



**CHALMERS**  
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# Investigating the Potential of an Electrified Fleet used for Last-mile in Urban Environments

A multiple case study at a last-mile delivery company

Master's thesis in the two master programmes Industrial Ecology and Sustainable Energy Systems

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A multiple-case study at a Last-Mile Delivery Company  
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## Abstract

The transportation sector, more specifically the road vehicles, accounts for 12% of global carbon emissions, and a large majority of these are due to freight transport. Today the preferred choice of fuel in the sector is diesel which, in addition to the global negative externalities it produces, also emits a lot of local pollution. These types of emissions are heavily apparent in last-mile deliveries, the last stretch of a supply chain entailing the transportation of goods from a transit point to the end customer. Last-mile is seen as one of the most challenging parts of the supply chain as freighters need to consider the complexities of urban environments. The last-mile delivery is an essential part of the supply chain with a lot of potential for sustainable development. A proposed solution being investigated at the present time is the utilisation of electric vehicles to mitigate negative externalities from last-mile deliveries in urban environments.

The aim of this paper was to investigate the potential electrification of a last-mile delivery company's vehicle fleet. A transition from their current fleet of internal combustion engine vehicles to electric vehicles. The issue was divided into two research questions, the first was to investigate the contributing factors, both internal and external to electrifying a vehicle fleet and the second was to find the potential for the case company to electrify their current routes. The answers to the research questions were found from a multiple case study on the four cities of Gothenburg, Stockholm and Malmö in Sweden along with Copenhagen in Denmark. This was accompanied by a literature review on relevant subjects, collection and interpretation of historical data of routes from the case company. Lastly, a scenario analysis with the basis in a route optimisation platform was conducted, by investigating the potential of deploying electric vehicles now or in a potential future where necessary infrastructure and policies are in place.

The results showed great potential for both electric vehicle types tested. With today's political climate, a smaller electric vehicle type is preferable for the cases in Sweden while in Denmark a vehicle more similar to the traditional diesel vehicles is plausible. The conclusion of the study was that it is not possible for the case company to attain full-scale electrification of their vehicle fleet without measures from the two countries' governments and other actors within society. With a need to strengthen the infrastructure required for large-scale electrification of the last-mile delivery industry in both Sweden and Denmark.

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# Nomenclature

Below depicts the system of terms used in the study with explanations. The terms and acronyms chosen to present and explain in the nomenclature were deemed unfamiliar for an average reader not specialised in the subject at hand and the term explained could ease the reading experience.

**RQ** = research question

**customer** = the customers that sell the goods that the company deliver to the end-customer

**end-customer** = customer that gets the final product

**EV** = Electric vehicle - in this study only pure electric battery vehicles are considered

**ICEV** = Internal combustion engine vehicle - for example vehicle fuelled by diesel or gasoline

**DC/distribution centre** = Warehouse with products to be redistributed to end-customers.

**route** = one vehicle's path from and to a depot with nodes in between

**route batch** = all routes distributed from one DC during one day

**supply chain** = all processes that together make up a commodity's production and distribution

**last mile** = the last section of the supply chain, from the last transit point to the end-customer

**cold chain** = supply chain of any product that requires a certain temperature, i.e food, perishable, vaccines

**active cooling system** = cooling of goods with an electronic system

**perishables** = food of different kinds (fruit, vegetables, meats, and so on), flowers, and plants

**foodstuff** = substances that are used to make food

# 1 Introduction

The transportation sector accounts for a fifth of global CO<sub>2</sub> emissions (Ritchie, 2020). Based on data sourced from IEA, road travels overall account for three-fifth of these emissions. These emissions from road vehicles, especially those run by internal combustion engines (ICE), have a large number of negative effects on the environment and the public. Firstly, CO<sub>2</sub> emissions are the main driver of global climate change. Secondly, air pollutants cause large amounts of local health problems in the form of poor air quality which are more apparent in urban environments with large densities of traffic flow in a small area (Quak et al., 2016). Thus, in an effort to cut down on emissions from road transport, policymakers aim to strangle emissions from emission-heavy vehicle types to incentives the usage of more sustainable types, preferably zero-emission vehicles. One example is that the EU has introduced several measures such as CO<sub>2</sub> emission targets, tax rebates for sustainable energy sources and purchase subsidies for alternative fuels.

Electric vehicles (EVs) have been seen as a worthy contender to today's conventional diesel vehicles in the climate of stricter policies. As described by Feng and Figliozzi (2013) and Quak et al. (2016), EVs do not produce local tailpipe emissions, are quieter and their use has been shown to reduce carbon emissions by a lot. A case study made in Milan showed that the use of EVs decreased greenhouse emissions by up to 54% when driving 120 km per day compared to diesel-fuelled vehicles (Siragusa et al., 2022). Electric vehicles overall are considered by many as a solution to tackling local emissions in an urban environment.

For freight companies in the transportation sector to accommodate the ever-changing policies towards an emission-free future, electrification of fossil-driven and/or hybrids to fully electric vehicles looks to be a promising possibility to become future-proof. This is especially true for last-mile delivery companies that handle the last transport of a customer delivery from a distribution centre (DC). Last-mile delivery is characterised by low speeds and multiple stops in urban environments (Jaller et al., 2021).

Diesel is currently the dominant fuel technology for medium- and heavy-duty trucks due to low costs, high efficiency and greater range compared to other alternatives. The combustion of diesel is also responsible for a large share of air pollutants in urban areas (Feng and Figliozzi, 2013). The report further claims that even though freight vehicles have a 10% share of urban vehicle distance travelled in the U.S., those that are diesel-powered account for almost 90% of the air pollutants from road traffic in the U.S. This share of urban vehicle distance is also increasing globally as the market for e-commerce is expanding, and also shifting towards home deliveries (Jaller et al., 2021). With this change in customer behaviour, every household in an urban environment becomes a potential destination of the cargo, increasing the likely share of externalities (noise and air pollutants etc) produced by freight transportation. This further emphasises the importance of sustainable solutions, and due to EVs' potential to reduce these externalities, it is a worthy technology for freight transportation.

Transitioning to electric commercial vehicles, however, comes with its own set of challenges when considering freight transportation. Batteries used in EVs are often big and heavy which sets a limit on the amount of freight a vehicle can handle (Noel et al., 2020). Additionally, EVs got a limited driving range, charging an electric vehicle is time-consuming compared to fuelling fossil-driven vehicles and charging infrastructure as of today is underwhelmingly available (Noel et al., 2020). Along with the change in customer behaviour, it becomes a determining factor to have the necessary driving range to accommodate all household demands in an urban environment (Noel et al., 2020). With all these aspects in mind, last-mile delivery companies need to plan their routes with more caution when operating with a vehicle fleet of EVs than for a fossil-driven fleet to ensure the same efficiency and security of their services (Basso et al., 2019).

The focus of this report will be on a Swedish last-mile delivery company which is currently operating in the four Scandinavian countries of Sweden, Denmark, Norway and Finland. The company specialise in the delivery of food in the form of meal kits and groceries. Their current fleet of commercial delivery vehicles consists of refrigerated trucks with an active cooling system to ensure a controlled temperature during the freight distribution. The company aims to now electrify its current vehicle fleet but as the aforementioned challenges exist with EVs, the new challenge with the charging of the active cooling system, and the underlying costs that come with it all, the company requests a strategy that will ensure a smooth transition.

## 2 Aim and Research Questions

The aim of this study is to identify and evaluate how a last-mile delivery company operating in Sweden and Denmark should approach the electrification of their current fossil-driven vehicle fleet with an active cooling system.

With the ever-changing policy climate towards zero emissions, especially regarding the transportation sector, companies strive to accommodate their businesses to stay relevant in the future. Changing their fleet of fossil-driven to fully electric vehicles is one of these changes that companies are striving towards, the company in question is one of them and is thusly the main issue presented in this report.

One part of the issue when working on a plan for transitioning from internal combustion engine vehicles (ICEVs) to EVs is to consider what impacts the transition the most. Also, consider what the company can affect and what lay beyond its scope. To tackle this issue the first research question was formulated:

- *Which factors, both alone and relative to each other, have the most significant contribution to the transition from ICEVs to EVs?*

The other part of the issue concerns what part of the company's current operation is beneficial to be electrified, to maintain the same efficiency The Company has today. The issue needs to be considered from both a current and prospective point of view. To analyse the current operation and how the factors could potentially change in different scenarios. This yielded the second research question:

- *Based on the considered factors, which scenarios show the optimal path to transitioning to an electrified fleet?*

## 3 Limitations

The technology connected to electric vehicles is under constant development, it is an area with high investments and with many actors involved. To limit the study only the technologies available at the time of the study will be considered, entailing both the technologies associated with the vehicles and the technologies with reference to charging the electric vehicles. Further, the study will be limited to the vehicles that are currently used by the company, as that is in the interest of the company. This entails two different models of ICEVs and two different models of EVs, which are specified in section 5.1.

A limitation regarding the company is that the study will not consider the customer behaviour, neither the end-customer nor the customer, as this would give the study a more social direction which is not a part of the study. In accordance with the study's purpose the focus lies on the company and its operation and what changes are available in the organisation. Although it is necessary to uphold the same quality of service before and after the transition it is not in the scope of the project to measure this from a customer perspective.

Another delimitation is that the study will not investigate how the charging of electric vehicles should be managed. Even though the availability to recharge the vehicles efficiently is an important aspect of a company's electrification of its vehicle fleet it is outside of the scope of the project and will not be studied. With similar reasoning, economic factors such as the costs of the potential changes that are proposed will not be part of the study.

## 4 Literature Review

To answer the aforementioned research questions and build a basis for the study a literature review was conducted. The literature review was based on two main topics, Electric Vehicles and Last-Mile Delivery, which were researched in relevant databases such as Google Scholar and Elsevier’s database ScienceDirect. The two topics are central to the organisation that was studied and from the findings of these, a list of keywords was gathered to further the literature review, see Fig 1 for an overview of the literature review approach. The publications found when searching on the keywords were put through initial filtering based on their abstract. If the publication was found relevant to the literature review the findings of the publication were interpreted and the relevant information was summarised under the corresponding section in the literature review. Additionally, governmental reports were also reviewed as a complement for some of the subjects researched to ensure that updated data was used and for added knowledge on technicalities.

First, the main topics, Electric Vehicles and Last-Mile Delivery, were researched with a broad scope, to build a theoretical framework for the study. This included literature on the subjects on their own and how electric vehicles are used in freight and last-mile delivery. Literature on how to approach the problem of electrifying freight vehicles was reviewed, with emphasis on literature that uses quantitative data to approach the subject. These were used as the basis for both research questions 1 and 2, with a focus on which factors have a greater impact on the electrification of a vehicle fleet and the methods used for analysing operational data.

Further narrowing down on the keywords presented in Fig 1, literature on Vehicle Routing Problem was researched to understand how the day-to-day operations within logistics companies are planned and analysed. This guided the literature review toward subjects such as Energy Consumption Modelling and Mixed Fleet Alternatives, both being important components of the Vehicle Routing Problem. From the literature review on Electric Vehicles used in freight another keyword was brought up, Alternative Fuel Sources. Electric vehicles are not the only option to attain a more sustainable last-mile delivery, hence the literature review was expanded to include Alternative Fuel Sources. One essential subject that is connected to Last-Mile Delivery is Cold Chain logistics, which concerns the distribution of chilled and frozen goods, a topic which is principal for this study, thus the literature review was complemented with the subject of Cold Chain. Lastly, concerning both Electric Vehicles and Last-Mile Delivery, a literature review on government regulations regarding governments’ policy changes to accommodate companies’ transition toward more sustainable vehicle types was conducted.

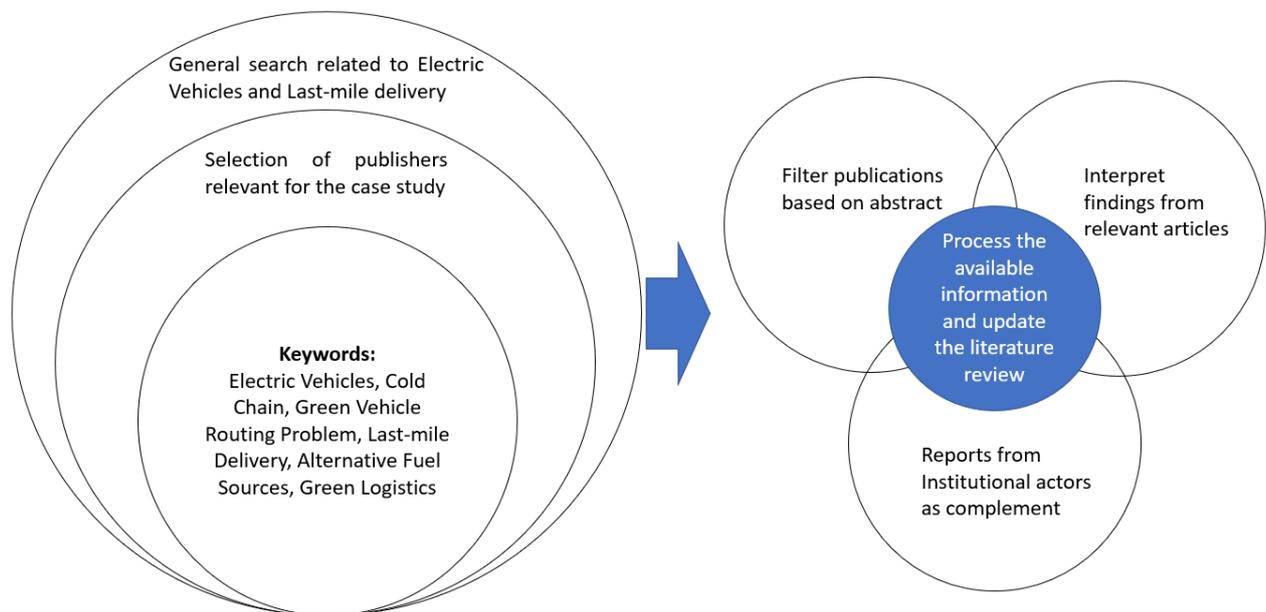


Figure 1: Overview of Methodology for the literature review

## 4.1 Last-Mile Delivery

Last-mile delivery is the last stretch of the supply chain, denoting the transportation of a good from the last transit point to the end customer (Hsiao et al., 2018a). The last-mile section of the supply chain is considered the most challenging, with studies showing that it is one of the most costly, inefficient, and polluting parts of the supply chain (Hsiao et al., 2018a; Buldeo Rai et al., 2019; Olsson et al., 2019; Leung et al., 2018). Buldeo Rai et al. (2019) indicates that last-mile distribution is responsible for 13-75 % of the total economic costs of the supply chain. The last mile often occurs in cities, areas with high population densities and traffic volumes, which increases the driving duration and mileage that is driven (Allen et al., 2017). This in combination with low order density decreases the efficiency of the supply chain and increases the cost and pollution (Hsiao et al., 2018a; Leung et al., 2018; Edwards et al., 2010; Gevaers et al., 2014).

Further challenging last-mile delivery, consumer behaviour has a large impact on its efficiency (Leung et al., 2018; Buldeo Rai et al., 2019) and the environmental effects (Edwards et al., 2010; Bjørgen et al., 2021). Many customers want specific time windows, studies have shown that offering a tighter time window increases the costs for last-mile significantly (Boyer and Chung, 2009; Cardenas et al., 2017). The irregularity in which customers place their orders adds to the complexities of distributing the last mile in an efficient way (Leung et al., 2018). Last-mile distribution to households is gaining traction each year and is quickly securing a bigger role in consumers' day-to-day life (Olsson et al., 2019; Lim et al., 2018). For many consumers, it is a way to procure goods in a more flexible and less time-consuming manner, not only as a way to procure household items, clothing, and toiletries but also as perishable goods (Lim et al., 2018). Perishable goods include groceries, pre-prepared meals and other types of goods that are at risk of spoiling if not handled with a correct system in place (Hsiao et al., 2018a).

The supply chain of perishables, a cold chain, involves several challenges and complexities that do not exist for the transportation of other types of goods (Hsiao et al., 2018a; Chaudhuri et al., 2018). Perishables require a higher level of hygiene and temperature control to ensure a high level of quality, and a large share of perishables have a strict temperature limit which cannot go above without compromising its constitution (Hsiao et al., 2018a; Hsiao et al., 2018b). Cold chains include goods such as food, pharmaceutical, and other chemical substances, the main purpose of a cold chain is to protect these goods from high temperatures, humidity, and contaminants that may soil them (Chaudhuri et al., 2018; Shashi et al., 2018). Not only is there a need to maintain good quality for the sake of profit and maintaining hygiene but also to minimise food waste during the cold chain (Hsiao et al., 2018b; Shashi et al., 2018), which is costly for the distribution companies and society (Orejuela-Cabrera et al., 2021; Shashi et al., 2018).

The interest in cold-chain distribution has increased concurrently with the increase in demand for home deliveries of perishables, with the end goal of delivering perishables without breaking the cold chain, all the way to the end customer (Hsiao et al., 2018a; Hsiao et al., 2018b; Q. Yin and Tian, 2022). As mentioned above, last-mile delivery is one of the most costly parts of the supply chain, concerning both economic and environmental aspects, last-mile distribution within the cold chain adds further challenges and complexities (Hsiao et al., 2018b). Studies show that cold chains emit great amounts of greenhouse gases (GHG) such as  $CO_2$  and refrigerant gases, CFC, HFC, and HCFC (Chavan et al., 2021; Bozorgi et al., 2014; Wang et al., 2013). Emissions of refrigerant gases are a result of the usage of active cooling systems, which are often used in cold chains (Chavan et al., 2021).

There have been studies done on how to build and keep an effective cold chain, both on a cold chain (Chaudhuri et al., 2018) and on a food cold chain, which is a type of cold chain with the focal point of distribution of foodstuff (Shashi et al., 2018). Traditionally, the entire food cold chain entails pre-cooling facilities, warehouses, carriers, and containers that require a cooling system, which often requires a greater energy demand compared to traditional supply chains (Saif and Elhedhli, 2016). The system also usually includes tools for measurements with temperature sensors to ensure that acceptable conditions are met (Chaudhuri et al., 2018; Shashi et al., 2018). All the aforementioned components of the food cold chain infrastructure are often not needed in other types of supply chains and consequentially food cold chains are more costly, from an economical, energy-demand, environmental (Saif and Elhedhli, 2016), and technological point of view (Shashi et al., 2018).

To ensure that the cold chain meets the temperature requirements of the goods a passive or active cooling system can be used (Ceva Logistics, 2022). A passive cooling system entails a system where the cooled good is surrounded by an insulating material to ensure that its internal temperature does not decrease under a certain temperature limit (Martínez-Val and Ramos, 2021). An active cooling system utilises some electronic heating system which continuously chills the goods (Martínez-Val and Ramos, 2021), for example with refrigerated trucks (ECA, 2022). Although an active cooling system can ensure good hygiene for the goods transported it comes with added complexities, an added weight for the vehicle and a greater demand for energy (Zanoni and Marchi, 2021).

## 4.2 Electric Vehicles

The basic definition of a pure EV is a vehicle that is powered by an electric motor using only energy stored in batteries or in fuel cells. EVs are seen as an important asset towards the decarbonisation of the transportation sector (Noel et al., 2020). The main advantages of an EV compared to an ICEV is that it is more energy efficient, has less local pollution due to zero tailpipe emissions, emits less noise and can over its lifetime emit less greenhouse gas depending on the electricity production mix (Karimpour et al., 2023). The main disadvantage, as stated in many studies, is the battery which in this case is primarily due to the range limitation (Quak et al., 2016; Melander et al., 2022), but also added vehicle weight due to the battery (Noel et al., 2020). Lastly, the convenience and speed of charging the vehicle are added complexities at the present time (Goeke and Schneider, 2015). These are all essential constraints to consider when thinking of utilising EVs in last-mile delivery.

### 4.2.1 EVs used in Last-Mile delivery

Experiments with electrical freight vehicles (EFV) in last-mile delivery and urban freight have been conducted globally over the last decennial for the sole purpose to mitigate the externalities caused by conventional diesel vehicles. Several experiments described by Rizet et al. (2016) all give contrasting results depending on the situation. The observation made was according to the source:

*...literature describes many experimentations of EVs in urban freight but there is no real assessment of generalising the use of these EVs for urban freight at a national scale -(Rizet et al., 2016, p. 502)*

Moreover, the report by Rizet et al considers two important problems with the large-scale use of EVs: the limited range of the battery and the payload of these vehicles. Noel et al. (2020) pointed out in a study regarding the acceptance rate for personal EVs in the Nordic countries, that the limited range works for 90% of routes conducted by EV users. Noel et al. (2020) pointed out that around 90% of routes driven by EV users in the Nordic countries could be operated without the need to recharge. Nonetheless, due to the fact that 10% of the routes could not be completed still hinders the speed of acceptance for transitioning as EVs can not be used for all routes (Noel et al., 2020). In the context of freight deliveries, this can lead to complications for longer delivery routes as more EVs are needed to replace routes performed by fewer conventional diesel vehicles. This task to address EFV for use in freight deliveries with respect to the environment is represented in studies as the Green Vehicle Routing Problem (Lin et al., 2014).

Green vehicle routing problems have been extensively researched about how to render EVs competitive for freight use by investigating environmental costs (see section 4.2.2 for more). A study made by Melander et al. (2022) investigated experiences of EFV transitions for a number of freight companies. A common acknowledgement from all companies in the study was the limited range, not only that it was not enough, but that the promised range from the specifications of the EVs was not its actual range. Leading to vehicles running out of power before they fully completed their route. Noel et al. (2020) expresses a few reasons for this phenomenon but one significant reason for the Nordic countries is the weather. Cold climates have a negative effect on the battery range. Noel et al. (2020) continued with one extreme example from their study conducted partly in Iceland where temperatures reached below zero degrees Celsius, and the battery range was reduced by more than 50% (Noel et al., 2020). Another reason for the range decreasing is also due to battery ageing, mostly due to poor energy management. As stated by Jia et al. (2022), the frequent starting and braking behaviour of EVs in motion consequently leads to the battery being constantly charged and discharged which in turn leads to accelerated battery ageing.

