Czech University of Life Sciences Prague

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Master's Thesis

Transition to Green Mobility in a Selected Company

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DIPLOMA THESIS ASSIGNMENT

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Economics and Management

Thesis title

Transition to green mobility in a selected company

Objectives of thesis

The main aim of the diploma thesis is to propose a process to green mobility adaptation in the context of last-mile delivery. Analysis of the current operation will be executed, upon which a simulation of the transition will be founded. Furthermore, economical evaluation of the alternative mobility will be carried out, to show whether it could be cost-beneficial for the selected company.

Methodology

In particular, economic costs will be evaluated using a cost model, for which Sensitivity analysis will be performed for defined uncertain parameters. Optimal alternative for the green mobility will be determined using Multiple-criteria decision analysis. The transition phases will be outlined using a Gantt chart. Finally, SWOT analysis will be used to determine the strengths and weaknesses of green mobility.

The proposed extent of the thesis

60 pages

Keywords

Green mobility, Alternative fuels, CO2 Emissions, European Legislative Adaption, Last Mile Logistic, Electromobility, Global climate change

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Recommended information sources

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Declaration

I declare that I have worked on my master's thesis titled "Transition to Green Mobility in a Selected Company" by myself and I have used only the sources mentioned at the end of the thesis. As the author of the master's thesis, I declare that the thesis does not break any copyrights.

In Prague on 30.3.2023 ______________________________

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Transition to Green Mobility in a Selected Company

Abstract:

This thesis deals with the transformation of an internal combustion engine fleet to electromobility in the Last Mile Delivery segment. The electrification takes place at a branch of an unnamed partner for the e-grocery segment. First, a general overview of electric vehicles and their environmental advantages over internal combustion engines is elaborated. Then the legislation in the European Union countries and the level of support for the development of electromobility in comparison with the Czech Republic are described. In the practical part an analysis of the current operation real world data using descriptive statistics is performed and a simulation of the electromobility operation is carried out. Based on the technical parameters of the current vehicle model a multi-criteria analysis is used to recommend an electric vehicle model that meets the requirements of the operation. The charging infrastructure development and construction is also taken into account, as it plays a key aspect in the cost-effectiveness of the transition to electromobility.

Keywords: Green mobility, Sustainable transport, Alternative fuels, CO2 Emissions, European Legislative Adaption, Last Mile Logistic, Electromobility, Electric vehicle (EV), Charging infrastructure, Subsidy for electromobility

Přechod na udržitelnou dopravu ve vybrané společnosti

Abstrakt:

Tato práce se zabývá transformací vozového parku se spalovacími motory na elektromobilitu v segmentu „dodávek na poslední míli“ (Last Mile Delivery). Elektrifikace probíhá na pobočce nejmenovaného partnera působícího v potravinovém segmentu. Nejprve je zpracován obecný přehled elektromobilů a jejich ekologických výhod oproti spalovacím motorům. Dále je popsána legislativa v zemích Evropské unie a míra podpory rozvoje elektromobility ve srovnání s Českou republikou. V praktické části je provedena analýza reálných dat současného provozu pomocí popisné statistiky a simulace provozu elektromobility. Na základě technických parametrů současného modelu vozidla je pomocí multikriteriální analýzy doporučen model elektromobilu, který splňuje požadavky provozu. V práci je také je zohledněn rozvoj a výstavba nabíjecí infrastruktury, která hraje klíčovou roli v ekonomické výhodnosti v přechodu na elektromobilitu.

Klíčová slova: Udržitelná doprava, alternativní paliva, emise CO2, adaptace evropské legislativy, logistika na poslední míli, elektromobilita, nabíjecí infrastruktura, dotace na elektromobilitu

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1 Introduction

Transport is an essential part of the daily life of the entire population. It helps us to move quickly and efficiently between two places across the world, whether it is ourselves or transportation of some goods. But with the ever-increasing convenience of mankind, it is becoming very common that the distance between two delivery points is getting shorter, especially in the express food delivery segment. Due to this trend, Last Mile Delivery is growing especially in urban locations, which brings the challenges of rising concentration of pollutants in the air due to the large number of vehicles with internal combustion engines. Transport vehicles are identified as the main producers of CO2 emissions in city centres. The climate crisis knows no national or continental boundaries and affects the whole world without compromise.

