population density. The urban areas are assumed to be areas surrounding city cores with a radius of tens of kilometres. The travel speeds in the urban areas are higher than in city cores, but traffic is still subject to speed limits of built-up areas. The assumed rural areas represent the remaining areas of the region and are characterized by highways with high average travel speeds and longer distances.

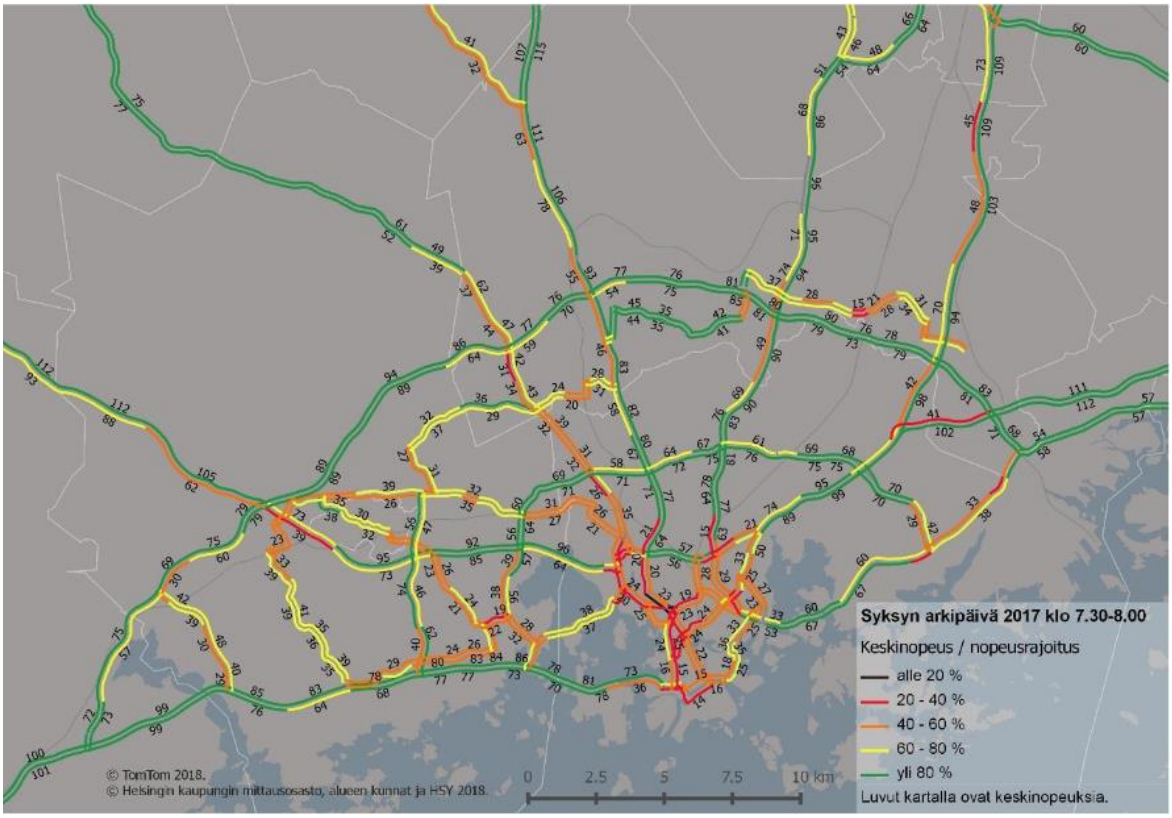

Figure 9. Map of Helsinki region including average travel speed on an autumn morning in 2017. (HSL 2018)

Table 5. Summary of the utilization of modal shares in areas

Modal shares in scenarios	**Area**	**Scenario 0: Current state of mobility**	**Scenario 1: Electrified mobility**	**Scenario 2: Multi-modal mobility**
ICE – vehicle, medium van	City Core	54.5 %	0 %	0 %
	Urban	54.5 %	0 %	0 %
	Rural	54.5 %	0 %	0 %
ICE – vehicle, small van	City Core	43.5 %	0 %	0 %
	Urban	43.5 %	0 %	0 %
	Rural	43.5 %	0 %	0 %
HEV - car	City Core	0.4 %	0 %	0 %
	Urban	0.4 %	0 %	0 %
	Rural	0.4 %	0 %	0 %
CNG – van	City Core	1.0 %	0 %	0 %

	Urban	1.0 %	0 %	0 %
	Rural	1.0 %	0 %	0 %
BEV – medium van	City Core	0.1 %	50 %	30 %
	Urban	0.1 %	55 %	55 %
	Rural	0.1 %	55 %	55 %
BEV – car	City Core	0.5 %	40 %	21 %
	Urban	0.5 %	45 %	45 %
	Rural	0.5 %	45 %	45 %
Cargo bikes	City Core	0 %	9 %	45 %
	Urban	0 %	0 %	0 %
	Rural	0 %	0 %	0 %
Light people movers (e.g., e-scooters)	City Core	0 %	1 %	3 %
	Urban	0 %	0 %	0 %
	Rural	0 %	0 %	0 %
Public transport	City Core	0 %	0 %	1 %
	Urban	0 %	0 %	0 %
	Rural	0 %	0 %	0 %

The utilization of different modes of mobility in the three scenarios and the different areas are summarized in table 5. The modal share is presented as a percentage of total travelled distance in each area. The parameters and their motivations for the different scenarios are listed below:

Share of ICE-vehicle, medium van:

Medium-sized ICE-vans currently represent a major share in the vehicle fleet. In scenario 0 the estimated share of this vehicle type is 54.5 per cent in all areas. The medium-sized ICE-vans are excluded from the scenarios 1 and 2 as the technological development of BEV vehicles and charging infrastructure is assumed to be rapid by 2030.

Share of ICE-vehicle, small van:

Small-sized ICE-vans currently represent a major share in the vehicle fleet. In scenario 0 the estimated share of this vehicle type is 43.5 per cent in all areas. The small-sized ICE- vans are excluded from the scenarios 1 and 2 as the technological development in BEV vehicles and charging infrastructure is assumed to be rapid by 2030.

Share of HEV – car:

HEV currently represent a marginal share of the total vehicle fleet. In scenario 0 the estimated share of this vehicle type is 0.4 per cent in all areas. The HEV are excluded from the scenarios 1 and 2 as the technological development in BEV vehicles and charging infrastructure is assumed to be rapid by 2030, and the true potential of CO_2 emissions reduction with the use of PHEVs is assumed to be limited.