A study by Quak et al. (2016) describes the known remark from other studies about the insufficient range of EFVs. It also remarks that companies that do not require high range in their operations are perfectly fine with these characteristics, leading to the same conclusion from Rizet et al. (2016) that usage of EFVs is case-specific. Quak et al. (2016) elaborates further stating that EFVs are best suitable for last-mile deliveries in dense urban areas with limited route lengths and low travel speeds. This fact is complemented by Erdelic et al. (2019), as they state that EVs are more suited for short distances in urban areas due to the ability to operate efficiently with low driving speeds and frequent stops in the areas. For a last-mile company to transition from ICEVs to EFVs it will often lead to changes in the operational level (Quak et al., 2016). As there might be cases where orders are out of reach for EFVs but not ICEVs, due to EVs' characteristics. This leads to less flexibility in the transition and more of a need to adapt their business to accommodate the limited vehicle range. Quak et al. (2016) finalises their findings by stating that the main strength of EFVs is its environmental performance, and one should not look to profit from it today but instead transition to it early to be ahead of the curve.

### 4.2.2 Vehicle Routing Problem

Ghiani and Improta (2000) defines Vehicle Routing Problem (VRP) as: *"the problem of determining optimal delivery or collection routes from a given depot to some geographically dispersed customers subject to operating restrictions."* (Ghiani and Improta, 2000, p. 3). Companies operating with fleet management and logistics rely heavily on VRPs

to optimise vehicle routes (Futalef et al., 2023). There are several formulated techniques over the years of research that are extensions of the VRP by incorporating real-life complexities. For example, the Generalised Vehicle Routing Problem (GVRP) aims to find the shortest routes to and from a depot after visiting each node in between at least once (Ghiani and Improta, 2000). A second example is the Vehicle Routing Problem with Time Windows (VRPTW) which asks for the optimal sets of routes to visit all nodes within assigned time windows (Truden et al., 2022). The latter is a vital tool in how companies specialising in grocery delivery services handle the logistics in today’s growing popularity of e-commerce due to the problem formulation’s wide range of applications (Truden et al., 2022). While GVRP also coincides directly with other types of formulations and real-world situations such as setting up optimal routes for post-box collection or routing for goods distribution by sea (Ghiani and Improta, 2000). There are plenty more variants of VRPs with real-life applications such as limited vehicle load capacity, multiple depots (see 4.5) or heterogeneous fleet (see 4.3) and over the years a lot of methods and procedures have been proposed to solve these different types of VRPs (Erdelic et al., 2019).

As noted by Futalef et al. (2023), most research going into different types of VRP variants deals with ICEVs as the selected vehicle. It is only recently that new variants to the traditional VRPs have emerged to accommodate environmental sensitivity known as the Green Vehicle Routing Problem (Gr-VRP) (Lin et al., 2014). Gr-VRP is directly correlated with the broader term Green Logistics which is defined as: -"*... supply chain management practices and strategies that reduce the environmental and energy footprint of freight distribution...*" (Seroka-Stolka, 2014, p. 303). Lin et al. (2014) performed a study that reviewed variants of VRP and the means to incorporate Green Logistics into these. Their findings proved that extending VRP objectives to consider environmental impact is achievable, but required more accurate formulations to be able to assess quantitative benefits. This observation is complemented by a study from Basso et al. (2019) that conducted routing experiments for electric vehicles in an urban environment. Their conclusions stated that accurate energy and time estimations are essential for the case of electric vehicles due to range limitations from the usage of EVs, they also added that further research going into other vehicle architectures could be of interest.

The variants of Gr-VRP that only focuses on EVs are called in literature Electric VRP (E-VRP) which takes into account the technical limitations of EVs (Futalef et al., 2023; Montoya et al., 2017). Futalef et al. (2023) further explains that researchers behind E-VRP have identified a few aspects that should be included in the problem formulation:

- Take into account recharging times, amount and charging station technology (fast versus slow)
- Have the option of allowing partial recharging instead of full
- Using realistic EV energy consumption models
- Consider the maximal charging station capacity to limit parallel charging

Although these factors were important in EV fleet management, most problem formulations for E-VRP dropped some of these key elements in favour of simplicity according to Erdelic et al. (2019), who conducted a survey on today’s ongoing research on E-VRPs. The survey further concluded that a lot of today’s research going into E-VRP takes a limited driving range of EVs and their energy consumption as the most vital parts of EV routing.

### 4.2.3 Energy Consumption

According to Basso et al. (2019), it is necessary to estimate energy consumption considering the factors that influence the energy capacity of the vehicle’s battery. Basso et al. (2019) continues by describing three different types of models for estimating energy consumption:

- Factor models - Looking at energy per distance travelled purely for one vehicle with relevant factors
- Macroscopic - Utilises fleet- or network-wide parameters to find a general energy consumption model
- Microscopic - Detailed second-by-second energy consumption modelling for every single route

While all these types of models are approximations of real-world energy consumption, microscopic models require a detailed driving cycle which is generally hard to acquire. However, Basso et al. (2019) also states that microscopic is the most preferable category of modelling as both factor and macroscopic models generally have lower precision. Basso et al. (2019) also emphasises that VRPs require the precision of microscopic models to accurately predict energy consumption but the problem stands that the driving cycle is not known beforehand. Basso et al. (2019) highlights the need for details of the path such as acceleration and braking, and a speed profile in general, as the most common workaround without these details is setting an average speed which in turn gives a hefty approximation error. Turkensteen (2017) complements this fact by stating that in some situations it can lead to estimating less than half of the actual needed fuel.

### 4.3 Mixed Fleet

In today's vehicle fleets, there are mostly ICEVs in operation, and transitioning to a pure electric fleet is a challenging task with operational and economic difficulties (Erdelic et al., 2019). Therefore most companies are instead gradually introducing EVs into their existing ICEV fleet so their route planning methods can gradually be altered to adopt a full-scale transition at a later time, in the meantime however strategies to consider the trade-off between the two vehicle types need to be considered (Goeke and Schneider, 2015). Erdelic et al. (2019) published a survey regarding different variants of EV-VRPs, one variant group was about Mixed Vehicle Fleets and today's research surrounding it. Their findings from various sources were that mixed fleets of ICEVs and EVs had an overall positive influence, mostly with the results showing lower total routing costs. When optimising mixed solution of vehicles, it was also shown from a study reviewed by Erdelic et al. (2019) that EVs were preferred for clustered instances, where nodes to visit were within close distances to each other, while ICEVs were preferred for the opposite, that is randomly distributed nodes in a widespread area.

A mixed fleet is not necessarily consisting of only EVs and ICEVs, different types of vehicle modes have been presented in the literature as of late (see 4.4). A rising potential strategy to introduce as a means to reduce negative impacts is to employ cargo bikes in a vehicle fleet (Narayanan and Antoniou, 2022). Narayanan and Antoniou (2022) continues by stating that cargo bikes offer the advantages of being generally environmentally friendly, reducing traffic congestion in urban areas and taking less space than commonly used freight vehicles. These characteristics make for perfect candidates in high-density urban areas like congested city centres (Perboli and Rosano, 2019; Narayanan and Antoniou, 2022). But as further described by Perboli and Rosano (2019), when comparing vehicle performances with one another, EVs and cargo bicycles offer similar advantages when delivering in urban areas, but the better of the two depends a lot on the circumstances (Perboli and Rosano, 2019). Still, the potential to expand cargo bicycles is hindered according to Narayanan and Antoniou (2022) by requiring supportive policies as a prerequisite for a transition from conventional vehicles.

### 4.4 Alternative fuel sources

Electric vehicles are one of many technological innovations introduced as a means for the vehicle industry to reduce carbon emissions and other externalities such as noise pollution and local emissions. Melander et al. (2022) made a study in which companies explored the possibilities of using EVs, the companies in question were open to different options, denoted AFVs (alternative fuel vehicles), such as hydrogenated vegetable oil (HVO) and hydrogen (Melander et al., 2022). The former is a fossil-free diesel product that with its usage results in reduced NO<sub>x</sub>, CO and other harmful emissions (Ghadimi et al., 2022). HVO can be utilised on its own or in a mixed blend with diesel to replace conventional diesel vehicles without modifications done to its engine (Preuß et al., 2021). Successes have been made to the transition of HVO as described by Melander et al. (2022) with a company referring to the fact that *"changing to HVO is easier and includes fewer costs than changing to electric vehicles"* (Melander et al., 2022, p. 8). However as mentioned by Roque et al. (2023), it is important to highlight that the production of biofuels such as HVO competes with food production. Moreover, large-scale production of these fuels has significant land use changes (Austin et al., 2022).

Hydrogen in fuel cells is another alternative fuel source for electric vehicles as a replacement to batteries commonly used now (Thomas, 2009). Thomas (2009) further concluded that fuel cells are superior to batteries in terms of initial greenhouse gas emissions and energy efficiency. Melander et al. (2022) comments that infrastructure is the main concern when adopting hydrogen as a fuel source, as the availability of hydrogen gas is insufficient. This lead to a dilemma for the companies in the study by Melander et al. (2022) as to who should be investing in hydrogen first: will investments from producers go into fuel stations, with no idea if there will be a market, or should companies invest in hydrogen vehicles, with no idea if there would be enough hydrogen available for use due to lack of infrastructure. This problem is likely to exist for many years, as a majority of alternative fuel vehicles in the US continued to utilise conventional gasoline due to a lack of alternative fuel stations (Erdoğan and Miller-Hooks, 2012). Conclusions from Sluijk et al. (2023) who studied the impact of fuel availability on demand for AFVs complement this fact stating that the failure to expand the network of alternative fuel stations significantly hinders the adoption of these vehicles.

### 4.5 Micro-hubs & Multi-Echelon Distribution System

A way to use EVs, as described by Quak et al. (2016), in cases where electrification is not possible due to battery range is to make use of a micro-hub to reach faraway areas. A typical micro-hub is a consolidation centre, in which the delivery process is divided into two sections, first delivery of freight to the micro-hubs which is followed by last-mile distribution to end customers (Pahwa and Jaller, 2022). Their findings show that micro-hubs allow sustainable means of transport to handle the last-mile distribution as the micro-hubs are typically stationed in close proximity to end customers.

A similar topic to micro-hubs as described by Sluijk et al. (2023) is a two-echelon vehicle routing problem (2E-VRP) where the distribution network is split into two levels/echelons. The first level as further explained by Sluijk et al. (2023) is between depots/warehouses and satellite depots, where larger vehicles operate, the second level is between the satellite depots and customers, where smaller vehicles operate. This division is performed to adhere to vehicle restrictions near customers, the two examples used in the study are vehicle weight and parking space. Ultimately a two-echelon distribution system keeps large vehicles out of urban areas to take into account the negative impact on safety and the environment (Sluijk et al., 2023).

Breunig et al. (2019) expanded on the subject of two-echelon vehicle routing problems by investigating the utilisation of conventional diesel vehicles with higher load capacity in the first echelon and electric vehicles with lower load capacity in the second echelon between depots and customers. Their findings suggest that EVs battery capacity has a large impact on the quality of routes and that there exists a need for either an increase of battery capacity and/or recharging infrastructure readily available. For instance, a battery capacity below 80 km rendered electric deliveries unfeasible for Breunig et al. (2019) while an increase of battery capacity to 150km made the test instances feasible without a need for en-route recharging. The authors concluded their research by emphasising the role of the placement and the number of charging stations or satellite depots available to optimise distribution further.

Another study by Hajghani et al. (2023) conducted experiments for the two-echelon vehicle routing problem through a multi-objective linear programming model. The authors noted that optimising for the three objectives of the problem was not entirely possible as they contradicted each other, these objectives in question were the minimisation of costs, minimisation of emissions and maximisation of social responsibility (job opportunities, customer satisfaction and community development) (Hajghani et al., 2023). Thus it was concluded by the authors that a trade-off solution should be provided for each objective depending on what should be prioritised.

## 4.6 Government policies and regulations

Influences from local authorities have a major impact on how businesses and customers should move forward with various decisions. In regards to the adoption of electric vehicles Kumar and Alok (2020) conducted a review on this topic and found three different categories of policies: Purchase-based incentives, use-based incentives and government regulations. Purchase-based incentive policies comprise financial benefits aimed at EVs such as tax exemptions and emission taxes for example. For the purpose of facilitating EV adoption through lower purchasing costs. Studies investigated through Kumar and Alok (2020) concluded that financial incentives were significant motivators for increased EV usage.

The use-based incentive policies as described by Kumar and Alok (2020) are designed to ease the usage of EVs, examples include free parking and highway lane excess. Quak et al. (2016) stated that the two aforementioned examples could improve the efficiency of EV operations. But another study reviewed by Kumar and Alok (2020) found that toll exemption and bus lanes for EV users were not significant for incentivising EV sales in Norway. So the conclusion made was that policy measures should be based on regional EV scenarios. One widely adopted policy that has been utilised in urban areas and can be classified as use-based is the Low-Emission zones (LEZ). An incentive-based regulation that targets emission-heavy vehicles with the aim of reducing local emissions in an urban environment (Zhai and Wolff, 2021). As concluded by “Low emission zones: Effects on alternative-fuel vehicle uptake and fleet CO<sub>2</sub> emissions” (2021) LEZ is a suitable measure for stimulating the adoption towards EVs and other low-emission vehicles but zero-emission zones would be required to effectively decarbonise vehicle fleets.

The final category brought up by Kumar and Alok (2020) is the government regulations. Which are outcomes of policy-level decisions taken by countries to support the electrification of the transportation sector. GHG-, carbon fuel standards and zero-emission directives are examples of such regulations that target manufacturers and fuel suppliers. Government regulations have massive long-term impacts and studies reviewed by Kumar and Alok (2020) noted several benefits through regulations that could boost the market penetration of EVs. One regulation that Rizet et al. (2016) stated that authorities needed to consider is the development of charging infrastructure for EVs to incentivise further adoption. Kumar and Alok (2020) complements this statement as many studies agreed on the importance of public fast chargers for urban and densely populated environments. Further stating that policy decisions and regulations surrounding incentives for the installation of charging facilities will further the likelihood of EV adoption.

A conclusion made by Melander et al. (2022) is that there exists uncertainty in the political will to argue for a transition towards EVs for transportation, despite clear forecasts on goals and targets to reach in different countries. Melander et al. (2022) concluded that long-term commitments and clear communication between actors should help companies and customers make investments in sustainable transport.

## 4.7 Factors

To connect the reviewed literature with the research questions, especially RQ1, factors of interest to the study will be presented. These factors are all relevant in the study as they have been prevalent in previous studies and are thus in some way linked to the problem of electrification. The factors are showcased below in Table 1. The factors are furthermore divided into three different types of dimensions according to the STO framework inspired by Arababadi et al. (2017). The three dimensions are:

- Strategical
- Operational
- Tactical

The strategic level is translated as the highest level of planning that encompasses the bigger goals of a community and provides direction to achieve these long-term goals. The strategic plans are referred to in this study as the external decision makings made by actors outside of the company such as the Government. The tactical level is translated to the incremental planning to achieve the company goals, in this case, this means the company’s own implementation of strategy and planning on a broader scale such as choice of vehicle. The operational level defines the day-to-day operations of the company. Specifically for this study factors that are included within the operational level are the vehicle’s performance operating in a route.

Table 1: Relevant factors gathered in the literature review along with the level of planning for each

Factor	Level of planning
Energy consumption	Operational
Battery capacity	Operational
Cooling power	Operational
Order Density	Operational
Route Duration	Operational
Velocity	Operational
Distance	Operational
Policy	Strategical
Number of vehicles	Tactical

A key limitation surrounding EVs that are bought up numerous times in literature is the **battery** along with its main disadvantages of increased vehicle weight and **driven distance**. For freight companies, this generally limits the distances of the routes performed by EVs or the route to be in close proximity to the DC. The added vehicle weight due to the battery’s size will also impact the number of goods a vehicle can carry in a single route. This leads to a limited choice of vehicles, more so when considering a functioning **cooling chain**.

Something that has a large impact on the operation when looking at a broader perspective is the **number of vehicles** deployed for distribution in a given area. When observing routes for orders in an area, the number of vehicles is a factor that may impact several other factors in the comprehensive analysis. Such as the **amount of population in an area**. This factor can be interpreted as either population density or order density. The latter might be of more interest for the case study as customers will be taken into consideration directly while the prior focuses more on a general level. Nonetheless, these factors are of interest when considering the factor of distance, the more customers there are close to each other less area needs to be covered by a single vehicle, and consequently, less energy needs to be consumed by either propulsion technology. This might prove to be a vital advantage for EVs as they are generally more energy efficient compared to ICEV, however, the reverse effect might occur as mentioned in the literature review: If the delivery routes need to cover large distances, more EVs are needed to replace routes performed by fewer conventional diesel vehicles due to range limit, thus both number of vehicles and order density is interesting parameters to consider in this study.

**Policies & Government Regulations** today are not enough, as for now there is not enough incentive to fully complete a mass transition. Although the prognosis of future policies is in favour of EVs, the uncertainty of when and how much they will alter the situation remains to be seen. So moving forward in the study, policies taken into consideration now and in the predicted future will be a key factor to discuss and get more knowledge about.

Lastly, an important factor regarding EVs is **energy consumption**. This factor coincides a lot with the former factors in that everything affects how much energy the EV consumes during a route. Also, due to the limitation that charging mid-route will not be considered, an energy consumption model from full battery charge to empty will be of special interest, thus a relevant **speed** profile as mentioned in the literature will be significant for precise modelling.

## 5 Methodology

This section describes the overall methodology to answer the research questions and thus forms the basis for this thesis. The methodology in detail is formally divided into research design, describing the multiple cases grounded in the case company, data collection and analysis, two sections that describe the gathering of data and the succeeding analytical methods used for said data to answer the research questions. Thereafter analysis of the preceding research will be done to check options for improvements.

### 5.1 Research Design

The study was based on comparing four different cases that are grounded in a Swedish last-mile logistics company that specialises in the distribution of meal kits and groceries with an active cooling system. With the goal to build a strategy for electrification and transitioning the company’s vehicle fleet. To achieve this, a multiple-case study analysing four different cases, all grounded in a single organisation was conducted. As per Bryman and Bell (2011), a case study focuses on a system with boundaries that have a distinctive purpose, with the aim of the study being to supply a comprehensive report on the system. A multiple-case study allows for a comparison of the different cases studied while still taking the uniqueness and differences of the cases into consideration. While still being able to examine the cases in their real situations (Bryman and Bell, 2011).

The cases are built around four cities located in two different countries. The choice of analysing two countries, instead of focusing on one, was made to facilitate a comparison of the operational, tactical, and strategic differences between the countries. This in turn allows for a greater variation in the study’s results and analysis to be used to derive general conclusions, also distinctive conclusions for both countries and for the four cases. As Eisenhardt and Graebner (2007) states, each case in a multiple-case study should be independent of the other cases with distinct differences to be able to build a more general conclusion from the study.

The four cases were based on two of the four countries the company operates in, Sweden and Denmark. The two countries were chosen as this is where the company in question has its largest operations and is more established within the market compared to the other countries. Therefore, starting a transition towards electric vehicles in Sweden and Denmark follows logically for the company. Furthermore, the study, with the same reasoning, focused on the cities of Gothenburg, Malmö, and Stockholm in Sweden and Copenhagen in Denmark, these four cities comprised the four cases. The four cities house a majority of the company’s customers so it was deemed most desirable to prioritise the transition in these regions.

As stated above in the limitations of the study, the vehicles are predetermined to four different models, two ICEVs and two EVs, see Table 2 for vehicle specifications on each model. The two ICEVs, Mercedes Sprinter and Peugeot Boxer are used today for everyday operations in both countries and are similar in their capacity regarding the weight and velocity limit. Entailing uniform operation for the company, independent of which of the two models are utilised. The two EVs contain significant differences, in the gross vehicle weight and the maximal velocity. The Maxus model has a considerably higher gross vehicle weight compared to the E-Tron, which facilitates a greater amount of orders per vehicle. It can also drive at a higher velocity which makes it possible for the vehicle to operate on highways and other road types on which the E-Tron is prohibited to drive.

Table 2: Vehicle Specification

Vehicle	Gross Vehicle Weight	Max Velocity
Maxus (EV)	4 050 kg	90 km/h
E-Tron (EV)	2 000 kg	30 km/h
Mercedes Sprinter (ICE)	3 500 kg	160 km/h
Peugeot Boxer (ICE)	3 500 kg	160 km/h

Table 3 presents an overview of the four cases; Copenhagen, Stockholm, Gothenburg, and Malmö, that were studied. The table presents the maximal gross vehicle weight that is legally allowed when using a class B license, and the population density for each case. Case 1 is located in Copenhagen, Denmark, a city that has a high population density compared to Stockholm and Gothenburg and is similar to Malmö. The case has one DC located in the southern parts of Copenhagen and is the most unique and different case compared to the three others. One big reason for this difference is the fact that in Denmark the maximal gross vehicle weight is higher than for Sweden when operating with a class B license. In Copenhagen, the company is currently operating an EV, model Maxus.

For the second case, Stockholm, the DC is located in the southern parts of the city and as described above, the maximal gross vehicle weight is lower for a class B license compared to case 1. In Stockholm, there are trials with the E-Tron,

which have been ongoing since before the start of the study. The third and fourth cases, Gothenburg and Malmö, are similar to case 2 as the same maximal gross vehicle weight limits apply. Although Malmö has a higher population density compared to Stockholm and Gothenburg, Gothenburg has the lowest population density of all four cases. The DC for case 3 is located in southern Gothenburg and the DC for case 4 is in northwestern Malmö. The cases are more thoroughly described in chapter 6.1.

Table 3: Case Description

Case	DC Location	Max Gross Vehicle Weight	Population density
Copenhagen	Southern Copenhagen	4 050 kg	4 611 $\frac{people}{km^2}$
Stockholm	Southern Stockholm	3 500 kg	3 829 $\frac{people}{km^2}$
Gothenburg	Southern Gothenburg	3 500 kg	2 632 $\frac{people}{km^2}$
Malmö	Northwestern Malmö	3 500 kg	4 150 $\frac{people}{km^2}$

The study is divided into two segments established on the two research questions (RQs), the first segment aims to answer what factors have the biggest influence on the transition from ICE to EVs. The second is to establish under what conditions that is most viable to transition to EVs in the four different cases described above. As a foundation for both RQs, data was collected and analysed on how the organisation operates today. This step of the study was to get an overview of how the company is organised and the potential obstacles to a transition to EVs.