Electromobility is often proposed as an alternative that could provide a solution for this difficult situation. Despite the significant weaknesses that electromobility brings, logistics companies are being pushed to make this step. The environment in last mile delivery is challenging and companies are very competitive in delivering the customer's goods the fastest and for the lowest price. Nowadays, moving towards electric mobility seems viable to gain the edge in this rough environment. Moreover, it is an aspect that end customers appreciate. For this reason, many partners in this day and age are already seeking the option to deliver their shipments maintaining carbon neutrality. For some it is even a prerequisite for establishing cooperation with the company, because they base their marketing strategies on the environmental protection, and so carbon neutral transport is a keyword for direct contact with their customers. However, it is important to establish whether an electric car really produces less CO2 emissions during its entire life cycle or whether this biggest advantage can only be discussed in context of local emissions.

Many logistics companies are already switching to electromobility, whether in the form of electric bicycles, electric scooters or electric vehicles of all sizes. However, the transformation of fleets to electric vehicles entails significant investments. A strong argument for electrification is the lower operating costs that will help to pay back the investment. The question is whether, even in the current energy crisis, operating electric cars is really economically more advantageous than cars with internal combustion engines. Many countries across Europe also support the purchase of an electric car with various benefits in the form of lower purchase tax or a purchase grant, however the extent to which this is reachable in the Czech Republic is questionable. Another important question mark also arises as to whether the electric operation is feasible in the current workload and what is a sufficient infrastructure of charging stations to support it.

2 Objectives and Methodology

2.1 Objectives

The main aim of this thesis is to propose and analyse the process to green mobility adaptation for a selected company in the context of last-mile delivery. The theoretical part aims to introduce the types of electric vehicles and possible charging methods and discuss the advantages of electromobility compared to cars with internal combustion engines. Furthermore, the theoretical part deals with the legislative framework of the European Union and the support of electromobility in EU countries with a comparison with the Czech Republic. The end of the theoretical part demonstrates the benefits of integrating electromobility with last mile delivery.

Based on an analysis of the current electric utility vehicle market, a suitable EV model is recommended for the operational needs. Furthermore, the aim is to analyse the public charging infrastructure and compare the prices of different energy suppliers. Analysis of the current operation real world data is carried out, to evaluate whether electromobility is feasible in the current operation workload and how does uncertain parameters affect the feasibility. Furthermore, economical evaluation of the alternative mobility will be carried out for 3 cases of charging the electric vehicles, to show whether it could be cost-beneficial for the selected company. At the end costs per kilometre are compared for EV and ICEV to demonstrate potential savings. A charging infrastructure development will be outlined and finally, all aspects will be considered in a SWOT analysis.

2.2 Methodology

2.2.1 Descriptive Statistics

According to [1], descriptive statistics are quantitative measures summarizing the characteristics of the examined data. Most commonly used statistic is the arithmetic average also referred to an arithmetic mean. Most frequently denoted as $\bar{x}$ can be obtained as

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i = \frac{x_1 + x_2 + \cdots + x_n}{n} \ . \tag{1}$$

The median, commonly denoted as $\tilde{x}$, is a value that separates the examined data in half, also referred to as the middle value. For odd numbers it can be calculated as

$$\tilde{x} = x_{\frac{n+1}{2}} \ , \tag{2}$$

whereas for even values as

$$\tilde{x} = \frac{x_{\frac{n}{2}} + x_{\frac{n}{2}+1}}{2} . \tag{3}$$

The mode or modus, commonly denoted as $\hat{x}$, is the value most frequently represented in the data. In contrast with mean, the median and modus can vary in value significantly, depending on the data spread. These statistics are used to describe so called central tendency of the examined data. To describe the dispersion of the data statistics called variance and standard deviation are used. Standard deviation commonly denoted as σ, can be calculated as a square root of the variance as