Share of CNG – van:

CNG-powered vans currently represent a marginal share of the total vehicle fleet. In scenario 0 the estimated share of this vehicle type is 1.0 per cent in all areas. The CNG-powered vans are excluded from the scenarios 1 and 2 as the technological development in BEV vehicles and charging infrastructure is assumed to be rapid by 2030, and the use of CNG vans is assumed to be limited due to lack of refuelling infrastructure and availability of vehicle models in required sizes.

Share of BEV – medium van:

Medium-sized BEV vans currently represent a marginal share of the total vehicle fleet. In scenario 0 the estimated share of this vehicle type is 0.1 per cent in all areas. The implementation of an electrified vehicle fleet is supported by proposed new policies by the EC. The share of BEV vans is estimated to increase significantly, and they represent a major share of the vehicle fleet, 50 per cent in city core operations and 55 per cent in urban and rural operations, in the scenario 1. The technological development of BEV vehicles and required charging infrastructure is estimated to be rapid by 2030, which supports the implementation of BEVs. In scenario 2, medium-sized BEV vans are estimated to also represent a major share, 30 per cent in city core operations and 55 per cent in urban and rural operations, due to the load capacity of vehicles this size. The lower share of BEV vans in city core operations is due to higher utilization of cargo bikes and light people movers. The BEV vans are estimated to be the main replacer to similar sized ICE, HEV, and CNG-vehicles in scenarios 1 and 2.

Share of BEV – car:

Passenger car sized BEVs currently represent a small share of the total vehicle fleet. In scenario 0 the estimated share of this vehicle type is 0.5 per cent. The implementation of an electrified vehicle fleet is supported by proposed new policies by the EC. The share of BEV cars is estimated to increase significantly, and they represent a major share of the vehicle fleet, 40 per cent in city core operations and 45 per cent in urban and rural operations, in the scenario 1. The technological development of BEV vehicles and required charging infrastructure is estimated to be rapid by 2030, which supports the implementation of BEVs. In scenario 2, BEV cars are estimated to also represent a major share, 21.5 per cent in city core operations and 45 per cent in urban and rural operations, due to the range of vehicles this size. The BEV cars are assumed to replace small-sized ICE-vehicles in scenarios 1 and 2, however the cargo bikes, light mobility solutions such as e-scooters and public transport is assumed to reduce the share of BEV cars in city core operations in scenario 2.

Share of cargo bikes:

Cargo bikes are currently practically non-existing in the maintenance operations. In scenario 0 the share of cargo bikes is therefore 0 per cent. The implementation of alternative modes of mobility is supported by e.g., congestion in cities and other external factors impacting the car and van use. The cargo bikes are assumed to be useful especially in inner city operations by 2030, which results in an increased share 10 per cent of the city core operations in scenario 1. The assumed increase is based on previous studies on the subject (Ploos van Amstel et al. 2018), the similar average speed of transportation in city core environments compared to cars and vans and the added flexibility of the utilization of cargo bikes. Several cities are also adding requirements on vehicles entering the inner cities, which is assumed to support the partial transition to other modes of mobility. The reduced total load capacity is compensated by additional logistics the required sites. The utilization of cargo bikes in urban and rural area operations is neglected due to the range and average speed of cargo bikes. In scenario 2 the share of cargo bikes is 45 per cent in city core operations which is based same aspects as in scenario 1, and additionally on previous academic studies (Wrighton et al. 2016), which estimated that up to 50 per cent of urban service and business logistics could be handled by cargo bikes. Also in scenario 2, the reduced total load capacity is compensated by additional logistics the required sites. The use of cargo bikes in urban and rural operations is neglected also in scenario 2 due to the range and average speed of cargo bikes.

Share of light mobility – (e.g., e-scooters):

Light mobility solutions such as e-scooters are currently practically non-existing in the maintenance operations. In scenario 0 the share of this type of mobility is 0 per cent in all areas. In scenario 1 the share stays at 0 per cent in all areas, as it is estimated that the utilization of this type of mobility would require a larger change to the operating model, mainly due to the lack of load capacity. In scenario 2, the share of light people movers is assumed to be marginal at 2.5 per cent, and they mainly support other modes of mobility at short-distance travel in inner cities. Light mobility solutions are assumed to be held back by the very limited load capacity, which rather supports the use of BEVs and cargo bikes.

Share of public transport:

The use of public transport in maintenance operations are currently non-existing. In scenario 0 the share of this type of mobility is 0 per cent. In scenario 1 the share stays at 0 per cent as the utilization is assumed to require a larger overhaul of the operating model. In scenario 2, the share of public transport is assumed to be marginal at 1 per cent, and it mainly supports other modes of mobility at short-distance travel in inner cities. This category of mobility is assumed to be held back by the very limited load capacity and by the low average speed, which supports the use of BEVs, cargo bikes and light mobility.

7.2. Parameters of mobility

7.2.1. Annual travel distance

The typical annual travel distance for vehicles and maintenance personnel depends on factors such as e.g., the region, area, and role of the technician. For the scenario creation an annual average of 225 workdays is used. For the scenario creation it is assumed that 15 per cent of the personnel drives on average 50 kilometres daily, 60 per cent of the personnel drives on average 150 kilometres daily and 25 per cent of the personnel drives on average 250 kilometres daily. These distances and shares are assumptions used in the calculations, but they do not represent actual company specific values for shares or daily travel distances. The personnel who drive on average 50 kilometres daily drive annually 11 250 kilometres, those who drive on average 150 kilometres daily totals in 33 750 kilometres and the rest who drives on average 250 kilometres daily drive 56 250 kilometres annually.

The annual total travel distance is impacted also by the number of vehicles in the fleet. For the scenarios it is assumed that the number of vehicles in the fleet is 12 000, which represents the total maintenance vehicle fleet. The annual total travel distance in areas is assumed to be constant through the different scenarios. With these parameters the annual total travel distance in the city core is 20 250 000 kilometres, in the urban area 243 000 000 kilometres and in the rural area 168 750 000 kilometres for the maintenance vehicle fleet. The parameters are summarized in table 6.

Table 6. Summary of annual travel distance in areas

	Daily travel distance per vehicle (km)	Share of vehicles (%)	Annual travel distance in areas (km)
City Core travel distance	50	15	20 250 000
Urban travel distance	150	60	243 000 000
Rural travel distance	250	25	168 750 000
Total travel distance	160 (on average)	100	432 000 000

7.2.2. Annual energy consumption

The annual energy consumption is calculated for each mode of mobility. The annual fuel consumption of ICE and HEV-vehicles is based on the vehicles manufacturers information about the vehicles fuel consumption for the models in question and it is presented in litres (L). The annual energy consumption of BEVs is based on the vehicle manufacturers data of the size of the battery pack in the vehicle and the estimated driving range of the BEV, and it is presented in kilowatt-hours (kWh). This same logic is used for calculating the annual energy consumption of light electric vehicles such as cargo bikes and e-scooters. The annual energy consumption of the CNG vehicle is calculated based on the vehicles manufacturers information about the vehicles fuel consumption for the model in question and it is presented in kilograms. The actual energy consumption of a vehicle depends also on factors such as e.g., driving profile and driving style, which makes the information provided by manufacturers approximations.