For RQ1 existing data from the organisation was collected and analysed concurrently with a literature review of similar research, see table 4. The data from the company was collected through meetings with the Head of Distribution Center Development & Procurement, Head of Business Development, CTO, Fleet Manager, and Routing Operations Manager. The data collection was also sourced from their own database where they store data from previous routes, such as route length in km and hours, order per route, and DPH.

The other segment, grounded in RQ2, uses scenario analysis to investigate the four cases. The analysis was based on the results and the data collection done in the first segment combined with data that were taken from the organisation’s own route optimisation platform, both as simulations of made-up delivery routes and real-life data from actual delivery routes made with EVs and ICEVs. The data analysis for both RQs was based on three methods: descriptive (what is the problem), predictive (how does the problem get solved), and prescriptive (solving the problem).

Table 4: Method overview

	Research Questions	Data	Method	Results
Question 1	Which factors have the biggest impact on the transition	- Factors used in prev. studies - Data on old routes - Data on energy consumption on present routes with EVs	- Literature study - Meetings with employees in the company - The company’s own database - Analyse the factors	- Weighted list of factors - based on how significant they are - Based on lit. study - How much each factor influences energy consumption
Question 2	Scenario Analysis	- Factors from RQ1 - Data from simulations - Lit. on previous scenarios	- Meetings with employees in the company - Route optimisation platform - Literature study	- Map of areas that are feasible for EV expansion under different conditions - Max distance - Optimal order density - Energy consumption etc.

### 5.1.1 Route Optimisation Platform

One important source of data and tool that was used during the study was the company’s own route optimisation platform. The platform was developed by the company to fit their needs. The algorithm used for the optimisation has the goal of choosing the route with the lowest possible route duration. It is possible to alter the setting in the platform to make it route after the shortest possible distance as well. The algorithm also takes other factors into account, such as minimising the number of vehicles used, the time window when the customers want their orders delivered, and service time (which is the time a driver takes from arriving at the customer’s home and delivering the order). There are two ways of determining the number of orders per vehicle, either by volume or weight. Which is decided by what is delivered and if the information on the weight of each order is available. The velocity limit of each road in the area that is being routed is also taken into account by the algorithm. The platform also takes the type of road (concrete, asphalt, or gravel road) into consideration.

As mentioned above and can be seen in Table 2, there is a distinction between the two electric vehicles that were utilised, the E-Tron has a lower gross vehicle weight and maximal velocity limit compared to the Maxus. This variance entailed that the two vehicles required different conditions and limitations when running simulations in the route optimisation platform. For the E-Tron a preset setting exists with the correct velocity limit and the limitation concerning the type of road that the E-Tron can operate on. A limit on the number of orders per vehicle was set in place for all simulations, for the E-Tron the limit was set to 78% of the orders per vehicle the ICEVs and the Maxus operate with, this is standard practice for the organisation to accommodate for the lower gross vehicle weight. The Maxus have a

gross vehicle weight of 4 050 kg entailing that even though the curb weight of the Maxus is greater than the ICEVs the EV can be implemented with the same condition and limitations as the ICEVs, with the same amount of orders per vehicle.

## 5.2 Data Collection

The data that was collected was mainly quantitative data, from both primary and secondary sources. Bryman and Bell (2011) describes a quantitative research strategy as a deductive research approach with the focal point to test theories to achieve the goal of the study. Quantitative data is data that is observable and can be measured which is true for the data that were collected for this study (Bryman and Bell, 2011). The primary data collection consisted of meetings with the company’s employees, data from their own database, and data from vehicles, the secondary sources were from published studies. From the meetings with the company’s employees qualitative data was collected, qualitative data differs from quantitative data as it concerns non-measurable subjects. The qualitative research approach has an inductive angle, entailing a generation of theories rather than a testing of theories (Bryman and Bell, 2011). Important to note that this study focused on quantitative data, even though qualitative data was collected, thus the study had a deductive research approach as it tested theories as opposed to generating theories.

The first step in the data collection consisted of quantitative data from the company’s own database, where data on all previous operations have been stored. The data that was collected was previous deliveries that have been completed in the four cities that the cases are comprised of. The purpose of collecting this type of data was to gain knowledge of the company’s current operations in the four cities, data included the number of orders and vehicles, route duration, route distance in km, and efficiency measures. The data that was collected comprised of data for a week in November 2022, this was determined to be an accurate representation of the company’s current operations in the four cities during an average week and was used for answering both research questions 1 and 2.

Table 5: Meetings with employees of the company

<b>Title of employees</b>	<b>Point of Discussion</b>	<b>Data Collected</b>
Head of Distribution Center Development & Procurement	The process of expanding DC locations & work towards electrification	Qualitative data on factors’ impact on electrification & decision-making
Head of Business Development	The company’s operational strategy & decision-making process	Qualitative data on decision-making and company’s way of work
Routing Operations Manager	The company’s route optimisation platform	How to operate the platform, changing the settings based on the different vehicle types
Fleet Manager	The company’s vehicle fleet & their work on expanding it towards an electrified fleet	Qualitative data on factors’ impact on electrification & quantitative data on vehicle and vehicle fleet specifications

Meetings with different employees in the company were conducted on various occasions throughout the study, resulting in findings connected to several areas of the study. An overview of the meeting’s point of discussion and participants of the meeting is presented in Table 5. A meeting with the Head of Distribution Center Development & Procurement gave insights into the company’s current work towards electrification and the decision-making process concerning the operational expansion of the company. Meetings with the Head of Business Development were conducted continuously during the study with the main goal of ensuring that the study’s scope is kept within the limits of the organisation. The meetings resulted in qualitative data on the company’s decision-making process and its operational strategy. The Routing Operations Manager gave a greater comprehension of the company’s route optimisation platform and how to operate it in regard to different vehicle types. A meeting with the Fleet Manager was conducted to understand how the company works with electrification and quantitative data on the vehicle fleet and the different vehicle types.

Table 6: Information sources

Information	Sources	Type of Source
Factors	RQ1 results	Primary
Routing techniques	Literature review + Meetings	Secondary + Primary
Policy forecast	Literature review	Secondary

The aim of RQ1 was to investigate which factors have the most significant contribution to the transition from ICEVs to EVs. The factors in question that were investigated were the ones described under section 4.7 narrated in the literature review and further described in Table 7 along with an overview of their sources and the type of source. RQ 2 had the aim to first look at the potential a transition to electric vehicles could have, considering potential changes in the political climate. The second part of RQ 2 was to identify scenarios which would yield the most efficient electrification for each case. Table 6 explains briefly what kind of information is required to move forward for this question.

Table 7: Relevant factors and their source

Factor	Sources	Type of Source
Energy consumption	Data from Maxus Model + Databases	Primary
Battery capacity	Vehicle Specifications + Meetings	Secondary + Primary
Cooling power	Vehicle specifications + Meetings	Secondary + Primary
Number of Orders	Databases	Primary
Route Duration	Databases	Primary
Velocity	Route Optimisation Platform	Primary
Distance	Route Optimisation Platform	Primary
Number of vehicles	Databases	Primary
Policy	Literature	Secondary

As seen in Table 7 there were nine factors that were of interest, many of them having the same or similar sources. Data on the factors, number of orders, route duration, distance, velocity, and the number of vehicles were acquired from the company's two databases which brought data from their routes for the selected week in November 2022. One database gave an overview of performed routes dated back several months. A huge amount of necessary parameters related to the study could be quickly gathered through it. To collect more detailed data surrounding specific routes in a day along with how vehicles travelled the company's own route optimisation platform was utilised. The platform saved data surrounding orders and maps out how vehicles travel between the orders for each day. Concerning battery capacity and cooling power, Melander et al. (2022) indicated that the actual battery capacity is not always equal to the battery capacity expressed by the vehicle specifications. Consequentially, meetings with the company's Fleet Manager and Route Operations Manager were conducted to gather more accurate data on the different vehicles' battery capacities.

Data surrounding energy consumption during a route was collected through real-time operations of EVs. Only in the case of Copenhagen where the company has deployed EVs of the model Maxus, was it possible to collect data on how much battery there was left in an electric vehicle after a completed route. Reliable sources of energy consumption were not available in the other three cases thus data from the Copenhagen case was used. Maxus have a feature that makes it possible for the user to see the distance in km the vehicle is able to drive with the current amount of energy, which enabled the drivers to log the number of km left after a completed route. This quantitative data was collected and used for a regression analysis on the energy consumption of the Maxus, with the purpose being to acquire an equation that represents the energy consumption of a route. From the company's own route optimisation platform, the rest of the data needed for the regression analysis was gathered for each route that had data on the energy consumption of EVs in Copenhagen.

From the literature review, data on how governmental instruments could be used to further logistics companies' possibility to transition toward an electric fleet was gathered. The sources used for the literature review had a general focus on the different instruments that are used today and specifics concerning policies in the two countries that are included in the study was also researched and collected. The sources included publications on policy changes for electric vehicles and the needed infrastructure and governmental reports and data. Meetings with the company's Head of Business Development and Fleet Manager were conducted to facilitate discussion and gather data on which current policies and potential policy changes could have an impact on their operations.

Data collection of the company's previous operations was also conducted to get an idea of how the company defines

efficiency. The intention was to analyse the efficiency measurements used today to acquire an understanding of how to make a reliable comparison of the study’s results. Meetings with the company’s employees were conducted concurrently with the data collection from the database, gathering qualitative data to gain greater knowledge of their operations. The meetings were conducted on various occasions and enabled a discussion on how the company defines efficiency and how to interpret the quantitative data from its database.

### 5.3 Data analysis

The data analysis that was conducted on the data collected was comprised of three methods, descriptive, predictive, and prescriptive analysis. Descriptive analysis is used for analysing current and past data to answer the question of how an organisation’s operation performs today. It uses statistics and mathematics to analyse data in the form of averages, summaries, and percentage changes. A descriptive approach to data analysis gives a good overview of the organisation and does not go deeper into analysis than the surface.

Predictive analysis on the other hand has a deeper focus, with the focal point being to gather an understanding of future potentials. This is accomplished by using the data analysed and comprised in the descriptive analysis and examining it to detect trends and predict what the future may entail. The last analysis method used Prescriptive analysis, answers the question of what action an organisation should take to further their operations, often used for decision-making. The analysis method utilises the results from the descriptive and predictive analyses and aims to realise what, when, and why actions should occur. The three data analysis methods are closely related and interdependent and should therefore influence each other (University of New South Wales, 2020).

The first step in the data analysis was to answer the question of how the company operates today. Firstly, the data that was collected was from a week in November 2022 and was analysed with a descriptive approach. For each case, the data on the number of orders and vehicles, route duration and distance, and efficiency measures were analysed and aggregated to get an overview of an average week of operations in the company. See Table 8 for the data and their aggregation type.

Table 8: Data aggregation type

Data	Aggregation Type
Number of Orders	Total (per DC and day) + Average (per vehicle) + Order Density (per capita)
Number of Vehicles	Total (per DC and day)
Route Duration (h)	Total + Average + maximal + Minimum (per DC and day)
Distance (km)	Total (per DC and day)
Efficiency Measures	Average (per DC and day)

The number of orders was aggregated in three different ways, the total number of orders per DC and day, the average number of orders per vehicle and lastly the order density. The average number of orders per vehicle was calculated according to Equation 1. The order density was calculated as described in Equation 2.

$$\frac{\text{Number of orders distributed to a city during a day}}{\text{Number of vehicles used within a city during a day}} \tag{1}$$

$$\frac{\text{Number of orders distributed to a city during a day}}{\text{Population size of a city}} \tag{2}$$

The route duration in the number of hours was calculated as the total number of hours per DC and day, the average, maximal and minimum route duration per DC and day. For the route distance, it was aggregated to total kilometres driven per DC and day. Lastly, the efficiency measures were aggregated as the average per DC and day. The aggregation of the efficiency measures was decided in accordance with the qualitative data collected from the meetings conducted with employees from the company.

Using the aggregated data mentioned above, together with the data collected for research question 1, the factors were categorised. The first division of the factors was based on the three organisational decision levels, operational, tactical, and strategical, see section 4.7 for a description of the levels. This is to gather knowledge on what type the factors are and if they affect the operational, tactical, or strategic decisions made by the company. To further categorise the factors they were analysed with the findings from the literature review, as well as the qualitative data from the

meeting with employees from the company on how they have worked with each factor. Resulting in each factor being categorised as a constraint or variable, the data for the factor that were categorised as a constraint was homogeneous while the data for the factors categorised as variables were heterogeneous.

One factor that required additional analysis was energy consumption, as data on the energy consumption was not available in the company's databases. To calculate the energy consumption of a route regression analysis was used, utilising the data collected from the Maxus model currently operating in Copenhagen. Regression analysis is a statistical tool to evaluate and model the relationship between different variables, which in this study are the factors. The regression analysis was used to evaluate the impact of three different factors (the total distance in km, the total time in hours, and the gross weight of the vehicle) on the energy consumption during a route.

The basic principle is using known data, with one dependent variable (denoted  $E_i$  in Eq 3) that is the outcome of the equation which in this case is the energy consumption of the route and several independent variables (denoted  $Dist$ ,  $Time$ , and  $Weight$  in Eq 3). The independent variables are the variables that are evaluated, how much of an impact each variable has on  $E_i$ , they are multiplied with unknown parameters (denoted  $\beta_1$ ,  $\beta_2$ , and  $\beta_3$ ). The independent variable  $Weight$  is the gross weight of the vehicle and was calculated according to Eq 4, where  $k$  is a constant that describes the average weight of a single order. The last term in the equation is the error term that takes the deviations of the regression analysis into account. The equation for the regression analysis resulted in Eq 5.

$$E_i = \alpha + \beta_1 * Dist + \beta_2 * Time + \beta_3 * Weight \quad (3)$$

$$Weight = Number\ of\ Orders * k \quad (4)$$

$$E_i = \left(1 - \frac{Number\ of\ km\ left\ after\ completed\ route}{Total\ Driving\ Range\ in\ km}\right) * Battery\ Capacity\ in\ kWh \quad (5)$$

With the help of the software Microsoft Office Excel, which has a built-in regression analysis tool, the regression analysis was constructed with the collected data. The results from the regression analysis were a complete equation for the energy consumption with coefficients  $\beta_{1,2,3}$  to be used to calculate future routes' energy consumption. Regression analysis was utilised for RQ2, first, as it investigated the impact of the different factors on energy consumption, the factor with the greatest impact being used as a determinant in the building of the scenarios concerning the Maxus model. Secondly, the resulting energy consumption equation, Eq 5, was used to calculate the energy consumption from the Maxus model scenarios simulated.

To build scenarios for all four cases, which had the purpose of answering RQ2, a predictive analysis was implemented. Resulting in scenarios that were distinctive for each case, that was in regards to current operations and potential futures. The predictive analysis was performed as follows:

1. Gather data from the preceding analysis of RQ1, data from the company and a literature review
2. For all cases, divide the observed area into different clusters and investigate the current potential with the route optimisation program
3. Create future scenarios for each case

### Gather and evaluate data

All the aggregated data, as presented in Table 8 was collected, this included the energy consumption model gained from regression analysis and the order densities for the days of the week in November that was observed in the study. The results from RQ1 were required to find out the necessary constraints with regard to the most important factors to move forward with relevant scenarios. With the energy consumption model along with the vehicle specifications for the two chosen vehicles, two definite constraints could be utilised further in the study:

$$Route\ Distance \leq Driving\ range\ for\ a\ vehicle \quad (6)$$

$$Energy\ Consumption\ of\ a\ route \leq Battery\ Capacity\ for\ a\ vehicle \quad (7)$$

The first constraint keeps the routes below the driving range of the observed vehicles. While the second one checks the energy consumption if a route does not. Both together ensures that routes observed and simulated for the cases with EVs are plausible.

### Cluster segmentation

The next step was to divide the preliminary observed areas for the cases into different zones to determine optimal routes for EVs. This was done by observing the population density of the zones. The procedure for Sweden's three cases was similar in that the E-Tron was considered when determining the area. While Copenhagen has the model Maxus which offers more freedom comparably in how much area the vehicle can reach.

Going into detail for Gothenburg. The orders originally taken into consideration were everything inside the urban area of Gothenburg. The next step after looking at the comparison results from the route optimisation program was then to divide the urban area into different segments/clusters. It was here decided to utilise the official division of urban areas in Gothenburg made by the government. These were Northeast, Downtown, Southwest and the island of Hisingen. Stockholm was deemed too big of a city to consider all suburban areas for routing with the E-Tron, this was found out at an early stage with supervision from the company. Instead, it was decided to find clusters of population densities close to the DC location. The chosen clusters were then Downtown, South, North and East. For the case of Malmö a division was made by looking at the entire city area along with the suburban areas, then with the results of the optimisation model limiting further into the city two times. The first cluster that was observed was Malmö city with highway E20 as the border, and the second zone will only look at the most populated area which is strictly in the downtown areas of Malmö city.

In the case of Copenhagen, which has access to model Maxus, had limit testing performed to see how far the model Maxus could reach outside of Copenhagen, instead of cluster segmentation as performed for the other cases. This was made with the route optimisation program to measure the distance from the DC location to the nearest clusters. As the total driving distance for the Maxus is 120 km we measured roughly 60 km out from the DC location and created a radius. Thereafter removing orders outside of this radius, then thereafter started routing for these orders inside the area. The resulting data was then inserted into the energy consumption equation with the found coefficients. This procedure had two purposes, first to see if the routes made with the optimisation model were technically plausible with the battery capacity and also to check the reliability of the model. If the routes went over the constraints of distance and/or energy consumption the orders were removed and consequently the radius of orders taken into consideration decreased. Then the process was repeated until all orders were within accepted constraints.

### Future Scenarios

When the division and route simulations were carried out for the present situation and data over optimal routes has been gathered it was time to determine how the future would optimally look for each case. Table 9 presents an overview of the decided different approaches for future scenarios for each of the four cases.

Table 9: Overview of Approach for Future Scenario

Case	Approach for future scenario
Copenhagen	Micro-hubs
Stockholm	Maxus Model
Gothenburg	Maxus Model
Malmö	Maxus Model + Micro-hubs

For the future scenario of Gothenburg, it was decided to investigate the potential of utilising a more versatile type of EV, such as the Maxus, compared to the E-Tron. This was also the case for Stockholm. To do this as thoroughly as possible for both cases, routes were simulated with the route optimisation program within the previously segmented areas, and the data results were checked with the energy consumption equation, 5, if it is below the constraints in Formulas 6.

The future scenario selected for Denmark was to see how far the Maxus could reach with added infrastructure support. Based on the same assumptions with the energy consumption and distance constraints connected to the Maxus, simulations with theoretical placements of additional micro-hubs were made. This was made considering the theory of micro-hubs as an alternative solution to alleviate the energy constraints by placing it in the midst of large clusters of customers. The goal for this case was to find the most optimal placements of as few additional micro-hubs as possible to get the most amount of customers.

For Malmö, it was decided to construct two scenarios. As it was requested by the company to check the viability of an EV fleet in Scania, at the same time it was desirable to also check the viability of the model Maxus in the city of Malmö in the previously constructed segments. The first scenario with an EV fleet in Scania was decided to utilise micro-hubs to expand the reach with EVs of the model Maxus, similar to the case of Copenhagen. With the same goal to reach as many customers as possible with optimally placed micro-hubs, simulations were made and tested with different micro-hub placements to get the most optimal. The second future scenario for Malmö is similar to the other cases for Sweden by utilising a more versatile EV model, similar to the Maxus, in the city of Malmö. For both scenarios in the case of Malmö, the results from the simulated routes were checked if the vehicles drove below the set distance and energy consumption constraints in Formulas 6.

For clarification of the study’s results presented with abbreviations such as *PS\_cph\_1*, the zones investigated were named depending on if they were Present or Future scenarios accordingly (PS or FS), what city it entails (CPH = copenhagen i.e), and the size of the zone, in ascending order with digit 1 in all cases being the smallest.

The last stage of the data analysis was to analyse the results from the aforementioned sections. To get a measure of how each and every factor correlates with each other, efficiency was a key factor that was considered. The company uses two measurement called Drops per Hour (DPh) and Drops per km (DPkm), DPh encompass the number of orders that are delivered during one hour of a route, see Equation 8, entailing that the higher DPH during a route the more efficient the route is. DPkm is a measurement of the number of orders delivered during one kilometre driven on a specific route, see Equation 9. The distance of a route is the amount of km driven from the vehicle leaving the DC to its return at the end of the route, similarly, the duration of a route is the number of hours the route is comprised of. The efficiency measures and the resulting analysis based on them were calculated and performed on the present scenarios, where the E-Tron was evaluated.

$$DPh = \frac{\text{Total nr of orders for a route batch}}{\text{Total duration of a route batch}} \quad (8)$$

$$DPkm = \frac{\text{Total nr of orders for a route batch}}{\text{Total distance of a route batch}} \quad (9)$$

For future scenarios, another type of analysis of the results was necessary. This is due to that there is no difference in how the Maxus and the ICEVs are simulated in the route optimisation platform thus, there were no differences in efficiency. In this instance, the focal point was at the maximal distance and the total energy consumption of each route was simulated and compared to the maxima distance and the energy consumption that the Maxus can operate without needing recharging, to find which scenarios that are plausible for the Maxus to operate under.

## 5.4 Research Quality

One important aspect when doing quantitative research is the reliability and validity of the research. The two concepts are used during the study to ensure that the research is done correctly and with objectivity in mind. Bryman and Bell (2011) describes reliability as the consistency of a measure, whether or not the same results would occur if the study was repeated. While validity regards the conclusions and their integrity if the results and the conclusions made from the results are sound (Bryman and Bell, 2011).