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2} \ . \tag{4}$$

Often so-called unbiased variance and standard deviation are used, giving a better estimate when evaluating partial samples from a larger population. Here a denominator $n - 1$ is used to give a slightly higher number, accounting to the sample variance bias

$$\hat{\sigma} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \ . \tag{5}$$

2.2.2 Multiple-criteria decision analysis

The multiple-criteria decision analysis (MCDA) also referred to as Multiple-criteria decision-making (MCDM) is a structured approach of decision-making process used for complex decisions that involve various factors. It involves a set of methods, models, and techniques that allow decision-makers to consider different criteria and their relative importance and to combine them to generate an overall score for each alternative. MCDA is frequently used to support decision-making in various fields including business, engineering, politics, and environmental management. One of the possible methods involve evaluating alternatives based on a set of criteria or attributes, each with its own weight, and then combining these evaluations using weighted sum into an overall score for each alternative, usually referred to as The Weighted sum model (WSM) [2]. First a set of n possible variants need to be identified, then a set of m relevant criteria are assigned for all variants. There are two types of criteria. First the minimisation criteria, which are desired to be the lowest, typically price. Second are the maximisation criteria, which are desired to be the highest. Weights w_j are than assigned to each criterium C_j giving it measure of importance. Weights are usually numbers between 0 and 1, while complying with

$$\sum_{j=1}^{m} w_j = 1 \tag{6}$$

The values are crucial for the result and can be determined either by using objective data or through subjective judgments and consensus-building. Values of each criterion have to be normalized to be between 0 and 1 to make them comparable. For the minimisation criteria this can be achieved for the C_j criterion of the A_i alternative for each value y_{ij} as

$$r_{ij} = \frac{B_j}{y_{ij}} \ , \tag{7}$$

where B_j is the best value for the minimisation criterion, therefore the minimal one. For the maximisation criteria this can be achieved as

$$r_{ij} = \frac{y_{ij}}{B_j} \ , \tag{8}$$

where B_j is the best value for the maximisation criterion, therefore the maximal one. The final result for each variant A_i is than obtained by

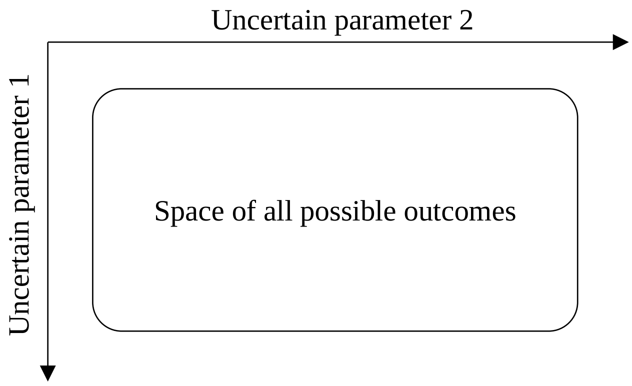
$$A_i^{WSM-score} = \sum_{j=1}^{m} w_j \cdot r_{ij} \ . \tag{9}$$

The resulting scores are then applicable from highest to lowest, meaning the variant with the highest score is optimal [3].

2.2.3 Sensitivity Analysis

Sensitivity analysis can be performed on any kind of mathematical model, which has input parameters and a defined output. It is sometimes quite simply referred to as "what-if" analysis. What happens if we vary the uncertain parameters in a given study. A parameter is considered to be uncertain, when it is likely to change, typically prices of resources in an economic model. By observing the results, we can then see how large an effect each parameter has on the final outcome. When only one parameter in the model is uncertain a One-way Sensitivity analysis can be performed. When multiple parameters are varying, a Multi-way Sensitivity analysis can be constructed. Typically, when two uncertain parameters are considered, the results can be displayed in a table.

Figure 1 – Diagram of Multi-way Sensitivity analysis table for 2 parameters



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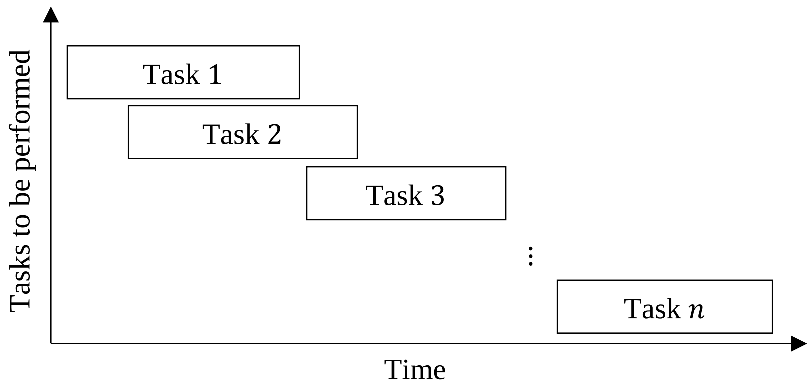
Sensitivity analysis for two uncertain parameters can be performed using MS Excel and its dedicated function. The function accepts an output cell, and two intervals of input parameters. The algorithm then iteratively quantifies the output for the whole grid of parameters and displays the result as a table [4].