The annual energy consumption for one vehicle with an average annual travel distance based on estimated average daily travel distance of 160 kilometres is presented in the table 7.

Table 7. Annual energy consumption of one vehicle

Type of mobility	Daily travel distance average (km)	Annual travel distance (km)	Energy consumption per 100 kilometres (L or kWh or kg)	Annual energy consumption (L or kWh or kg)
ICE van, medium	160	36 000	7.01 (L)	2524 (L)
ICE van, small	160	36 000	5.88 (L)	2117 (L)
HEV car, medium	160	36 000	4.5 (L)	1620 (L)
BEV van, medium	160	36 000	22.74 (kWh)	8182 (kWh)
BEV car, medium	160	36 000	14.04 (kWh)	5056 (kWh)
CNG van, small	160	36 000	4.0 (kg)	1440 (kg)
Cargo bike	160	36 000	1.25 (kWh)	450 (kWh)
E-scooter	160	36 000	1.0 (kWh)	360 (kWh)

7.2.3. Annual emissions

The calculation of annual emissions of vehicles is important for the comparison of different modes of mobility. A comparison of emissions from different modes of mobility is presented in table 8. The calculation is based on an annual average travel distance of 36 000 kilometres and takes into consideration the TTW scope 1 and 2 emissions. The tailpipe emissions from ICE, HEV and CNG-vehicles are calculated as scope 1 emissions. The emissions of consumed energy in electric vehicles are calculated as scope 2 emissions. The emissions of ICE, HEV and CNG vehicles are based on information provided by vehicle manufacturers on the tailpipe emissions of the respective vehicles. The emissions of BEVs and light electric vehicles are calculated based on the carbon intensity of average grid electricity and low emission electricity, with a share of 60/40 ratio respectively. The ratio assumes that 60 per cent of charging of BEVs and light electric vehicles occur at homes where the company cannot impact the type of purchased electricity. Of the remaining 40 per cent of charging, 30 per cent occur at company premises and 10 per cent at public charging locations where the company can impact the type of purchased electricity either directly or through the charging solutions provider.

The value for carbon intensity of electricity used is 250 gCO_2e/kWh, which represents the average carbon intensity of electricity in Europe (European Environment Agency 2021). It is noted that the scope 2 reporting guidelines instruct the use of the residual mix, for untracked electricity with unknown emission factor, which would be used if calculations were based on consumption in a specific country. The European Environment Agency (2021) estimates that the average carbon intensity of electricity in Europe will continue to decrease to approximately 100 to 150 gCO_2e/kWh by 2030. The value for carbon intensity of low emission electricity used is 20 gCO_2e/kWh, which represents an estimated average of life-cycle emissions per kilowatt-hour for nuclear, solar, wind and hydropower (World Nuclear Association 2021).

Table 8. Annual emissions of one vehicle

Type of mobility	Emissions per kilometre ($kgCO_2e/km$)	Annual emissions ($kgCO_2e$)	Scope of emissions (1 or 2)
ICE van, medium	0.186	6696	Scope 1
ICE van, small	0.156	5616	Scope 1
HEV car, medium	0.101	3636	Scope 1
BEV van, medium	0.036	1293	Scope 2
BEV car, medium	0.022	799	Scope 2
CNG van, small	0.109	3924	Scope 1
Cargo bike	0.002	71	Scope 2

E-scooter	0.002	57	Scope 2

7.2.4. Annual load capacity

The annual load capacity is an important parameter as regularly maintenance technicians are required to carry equipment and parts with them during workdays. The annual load capacity is estimated as the load capacity of the type of mobility multiplied with annual working days, in this case 225 working days. In this calculation it is assumed that the technicians collect the required parts once each day and the maximum load capacity is used. The load capacity is a crucial factor also as it is assumed that the mass of cargo that must be transported will not decrease. If the type of mobility changes, the mass must be transported in some other way by e.g., a logistics partner. A comparison of the annual load capacity is presented in table 9.

The load capacity of vehicles is based on information provided by manufacturers with some exceptions. The load capacity of the BEV car is 533 kilograms which includes the weight of the driver. For this calculation the weight of the driver is assumed to be 80 kilograms which leaves room for 453 kilograms of freight. The load capacity of the cargo bike is 200 kilograms which includes the weight of the driver. For this calculation the weight of the driver is assumed to be 80 kilograms which leaves room for 120 kilograms of freight. The load capacity of the e-scooter and public transport is assumed based on a backpack weighing 8 kilograms as these modes do not enable additional freight transportation.

Table 9. Annual load capacity of one vehicle

Type of mobility	Load capacity (kg)	Annual load capacity (kg)
ICE van, medium	1000	225 000
ICE van, small	853	191 925
HEV car, medium	535	120 375
BEV van, medium	925	208 125
BEV car, medium	453	101 925
CNG van, small	750	168 750

Cargo bike	120	27 000
E-scooter	8	1 800
Public transport	8	1 800

7.2.5. Annual energy cost

The annual energy cost for different types of mobility presents the estimated annual energy cost based on the annual energy consumption. The annual energy cost is impacted by many external factors. The global oil and natural gas prices have risen a lot recently e.g., due to the ongoing war in Ukraine. It is however assumed that the price of fuels from finite resources such as oil and gas would increase also in the long-term. It is currently challenging to estimate the future prices of energy. In the calculation of the annual energy cost, the cost of gasoline is assumed to be 2.30 euros per litre, diesel is assumed to cost 2.27 euros per litre, the cost of CNG is assumed to be 2.58 euros per kilogram and the cost of electricity is assumed to be 0.25 euros per kilowatt-hour (Tilastokeskus 2022; Gasum 2022). These energy costs reflect the current price of energy in Finland. It is also assumed that the recent changes in energy prices are reflected throughout Europe. A comparison of the annual energy consumption and annual energy costs are presented in table 10.

Table 10. Estimated annual energy cost for one vehicle

Type of mobility	Annual energy consumption (L or kWh or kg)	Annual energy cost (euros)
ICE van, medium	2524 (L)	5728.57
ICE van, small	2117 (L)	4805.14
HEV car, medium	1620 (L)	3726.00
BEV van, medium	8182 (kWh)	2045.45
BEV car, medium	5056 (kWh)	1263.92
CNG van, small	1440 (kg)	3715.20
Cargo bike	450 (kWh)	112.50
E-scooter	360 (kWh)	90.00

7.2.6. Daily travel time

The daily travel time impacts the productivity of maintenance technicians. It is therefore important to minimize the travel time and the impact of mobility choices on the travel time. The used values are assumptions based on publicly available generic data on average travel speeds in different European cities and estimated daily travel distances. The data used in the calculation is not based on actual company specific values and the reality might differ from the calculation. The calculation does also not take into consideration e.g., time wasted on finding parking spots for cars and vans, as the theme lacks recent credible sources.