Regarding reliability for quantitative research, the main focus is to reassure that the study’s process is described to a degree so if it were to be repeated the errors would be minimal and the result of the new study would be consistent with those of this study (R. Yin, 2014). External reliability is a concept that could be applied to ensure the repeatability of a study (Bryman and Bell, 2011), for this study two other factors were used to increase the external reliability, stability and internal reliability. Stability over time, when using different measurements in the study it is important that the results do not fluctuate over time, and that the results of the study are not dependent on the time of the study (Bryman and Bell, 2011). To make sure the study is stable over time, data from different time points were collected and analysed, using aggregated data which minimises the risk of using outliers as the main data source. Internal reliability is another factor, when using a mix of measurements they need to relate to each other to make sure that the measure correlates to the study (Bryman and Bell, 2011). The study handled this criterion by discussing of findings and choice of measurements with relevant employees of the case company and experts to verify that the data and the measurements used in the study were correct.

Concerning validity, the measurement that measures a concept is evaluated to check that it actually measures the concept, it is closely related to reliability as the study is not valid if it is unreliable (Bryman and Bell, 2011). This is specifically related to measurement validity which concerns validating that the right measures are being measured, to fulfil this several sources should be used (Bryman and Bell, 2011). For the case of this study, a literature review was performed on related studies using similar measurements concurrently with meetings with the case company’s employees who could validate the choice of measurements and the usage of measurements. Internal validity is another aspect to consider it is related to the robustness of the results if the results represent reality (Bryman and Bell, 2011). This was validated similarly to how internal reliability was ensured, by a discussion with employees from the company to check the quality of the results and planning each step of the study using established methods for data analysis. External validity is another aspect that needs to be considered, which takes generalisation into account and if the findings are generalisable or not (Bryman and Bell, 2011). According to R. Yin (2014) is a multiple case study seen as more valid as opposed to a case study as it often, naturally, replicates findings. While the results of this study are based on one organisation, it could be possible to apply the findings to other similar logistics companies in the same geographical sphere, as many companies operate within similar boundaries. The study also compared the methods applied and the resulting findings with the results of the literature review to further strengthen the generalisability of the study.

## 6 Results

In this section, the results from the data collection and analysis are presented. Including the quantitative data from the case company’s database, the qualitative data from the meetings with the company’s employees, the literature review, the data from the regression analysis, and the data from the simulations run in the route optimisation platform.

### 6.1 Case description

The four cases are presented in Tables 10 - 13, enabling an overview of the operative data for an average week for each case. The tables consist of information on the share of the weekly quantity of orders, the order density, the number of vehicles used for a day, the total distance driven during a day, the total driving duration during a day, and the DPh and DPkm of a route batch during a day. This data is represented as large *L*, medium *M*, small *S* and extra small *XS*, as a means to hide the true values due to confidentiality. The share of the weekly quantity of orders is calculated according to Eq 10, the quota between a weekday’s number of orders and the total number of orders for the whole week.

$$\frac{\text{number of orders for a weekday}}{\text{total numbers of orders for a week}} \quad (10)$$

Table 10, represents case 1, Copenhagen. The first trend that can be identified during an average week in Copenhagen is that days with low quantities of orders and low order density have lower values of vehicles, DPh, and DPkm. While for distance and duration, the connection to the number of orders and order density is not as obvious, neither of the two follows the other factors. Although, there are some correlations between the number of orders, distance and duration, a day with a high quantity of orders and a high order density yields a long distance yield and a high duration. For the two efficiency measurements, DPh and DPkm, there seems to be no obvious correlation between the number of orders and order density and the two measures. Although for DPh, evaluating the connection between the number of orders, duration and DPh, showcases a trend that a bigger difference between the number of orders and the duration results in a bigger DPh. For DPkm, the results indicate that a large quantity of orders combined with a long distance yields a high DPkm.

Table 10: Average Week in Case 1 - Copenhagen

Weekday	Share of weekly quantity of orders	Order Density	Vehicles	Distance (km)	Duration (h)	DPh	DPkm
Monday	L	L	L	L	M	L	L
Tuesday	M	M	M	S	M	M	M
Wednesday	L	L	L	S	M	L	S
Thursday	S	S	S	M	S	M	S
Friday	S	S	S	M	S	S	S
Saturday	S	S	S	L	L	M	S
Sunday	L	L	L	L	L	L	L

For Case 2, Stockholm, an average week is showcased in Table 11. Similarly to Case 1, vehicles and DPh follow the trends in the number of orders and order density, while Case 2 presents data that show that duration follows along with that trend. Distance and DPkm, seem to not have any significant correlation with the number of orders. The data for DPh show a correlation between the number of orders and the duration as a high number of orders and large duration yields a greater DPh. A correlation between the number of orders, distance, and DPkm seems to exist as the DPkm is dependent on the other two values.

Table 11: Average Week in Case 2 - Stockholm

Weekday	Share of weekly quantity of orders	Order Density	Vehicles	Distance (km)	Duration (h)	DPh	DPkm
Monday	L	L	L	S	M	M	L
Tuesday	M	M	M	L	L	M	S
Wednesday	M	M	M	S	M	M	L
Thursday	S	S	S	S	S	S	S
Friday	S	S	S	S	S	S	S
Saturday	L	L	L	L	L	M	M
Sunday	L	L	L	S	L	L	L

Table 12 presents data from Case 3, Gothenburg on an average week. The number of vehicles, duration, and DPkm clearly follow the trend of the number of orders and order density, a large number of orders and order density results in high values. While distance and DPh do not indicate any correlation to the trends of the number of orders or order density. Evaluating the quantity of orders, distance, and DPkm together on the other hand presents a trend of a small distance together with a large quantity of orders resulting in a large DPkm. While a small quantity of orders and a small distance yields a low DPkm.

Table 12: Average Week in Case 3 - Gothenburg

Weekday	Share of weekly quantity of orders	Order Density	Vehicles	Distance (km)	Duration (h)	DPh	DPkm
Monday	M	M	M	S	M	L	L
Tuesday	L	L	L	L	M	M	L
Wednesday	L	M	L	S	M	L	L
Thursday	S	S	S	S	S	M	S
Friday	S	S	S	S	S	S	S
Saturday	M	M	M	S	M	L	M
Sunday	M	M	M	S	L	L	L

Case 4, Malmö is presented in Table 13. All values for Malmö, except the distance, show a correlation to the number of orders and order density, with the two days with the lowest quantity of orders and order density resulting in low values for all of the other values. Concerning the DPh values, the correlation between the number of orders, duration and DPh is clear. High values of quantity of orders and duration yield a high DPh, with only Sunday having a large DPh. DPkm on the other hand does not follow a trend with quantity of orders and distance as clearly, although the results indicate some connection between the three.

Table 13: Average Week in Case 4 - Malmö

Weekday	Share of weekly quantity of orders	Order Density	Vehicles	Distance (km)	Duration (h)	DPh	DPkm
Monday	L	L	L	S	M	M	L
Tuesday	M	S	M	S	M	M	M
Wednesday	L	L	L	S	M	M	L
Thursday	S	S	S	S	S	S	S
Friday	S	S	S	S	S	S	S
Saturday	M	M	M	M	M	M	M
Sunday	L	L	M	L	L	L	M

From the meeting with the case company's fleet manager data on the vehicle types was gathered and Table 14 presents an updated version of the vehicle specification for each vehicle type. Added data on the battery capacity of the two types of EVs, the Maxus having a battery capacity of 65 kWh and the E-Tron a capacity of 30 kWh, and the maximal number of orders per vehicle that is used for each vehicle type when routing in the case company's route optimisation platform. The Maxus and the two ICEVs all take a large number of orders per vehicle while the E-Tron, due to its lower gross vehicle weight, consequently takes marginally less, 78% of the number of orders that the ICEVs and Maxus distribute, orders per vehicle, exact numbers are hidden due to confidentiality.

Table 14: Vehicle Specification

Vehicle	Battery Capacity	Gross Vehicle Weight	maximal Velocity	maximal number of orders per vehicle
Maxus (EV)	65 kWh	4 050 kg	90 km/h	Full capacity
E-Tron (EV)	30 kWh	2 000 kg	30 km/h	78%
Mercedes Sprinter (ICE)	-	3 500 kg	160 km/h	Full capacity
Peugeot Boxer (ICE)	-	3 500 kg	160 km/h	Full capacity

## 6.2 Factors

Table 15 depicts the resulting factors that are relevant to look into when routing for the case company. The relevance of each factor is based on information gathered from the literature review and meetings with the company’s employees (see Table 5). Each of the factors was labelled as either constraint or variable.

Table 15: Relevant factors

Factor	Unit	Explanation	Constraint/Variable
Energy consumption	kWh	Energy demand for a specific route	Variable
Battery capacity	kWh	Specified in the vehicle specification	Constraint
Number of Orders	pc	The number of orders in a given area	Variable
Route Duration	h	Total time for a specific route to finish	Variable
Max velocity	km/h	maximal velocity a vehicle can travel	Constraint
Route Distance	km	Total distance a route drives	Variable
Number of vehicles	pc	Total number of vehicles in a batch	Variable
Policy	N/A	Impact of government regulations	N/A

The relevant factors selected as constraints were battery capacity, maximal distance and velocity. Battery capacity was mentioned several times in reviewed literature to be a large constraint when adopting EVs into the transportation sector, so it was natural to have it as a constraint in this study when moving forward with scenarios. Velocity was selected as a constraint due to two main reasons. One of the chosen EVs used in the report (E-tron) is slow-going and precise measurements for energy consumption and the need for a speed profile. The latter reason was stated by reviewed studies as a necessity for the exact modelling of routes, but as the information could not be accessed with the present tools, it could not be presented as a variable in this study. This is especially amplified with the former reason with E-tron as the currently utilised EV and its maximal speed of 30 km/h, making it a natural constraint for this study in question.

Energy consumption was mentioned by several studies as an essential part when routing with EVs, as it is stated to be the vehicle mode’s biggest limiting factor along with the vehicle range, denoted as factor Distance. Both factors however take into account several different parameters. For instance, the distance an EV is able to drive is not a set value and depends according to the literature on the aforementioned speed profile of a route, the duration when the EV operates and the gross weight of the vehicle for example. Distance also directly correlates with the former factor of energy consumption, with EVs in the form of the chosen constraint battery capacity. Thus it was selected that both factors Distance and energy consumption were deemed as relevant variables as they depend a lot on other factors in question.

For the case of Copenhagen, where the case company has EVs of the model Maxus in operation, the energy consumption, which was the outcome data used for the regression analysis, could be calculated with Eq 11. Running the regression analysis on the data collected from the Maxus resulted in Eq 12, with variables *Dist*, *Time*, and *Weight*.

$$E_i = \left(1 - \frac{\text{Number of km left after completed route}}{130}\right) * 65 \quad (11)$$

$$E_i = 2.04 + 0.58 * \text{Dist} + 0.007 * \text{Time} + (-0.002) * \text{Weight} \quad (12)$$

Route duration was found from meetings with employees from the case company to be readily accessible with present data and was deemed a variable to consider in this study with the reasoning that it varies from vehicle to vehicle. It was necessary to consider the route optimisation program’s role in this study, as it was the main tool in simulating routes in all cases. The two factors that played a large role when simulating beyond the aforementioned factors were the number of orders in an area and the number of vehicles utilised in said area. The number of orders is a stochastic variable and clearly determines the amount for the latter factor. This consequently determines all the other aforementioned factors in that more vehicles utilised means less distance, energy consumed and partly less duration for each individual vehicle, and vice versa for a small share of orders. These two factors heavily determine the efficiency of the routes in several ways that will be discussed further moving forward in the study.

Lastly, when moving forward in the study it is necessary to consider the overarching impact of regulations and policies that effects EVs and even the transportation sector overall in some way. Reviewed literature for relevant policies and regulations in the two countries of Sweden and Denmark are presented in Table 16.

Table 16: Relevant reviewed literature regarding regulations and policies

Country	Policy/Regulations	Source
Sweden	Reduce transport emissions by 70% in 2030 compared to 2010	Energimyndigheten (2022)
	Environmental zones to restrict emission-heavy	Transportstyrelsen (2023)
	Weight limit on light duty vehicle (3.5 tonnes)	Transportstyrelsen (2022)
Denmark	New investments in public fast-charging stations over the country	Clean Technica (2023)
	Low emission zones in major cities with plans for further expansion	EcoSticker.dk (2008) & ICCT (2022)
	Investments into fast-charging stations	Skatteministeriet (2020)
	Weight limit on light-duty vehicles (4.25 tonnes)	Meetings with employees of the Case Company

Sweden has high ambitions for more sustainable road transport, with clear comprehensive goals and milestone targets displayed on the government’s own website (Regeringskansliet, 2017). The decisions and incentives to reach certain goals are being made such as environmental zones in the largest cities for example and more legal actions towards sustainability will be incorporated. However Melander et al. (2022) emphasises the need for better communication surrounding future changes towards continued usage between the government and companies that wish to adopt EVs. Melander et al. (2022) explains further the need for necessary changes such as long-term commitments surrounding regulations and subsidies for EVs and implementing policies that benefit in the long run sustainability.

Denmark is similar to Sweden in that they are also investing in their infrastructure and altering their policies to strengthen the ability to own and operate an electric vehicle, furthering the push for a larger number of EVs in the country. In 2020 the Danish government’s new legislation and subsidies accelerated the number of electric fleets and charging stations in the country (Skatteministeriet, 2020). Leading to an increase of 70% more EVs in 2022 in Denmark (CPH Post, 2023). Denmark is also an early bird in the adoption of zero-emission zones (ZEV-F), with zones in major cities already in place that prohibit certain ICE vehicles. More pilot projects are under development in 2023 in their capital city of Copenhagen with three types of these ZEV-F that will affect all or some vehicle types (ICCT, 2022). The future for EVs looks more in reach in Denmark compared to Sweden with the former’s more advanced development in charging stations and ZEV-F. The Danish government plans to invest in 2000 fast charging stations to reach their goal of 2030 to ban new gasoline and diesel cars (Haustein et al., 2021).

### 6.3 Scenarios

This section presents all the relevant results gained from simulating routes in all four cases for both present and future scenarios. The results brought up differ for every case, especially between the case of Copenhagen’s present scenario compared to the other cases’ present scenarios. For the present scenarios in Case 1, the results from the simulations are presented as the number of orders each scenario encompasses, the order density and if simulated routes crossed the two constraints of maximal distance and energy consumption limits which is unique for the Maxus, see Formulas 13. If the route distance or energy consumption of a route is over the two limits then it will be indicated with *Above*, if it does not cross the limits then it will be indicated with *Below*. Lastly, the results showcase the percentage of orders that is above the maximal range limit for each scenario and weekday.

$$\text{Route Distance} \leq \text{Driving range for a vehicle} \quad (13)$$

$$\text{Energy Consumption of a route} \leq \text{Battery Capacity for a vehicle} \quad (14)$$

For the present case scenarios performed in the three Swedish cases, Stockholm, Gothenburg, and Malmö, results depict different scenarios where the E-Tron and ICEV were compared in regards to efficiency and difference in distance, duration, and number of vehicles per batch. The number of orders per day is presented as the share of the weekly quantity of orders, due to confidentiality this share of orders and the order density is presented in the same manner as results for the average week with a scale of large *L*, medium *M*, small *S* and extra small *XS*. The number of vehicles, total distance, total duration, DPh, and DPkm during a batch are represented as the difference between the values for the ICEV and the E-Tron. Entailing that if a difference is of negative value the E-Tron had a greater value than the ICEV, a positive value indicating the opposite. For a majority of the future scenarios the presented results are the same as for Copenhagen’s present scenario as the Maxus is deployed to check if the cases exceed the constraints set, with or without the use of micro-hubs.

#### 6.3.1 Present Scenarios

Here the results for the present scenarios investigated for each case are presented. The case for Copenhagen’s present scenarios will be presented first which will be followed by the three cases and their results in Sweden, Stockholm,

Gothenburg, and Malmö, in that order. Furthermore, an analysis of the efficiency measurements for the present scenarios for Stockholm, Gothenburg, and Malmö is presented.

Table 17: Size of each present scenario in Copenhagen

Scenario	Percentage of the total amount of orders
PS_cph_4	77%
PS_cph_3	68%
PS_cph_2	57%
PS_cph_1	44%

The first case, Copenhagen, had 4 different present scenarios. Table 17, gives an overview of the number of orders each scenario could cover the total amount of orders distributed from the Copenhagen DC during a week and the name of each scenario, *PS\_cph\_x* which stands for present scenario Copenhagen and the number of the scenario which corresponds to the number in the Figure 2. Figure 2 presents the geographical area of all four scenarios on a map of the Copenhagen area. The first scenario, *PS\_cph\_4*, covers the largest geographical area and encompasses the other three numbered areas, *PS\_cph\_3* is the second largest and includes the geographical areas for *PS\_cph\_2* and *PS\_cph\_1*, *PS\_cph\_2* is the second smallest and encompass *PS\_cph\_1* area, while *PS\_cph\_1* is the smallest.

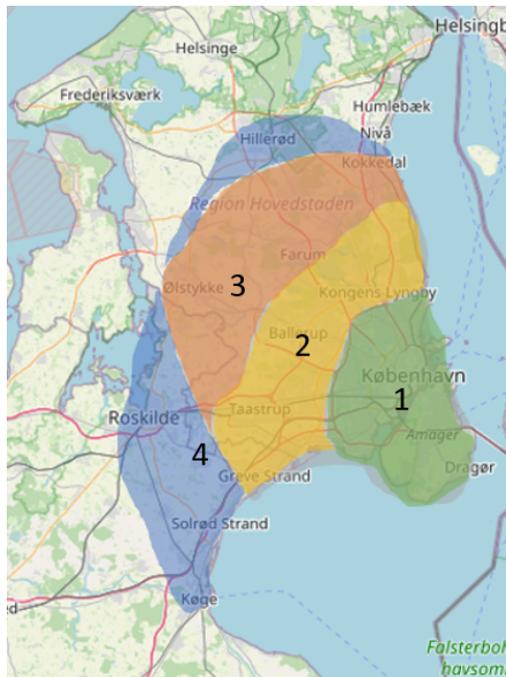


Figure 2: Map over the observed areas for case Copenhagen's present case

Table 18 depicts the results gained from routing the Maxus EV in the present case of Copenhagen, the mapped-out areas routed are depicted in Figure 2. Directly from the table, it is clear that only the smallest observed zone (*PS\_cph\_1*) are the results "below" for both the range and energy consumption limit, with the exception of weekday Friday when the range limit is exceeded.

Table 18: Present Scenario - Copenhagen

Weekday	Name	Density	Orders	Above/Below max range limit	Above/Below energy consumption limit	Percentage that is above the max range limit
Monday	PS_cph_4	L	L	Above	Below	38%
	PS_cph_3	L	L	Above	Below	33%
	PS_cph_2	L	L	Above	Below	23%
	PS_cph_1	L	L	Below	Below	N/A
Tuesday	PS_cph_4	M	M	Above	Above	37%
	PS_cph_3	M	M	Above	Above	39%
	PS_cph_2	M	M	Above	Below	21%
	PS_cph_1	S	M	Below	Below	N/A
Wednesday	PS_cph_4	L	L	Above	Below	30%
	PS_cph_3	L	L	Above	Below	33%
	PS_cph_2	L	L	Above	Below	23%
	PS_cph_1	L	L	Below	Below	N/A
Thursday	PS_cph_4	XS	XS	Above	Above	60%
	PS_cph_3	XS	XS	Above	Above	40%
	PS_cph_2	XS	XS	Above	Above	25%
	PS_cph_1	XS	XS	Below	Below	N/A
Friday	PS_cph_4	XS	XS	Above	Above	100%
	PS_cph_3	XS	XS	Above	Above	75%
	PS_cph_2	XS	XS	Above	Above	67%
	PS_cph_1	XS	XS	Below	Above	N/A
Saturday	PS_cph_4	M	S	Above	Above	38%
	PS_cph_3	S	S	Above	Below	40%
	PS_cph_2	S	S	Above	Below	31%
	PS_cph_1	S	S	Below	Below	N/A
Sunday	PS_cph_4	L	L	Above	Below	33%
	PS_cph_3	L	L	Above	Below	28%
	PS_cph_2	L	L	Above	Below	34%
	PS_cph_1	L	L	Below	Below	N/A

An observation can be made from the results when studying Table 18 along with the results gained from Table 10. That is the apparent correlation between the number of vehicles with energy consumption limits. For weekdays Monday, Wednesday and Sunday the number of vehicles is shown as "L", which correlates for these days that the energy consumption limits are never exceeded. This brings up an interesting point surrounding order quantity and its impact on the number of vehicles necessary. The reasoning behind the smallest zone's result for Friday is also shown when observing Table 18 as the share of the number of orders for the day is the smallest for the week but the distance travelled is classed as medium length.

With a basis in the results presented in Table 18, the number of orders able to be covered by the Maxus, taking the maximal range limit and energy consumption limit into account, is presented in Table 19. The percentages represent the number of orders the Maxus can cover compared to the total amount of orders distributed from Copenhagen DC during one week in each scenario. From the results of Table 19 it is clear that the percentage of the number of orders able to be covered by Maxus vehicles in each scenario increases with the size of the scenario, with the biggest scenario, *PS\_cph\_4*, having the greatest percentage. This follows the trend identifiable in Table 17, that with a larger geographical area able to be covered the greater number of orders are than available for the Maxus vehicles to cover.

Table 19: The potential of utilising Maxus in the present scenarios in Copenhagen

Scenario	Percentage of the total amount of orders able to be covered by Maxus
PS_cph_4	50%
PS_cph_3	45%
PS_cph_2	42%
PS_cph_1	44%

Table 20: Size of each present scenario in Stockholm

Scenario	Percentage of the total amount of orders
PS_sthlm_3	35%
PS_sthlm_2	29%
PS_sthlm_1	19%

Case 2, Stockholm, had 3 different present scenarios. As presented in Table 20 and Figure 3 *PS\_sthlm\_3* (stands for the third present scenario of Stockholm), covers the largest geographical area and includes scenarios' *PS\_sthlm\_2* and *PS\_sthlm\_1* areas and similar for *PS\_sthlm\_2*, while *PS\_sthlm\_1* is the smallest scenario.