For the daily travel time the average speed in city cores, urban areas and rural areas are estimated. The average speed of cars and vans in city centres is estimated to be 15 km/h, in urban areas the average speed is estimated to be 40 km/h and in rural areas 68 km/h. The average speed of cars and vans in city centres is based on data from the city of Paris where the average speed of traffic is 11.6 km/h (Ville de Paris 2020). In Helsinki city centre the average speed on streets are in the range of 17-22 km/h. (HSL 2018). The average speed in urban areas is estimated based on the general speed limit in urban areas in Europe which is typically 40-50 km/h. The average speed in rural areas is estimated based on average highway speed 80 km/h and combining this with urban speed of 40 km/h in a 70/30 ratio.

The same average speed is used for both cargo bikes and e-scooters in city cores, urban areas, and rural areas. The cargo bikes and e-scooters use the same infrastructure (e.g., bike lanes) and similar technology, which is the motivation to use same speed for both modes of transportation. The average speed used for cargo bikes and e-scooters in city cores and urban areas is 19 km/h, which is based on cycling data from Strava (Tarnanen et al. 2017). The technical top speed of non-registered e-bikes and e-scooters is 25 km/h in the EU, and this is assumed as the average speed in rural areas where external impacts on traffic flow is low. The average speed of public transport used in the scenario creation is 5 km/h. It is simultaneously acknowledged that public transport, which relies on population density, is developed mainly in urban areas and therefore no average speed for public transport in rural areas is used.

For the travel time calculations an estimated daily travel distance of 50 kilometres is used for city cores, 150 kilometres is used for urban areas and 250 kilometres is used for rural areas. The daily travel time with one vehicle of different types of mobility in city cores is summarized in table 11, travel time in urban areas is summarized in table 12 and travel time in rural areas is summarized in table 13.

Table 11. Daily travel time in city cores with one vehicle

Type of mobility	Average travel speed (km/h)	Daily travel distance (km)	Daily travel time (h)
ICE van, medium	15	50	3.33
ICE van, small	15	50	3.33
HEV car, medium	15	50	3.33
BEV van, medium	15	50	3.33
BEV car, medium	15	50	3.33
CNG van, small	15	50	3.33
Cargo bike	19	50	2.63
E-scooter	19	50	2.63
Public transport	5	50	10

Cargo bikes and e-scooters are the fastest mode of transport in city cores, based on the average speed, followed by cars and vans, and public transport. Public transport is significantly slower which supports the assumption that it can mainly be used for specific trips and not as a general transportation mode requiring several stops during a workday.

Table 12. Daily travel time in urban areas with one vehicle

Type of mobility	Average travel speed (km/h)	Daily travel distance (km)	Daily travel time (h)
ICE van, medium	40	150	3.75
ICE van, small	40	150	3.75
HEV car, medium	40	150	3.75
BEV van, medium	40	150	3.75
BEV car, medium	40	150	3.75
CNG van, small	40	150	3.75
Cargo bike	19	150	7.89

E-scooter	19	150	7.89
Public transport	5	150	30

Cars and vans are the fastest mode of transportation, based on the average travel speed, when the daily travel distance reaches 150 kilometres in urban areas. The cargo bikes, e-scooters and public transport have significantly lower average travel speeds in urban areas, which supports the assumption of favouring cars and vans in urban areas.

Table 13. Daily travel time in rural areas with one vehicle

Type of mobility	Average travel speed (km/h)	Daily travel distance (km)	Daily travel time (h)
ICE van, medium	68	250	3.68
ICE van, small	68	250	3.68
HEV car, medium	68	250	3.68
BEV van, medium	68	250	3.68
BEV car, medium	68	250	3.68
CNG van, small	68	250	3.68
Cargo bike	25	250	10
E-scooter	25	250	10
Public transport	5	250	N/A

The difference between the travel time of cars and vans, and other types of mobility increases as the daily travel distance increased. The cargo bikes, e-scooters and public transport have significantly lower average travel speeds in rural areas, which favours the use of cars and vans in these areas.

7.3. Scenario set-up

7.3.1. Scenario 0: Current State of Mobility

The scenario 0 represents no change to the current state of mobility. In the scenario 0 calculations the total CO_2 emissions of scenario 0 is estimated based on total number of vehicles, their modal shares and average annual vehicle emissions. The values will be comparable to emissions estimates of scenario 1 and 2.

The typical daily driving distance is assumed to conclude of 50 kilometres of travel in city cores (15 per cent of total travel), 150 kilometres of travel in urban areas (60 per cent of travel) and 250 kilometres of travel in rural areas (25 per cent of travel). The vehicles in use are used in a mixed manner in all three areas. The modal shares of scenario 0 along with the modal total annual travel distance are displayed in table 14.

Table 14. Summary of modal shares and annual travel distances in scenario 0

Scenario 0: Current state of mobility	Area	Modal share in area (%)	Average daily travel distance (km)	Total annual travel distance (km)
ICE – vehicle, medium van	City Core	53.5 %	50	10 833 750
	Urban	53.5 %	150	130 005 000
	Rural	53.5 %	250	90 281 250
ICE – vehicle, small van	City Core	41.5 %	50	8 403 750
	Urban	41.5 %	150	100 845 000
	Rural	41.5 %	250	70 031 250
HEV - car	City Core	1.5 %	50	303 750
	Urban	1.5 %	150	3 645 000
	Rural	1.5 %	250	2 531 250
CNG – van	City Core	2 %	50	405 000
	Urban	2 %	150	4 860 000
	Rural	2 %	250	3 375 000
BEV – medium van	City Core	0.2 %	50	40 500
	Urban	0.2 %	150	486 000

	Rural	0.2 %	250	337 500
BEV – car	City Core	1.3 %	50	263 250
	Urban	1.3 %	150	3 159 000
	Rural	1.3 %	250	2 193 750
Cargo bikes	City Core	0 %	50	0
	Urban	0 %	150	0
	Rural	0 %	250	0
Light mobility (e.g., e-scooters)	City Core	0 %	50	0
	Urban	0 %	150	0
	Rural	0 %	250	0
Public transport	City Core	0 %	50	0
	Urban	0 %	150	0
	Rural	0 %	250	0

The total emissions of areas in scenario 0 are calculated based on the total annual travel distance, the emission value of each mode of mobility and the modal share. The emissions of travel with one mode of mobility in different areas are calculated with same emission factors, even though the energy consumption and emissions may vary depending on different average speeds. The total emissions of scenario 0 in city core are 3 460 135 kgCO_2e, in urban areas 41 521 617 kgCO_2e and in rural areas 28 834 457 kgCO_2e, which equals total emissions of 73 816 209 kgCO_2e.

The annual transportation capacity or load capacity of the scenario 0 is calculated based on the number of workdays, the load capacity of modes of mobility, number of vehicles, the modal share, and the share of total kilometres by area. The calculation takes into consideration the hypothetical total load capacity without reductions. The total load capacity in scenario 0 is 2 507 990 tons.

The total travel time is a crucial parameter as it impacts the productivity. It is calculated based on the estimated daily travel time in city cores, urban areas, and rural areas, number of workdays and modal shares. The total travel time in city cores is 1 350 000 hours, in urban areas 6 075 000 hours and in rural areas 2 481 618 hours.

The energy cost is calculated based on the current energy prices in Finland. In the calculation of the annual energy cost, the cost of gasoline is assumed to be 2.30 euros per litre (Tilastokeskus 2022), diesel is assumed to cost 2.27 euros per litre (Tilastokeskus 2022), the cost of CNG is assumed to be 2.58 euros per kilogram (Gasum 2022), and the cost of electricity is assumed to be 0.25 euros per kilowatt-hour, including the total cost of electricity. In scenario 0 the annual energy cost is 63 272 724 euros. A summary of the annual totals for scenario 0 is presented in table 15.

Table 15. Scenario 0: Summary of annual totals

Scenario 0: Current state of mobility	Annual totals
Total emissions ($kgCO_2e$)	73 816 209
Total load capacity (t)	2 507 990
Total travel time (h)	9 906 618
Total energy cost (euros)	63 272 724

7.3.2. Scenario 1: Electrified Mobility

The scenario 1 represents a major change to the current state of mobility. In the scenario 1 calculations the total CO_2 emissions of scenario 1 is estimated based on total number of vehicles, their modal shares and average annual vehicle emissions. The values will be comparable to emissions estimates of scenario 0 and 2.

The typical daily driving distance is estimated to conclude of 50 kilometres of travel in city cores (15 per cent of total travel), 150 kilometres of travel in urban areas (60 per cent of travel) and 250 kilometres of travel in rural areas (25 per cent of travel), like the values in scenario 0. The vehicles in use are used in a specified manner in the three areas. The modal shares of scenario 1 along with the modal total annual travel distance are displayed in table 16.

Table 16. Summary of modal shares and annual travel distances in scenario 1

Scenario 1: Electrified mobility	Area	Modal share in area (%)	Average daily travel distance (km)	Total annual travel distance (km)
ICE – vehicle, medium van	City Core	0 %	50	0
	Urban	0 %	150	0
	Rural	0 %	250	0
ICE – vehicle, small van	City Core	0 %	50	0
	Urban	0 %	150	0
	Rural	0 %	250	0
HEV - car	City Core	0 %	50	0
	Urban	0 %	150	0
	Rural	0 %	250	0
CNG – van	City Core	0 %	50	0
	Urban	0 %	150	0
	Rural	0 %	250	0
BEV – medium van	City Core	50 %	50	10 125 000
	Urban	55 %	150	133 650 000
	Rural	55 %	250	92 812 500
BEV – car	City Core	40 %	50	8 100 000
	Urban	45 %	150	109 350 000
	Rural	45 %	250	75 937 500
Cargo bikes	City Core	10 %	50	2 025 000
	Urban	0 %	150	0
	Rural	0 %	250	0
Light mobility (e.g., e-scooters)	City Core	0 %	50	0
	Urban	0 %	150	0
	Rural	0 %	250	0
Public transport	City Core	0 %	50	0
	Urban	0 %	150	0
	Rural	0 %	250	0

The total emissions of areas in scenario 1 are calculated based on the total annual travel distance, the emission value of each mode of mobility and the modal share. The emissions of travel with one mode of mobility in different areas are calculated with same emission factors, even though the energy consumption and emissions may vary depending on different average speeds. The total emissions of scenario 1 in city core are 547 309 kgCO_2e, in urban areas 7 225 602 kgCO_2e and in rural areas 5 017 779 kgCO_2e, which equals total emissions of 12 790 690 kgCO_2e.

The annual transportation capacity or load capacity of the scenario 1 is calculated based on the number of workdays, the load capacity of modes of mobility, number of vehicles, the modal share, and the share of total kilometres by area. The calculation takes into consideration the hypothetical total load capacity without reductions. The total load capacity in scenario 1 is 1 900 976 tons.

The total travel time is a crucial parameter as it impacts the productivity. It is calculated based on the estimated daily travel time in city cores, urban areas, and rural areas, number of workdays and modal shares. The total travel time in city cores is 1 321 579 hours, in urban areas 6 075 000 hours and in rural areas 2 481 618 hours.

The energy cost is calculated based on the current energy prices in Finland. In the calculation of the annual energy cost, the cost of gasoline is assumed to be 2.30 euros per litre (Tilastokeskus 2022), diesel is assumed to cost 2.27 euros per litre (Tilastokeskus 2022), the cost of CNG is assumed to be 2.58 euros per kilogram (Gasum 2022), and the cost of electricity is assumed to be 0.25 euros per kilowatt-hour, including the total cost of electricity. In scenario 1 the annual energy cost is 20 238 433 euros. A summary of the annual totals for scenario 1 is presented in table 17.

Table 17. Scenario 1: Summary of annual totals

Scenario 1: Electrified mobility	Annual totals
Total emissions (kgCO_2e) (excl. freight)	12 790 690
Total load capacity (t)	1 900 976
Total travel time (h)	9 878 197
Total energy cost (euros)	20 238 433

7.3.3. Scenario 2: Multi-modal mobility

The scenario 2 represents a major change to the current state of mobility. In the scenario 2 calculations the total CO_2 emissions of scenario 2 is estimated based on total number of vehicles, their modal shares and average annual vehicle emissions. The values will be comparable to emissions estimates of scenario 0 and 1.

The typical daily driving distance is estimated to conclude of 50 kilometres of travel in city cores (15 per cent of total travel), 150 kilometres of travel in urban areas (60 per cent of travel) and 250 kilometres of travel in rural areas (25 per cent of travel), like the values in scenario 0 and 1. The vehicles in use are used in a specified manner in the three areas. The modal shares of scenario 2 along with the modal total annual travel distance are displayed in table 18.