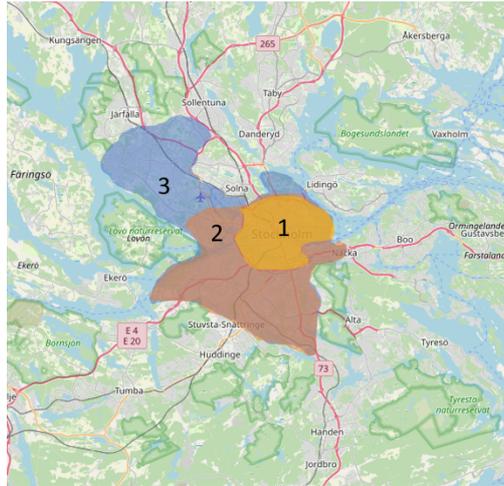


Figure 3: Zone-division of present scenarios in Stockholm

The present scenario for Stockholm is presented in Table 21, where the three different present scenarios for Stockholm are represented by the names *PS\_sthlm\_3*, *PS\_sthlm\_2*, and *PS\_sthlm\_1*. The geographical division for the three scenarios is showcased in Figure 3, *PS\_sthlm\_3* represents the largest geographical area while *PS\_sthlm\_1* represents the smallest. The results from Table 21 exhibit that for all three scenarios the E-Tron has a greater value almost every time for the number of vehicles, total distance, and total duration. The difference in the number of vehicles and total duration is always greater for the E-Tron, while the difference in distance is greater for the E-Tron in the majority of the scenarios. The difference in the number of vehicles per batch is the smallest for the scenario *PS\_sthlm\_1* for each day, while no such trend is identifiable for the difference in total distance and duration per batch. The order density for each scenario and day follows the number of orders quite well, although for Wednesday all three scenarios have a greater order density compared to the number of orders and for Saturday the first two scenarios are greater than the number of orders.

Table 21: Present Scenario - Stockholm

Weekday	Name	Density	Share of weekly quantity of orders	Difference in quantity of vehicles	Difference in distance (km)	Difference in duration (h)
Monday	PS_sthlm_3	L	L	-7	-1.6%	-7.0%
	PS_sthlm_2	L	L	-6	-0.7%	-6.5%
	PS_sthlm_1	L	L	-4	-1.7%	-10%
Tuesday	PS_sthlm_3	M	M	-5	-1.1%	-7.6%
	PS_sthlm_2	M	M	-3	-0.4%	-5.2%
	PS_sthlm_1	M	M	-3	-0.7%	-12%
Wednesday	PS_sthlm_3	L	M	-6	-2.2%	-5.6%
	PS_sthlm_2	L	M	-5	0.3%	-25%
	PS_sthlm_1	L	M	-3	-0.8%	-7.7%
Thursday	PS_sthlm_3	XS	XS	-1	1.6%	-11.7%
	PS_sthlm_2	XS	XS	-1	2.5%	-20%
	PS_sthlm_1	XS	XS	-1	0%	-28%
Friday	PS_sthlm_3	XS	XS	-1	-2.0%	-10%
	PS_sthlm_2	XS	XS	-1	9.6%	-15%
	PS_sthlm_1	XS	XS	-1	4.5%	-40%
Saturday	PS_sthlm_3	M	S	-4	-1.8%	-6.2%
	PS_sthlm_2	M	S	-2	-1.0%	-7.5%
	PS_sthlm_1	S	S	-1	-3.9%	-10%
Sunday	PS_sthlm_3	L	L	-6	-1.7%	-6.8%
	PS_sthlm_2	L	L	-7	-0.8%	-10.3%
	PS_sthlm_1	L	L	-6	-1.9%	-17%

Further, Figures 4 and 5 present the difference in DPkm and DPh during a batch for each scenario and each day. For these two values, the ICEV has the greater value for every DPh value and for the majority of the DPkm values. The results from Figure 4 showcase no particular difference between the first and the third scenario, while for *PS\_sthlm\_2* three out of seven days, the E-Tron has a greater DPkm value. The two days at which the DPkm is greater for E-Tron than for the ICEVs, Thursday and Friday, are also the two days with low order density and where the distance is greater for the ICEVs. The DPh values presented in Figure 5 indicate that the ICEV is greater in every scenario and every day, and generally the lowest DPh difference is for scenario *PS\_sthlm\_3* while the highest is for *PS\_sthlm\_1*. Similarly to the DPkm, the two days with the biggest drop in DPh for the E-Tron are the two days with the lowest order density, Thursday and Friday, and the days with the biggest increase in duration for the E-Tron.

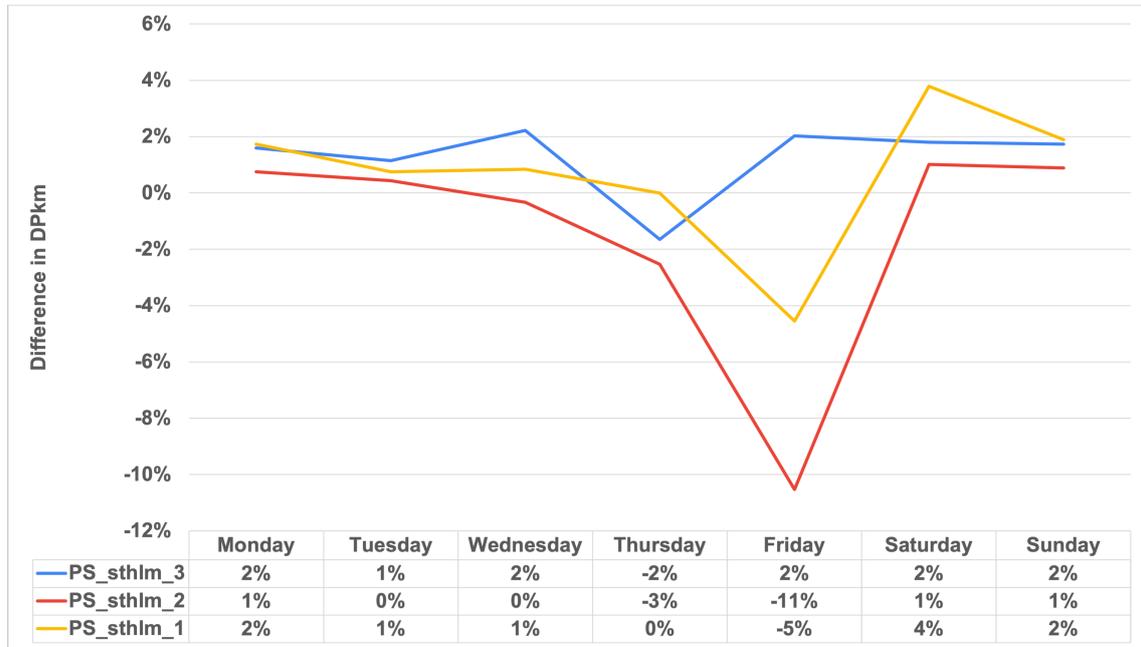


Figure 4: The difference in DPkm for Present Scenario in Stockholm compared to ICEVs

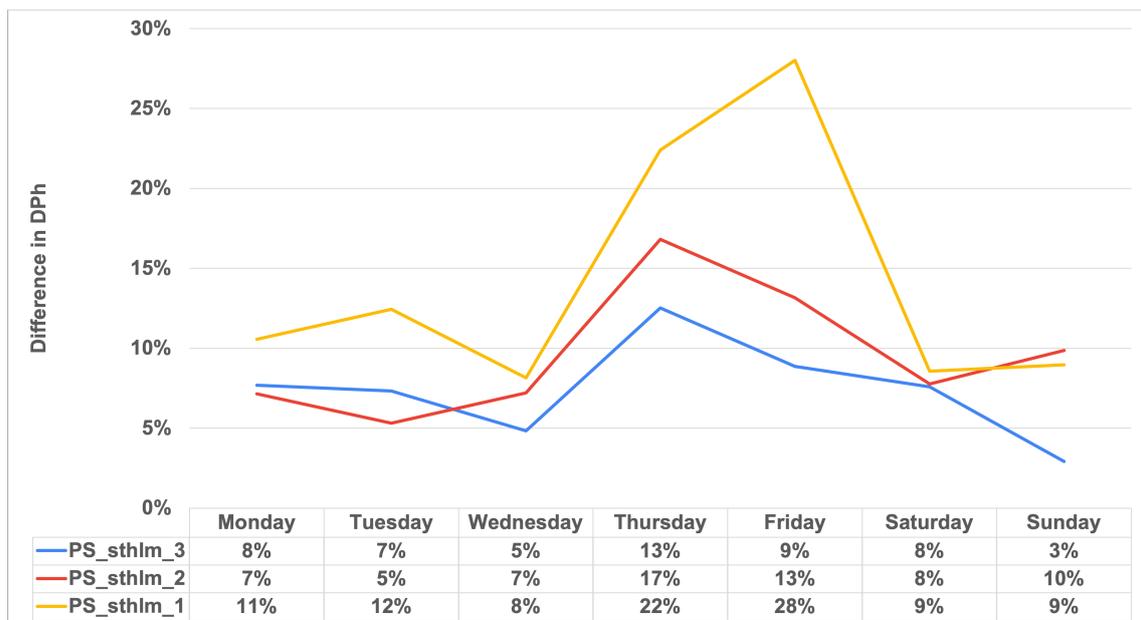


Figure 5: The difference in DPh for Present Scenario in Stockholm compared to ICEVs

Table 22: Size of each present scenario in Gothenburg

Scenario	Percentage of the total amount of orders
PS_gbg_3	41%
PS_gbg_2	22%
PS_gbg_1	10%

For the third case, Gothenburg, each scenario is presented in Table 22, with the number of orders each scenario covers of the total number of orders from the Gothenburg DC in a week. The names of the three scenarios are *PS\_gbg\_x*, which stands for present scenario Gothenburg and the number of the scenario which corresponds to the number in Figure 6. The figure gives an overview of the geographical division of the three present scenarios. With *PS\_gbg\_3* covering *PS\_gbg\_2* and *PS\_gbg\_1* geographical areas, *PS\_gbg\_2* encompass *PS\_gbg\_1* in a similar manner.

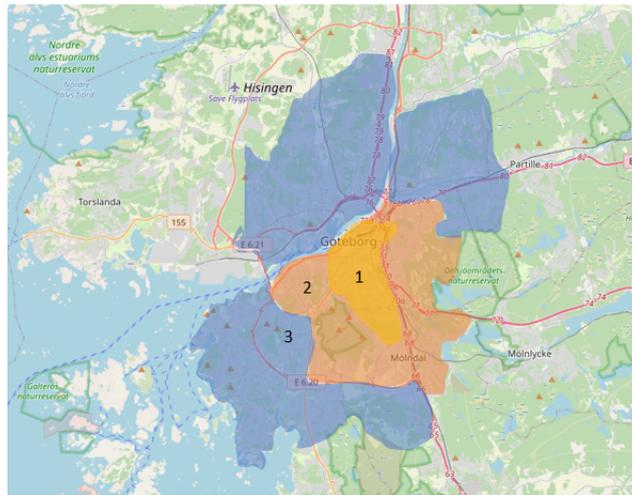


Figure 6: Zones investigated for the present scenario of Gothenburg

Case 3, Gothenburg and its present scenarios are presented in Table 23, which represents the number of orders per scenario and day, the difference in vehicles, distance and duration per batch, Figures 7 and 8 presents graphs over the DPKm and DPh difference. Evaluating Table 23, the results showcase that the difference in the number of vehicles and duration per batch and day is mostly a negative value entailing that the E-Tron had the greater value. The data for the difference in distance per batch and day are in the majority positive meaning that the ICEV had the greater values. For the majority of the days the scenario *PS\_gbg\_1* has the lowest difference while *PS\_gbg\_3* has the biggest difference, for all three differences. Concerning the order density, the values follow a similar size to the number of orders, except for Tuesday, where scenario *PS\_gbg\_3* has a greater order density than the number of vehicles.

Table 23: Present Scenario - Gothenburg

Weekday	Name	Density	Share of weekly quantity of orders	Difference in quantity of vehicles	Difference in distance (km)	Difference in duration (h)
Monday	PS_gbg_3	M	M	-3	1.8%	-7.9%
	PS_gbg_2	M	M	-2	0.4%	-13.5%
	PS_gbg_1	M	M	-1	0%	-4%
Tuesday	PS_gbg_3	M	S	-2	0.8%	14.4%
	PS_gbg_2	S	S	-1	4.6%	-13.5%
	PS_gbg_1	S	S	0	0%	-27%
Wednesday	PS_gbg_3	M	M	-3	1.4%	-14%
	PS_gbg_2	M	M	-2	3.2%	-11.3%
	PS_gbg_1	M	M	-1	0%	-4.3%
Thursday	PS_gbg_3	XS	XS	0	-0.7%	-17.8%
	PS_gbg_2	XS	XS	0	4.8%	-20%
	PS_gbg_1	XS	XS	0	1.6%	0%
Friday	PS_gbg_3	XS	XS	-1	4.4%	-28%
	PS_gbg_2	XS	XS	-1	8%	-72%
	PS_gbg_1	XS	XS	0	0%	0%
Saturday	PS_gbg_3	S	S	-2	2.4%	-18%
	PS_gbg_2	S	S	-1	6.4%	-7.4%
	PS_gbg_1	S	S	-1	1.7%	-22%
Sunday	PS_gbg_3	L	L	-3	0.9%	-13.8%
	PS_gbg_2	L	L	-4	0.7%	-25%
	PS_gbg_1	L	L	-3	0%	-25%

Concerning the DPkm and the DPh differences for present scenarios in Gothenburg, as presented in Figures 7 and 8, the results for the DPkm vary for each day and scenario while for the DPh all days and scenarios had a greater value for the ICEV. For DPkm, scenario *PS\_gbg\_1* has the smallest differences the majority of the days, while scenario *PS\_gbg\_2* has the biggest. The biggest differences in DPkm are found on Friday and Saturday, with the E-Tron having the greater DPkm compared to the ICEVs, which is also two days with the lowest order densities and with the greatest difference in the distance with the ICEVs. The difference in distance for these two days all entails that the ICEVs have longer distances, as the difference is positive. The scenario *PS\_gbg\_1* also has the smallest difference for the DPh values for the majority of the days. For the DPh, the greatest difference, in favour of the ICEVs, is during Friday, which is one of the days with the lowest order density and the day with the biggest increase of duration for the E-Tron, for scenario *PS\_gbg\_2* the E-Tron has a duration that is 72% longer than the ICEVs.

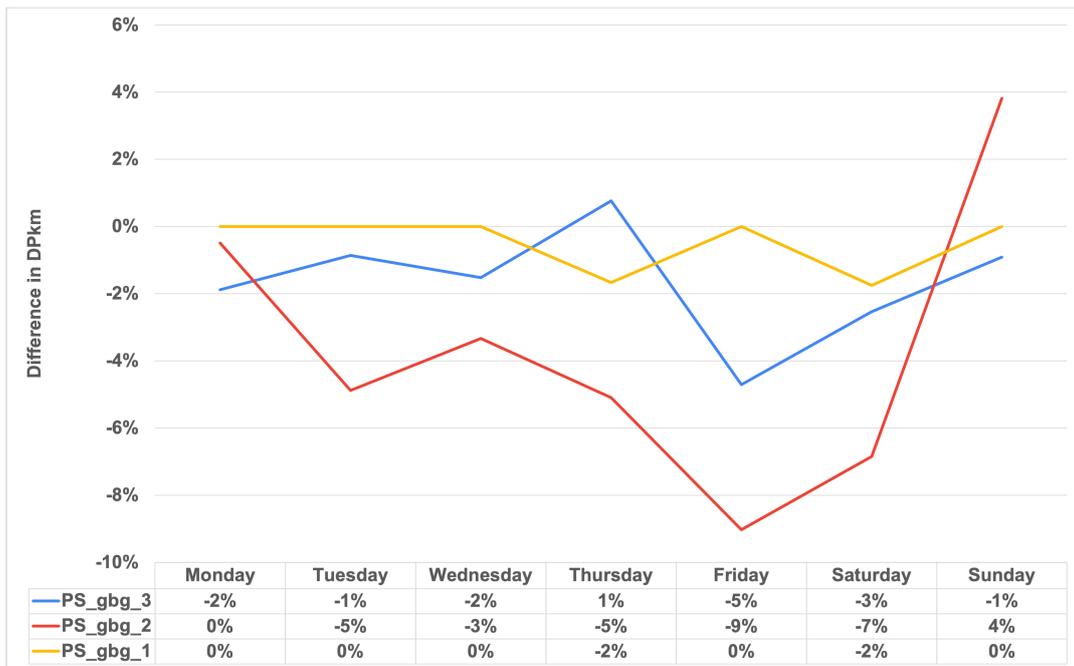


Figure 7: The difference in DPkm for Present Scenario in Gothenburg compared to ICEVs

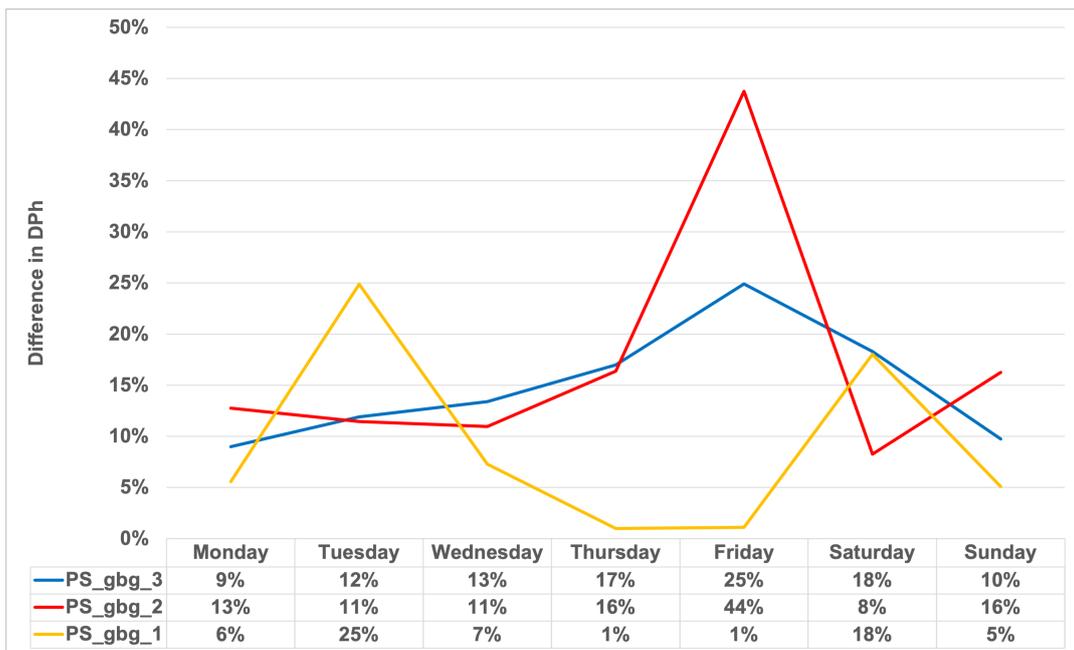


Figure 8: The difference in DPh for Present Scenario in Gothenburg compared to ICEVs

Table 24: Size of each present scenario in Malmö

Scenario	Percentage of the total amount of orders
PS_malmö_3	28%
PS_malmö_2	20%
PS_malmö_1	12%

Table 24, gives an overview of the percentage of the total number of orders that are distributed from the Malmö DC in each scenario, and Figure 9 which presents the three present scenarios used for Case 4. The third present scenario for Malmö, *PS\_malmö\_3*, covers the greatest geographical area and encompasses the other two scenarios' geographical areas while *PS\_malmö\_2* covers *PS\_malmö\_1* geographical area, and *PS\_malmö\_1* is the smallest scenario as seen in Figure 9.

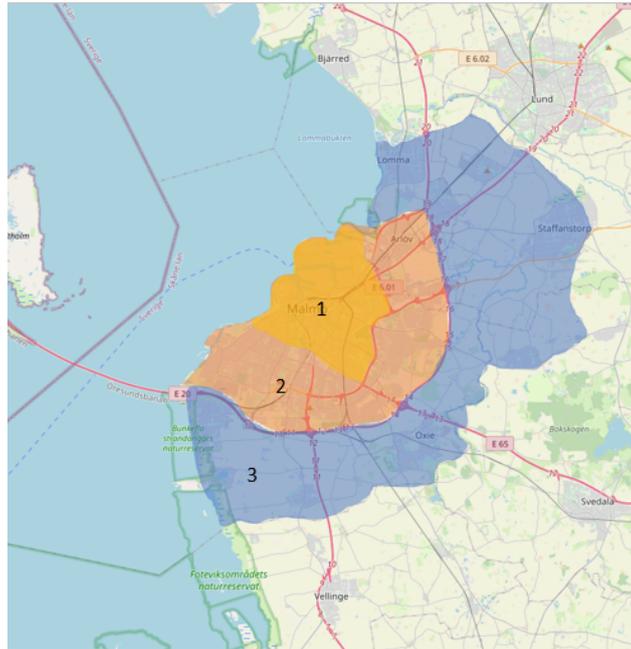


Figure 9: Zones investigated for the present scenario of Malmö

The results for the simulations of EV and diesel vehicles simulated in the present case of Malmö are presented below in Table 25, DPkm and DPh measurements are presented in Figures 10 and 11 respectively. Aforementioned the zones investigated are shown in numerical order from largest to smallest in Figure 9.

Table 25: Present Scenario - Malmö

Weekday	Name	Density	Share of weekly quantity of orders	Difference in quantity of vehicles	Difference in distance (km)	Difference in duration (h)
Monday	PS_malmö_3	L	L	-3	3.5%	-16%
	PS_malmö_2	L	L	-2	2.7%	-18%
	PS_malmö_1	L	L	-2	-1.9%	-30%
Tuesday	PS_malmö_1	M	M	-2	-0.7%	-5%
	PS_malmö_2	L	M	-2	2.7%	25%
	PS_malmö_1	M	M	-1	1.3%	-25%
Wednesday	PS_malmö_3	L	L	-3	1.7%	-18%
	PS_malmö_2	L	L	-2	1.5%	-13.8%
	PS_malmö_1	L	L	-1	2.5%	-6.7%
Thursday	PS_malmö_3	S	S	-1	7.8%	-18%
	PS_malmö_2	S	S	0	5%	-3%
	PS_malmö_1	S	S	0	-3%	-4.7%
Friday	PS_malmö_3	S	S	0	6.9%	0%
	PS_malmö_2	S	S	0	-2%	-10%
	PS_malmö_1	S	S	-1	7.4%	-63%
Saturday	PS_malmö_3	M	M	-1	3%	-6%
	PS_malmö_2	M	M	-1	1.8%	-6%
	PS_malmö_1	M	M	0	-2.0%	-4.1%
Sunday	PS_malmö_3	L	L	-3	4%	-15%
	PS_malmö_2	M	M	-2	-3.4%	-16%
	PS_malmö_1	M	S	-1	0%	-22%

From Table 25 it is apparent that the E-Tron takes more time compared to the conventional diesel to complete routes. At the same time, the quantity of EVs is either more or equal to that of conventional diesel vehicles, which consequently explains why the average conventional diesel vehicle covers more distances comparably for all zones in a majority of the days. The best days to operate an E-tron looking at the results from the table alone would be on the days with low order density, that is Thursday and Friday, especially for zone *PS\_malmö\_2*. The differences are minimal as both days for this zone require an equal amount of E-Trons as conventional diesel.

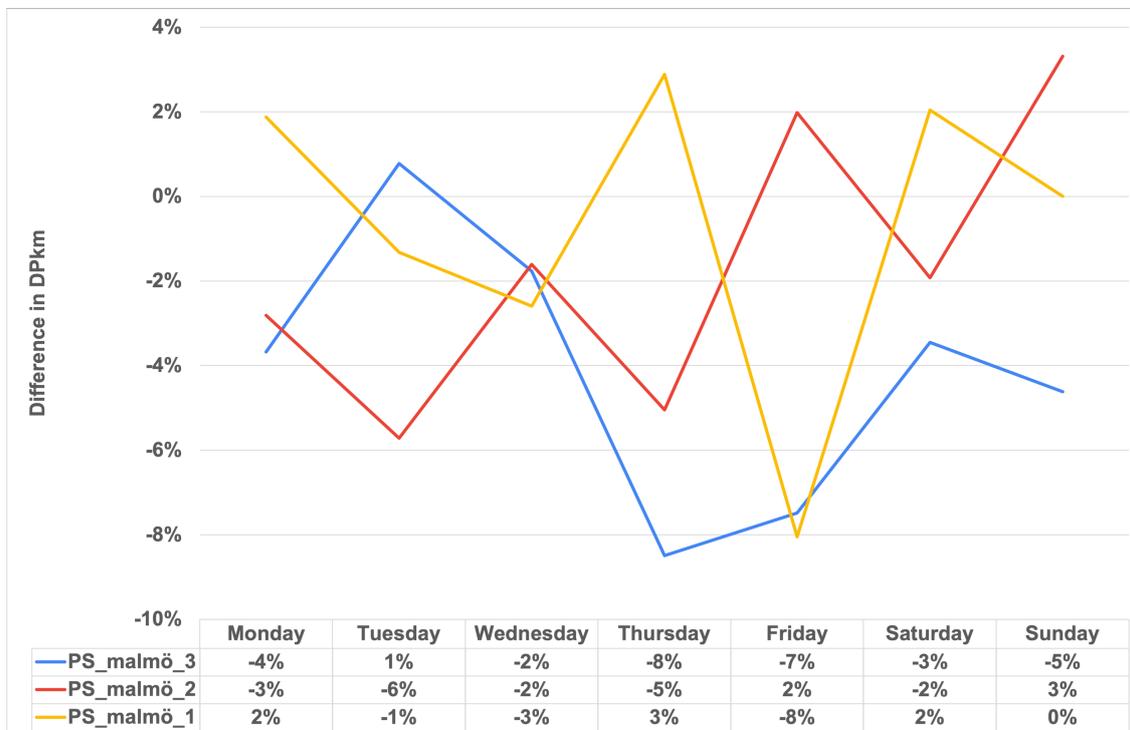


Figure 10: The difference in DPkm for Present Scenario in Malmö compared to ICEVs

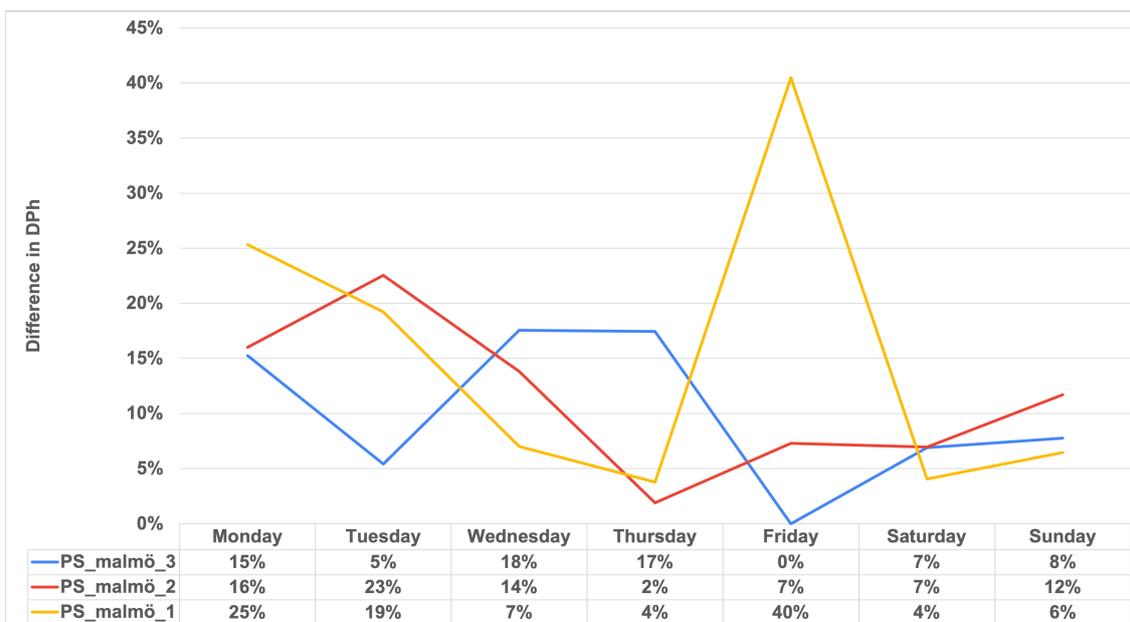


Figure 11: The difference in DPh for Present Scenario in Malmö compared to ICEVs

The difference in DPkm is slightly in favour of the E-Tron for the majority of the week which is partly explained by the aforementioned observation seen from Table 25 that there is a higher quantity of EVs deployed compared to conventional diesel vehicles. This is however not the case for all observations, a few days have more or equal amounts of E-Trons deployed compared to diesels yet the DPkm is in favour of one or more zones. Whenever the number of vehicles is equal for both modes, which consequently means a small share of orders for those days (see Thursday and Friday in Table 25), the DPh differences are often times minimal, however always slightly in favour of diesel vehicles. The only time the DPh difference is null between the two is for the larger area (*PS\_malmö\_1*) on weekdays Friday (see Table 25) when the order quantity is low and the quantity of vehicles is equal. This is also the only time the difference in duration is null, but this correlation is not shown in the results for the other days of the week.

To concretise the results from the present scenario simulations of the Swedish cases, all simulated with E-Tron and compared to the traditionally used ICEVs, further analysis of the DPh values of all three cases and their present scenarios are presented in Tables 26, 27, and 28. The three tables present the number of orders, in percentage, that are able to be covered by the E-Tron out of the total number of orders of the whole week for each of the three cases, if a decrease in the DPh values up to 10%, 15%, and 20% were accepted. For all three cases, it is apparent that the potential of covering a greater number of orders when accepting a decrease in DPh of 20%. Although for the case of Stockholm, the difference between the number of orders able to be covered by E-Tron vehicles when accepting a decrease of 10%, 15%, and 20% is not insignificant. While for Gothenburg and Malmö the difference is much more prominent, especially when comparing a 10% decrease to a 20% decrease.

Table 26: Size of each present scenario in Stockholm able to be covered by E-Tron

	Decrease of 10%	Decrease of 15%	Decrease of 20%
PS_sthlm_3	34%	35%	35%
PS_sthlm_2	27%	28%	29%
PS_sthlm_1	11%	18%	19%

Table 27: Size of each present scenario in Gothenburg able to be covered by E-Tron

	Decrease of 10%	Decrease of 15%	Decrease of 20%
PS_gbg_3	21%	34%	39%
PS_gbg_2	2%	13%	22%
PS_gbg_1	8%	8%	9%

Table 28: Size of each present scenario in Malmö able to be covered by E-Tron

	Decrease of 10%	Decrease of 15%	Decrease of 20%
PS_malmö_3	14%	21%	28%
PS_malmö_2	4%	12%	17%
PS_malmö_1	7%	7%	9%

### 6.3.2 Future Scenarios

For the future case scenarios performed in the three Swedish cases, results depict the simulations of an EV akin to the Maxus where the order density of the areas investigated along with the number of orders are presented. Next, if the constraints of maximal distance and energy consumption are exceeded, which is either indicated *Above* or *Below*, similar to the proceedings of the present case of Copenhagen. The size of each zone will also be presented in the form of a percentage of the total amount of orders originally taken into consideration from the distribution centre, and lastly how many of these orders could be routed with EVs in the future scenarios. For the use of micro-hubs, coverage will be presented for each zone and also the total coverage gained for all combined.

Table 29: Size of each future scenario in Stockholm

Scenario	Percentage of total amount of orders
FS_sthlm_4	74%
FS_sthlm_3	55%
FS_sthlm_2	35%
FS_sthlm_1	29%

For the future scenarios for Stockholm, there were four scenarios considered, as seen in Table 29, which summarises the number of orders each scenario covers in relation to the total number of orders that are distributed from the Stockholm DC during an average week, and Figure 12, which presents the areas each scenario encompasses. The names of each scenario are based on *FS\_sthlm\_x*, which stands for future scenario Stockholm with the x denoting the number of the scenario, the greater the number the bigger the geographical area it encompasses. *FS\_sthlm\_4* covers all other scenarios' areas, *FS\_sthlm\_3* covers *FS\_sthlm\_2* and *FS\_sthlm\_1* areas and *FS\_sthlm\_2* encompasses *FS\_sthlm\_1* area.

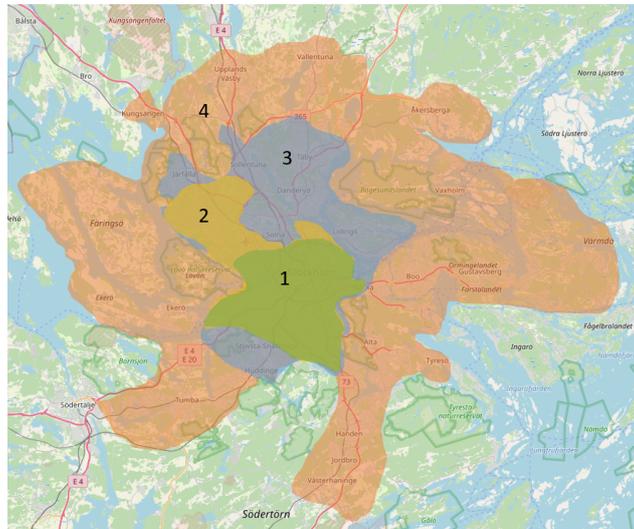


Figure 12: Zone-division for Stockholm's future scenarios

Table 30 gives an overview of the share of the weekly quantity of orders per scenario and day and an indication if the scenario results in a maximal range and energy consumption above or below the limit for the Maxus. The table also presents, for the scenarios and days that are above the maximal range limit, the percentage of routes that are above the limit. These values showcase that scenario *FS\_sthlm\_4* has the biggest amount of routes that are above the maximal range limit, except for Saturday and Sunday where scenario *FS\_sthlm\_3* has the most amount of routes above the limit. Most notably for Saturday, when the second scenario has the greatest amount of routes above the range limit, are the order density smaller for the second scenario than the first one.

The results show that scenarios *FS\_sthlm\_4* and *FS\_sthlm\_3* are above the maximal range limit the majority of days although they have an energy consumption below the energy consumption limit. Scenario *FS\_sthlm\_2* is predominately below the maximal range and energy consumption limits, while scenario *FS\_sthlm\_1* is always below the two limits except for one day. Friday, which is the day with the lowest number of orders for all four scenarios,

is the one day where three out of four scenarios are above both the maximal range limit and all four are above the energy consumption limit. The day with the greatest number of orders for all four scenarios, Sunday, is the day where all four scenarios are below the two limits, except for scenario *FS\_sthlm\_4* which is above the maximal range limit.

Table 30: Future Scenario - Stockholm

Weekday	Name	Density	Orders	Above/Below max range limit	Above/Below energy consumption limit	Percentage that is above the max range limit
Monday	FS_sthlm_4	L	L	Above	Below	20%
	FS_sthlm_3	L	L	Above	Below	13%
	FS_sthlm_2	L	L	Below	Below	N/A
	FS_sthlm_1	L	L	Below	Below	N/A
Tuesday	FS_sthlm_4	M	M	Above	Above	41%
	FS_sthlm_3	M	M	Above	Below	17%
	FS_sthlm_2	M	M	Above	Below	6%
	FS_sthlm_1	M	M	Below	Below	N/A
Wednesday	FS_sthlm_4	L	L	Above	Below	25%
	FS_sthlm_3	L	L	Above	Below	17%
	FS_sthlm_2	L	L	Below	Below	N/A
	FS_sthlm_1	L	L	Below	Below	N/A
Thursday	FS_sthlm_4	XS	XS	Above	Above	80%
	FS_sthlm_3	XS	XS	Above	Above	14%
	FS_sthlm_2	XS	XS	Above	Below	25%
	FS_sthlm_1	XS	XS	Below	Below	N/A
Friday	FS_sthlm_4	XS	XS	Above	Above	100%
	FS_sthlm_3	XS	XS	Above	Above	43%
	FS_sthlm_2	XS	XS	Above	Above	33%
	FS_sthlm_1	XS	XS	Below	Above	N/A
Saturday	FS_sthlm_4	S	M	Above	Above	41%
	FS_sthlm_3	S	S	Above	Below	80%
	FS_sthlm_2	S	M	Below	Below	N/A
	FS_sthlm_1	S	M	Below	Below	N/A
Sunday	FS_sthlm_4	L	L	Above	Below	13%
	FS_sthlm_3	L	L	Below	Below	22%
	FS_sthlm_2	L	L	Below	Below	N/A
	FS_sthlm_1	L	L	Below	Below	N/A

The amount of orders able to be covered by the Maxus, taking the maximal range limit and energy consumption limit into account, is presented in Table 31. The percentages represent the number of orders the Maxus can cover compared to the total amount of orders distributed from the DC located in Stockholm during one week in each scenario. Similarly to the present scenarios of the first case, Copenhagen, the potential of utilising Maxus vehicles in Stockholm is greater for the scenarios that encompass a bigger geographical area. This follows the trend presented in Table 29, the bigger area the greater number of orders.

Table 31: The potential of utilising Maxus in future scenarios in Stockholm

Scenario	Percentage of the total amount of orders able to be covered by Maxus
FS_sthlm_4	52%
FS_sthlm_3	47%
FS_sthlm_2	34%
FS_sthlm_1	29%

Table 32: Size of each future scenario in Gothenburg

Scenario	Percentage of total amount of orders
FS_gbg_3	52%
FS_gbg_2	41%
FS_gbg_1	22%

For Case 3, Gothenburg, and its future scenarios the results are presented in Table 32 and Figure 13. Giving an overview of the number of orders in each scenario covers the total number of orders distributed during one week from the Gothenburg DC. Similar to the future scenarios in Stockholm, the names  $FS\_gbg\_x$  indicate future scenario Gothenburg and its number,  $FS\_gbg\_3$  and  $FS\_gbg\_2$  encompasses the scenarios within their geographical areas.

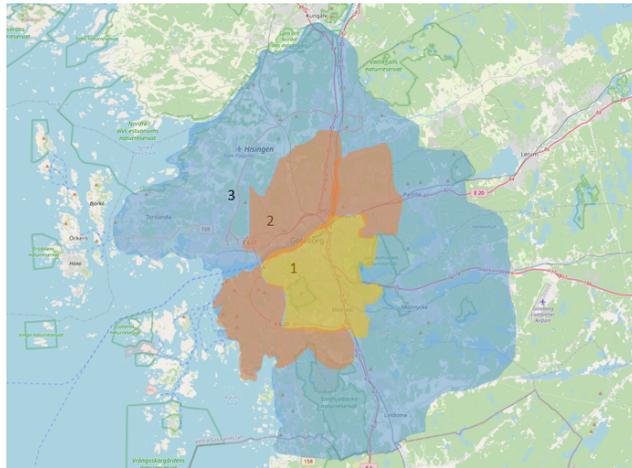


Figure 13: Zone division for Gothenburg's future scenarios

Table 33 which gives the results from the simulations in the same form as for the future scenarios presented above. Similarly to Case 1, the first future scenario ( $FS\_gbg\_3$ ) for Gothenburg has the most amount of routes above the maximal range limit. With the exception of Friday, where both scenarios  $FS\_gbg\_2$  and  $FS\_gbg\_1$  have all their routes above the maximal range limit. The scenario with the smallest geographical area,  $FS\_gbg\_1$  has a maximal range and energy consumption that is below for every day except one, while  $FS\_gbg\_2$  is below the limits for the majority of days.  $FS\_gbg\_3$ , which is the scenario with the largest geographical area, is above the maximal range limit for all seven days while it has energy consumption above the limit for four out of seven days. For the day with the lowest number of orders, Friday, all three scenarios are above the two limits. While for the two days with the greatest number of orders, Monday and Sunday, all three scenarios are below the energy consumption limit and two out of three scenarios are below the maximal range limit.

Table 33: Future Scenario - Gothenburg

Weekday	Name	Density	Orders	Above/Below max range limit	Above/Below energy consumption limit	Percentage that is above the max range limit
Monday	FS_gbg_3	L	L	Above	Below	29%
	FS_gbg_2	M	M	Below	Below	N/A
	FS_gbg_1	M	M	Below	Below	N/A
Tuesday	FS_gbg_3	M	M	Above	Above	30%
	FS_gbg_2	M	M	Below	Below	N/A
	FS_gbg_1	S	S	Below	Below	N/A
Wednesday	FS_gbg_3	L	L	Above	Below	47%
	FS_gbg_2	M	M	Below	Below	N/A
	FS_gbg_1	M	M	Below	Below	N/A
Thursday	FS_gbg_3	XS	XS	Above	Above	100%
	FS_gbg_2	XS	XS	Above	Above	33%
	FS_gbg_1	XS	XS	Below	Below	N/A
Friday	FS_gbg_3	XS	XS	Above	Above	75%
	FS_gbg_2	XS	XS	Above	Above	100%
	FS_gbg_1	XS	XS	Above	Above	100%
Saturday	FS_gbg_3	M	M	Above	Above	38%
	FS_gbg_2	S	S	Below	Below	N/A
	FS_gbg_1	S	S	Below	Below	N/A
Sunday	FS_gbg_3	L	L	Above	Below	5%
	FS_gbg_2	L	L	Below	Below	N/A
	FS_gbg_1	L	L	Below	Below	N/A

The amount of orders able to be covered by the Maxus, taking the maximal range limit and energy consumption limit into account, is presented in Table 34. The percentages represent the number of orders the Maxus can cover compared to the total amount of orders distributed from the Gothenburg DC during one week in each scenario. Here the trend of a greater potential of utilising Maxus vehicles in the bigger scenarios stays true, with similarities to the present scenarios of Copenhagen and the future scenarios of Stockholm.

Table 34: The potential of utilising Maxus in future scenarios in Gothenburg

Scenario	Percentage of the total amount of orders able to be covered by Maxus
FS_gbg_3	35%
FS_gbg_2	39%
FS_gbg_1	22%

Table 35: Size of each future scenario in Malmö

Scenario	Percentage of total amount of orders
FS_malmö_2	28%
FS_malmö_1	20%

For case 4 Malmö, two scenarios were made, see Table 35 for the amount of orders each scenario cover. The results for the first future scenario are presented in Table 36 and the zones investigated are the two largest from the present case (see Figure 9), these are shown in Figure 14. The second scenario, *FS\_malmö\_2* covers the area of *FS\_malmö\_1* and the names denote future scenario Malmö, with the numbers of each scenario corresponding to the number in Figure 14.

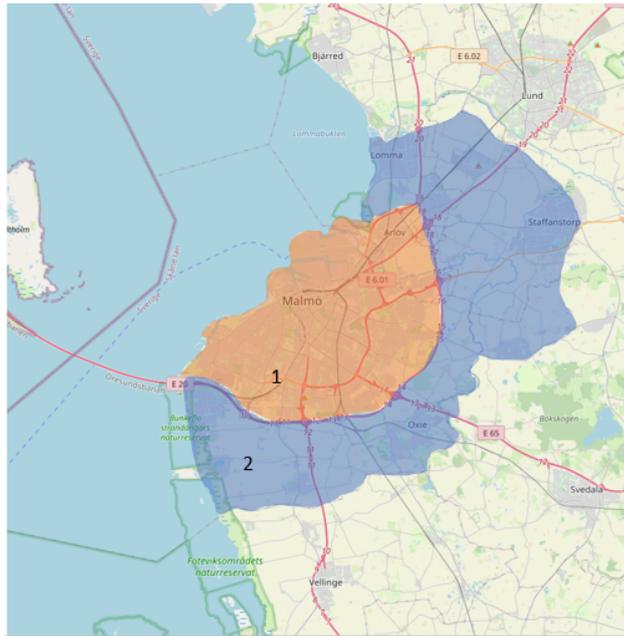


Figure 14: Zone-division for the future scenario for case 4, Malmö, with Maxus model

Deploying the Maxus model in case Malmö netted overall good results for the entire week with the exception of the larger area (*FS\_malmö\_2*) for Thursday and Friday, which are the days with the lowest shares of orders, that exceeded both range and energy limits. More on Friday than Thursday when looking at the percentage. For the larger area, Saturday also went the range limit above by a small margin (20%) but not the energy consumption.