Table 18. Summary of modal shares and annual travel distances in scenario 2

Scenario 2: Multi-modal mobility	Area	Modal share in area (%)	Average daily travel distance (km)	Total annual travel distance (km)
ICE – vehicle, medium van	City Core	0 %	50	0
	Urban	0 %	150	0
	Rural	0 %	250	0
ICE – vehicle, small van	City Core	0 %	50	0
	Urban	0 %	150	0
	Rural	0 %	250	0
HEV - car	City Core	0 %	50	0
	Urban	0 %	150	0
	Rural	0 %	250	0
CNG – van	City Core	0 %	50	0
	Urban	0 %	150	0
	Rural	0 %	250	0
BEV – medium van	City Core	30 %	50	6 075 000
	Urban	55 %	150	133 365 000
	Rural	55 %	250	92 812 500

BEV – car	City Core	21 %	50	4 353 750
	Urban	45 %	150	109 350 000
	Rural	45 %	250	75 937 500
Cargo bikes	City Core	45 %	50	9 112 500
	Urban	0 %	150	0
	Rural	0 %	250	0
Light mobility (e.g., e-scooters)	City Core	3 %	50	506 250
	Urban	0 %	150	0
	Rural	0 %	250	0
Public transport	City Core	1 %	50	202 500
	Urban	0 %	150	0
	Rural	0 %	250	0

The total emissions of areas in scenario 2 are calculated based on the total annual travel distance, the emission value of each mode of mobility and the modal share. The emissions of travel with one mode of mobility in different areas are calculated with same emission factors, even though the energy consumption and emissions may vary depending on different average speeds. The total emissions of scenario 2 in city core are 333 550 kgCO_2e, in urban areas 7 225 602 kgCO_2e and in rural areas 5 017 779 kgCO_2e, which equals total emissions of 12 576 931 kgCO_2e.

The annual transportation capacity or load capacity of the scenario 2 is calculated based on the number of workdays, the load capacity of modes of mobility, number of vehicles, the modal share, and the share of total kilometres by area. The calculation takes into consideration the hypothetical total load capacity without reductions. The total load capacity in scenario 2 is 1 809 233 tons.

The total travel time is a crucial parameter as it impacts the productivity. It is calculated based on the estimated daily travel time in city cores, urban areas, and rural areas, number of workdays and modal shares. The total travel time in city cores is 1 242 000 hours, in urban areas 6 075 000 hours and in rural areas 2 481 618 hours.

The energy cost is calculated based on the current energy prices in Finland. In the calculation of the annual energy cost, the cost of gasoline is assumed to be 2.30 euros per litre

(Tilastokeskus 2022), diesel is assumed to cost 2.27 euros per litre (Tilastokeskus 2022), the cost of CNG is assumed to be 2.58 euros per kilogram (Gasum 2022), and the cost of electricity is assumed to be 0.25 euros per kilowatt-hour, including the total cost of electricity. In scenario 2 the annual energy cost is 19 900 207 euros. A summary of the annual totals for scenario 2 is presented in table 19.

Table 19. Scenario 2: Summary of annual totals

Scenario 2: Multi-modal mobility	Annual totals
Total emissions (kgCO_2e) (excl. freight)	12 576 931
Total load capacity (t)	1 809 233
Total travel time (h)	9 798 618
Total energy cost (euros)	19 900 207

7.4. GHG emission reduction potential

The GHG emission reduction potential is modelled based on the calculations for GHG emissions in specified areas. The GHG emission reduction potential is calculated for scenarios 1 and 2 compared to the baseline scenario 0. All values are presented in kilograms of CO_2 equivalent. The emissions of scenarios are summarized in table 20.

Table 20. Summary of CO_2eq emissions of all scenarios

	Scenario 0 (kgCO_2e)	Scenario 1 (kgCO_2e)	Scenario 2 (kgCO_2e)
City Core	3 460 135	547 309	330 550
Urban	41 521 617	7 225 602	7 225 602
Rural	28 834 457	5 017 779	5 017 779
Total emissions	73 816 209	12 790 690	12 576 931
Reduction potential	Baseline	-82.7%	-83.0%

In scenarios 1 and 2 new modes of mobility are implemented which impacts the load capacity available for transports. The decrease in load capacity is compensated with purchasing capacity from e.g., a freight partner, who transports the freight to the needed location. The emissions of additional freight transport are modelled to provide an understanding of the total emissions of maintenance mobility in scenarios 1 and 2. When modelling the emissions of the additional transports, it is assumed that the transports are carried out with a fully loaded ICE delivery truck able to carry nine tons of freight. The delivery truck meets the Euro 6 emissions standard and emits on average 0.611 kilograms of CO_2 equivalent per kilometre or 0.068 kilograms per tonne kilometre.

In scenarios 1 and 2 the required additional freight capacities are annually in total 607 014 tons and 698 757 tons respectively. The daily driving distance is 50 kilometres in city core, 150 kilometres in urban areas and 250 kilometres in rural areas. The required additional freight mass is based on the reduced load capacity in scenarios 1 and 2 compared to load capacity in scenario 0. The results for additional emissions in city core, urban and rural areas are listed in table 21.

Table 21. Emissions of additional freight transports in scenarios 1 and 2 compared to scenario 0 baseline

	Scenario 1: Electrified mobility	Scenario 2: Multi-modal mobility
City Core additional demand (tons)	110 640	202 383
Trips with full 9t truck	12 293	22 487
Total emissions ($kgCO_2eq/a$)	375 561	686 976
Urban additional demand (tons)	350 382	350 382
Trips with full 9t truck	38 931	38 931
Total emissions ($kgCO_2eq/a$)	3 568 054	3 568 054
Driving distance	168 750 000	168 750 000
Rural additional demand (tons)	145 992	145 992
Trips with full 9t truck	16 221	16 221
Total emissions ($kgCO_2e/a$)	2 477 815	2 477 815

Total additional capacity demand (tons)	607 014	698 757
Total emissions of additional freight transport (kgCO_2e/a)	6 421 430	6 732 845

8. Results

The table 22 summarizes the results of GHG emissions and the reduction potential from scenarios 0, 1 and 2. The percentual reductions of GHG emissions are significant in scenarios 1 and 2, when compared to scenario 0, even when the emissions of additional freight transports are included. The emissions of additional freight transports overturn the GHG emissions savings from multi-modal mobility in scenario 2 when compared to electrified mobility in scenario 1.

Table 22. Summary of emissions reduction potential

	Scenario 0: Current state of mobility	Scenario 1: Electrified mobility	Scenario 2: Multi-modal mobility
City Core ($kgCO_2e$)	3 460 135	547 309	330 550
Urban ($kgCO_2e$)	41 521 617	7 225 602	7 225 602
Rural ($kgCO_2e$)	28 834 457	5 017 779	5 017 779
Total emissions (excl. additional freight) ($kgCO_2e$)	73 816 209	12 790 690	12 576 931
Reduction potential (excl. additional freight)	Baseline	-82.7%	-83.0%
Total emissions (incl. additional freight) ($kgCO_2e$)	73 816 209	19 212 120	19 309 776
Reduction potential (incl. additional freight)	Baseline	-74.0%	-73.8%

A transition from the current state of mobility in scenario 0 to electrified mobility in scenario 1 seems more likely than a transition to multi-modal mobility in scenario 2, as the total cost of ownership in scenario 1 is likely easier to estimate than the total cost of ownership of multiple modes of mobility in scenario 2. The ease of a transition to scenario 1 type of mobility is also supported by the fact that the transition occurs in the existing car-centric regime and thus the transition does not require significant changes to the operating model. The transition to low-emission modes of mobility from the current state of mobility is currently mainly hindered by the availability of suitable vehicles and lack of mobility infrastructure such as e.g., charging stations to support the utilization of low-emission modes of mobility, however the infrastructure related to BEV use is subject to major investments during this decade.

The table 23 summarizes the results of total travel time from scenarios 0, 1 and 2. The scenario 1 is mainly subject to same constraints in traffic as the current state of mobility in scenario 0. Multi-modal mobility in scenario 2 results in time savings in city core operations, when compared to scenarios 0 and 1. Additional time savings could be achieved if the impact of e.g., time spent on searching for parking spots would be included in calculations. The time saving potential indicates potential of time saving in scenarios 1 and 2 when compared to scenario 0. The results indicate that time savings potential lies in utilization of light electric mobility in the city core area. To make use of the advantages enabled by light electric mobility would require a change in the operating model. The change would include support for the utilization of light electric mobility through e.g., additional logistics, providing weather resistant clothing and enabling the flexible change in type of mobility depending on other requirements. Required flexibility could e.g., be provided by implementation of a MaaS solution. The cost impact of the additional requirements is uncertain and would require further assessment.

Table 23. Summary of travel time saving potential

	Scenario 0: Current state of mobility	Scenario 1: Electrified mobility	Scenario 2: Multi-modal mobility
City Core (hours)	1 350 000	1 321 579	1 242 000
Urban (hours)	6 075 000	6 075 000	6 075 000
Rural (hours)	2 481 618	2 481 618	2 481 618
Total time (hours)	9 906 618	9 878 197	9 798 618
Time saving potential (%)		0.3%	1.1%

The table 24 summarizes the results of estimated energy costs from scenarios 0, 1 and 2. The potential savings in estimated energy costs are similar in scenarios 1 and 2 when compared to scenario 0, as most of the travel in scenarios 1 and 2 is made by cars or vans. The energy cost savings in city core operations in scenario 2 is mainly due to the lower energy consumption of light mobility solutions such as cargo bikes and e-scooters. The energy cost savings potential of a transition from the current state of mobility to electrified and multi-modal mobility are significant. The energy cost savings potential combined with estimates that EVs have similar upfront costs compared to ICE vehicles in 2024-25 indicates that utilization of EVs enable significant cost savings in operations.

Table 24. Summary of energy cost savings potential

	Scenario 0: Current state of mobility (euros)	Scenario 1: Electrified mobility (euros)	Scenario 2: Multi-modal mobility (euros)
City Core	2 965 909	865 995	527 768
Urban	35 590 907	11 432 915	11 432 915
Rural	24 715 908	7 939 524	7 939 524
Total costs	63 272 724	20 238 433	19 900 207
Cost savings potential	Baseline	43 034 290	43 372 517

9. Discussion

This study analysed primarily the GHG reduction potential in the European maintenance mobility by 2030 with a socio-technical approach. The aim was also to analyse impacts of low-emission mobility transitions on the personnel. This chapter assesses critically the reliability of the research and its results.

From the theoretical perspective, this research was structured around the multi-level perspective (MLP) framework, which was identified to support the understanding barriers and enablers of the low-emission mobility transition. The landscape level of the MLP framework was analysed through existing and future policies and regulation of the EC and local governments. This analysis provided an understanding of the changes to the sector of mobility in Europe until the year 2030. The analysis aimed at including the major changes to the landscape of mobility which could impact the maintenance services in Europe. The policy proposals, which have not yet been confirmed to regulation, pose uncertainties for the assumptions regarding the changes on the landscape level. The EC announced e.g., in June 2022 that the proposed "Fit for 55" legislation package was returned to preparation due to disagreement related to it. The policies of local governments related to the sector of mobility may also be impacted by political decisions of which some might not be included in the theoretical assessment.

The landscape level changes directly impact the existing regime, and niches which try to compete with the existing regime. The existing technological regime can be said to be structured around ICE vehicles and the car/van use in general. The landscape changes are impacting the ICE vehicle use already as policies and incentives support the transition towards electrified mobility. It is a widely accepted thought that EVs could rise to become the regime of mobility in the future. This is supported also by proposed changes on the landscape level. This requires however that the infrastructure supports the use of EVs, and uncertainties are related e.g., to the development of the charging infrastructure. The landscape changes might also result in and enhance lock-in conditions if the future of vehicle mobility becomes BEV centred. The existing regime of vehicle use in general cause challenges to potentially viable alternatives that are being developed in the niche.

Mobility solutions such as MaaS, cargo bikes and e-scooters can be identified to compete against the existing regime and are so called niche level innovations. These technologies have not been researched enough for it to be possible determine if these truly are viable alternatives to the regime. The uncertainties of these modes of mobility are primarily related to the cost of use and real-life usability. The development of light mobility solutions such as cargo bikes and e-scooters are supported by the regulators, however the wide utilization would require also major changes to the infrastructure, which currently mainly supports the use of vehicles. The possible infrastructure changes related to societal reduction in total vehicle use could result in increased demand of high-density high-rise construction.

The scenarios created in the research make it possible to forecast alternative futures of the mobility sector. The scenarios should not be taken as knowledge of what the future will look like. Even though the assumptions are based on rapid technological change, the uncertainties may decrease the speed of the change. In the scenario creation it was assumed that landscape level changes impact favourably the implementation of low-emission modes of mobility. Landscape level changes and new policies usually tend to set a trajectory which impacts the sector in the long-term. It is safe to assume that when policies are set, the change will happen even if setbacks in the changes might slow it down.

The chosen methodologies for the research supported the responding to the set research questions. The mixed methodology made it possible to gather qualitative insights about aspects impacting the low-emission mobility transition and the quantitative methodology made it possible to quantify the GHG reduction potential and other impacts of the transition in a comparable style.