Table 36: Future Scenario - Malmö

Weekday	Name	Density	Orders	Above/Below max range limit	Above/Below energy consumption limit	Percentage that is above the max range limit
Monday	FS_malmö_2	L	L	Below	Below	N/A
	FS_malmö_1	L	L	Below	Below	N/A
Tuesday	FS_malmö_2	M	M	Below	Below	N/A
	FS_malmö_1	L	M	Below	Below	N/A
Wednesday	FS_malmö_2	L	L	Below	Below	N/A
	FS_malmö_1	L	L	Below	Below	N/A
Thursday	FS_malmö_2	S	S	Above	Above	33%
	FS_malmö_1	S	S	Below	Below	N/A
Friday	FS_malmö_2	S	S	Above	Above	67%
	FS_malmö_1	S	S	Below	Below	N/A
Saturday	FS_malmö_2	M	M	Above	Below	20%
	FS_malmö_1	M	M	Below	Below	N/A
Sunday	FS_malmö_2	L	M	Below	Below	N/A
	FS_malmö_1	M	M	Below	Below	N/A

The amount of orders able to be covered by the Maxus, taking the maximal range limit and energy consumption limit into account, is presented in Table 37. The percentages represent the number of orders the Maxus can cover compared to the total amount of orders distributed from the original DC in Malmö during one week in each scenario.

Table 37: The potential of utilising Maxus in future scenarios in Malmö

Scenario	Percentage of the total amount of orders able to be covered by Maxus
FS_malmö_2	26%
FS_malmö_1	20%

### 6.3.3 Micro-Hubs

This section covers the results gained from employing a vehicle fleet of EVs that are equivalent to the Maxus along with the utilisation of established infrastructure in the form of micro-hubs. The results for micro-hubs in Copenhagen will be presented first which will be followed by the results from the Malmö case.

Table 38: Size of each future scenario in Copenhagen - Micro Hubs

Scenario	Percentage of total amount of orders
MH_cph_1	14%
MH_cph_2	4%
MH_cph_3	8%
MH_cph_4	8%
MH_cph_5	44%
Total	78%

For Copenhagen, four different geographical locations were used for Micro Hubs, as seen in Figure 15, these scenarios were, combined with each other, compared to the scenario of using only the DC in Copenhagen and Table 38 presents the number of orders each micro-hub covers and the total amount of orders all four micro hubs combined with the Copenhagen DC are able to cover. Each scenario has its unique name, *MH\_cph\_x*, denoting micro hub Copenhagen and its number which corresponds to the numbered areas in Figure 15. Differing from the other cases and scenarios, none of the scenarios' areas covers any of the other scenarios' areas, the area marked in the figure is what each scenario includes.

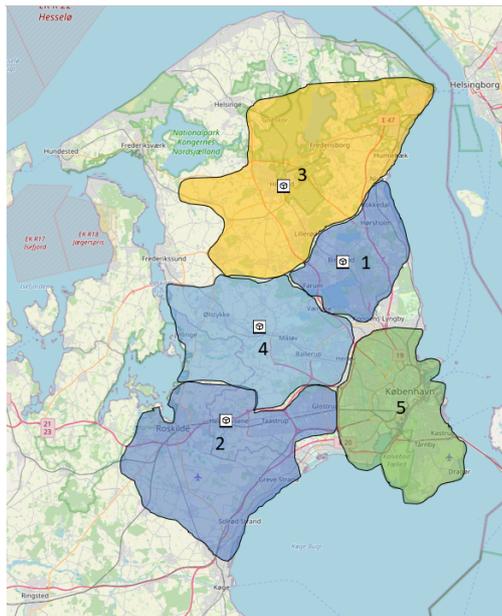


Figure 15: Zone-division of every hub for the future scenario of Case 1, Copenhagen

For the future scenario for case Copenhagen the results depicted above in Table 39 shows overwhelmingly positive results for a majority of the zones for all days except the weekends. Individually the hub in Birkerød (*MH\_cph\_1*) never exceeds both of the limits but as seen in Figure 15 it is also the smallest area for the Maxus to cover, so the results do not come as big of a surprise. However, the hub in Hillerød (*MH\_cph\_3*) which covers the largest zone by size is almost all below the limits with the exception of Tuesday, where routes exceeded the maximal range limit for that day. The number of orders (13% of the share) was also not that much, fewer vehicles had to be used to maximise load for each, thus netting larger individual distances to travel for each vehicle. Arguably the worst results were observed from the hub in Målöv (*MH\_cph\_4*), only showing purely positive for Monday and Tuesday. The argument for this result might be due to order spread, the results for Tuesday (with 11% share) show all green while for Sunday (with 12% share) the Maxus exceeded the energy consumption limit. The weekend days of Saturday and Sunday gave overwhelmingly bad results for a majority of the hubs with an exception for zones Birkerød and Hillerød.

Table 39: Micro Hubs - Copenhagen

Weekday	Name	Density	Orders	Above/Below max range limit	Above/Below energy consumption limit	Percentage that is above the max range limit
Monday	MH_cph_1	L	L	Below	Below	N/A
	MH_cph_2	S	M	Above	Below	50%
	MH_cph_3	L	L	Below	Below	N/A
	MH_cph_4	L	L	Below	Below	N/A
	MH_cph_5	L	L	Below	Below	N/A
Tuesday	MH_cph_1	M	M	Below	Below	N/A
	MH_cph_2	XS	S	Below	Below	N/A
	MH_cph_3	M	M	Above	Below	33%
	MH_cph_4	M	M	Below	Below	N/A
	MH_cph_5	S	S	Below	Below	N/A
Wednesday	MH_cph_1	M	M	Below	Below	N/A
	MH_cph_2	L	L	Above	Below	20%
	MH_cph_3	L	L	Below	Below	N/A
	MH_cph_4	L	L	Above	Below	20%
	MH_cph_5	L	L	Below	Below	N/A
Thursday	MH_cph_1	XS	XS	Below	Below	N/A
	MH_cph_2	XS	XS	Below	Below	N/A
	MH_cph_3	XS	XS	Below	Below	N/A
	MH_cph_4	XS	XS	Below	Above	N/A
	MH_cph_5	XS	XS	Below	Below	N/A
Friday	MH_cph_1	XS	XS	Below	Below	N/A
	MH_cph_2	XS	XS	Below	Below	N/A
	MH_cph_3	XS	XS	Below	Below	N/A
	MH_cph_4	XS	XS	Above	Above	100%
	MH_cph_5	XS	XS	Above	Above	N/A
Saturday	MH_cph_1	S	S	Below	Below	N/A
	MH_cph_2	S	S	Above	Above	100%
	MH_cph_3	M	S	Below	Below	N/A
	MH_cph_4	M	M	Above	Below	33%
	MH_cph_5	S	S	Below	Below	N/A
Sunday	MH_cph_1	L	L	Below	Below	N/A
	MH_cph_2	M	M	Below	Below	N/A
	MH_cph_3	L	L	Below	Below	N/A
	MH_cph_4	L	L	Below	Below	N/A
	MH_cph_5	L	L	Below	Below	N/A

The number of orders able to be covered by the micro hubs, taking the maximal range limit and energy consumption limit of the Maxus into account, is presented in Table 40. The percentages represent the number of orders the Maxus can cover in each micro hub and all the micro hubs combined compared to the total amount of orders distributed from the Copenhagen DC during one week in each scenario. Comparing Table 40 with Table 38 it is apparent that the difference in the number of orders that each scenario encompasses and the number of orders of each scenario that could be covered by Maxus vehicles is small. For *MH\_cph\_1* and *MH\_cph\_5*, the percentage of orders is the same in both tables, while for the other three, the difference is only one percentage point.

Table 40: The potential of utilising Micro Hubs in future scenarios in Copenhagen

Scenario	Percentage of the total amount of orders able to be covered by Maxus
MH_cph_1	14%
MH_cph_2	3%
MH_cph_3	7%
MH_cph_4	7%
MH_cph_5	44%
Total	76%

For the case of Malmö, it was decided to simulate an installation of an additional micro-hub in the neighbouring city of Lund. As per request from the case company, to investigate the potential of established infrastructure in the form of micro-hubs in the Swedish province of Scania.

Table 41: Size of each future scenario in Malmö - Micro Hubs

Scenario	Percentage of total amount of orders
MH_malmö_1	16%
MH_malmö_2	20%
Total	35%

The micro hubs scenarios for Malmö are viewed in Figure 16. The increase in the number of orders this accounted for is presented in Table 41. *MH\_malmö\_1* denoted the first micro hub scenario for Malmö, which is presented in Figure 16 as the area surrounding the city of Lund. *MH\_malmö\_2* is the second micro hub scenario for Malmö, the area within the city limits of Malmö.

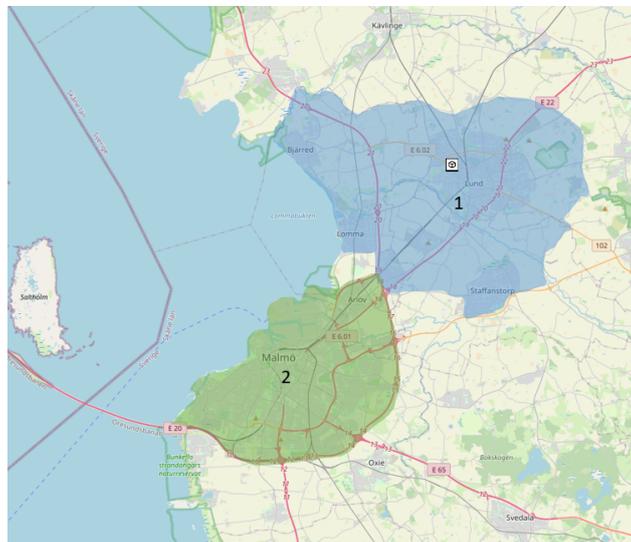


Figure 16: Zone-division for micro hubs in the future scenario for Malmö

Results for the second future scenario of case Malmö are depicted in Table 36 and the two areas where the hubs cover are illustrated in Figure 16. Directly from the table, it looks viable to route with EVs for the entire week for Malmö city (*MH\_malmö\_2*) and the majority of the week for the city of Lund (*MH\_malmö\_1*) and surrounding areas. For the latter, the exceptions are for Thursday and Friday, which as seen from present cases are the days with the lowest amount of orders.

Table 42: Micro Hubs - Malmö and Lund

Weekday	Name	Density	Orders	Above/Below max range limit	Above/Below energy consumption limit	Percentage that is above the max range limit
Monday	MH_malmö_1	L	L	Below	Below	N/A
	MH_malmö_2	L	L	Below	Below	N/A
Tuesday	MH_malmö_1	M	M	Above	Above	25%
	MH_malmö_2	L	L	Below	Below	N/A
Wednesday	MH_malmö_1	L	M	Above	Below	20%
	MH_malmö_2	L	L	Below	Below	N/A
Thursday	MH_malmö_1	XS	XS	Above	Above	50%
	MH_malmö_2	XS	XS	Below	Below	N/A
Friday	MH_malmö_1	XS	XS	Above	Above	100%
	MH_malmö_2	XS	XS	Below	Below	N/A
Saturday	MH_malmö_1	S	S	Below	Below	N/A
	MH_malmö_2	S	M	Below	Below	N/A
Sunday	MH_malmö_1	L	M	Below	Below	N/A
	MH_malmö_2	M	M	Below	Below	N/A

The number of orders able to be covered by the micro hubs, taking the maximal range limit and energy consumption limit of the Maxus into account, is presented in Table 43. The percentages represent the number of orders the Maxus can cover in each micro hub and the third row represents all the micro hubs combined compared to the total amount of orders distributed from the Malmö DC during one week in each scenario. Similar to the micro hub scenario of Copenhagen the percentage of orders able to be covered by Maxus vehicles in combination with micro hubs is close to the percentage of orders both scenarios cover. Only *MH\_malmö\_1* has a slight decrease in the number of orders able to be covered by Maxus vehicles.

Table 43: The potential of utilising Micro Hubs in future scenarios in Malmö

Scenario	Percentage of the total amount of orders able to be covered by Maxus
MH_malmö_1	13%
MH_malmö_2	20%
Total	33%

## 7 Analysis & Discussion

In this chapter analysis and discussion of the results presented in chapter 6 will be presented. Analysis and discussion of the findings regarding the first research question will be presented, arguing for the choice of factors and their role in the transition towards electrification. Furthermore, an analysis of the company's current operations will be purveyed, connecting the findings from the results to the literature review to give an account of each case the study is based upon. Similarly, a discussion of the results from the simulations of both present and future scenarios in all four cases will be conducted, both on the potential of every scenario as its own and in regard to each other. The **arguments** from these discussions and analyses are connected in a general discussion and recommendations for the company.

### 7.1 Factors

The factors that contributed to the transition from ICEVs to EVs for the case company, which was shown in Table 15 under results, all vary in how much they impact the EV adoption for the company. The utilisation of EVs compared to conventional diesel in routes proved to give varying results for all the different cases, which complemented a reviewed study's conclusion that EVs' impact is case-specific. Reasoning behind the varying results is due to what and how the factors influence each other but also how the route optimisation program worked with the information given.

One indirectly important factor, in this case, was route duration, as the route optimisation program used this factor as its objective function to minimise when constructing route batches. Duration is valid to have as a function to minimise time windows for each customer's orders and consequently operational costs. This however brought up problems for routing with EVs as its biggest concern is distance and energy consumption which were not taken into heavy consideration when minimising distance in the optimisation program. This issue was minimised with the usage of external constraints, see Formulas<sup>6</sup>, which were checked after the simulations.

Energy consumption, although an essential factor to determine the feasibility of EVs, could not be utilised to its full potential other than a rough constraint due to the lack of precise data. The aforementioned data required was the speed profile of the route that was not accessible which made velocity a far less relevant factor in this study than what reviewed literature stated, only maximal velocity was considered as a constraint due to the E-Trons speed limit. But it might become irrelevant as a factor in the future in regard to policies. In Denmark's case, the maximal velocity is obsolete for the reason that the weight limit tolerates the usage of a fast-moving EV while in Sweden it does not, therefore the maximal velocity is a constraint as of now. Cooling power was a factor looked into early in the study but was deemed irrelevant to have as it became clear for both EVs used that the energy consumed for the cold chain was already taken into consideration for the case company.

As route optimisation program minimised total operational costs through route duration. It might have inadvertently made EVs look more inadequate compared to diesel than necessary, due to the number of vehicles it deployed in the simulations. As the program minimises costs, it does not deploy additional vehicles unless necessary, which is only the case when orders exceed the total load capacity. This led to route simulations with EVs exceeding the range and energy limits as too few vehicles were utilised due to cost minimisation. This shows an interesting result that utilising EVs as of now is not cost-effective to achieve the same efficiency prior to usage. Manipulating the number of vehicles used for a route batch might therefore have potential.

The number of orders in an area proved to be a substantial factor to look into as it directly influenced the aforementioned number of vehicles in the route optimisation program which consequently influenced all the other operational factors. This is complemented by reviewed literature surrounding last-mile delivery, stating that order density, especially low, impacted the efficiency of the operations. Orders are however stochastic in nature in that consumer behaviour heavily regulates how the current day-to-day operation will look like.

### 7.2 Scenarios

Evaluating how the case company operates in the four cases today and the quantitative data for an average week, similarities and differences can be identified. To start with, Case 1, Copenhagen is the case with arguably the most significant differences. From the literature review, it was made clear that the governmental regulations connected to electric vehicles in Denmark compared to Sweden are considered beneficial for the user as the gross vehicle weight is higher for EVs in Denmark. Thus, Case 1 does not have the same limitations that the other cases have. And opens up the opportunity to utilise other types of EVs than the E-Tron, EV-types that can be operated under similar conditions as an ICEV, can be driven on highways, drive long distances, and can be loaded with the same amount of orders as a conventional diesel used prior.

Although it is important to note that it does come with some limitations such as no charging possible during a route, due to the long recharging time compared to refuelling an ICEV. Due to this, the Maxus can be utilised in Denmark,

which the case company is already trialling. For the other three cases, all located in Sweden, an EV such as the Maxus is not possible to be used with the current policies regarding maximal gross vehicle weight for EVs. Therefore an EV such as the E-Tron is a feasible option, which is currently being trialled in Stockholm.

Analysing the average week for all four cases, one trend that is identifiable is that the share of the weekly quantity of orders, order density, number of vehicles, and DPh all follow each other with almost identical scales for each day. DPkm shows a similar trend, although with a bigger variation than the other factors. While the distance and duration imply no such trends or correlation between each other. The days with the lowest share of the weekly quantity of orders, and the order density, tends to be the days with the smallest distance and duration while the days with a medium and large number of orders vary a lot more. To conclude, all four cases have similarities regarding the trends during the week, and for all of them, Thursdays and Fridays are the days with the least number of orders. Although Copenhagen also has Saturday as a smaller day.

### 7.2.1 Present Scenarios

Different scenarios for the four cases were simulated, with a basis in the present conditions that the case company is operating under. For Copenhagen, there were four different scenarios built, which were simulated with the Maxus model. *PS\_cph\_1* is the one scenario where all its routes for all days of the week were below both the maximal range and the energy consumption limits, except for Friday where the average routes for that day were above the energy consumption limit. Important to note that data on how many of the routes were above the energy consumption limit is not available, although the routes of that day were all below the maximal range limit. Overall, the smallest scenario is a reasonable scenario to operate the Maxus in without needing recharging during the day.

For the other three scenarios, all have routes above the maximal range limit for all days. Although scenario *PS\_cph\_2* is below the limit for energy consumption for all days, except for Thursday and Friday, which are both days with low amounts of orders and order density. The two biggest scenarios are also above the energy consumption limits on Tuesday and the biggest one is above the limit on Saturday as well. Tuesday is a medium-sized day regarding order density and the number of orders for both scenarios. Saturday has a medium order density for the biggest scenario, which could explain why the limit for energy consumption is crossed. Concerning the maximal range limit, all days except for Thursday and Friday the percentage of routes for each scenario that is above the limit is between 20% and 40%. Entailing that a majority of the routes could potentially be operated with the Maxus during days with similar conditions to these.

Monday, Tuesday, Wednesday, and Sunday are days with large or medium numbers of orders and order density while Thursday, Friday, and Saturday, are smaller days, which could imply that the days with a greater amount of orders and order density are more suitable for distribution with an EV. Although Saturday, which is a smaller order day, still have a majority of routes below the maximal range limit. One explanation for this difference in the smaller order days is that Saturday still has a significantly greater number of orders and order density compared to Thursday and Friday. Entailing that the vehicles utilised during those two days, which operate in the same geographical areas as for the other days and still have a load factor of 100%, drive long distances as there are a lower number of orders to distribute.

To accommodate the issues of days with a low number of orders and order density the load factor could be lowered to be able to lower the total distance that is driven for each vehicle, although this would entail utilising more vehicles during those days which would bring with it a higher economic cost. Another solution to these issues with the Maxus' limited range would require some additional operational changes such as utilising a mixed vehicle fleet with diesel vans to account for the routes not able to be covered by the Maxus.

For the present scenarios in Sweden, Cases 2, 3, and 4, are all simulated with E-Tron, with three different scenarios each. The results for all three cases indicate that the E-Tron requires a greater number of vehicles, regardless of the number of orders and order density. One trend identifiable in all three cases is for the high-order density days, where the difference in the number of vehicles when utilising E-Tron and ICEVs is greater than for the lower-order density days. This implies that it may not be as beneficial to utilise E-Tron vehicles during high-order days, as these days require a significant increase in available vehicles to be able to deliver the same amount of orders, this could bring with it an increase in economic costs for the company as they would need to invest in a higher number of vehicles which in turn would require more drivers. Analysing the second case of Stockholm, one answer to why high-order days have a bigger difference in the number of vehicles becomes apparent, these days have a greater geographical area to cover and a higher number of orders to deliver comparing them to low-order density days. Entailing that there is a bigger demand for a greater quantity of E-Tron vehicles compared to ICEVs as the E-Tron can only take 78% of the number of orders per vehicle that the ICEVs can.

The same argument could be made for the cases of Gothenburg and Malmö, although here the difference in the number of vehicles needed for high-order density days and low-order density days is not as prominent, most likely due to the overall lower order density of the two cases compared to Stockholm. The claim that E-Tron vehicles are preferable on low-order density days stays true for Gothenburg and Malmö as the difference in the number of vehicles is insignificant or there is no difference at all for these days. Implying that the E-Tron can operate with similar conditions to the ICEVs if the number of orders and order density is low for all three Swedish cases. Albeit, the E-Tron is significantly slower as the duration for the E-Tron simulation is higher than the ICEVs for all days, especially for the low-order days. This could entail higher economic costs as the driver would be required to work longer days, increasing the risk of the vehicle needing recharging.

The difference in distance is not significant for any of the scenarios. In Stockholm, for Thursday and Friday, the E-Tron operates a shorter distance than the ICEVs further implying that the days with a low number of orders are feasible for E-Tron to operate. And in Gothenburg and Malmö the majority of the days, for all three scenarios, the ICEVs drive longer distances than the E-Tron, although at a slower pace. With the distance in regard to Gothenburg and Malmö, it is preferable to use the E-Tron and as the difference in distance for Stockholm is so minuscule the argument for E-Tron could be made. However, taking the number of vehicles and duration into account, a transition to E-Tron in these scenarios would entail a greater quantity of vehicles and longer hours for the drivers.

Regarding DPh, arguments against utilising E-Tron during days with a smaller number of orders and order density in Stockholm could be made as those days have the greatest drop in efficiency. Especially critical is scenario *PS\_sthlm\_1*, which has significantly lower DPh values (>9%) for the E-Tron four out of seven days, on Thursday and Friday the ICEVs have 22% and 28% greater DPh values compared to the E-Tron. This follows the trends in duration, as the DPh is the number of orders per hour, it should follow that the days with a smaller difference in duration should have DPh values similar to the ICEVs. To conclude, in regards to the duration and DPh, the results are in favour of utilising the E-Tron in Stockholm on high-order days.

Gothenburg somewhat follows that trend as well, as scenarios *PS\_gbg\_3* and *PS\_gbg\_2* have their biggest drop in DPh for the E-Tron on Friday, although both scenarios have significant differences in DPh for all seven days. Scenario *PS\_gbg\_1* has less of an efficiency drop, except for Tuesday and Saturday, which are small order days for the scenario. Pointing towards a dependency on a high level of the number of orders and order density but also a greater difference between the different scenarios, which Case 2 does not have, in favour of the scenario with the smallest geographical area.

In the case of Malmö, it follows the two aforementioned cases, as the singular biggest drop in DPh is at the lowest order day, Friday, although it parallels Stockholm more. As the three scenarios for Malmö vary a lot, with the three scenarios mirroring each other in that of the size of the difference in DPh. Although Malmö is unique in that the high-order days have significant drops in DPh as well.

Concerning the DPkm, the results argue in favour of the E-Tron, as for Gothenburg and Malmö the majority of scenarios and days have a DPkm greater for the E-Tron than the ICEVs. For Stockholm, the small-order days have higher DPkm values for the E-Tron and the other days have a drop in the DPkm although quite insignificant.

To conclude, for Stockholm regarding the number of vehicles, distance, and DPkm, E-Tron vehicles are more favourable to utilise on low-order days, regardless of the geographical area. As the high-order days require a bigger increase in the number of E-Tron vehicles compared to ICEVs, E-Tron vehicles would also operate longer distances and yield a lower DPkm on these days. Although considering the duration in hours and the DPh of the low-order density days the results are in favour of high-order days as the difference when comparing E-Tron and ICEVs is not as prominent on days with a high number of orders. Furthermore, as all three Stockholm scenarios would entail some decrease in DPh for E-Tron vehicles for all days of the week, accepting a decrease of DPh up to 10%, 15% or 20% does not differ when considering the number of orders the E-Tron vehicles could cover. However, utilising E-Tron vehicles in a geographical area similar to the third scenario would bring with it a greater number of orders covered by E-Tron than the other two scenarios. Implying that, for Stockholm today, the conclusion is to utilise E-Tron vehicles in an area similar to the third scenario (*PS\_sthlm\_3*) on low-order days.

Concerning Gothenburg, all factors except the DPh are similar for all three scenarios, while the results from the DPh graph favour the scenario with the smallest geographical area. There is some increase in the number of vehicles that are needed for high-order density days compared to low-order density days, albeit almost insignificant. For the distance and the DPkm, the results are in favour of E-Tron vehicles for all days and scenarios. The most significant aspect is the DPh, where the two larger scenarios have greater decreases in DPh than the smallest scenario for all days except two. Which argues in favour of utilising E-Tron vehicles in an area similar to the smallest scenario. Although taking the percentage of orders each scenario is able to cover if accepting a drop in DPh of 10%, 15% or 20% into account

the preferable choice is the biggest scenario as it would cover a significantly higher number of orders. To conclude, for Gothenburg, there is no clear indication that high- or low-order days are the preferable choice for E-Tron vehicles, the debate lies more with how large of a geographical area the E-Tron is operating within. The results point towards a preference for the bigger area, similar to the third scenario (*PS\_gbg\_3*).

For the fourth case, Malmö, the number of orders and the size of the geographical area does not seem to dictate if the E-Tron is feasible to operate or not. There is no significant difference in the number of vehicles, distance or DPkm the E-Tron vehicles would bring with them for any of the days or scenarios. However, some inclination towards the low-order density days exists when considering the duration and DPh. The E-Tron vehicles would require a longer duration for each route the majority of times although the difference between E-Tron and ICEVs is slightly lesser for low-order days. For the DPh, disregarding the outlier of a decrease in DPh of 40% for the first scenario on Friday, the smallest differences are found on the low-order days. Furthermore, analysing the results of accepting a decrease in DPh of 10%, 15% or 20% indicates that the preferable choice is the third scenario *PS\_malmö\_3*, as it could cover a significantly greater number of orders than the other two scenarios. Implying that the preferable conditions for utilising E-Tron vehicles in Malmö are low-order days in a geographical area similar to the third scenario.

### 7.2.2 Future Scenarios

Evaluating how a prospective future could look through scenarios for all cases, the first observation that can be identified across the board is that Thursday and Friday show overwhelmingly negative results. For all cases, these two days have coincidentally both low density and low amount of orders. This, most probable, comes from the fact that few vehicles are being deployed as the number of orders are few and consequently the travelled distance for the deployed EVs becomes larger due to low density, this follows from reviewed literature stating EVs excel at high-density urban areas.

Another similarity that is comparable to the previous observation is that the larger zones by geographical area often show negative results. More often than not, independent of the weekday, population density and amount of orders, only distance as the main limiting factor. This is emphasised due to the fact that the maximal range limit is being exceeded more times than the energy consumption limit across all future cases. Thus it can be generally argued for solutions like fast-charging infrastructure to be established to be able to utilise EVs to the maximum.

For Case 2 of Stockholm, the future simulations with the Maxus gave overall positive prospects for the deployment in Stockholm city, which is scenario 1, for all days except for Thursday and Friday which are low-order density days, with a slight infringement of the maximal range limit on Tuesday. Generally, the future prospects of achieving 100% electrification for some days of the week beyond scenario 2 require more investigation. Expanding to scenario 2 could be plausible as the percentages of vehicles going beyond the maximal range limits for the high-order density days are 22% at worst.

Case 3 of Gothenburg is similar to Stockholm in that low-order density days in the largest scenario 3 investigated lead to improbable routes, reaching above the constraints set. Regardless of the point above, utilising EVs such as the Maxus in Gothenburg looks promising up to the second scenario on all days except Thursday and Friday. Expanding to scenario 3 indicates impracticality and inefficiency as the maximal range limit was always exceeded for the largest zone for every weekday, which might be due to the sheer size of the area observed along with a more spread-out order density. Further expansion would probably require infrastructure support like fast-charging stations in suburban areas could be of value for Gothenburg's case.

Studying the overarching results for the entire week. More specifically through the percentages of all orders that could be covered in theory with Maxus, the results showed great potential for all case scenarios, ranging from around 20% for some of the cases all the way to 52% for the smallest zone of Stockholm. The understanding that roughly half of all orders for an entire week on average could be covered with EVs similar to the Maxus in the urban areas of Stockholm, and on average a quarter of all orders originating from all cases' respective DC, is a major achievement of the potential for EVs in Sweden. These results indicate strong prospects to utilise a vehicle fleet incorporating days and areas.

Utilising micro-hubs in Case 1 and 4, Copenhagen and Malmö respectively, gave varying results when compared to the other case without. The apparent similarity that can be uncovered coincides with the general analysis that a larger area usually equals restricted access for EVs in the form of violating the set constraints of maximal driving range, although this occurred less with the use of micro-hubs. Another similarity when comparing results with Maxus and E-tron, which is apparent when observing the Malmö case, is that Thursday and Friday are better to route with the E-tron according to the route optimisation platform. The reason that follows from the analysis made with Maxus scenarios is due to the number of vehicles deployed. Nevertheless, solving this will result in the utilisation of established micro-hubs to greatly expand the reach for EVs, covering relatively more orders compared to cases without.

However, expanding and analysing in-depth upon each future scenario with micro-hubs leads to less hopeful results seen from a wider perspective. For the case of Copenhagen, expanding with micro-hubs will greatly increase the reach for EVs, but the matter to expand with the amount of micro-hubs necessary will ultimately become a cost-optimisation problem. As building four additional micro-hubs for a larger reach could become more of an expense than a profit. When comparing Malmö's future scenarios with and without micro-hubs the results showed a larger increase with the added benefit of a smaller infrastructure cost compared to Copenhagen. Further instalments of micro-hubs beyond Malmö and Lund proved to be too inefficient as it was known to be low order density outside of the area investigated. Establishing micro-hubs to reach other urban areas, which were often far away, in the province of Scania was deemed improbable and thus the verdict was made to only establish a singular micro-hub in Lund. Which proved to be a valid decision based on the results of the increased reach of customers gained.

### 7.3 General Implications

This section will cover the general analysis gained from the results. These discussions will be overlooking details and looking at general issues with help from findings from the literature review.

Looking at the aspects surrounding the electric vehicle along with the general results from the study. It is shown that the EVs characteristics with range limitations are the main hindrance to full-scale adoption. This is especially true for freight companies similar to the case company as the EVs characteristics limit the amount of orders companies can consider when routing. Which follows from the route length becoming a larger limit to consider. But these characteristics should not be detrimental to the utilisation of EVs, and a company should look into where the range limit could be used to its full advantage. Which, as shown from the results, in high-density urban areas in close approximation to the DC.

For Sweden today, with its current policies and technologies, it is more complex to maintain the same efficiency with electric vehicles compared to traditionally used ICEVs. Due to the low maximal gross vehicle weight for electric vehicles, and their heavier gross vehicle weight, the electric vehicles can not be utilised as efficiently as the ICEVs. The findings of the study show that no matter the size of the delivery area nor the order density operating with electric vehicles such as the E-Tron will entail some decrease in efficiency for all three Swedish cases. Thus, there will be a need for logistics companies to find acceptance in a certain level of decrease in efficiency, in favour of the environment. This, circling back to Quak et al. (2016), could benefit the companies long-term as it gives them a chance to be in the foreground of sustainable development within the industry, strengthening their competitiveness towards other companies.

Furthermore, with trends of rising e-commerce, establishing a more sustainable last-mile delivery is imperative for all sectors of society. As stated by Hsiao et al. (2018a) last-mile delivery is one of the most costly parts of the supply chain, in regard to its effects on the environment. This can be seen as further justification for companies to accept a drop in efficiency. Important to note that a significant decrease in efficiency could affect companies in regard to their economic profit, here collaboration with governments could be necessary. Kumar and Alok (2020) summarises studies' findings such that economic incentives promoting the usage of electric vehicles have a significant role in encouraging electric vehicles within the industry and having tax-exemptions or subsidies could lessen the consequence of a decrease in efficiency.

For Copenhagen or Denmark overall, the limitation as of now is the infrastructure needed to facilitate the adoption of EVs. But as the country is at the forefront of policies for the implementation of EVs, along with investments in the required infrastructure, Denmark is close to facilitating a larger scale of EV usage. The simulations of micro-hubs outside Copenhagen showed great potential for further expansion of EVs. Disregarding the costs, covering rural areas with EVs is still, at present time, ineffective, as wide order spread is arguably a huge weakness for EVs compared to conventional diesel vehicles. Infrastructure, like micro-hubs, helps to mitigate this weakness but ultimately could become a largely economic issue due to the investments needed for 100% electrification. In conclusion, infrastructure is needed but not enough on its own to facilitate large-scale use, technological developments and improvements for the EVs and the fast charging, all aimed to mitigate the limited range and enable better charging during the route, are necessary for further large-scale adoption.

While the E-Tron is a suitable choice, with good potential for utilisation within high-order density areas, the vehicle type can not operate in all areas of Sweden. With goals to attain fossil-free supply chains within all industries, there is a need for policy changes in Sweden. The results of the study are clear, utilising EVs similar in size and capacity to the Maxus has a greater potential of reaching a bigger geographical area, and therefore better order coverage, compared to the E-Tron. To enable the usage of Maxus in Sweden, without the need for companies to lower their load factor and efficiency, policy changes are required. Policy changes that entail a heavier maximal gross vehicle weight for electric vehicles when operating with a licence of class B. This would not only facilitate the electrification of last-mile delivery companies' vehicle fleets but also encourage it.

Changing regulations regarding the maximal gross vehicle weight allowed is only one of the essential developments needed within the political sphere in Sweden. Further on as aforementioned implied, investments in charging infrastructure are also required to attain full-scale electrification within society in both countries investigated. The current infrastructure is not enough to withhold an increase of electric vehicles on the roads, especially critical are the more rural areas where the necessary infrastructure is particularly insufficient. To enable charging during a route collaboration between different sectors of society is needed, as there is a need for technological development within fast charging as well. Actors such as companies producing charging stations, electric vehicles for last-mile delivery, the last-mile delivery companies operating within Sweden, and the Swedish government are all needed to acquire the goal of a fossil-free last-mile delivery.

## 7.4 Case Company Implications

Managerial implications for the case company to transition to EVs are presented here. These recommendations for changes or overall improvements are for the benefit of utilising EVs in their operations and simultaneously attempt to uphold the same levels of efficiency as before for the company.

The route optimisation platform used to simulate the routes was found to minimise the route duration of a route batch, to ultimately reduce the operational costs. Which as of now are not the most optimal settings for routing with EVs due to their special characteristics with limited range, as seen from the resulting simulations made with EVs in the study. The objective function for EVs to minimise should arguably be route distance, or in some way set a hard constraint on the distance routes designated for EV could be. This would directly mean more operational costs in two apparent ways, working hours could potentially become longer and the number of vehicles deployed would most likely increase. But ultimately favour the use of EVs and improve the local environment due to their usage.

To accommodate the recommendation above, it might be of value to investigate the value of optimising the route optimisation program aligned with Electric vehicle routing problems (EV-VRPs) of the variant Mixed Vehicle Fleet. That is optimising routes considering EVs and conventional diesel simultaneously in the program. An aforementioned reviewed study showed that the characteristics of ICEVs and EVs were optimised to an extent that lowered total routing costs relative to before the usage of EVs (Erdelic et al., 2019). EVs were employed for clustered instances such as urban areas while ICEVs handled the opposite, rural areas out of reach for EVs. Altering the optimisation platform to accommodate different vehicle modes simultaneously during their transition to EVs is therefore a recommendation for the case company.

A complete electrification of the case company's vehicle fleet would be difficult to achieve without collaboration between different actors in society and the company. While the company has the responsibility to invest in new electric vehicles and ensure electrification occurs they need support from the government in both countries. As discussed above, infrastructure for charging electric vehicles is underdeveloped in both countries, including both public charging stations along the street network and fast charging. Furthermore, for Sweden, policy changes are needed to enable more efficient usage of electric vehicles in last-mile delivery. The results of the study indicate that while the E-Tron is a feasible choice in electric vehicles, able to be operated within certain areas of the company's current operations in Sweden, utilising a bigger electric vehicle such as the Maxus would yield better order coverage. Additionally, the Maxus is severely hindered by the inability to charge during a route, thus for full electrification the company requires governmental support and collaboration with other last-mile companies.

A transition such as this is costly, both in regards to economy and time, full-scale electrification will take time and require investments for the company. The cost of electric vehicles alone is significant, adding on the investment for charging stations needed at the company's DC and the potential micro-hubs, the final price tag for the electrification would be weighty. Thus, the transition would need to occur gradually and in line with the results of this study, the recommendation is to start with high-order density areas and days. Steadily increasing the order coverage and the geographical area the electric vehicles covers in pace with the development of political changes, technological developments, and the number of electric vehicles in their fleet.

## 7.5 Errors and Limitations

This section will go through in short limitations experienced and simplifications done in the study, and consequently, the potential errors that might have arisen. Both in regard to internal decisions, such as calculations and assumptions made during the study, and external constraints, concerning the tools and databases utilised. For the energy consumption estimation, it was of value to have the velocity given as a speed profile to get more precise results, but this information could not be attained and thus an average velocity from each route in the forming of the regression analysis was used instead, which consequently lead to a less accurate model.

Meetings were performed and used as a source throughout the study for extensive information from the case company. These meetings were used as oral sources much like interviews as the authors asked questions to gain knowledge from trusted sources. The meetings could therefore have been transcribed or recorded to in some way give the data added validity and authenticity. As the case company wanted sensitive data to be confidential, it decreased the transparency of the study and made results less thorough and consequently more difficult to analyse in detail, but in turn, lead to more focus for the authors to elaborate on the general results.

Concerning the company's route optimisation platform, there are some points which lessen the internal validity of the study. As the platform only performs simulations there will be some amount of errors in the results when they are put in regards to reality.

The optimisation platform does not consider the topography of the area simulated, meaning the change in slope, if there are some parts of the route which entail operating uphill or downhill. This aspect will also alter the velocity and the energy needed to operate in a particular area, and an area with a lot of hills and slopes would entail that the vehicle would need recharging quicker compared to operating on a flat road.

Lastly, the simulations were based on the assumption that all orders are of the same weight and that there is only one package per order. This is not true to reality, as some customers have several packages and orders of different sizes and weights. Although it is not far from reality as the weight was assumed to be of an average value which has been estimated through data from the company. Moreover, the data used for the simulations were meant to represent an average, arbitrary, week for the company and not a singular, specific, case. Entailing that using estimated and averaged data is sufficient for this study.

## 7.6 Research Implications

As the study did not focus on the economic impact the utilisation of EVs might have, including investments into micro-hubs or the operational and purchase costs of the amount of EVs necessary for transitioning, a cost analysis might be of interest, to the case company, to find out the full potential. A cost analysis would also yield a more detailed plan on how the transition could occur, to establish a time horizon for the electrification. For the case of the E-Tron, the company should analyse the cost of a decrease in efficiency as this would provide answers to the true potential, concerning the order coverage, of the E-Tron.

Another point of interest is to follow the political climate of both countries in detail. In Denmark's case, for example, looking at the potential of the ongoing investments and construction of public battery charging might be of interest to relevant actors. Checking the potential of en-route fast charging and the impact it has for freight companies such as the case company to utilise this. In Sweden, there is an ongoing debate concerning the weight limit for electric vehicles at the time of the study, this is necessary to follow as, depending on the outcome, the alternatives of electric vehicle types could increase. And similarly to Denmark, further analysis of the country's infrastructure development is needed.

A minor inquiry that could be performed is to investigate other options for fuel sources, such as biofuels or hydrogen as an alternative to battery-driven electricity. Even though present research states the negative implications of alternative fuels a large majority of them are at an early stage of development and the future is still uncertain. Following up on research performed with AFVs should therefore be of interest to figure out the optimum vehicle mode for the environment and profits combined.

Finally when looking at a broader perspective, the implications of full-scale adoption of EVs and the impact it has on other sectors of relevance. What happens to the energy system during the ongoing energy crisis if a majority of freight companies start to utilise EVs? Are the resources and investments required for the manufacturing of vehicles and construction of the necessary infrastructure available? Is this something stakeholders for freight companies want? Are they ready to invest in EVs, with an efficiency loss in mind, for the sake of preserving the environment? And is even the use of EVs in the transportation sector the correct way to approach environmental issues? The scope of these questions stated is vast but is essential to grasp to achieve a better tomorrow.

## 8 Conclusions

The first conclusion to be made is regarding the factors, from the findings of the literature review and the scenario analysis the distance is the factor with the greatest impact as it sets a limit for EVs and no recharging is allowed during a route. However duration also plays an important role, as the route optimisation platform work towards minimising it, but the findings indicate that when routing for EVs it would be preferable to change this and route with the objective function as distance in mind instead. To get a greater understanding of the impact of routing with the main goal to minimise the distance and not the duration further analysis with an economic perspective would be needed.

Concerning the present scenarios for Copenhagen where different geographical areas were evaluated with the Maxus, the results indicate that all four scenarios are possible as the majority of the route is below the maximal range limit. Although, as mentioned above, changing the perspective of the routing would be needed to accommodate the routes that are above the limit. Further, the low-order days are more critical than the high-order days for the scenario analysis, with the findings from the literature review indicating that EVs are preferably operated in high-order density areas.

For the present scenarios in Sweden, where the E-Tron was used for simulation in Stockholm, Gothenburg, and Malmö a general conclusion is that the E-Tron would entail shorter distances but would require a greater number of vehicles and longer hours for the driver. Concerning the DPh, both Stockholm and Gothenburg indicate a dependency on the number of orders, as the DPh values show better results for the days with a bigger number of orders. For Gothenburg, there is also a dependency on the geographical area of the scenario as the smallest scenario showcases less of a drop in DPh for the E-Tron compared to the other two scenarios. Malmö varies over the scenarios and days for the DPh values and thus, a conclusion is not able to be made. The other efficiency measurement, DPkm, presents a result in favour of the E-Tron as the majority of scenarios for all three cases have a higher DPkm for the E-Tron compared to ICEVs. To conclude, the most optimal scenario for each case depends on which efficiency measure is taken into account and how big of a difference in DPh between the E-Tron and ICEVs that is acceptable.

For all the future scenarios in Sweden where the E-tron utilised in the present scenarios were replaced with the more powerful Maxus, the general results yielded optimism for electrification of the urban, populated areas of Gothenburg, Stockholm and especially Malmö during high-order density days. The main limitations to reaching 100% electrification with the use of the Maxus are the driving range and when the EV is deployed on days with low order density. The latter could be solved by adding more vehicles, although at the cost of reducing the overall efficiency of the routes through reduced load factor. The former solution would be to investigate infrastructure solutions such as micro-hubs or fast-charging stations mid-route to further increase the range of the Maxus.

For the second case of Malmö with the utilisation of a singular micro-hub in the neighbouring city of Lund, it gave 45% more orders that are reachable a majority of the time with EVs, with critical results from days with low order density in Lund. Further expansion to cover more of Scania would not see as much improvement as areas neighbouring Lund and Malmö have low order density, and it becomes more of an economic issue with the trade-off between the profits of more customers against the costs of more infrastructure. A similar conclusion could be drawn for Copenhagen in that the results showed that it was highly plausible to use EVs with the usage of micro-hubs in the suburban areas outside of Copenhagen, even during low-density days. But the economic side of things should be further investigated as utilising four micro-hubs for a net gain of 72% more orders compared to Copenhagen only could become too inefficient.

Independent of the type of electric vehicle, a full scale-electrification is plausible for last-mile delivery companies in Sweden and Denmark. However, to achieve this, a collaboration between the companies, actors operating within technological developments of fast-charging and electric vehicles, and the government is vital. There is a demand for an exchange of knowledge between the different actors and an alliance, as no actor can attain this goal on their own. The current regulations regarding electric vehicles in Sweden do not allow for full-scale electrification of a company's vehicle fleet without considerable consequences on its efficiency and operations. Therefore, it is essential that the Swedish government adopt new policies allowing logistics companies to expand their vehicle fleets and enable full-scale electrification, for the benefit of the companies and to further Sweden's work towards a greener future.

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