9.1. GHG emissions reduction potential

The target for scope 1 and 2 GHG emissions reduction has been set to 50 per cent absolute reduction by 2030 from 2018 base-year. The vehicle fleet accounted for 84 per cent of the scope 1 and 2 emissions in 2021. The vehicle technology in ICE vehicles could result in a 20 per cent decrease in emissions by 2030. This would require a significant increase in the use of alternative modes of mobility in the vehicle mix to reach the set target by 2030.

The results of the GHG reduction potential calculations are in line with previous academic studies regarding e.g., life cycle assessments of EVs and comparisons on life cycle emissions of EVs and ICE vehicles. The calculations in this research are however not directly comparable with each other between the energy sources, as the scope 1 emissions of fuel consumption only considers the use phase emissions and the scope 2 emissions of purchased electricity takes into consideration the emissions of electricity generation. The values of emissions could be better comparable if the life cycle emissions of energy were to be considered. The emissions from fuel production of fossil fuels use are estimated to increase the total emissions of fuel, including production and consumption, with approximately 30 per cent (Bieker 2021). The calculations on GHG emissions of electricity could also be more accurate if the residual mix value would be used for emissions calculation. The residual mix covers the share of electricity for which the emissions factor is unknown. In the GHG calculation the value used was an estimate on the emissions of grid electricity in the EU. It could be stated that the emissions comparison between electric and fossil fuel mobility is not exactly fair when the life cycle emissions of energy is not taken into consideration and the emissions of fuel production are not reported in scope 1. In addition, the emissions from vehicle manufacturing, which is categorized as scope 3 emissions, is currently higher for EVs than for ICE vehicles. This will decrease the actual total emissions reduction potential of EVs when compared to their ICE counterparts.

The additional demand for logistics, which is related to the assumed implementation of light electric mobility solutions were calculated with the values of an ICE truck. The technological development in this vehicle category was not in the focus of this study and it is uncertain how the future of this vehicle category will unfold. The possible use of alternative technologies such as e.g., electric trucks could lower the impact of these transports, which according to the calculation significantly increase the total emissions of maintenance operations in scenarios 1 and 2.

9.2. Travel time and costs

The travel time and costs of mobility were calculated based on the average travel time and estimated cost of energy. These calculations represent simplified estimates on the travel time and the cost of energy. The travel time of cars and vans in city core areas could also be impacted by factors such as e.g., finding parking. In an interview it was estimated that finding parking in extreme cases could take more than half an hour. A possible transition to EVs do not impact externalities of vehicle use, other than the emissions, as EVs are subject to same constraints in city core and urban areas as current ICE vehicles. The impact of these other factors was however not included in the calculation as quantifiable data on the additional time spent was not available. Possible utilization of telematics could provide information on how significant the impact truly is. The impact of additional time spent is possibly significant and it could be a possible case for future study.

The cost of vehicle use includes many factors which are included in TCO calculations. The TCO calculations are region dependent as e.g., incentives and taxation vary depending on the region. The cost estimates in this research included the cost of used energy based on cost of energy in Finland. In the current situation it is challenging to estimate in which direction the energy costs will evolve in the future. It could be assumed that the total costs of fossil fuel use including taxation would increase in the future as the trend is shifting towards low-emissions technologies. The calculations estimate that with the current energy costs, where both the fossil fuels and electricity have increased in price recently the cost of energy on the annual driving distance is significantly lower for BEVs. This is also in line with other estimates. It remains also to be seen how the BEV use will be taxed by the governments when the tax receivables from ICE vehicles decrease in case of transition to low-emission modes of mobility.

9.3. Social aspects

The social impacts of low-emission mobility transition can be major. According to a questionnaire conducted with maintenance personnel a majority were open to BEV use in the future. Conducting similar questionnaires in several regions could be useful for the assessment of acceptability of alternative modes of mobility in different geographical contexts. The implementation of alternative mobility solutions requires behavioural change which can be achieved e.g., through showing example and letting individuals test new solutions themselves. The behavioural change is an important factor on the road towards low-emission mobility. The transition to EVs can be easier than the transition to light mobility solutions, which require e.g., weather resistant clothing and an enhanced operating model. Light mobility solutions combined with low-emission logistics could provide even larger reduction in the GHG emissions in the city core operations. MaaS could work as the enabler of multi-modality in maintenance operations, where it could possibly provide needed flexibility to mobility. The corporate MaaS solutions are still in development and require further research. The implementation of corporate MaaS including the costs and use cases could be a case for future study.

10. Conclusions & Summary

This thesis has provided insights to the different possible modes of low-emission mobility in maintenance by 2030. This research provides information on the impact of the modes of mobility on the GHG emissions of the company, on the daily work of the maintenance technicians and the estimated costs of the use of alternative modes of mobility. The approach enabled the creation of a holistic view of the mobility sector in Europe by 2030, supported by region specific information from case regions in France and the Netherlands.

Three scenarios were created with the first (scenario 0) being the baseline structured around the current state of mobility, the second (scenario 1) scenario were structured around vehicle fleet electrification and the third (scenario 2) scenario multi-modal mobility including several types of mobility. The scenarios 1 and 2 were compared to the baseline scenario to identify the carbon footprint reduction potential, travel time savings potential, and energy cost savings potential of the scenarios. Additional logistics required for scenarios 1 and 2 and their GHG emissions impact were modelled to identify the total impact of logistics in scenario 1 and 2. The GHG emissions reduction potential of scenarios 1 and 2 are 82.7 per cent and 83.0 per cent respectively excluding the additional logistics. The GHG emissions reduction potential including the additional logistics are 74.0 per cent and 73.8 per cent respectively.

The results of the research are in line with previous academic studies of possible GHG emissions reduction potential of EVs compared to ICE vehicles. The results also support the use of light mobility solutions in GHG emissions reduction, but they require more research to determine their cost impact and usability. MaaS could be an enabler for multi-modality in maintenance operations, but the utilization of MaaS in a corporate setting requires more research.

The landscape changes impact favourably the transition towards low-emission modes of mobility. Landscape changes might create a lock-in around EVs in cars and vans, which is assumed to replace the ICE vehicles as the existing regime. The possible future success of alternative solutions such as e.g., cargo bikes, e-scooter and MaaS depend on investments to the research and development of these technologies.

Mobility has a key role in shaping the future and in tackling the climate change. This thesis has highlighted the importance of transition to low-emission mobility on a corporate and societal level. The co-operation of several agents is required to decrease the impact of current infrastructural barriers and to enable the transition to low-emission mobility by 2030. Low-emission mobility solutions can enable significant reductions in GHG emissions, while simultaneously reducing the travel time and energy costs related to mobility. This thesis can be seen to have provided answers to the research questions set in the beginning of the thesis and to provide insights to the feasibility of alternative mobility solutions in maintenance operations.

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