2.2.4 Gantt Chart

Gantt chart is a tool used for illustration of project time plan. It is essentially a bar chart rotated 90 degrees, where the vertical axis lists all the tasks necessary to complete the project and the horizontal axis represents time needed to complete each task. An illustrative example shown in Figure 2 demonstrates the principle for an imaginary project. Tasks can take place simultaneously (Tasks 1 and 2), or there is so called finish-to-start dependency (Tasks 1 and 3), where the previous task has to be finished before next can begin [5].

Figure 2 – Illustrative example of a Gantt chart



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2.2.5 SWOT Analysis

The SWOT analysis is a well proven technique to summarise important characteristics of a proposed project in a 2 by 2 matrix. It is often used in the beginning stages of project planning, typically as a part of a business plan. Each letter in SWOT stands for a characteristic and identifies the strengths, weaknesses, opportunities, and threats of the project [6].

Figure 3 – Illustration of SWOT analysis

	Helpful	Harmful
Internal	Strengths	Weaknesses
External	Opportunities	Threats

Source: custom editing

Strengths and weaknesses are considered to be internal factors according to the organization's attributes, whereas opportunities and threats are considered to be external including more broad view on the subject, incorporating the attributes of the environment such as legislation and macroeconomics. Many authors prefer reverse order of the characteristics, referring to the same matter as TOWS, as the external factors are more significant [7].

3 Theoretical Part

Alternative mobility can be defined as an effort to minimise impact of transport on the environment either by reducing emissions or by saving supplies of non-renewable energy resources, mainly crude oil. The interest for replacing fossil fuel powered vehicles to vehicles utilizing renewable energy resources has significantly risen in recent years. There are two main reasons for this: the global climate crisis and general awareness of oil reserves depletion. Alternative mobility is one of the most topical issues of transport and environment protection, with electromobility being marked as the most feasible option for now as it is encouraged by many states through their regulations and laws [8].

3.1 Environmental Aspect of Electromobility

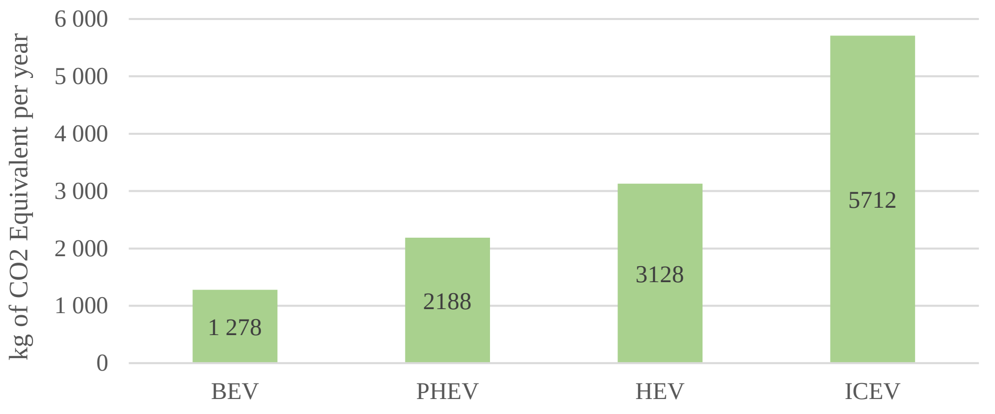
The climate change has become one of the most significant challenges in recent years with economic, social, and political risks at stake. Fossil fuel emissions are a key driver of climate change. According to Green Peace Organization [9] approximately half of emissions must be cut by 2030 to keep global warming below 1,5 °C. Therefore, fossil fuel energy production must fall by roughly 6 % a year between 2020-2030. Switching energy systems from fossil fuels to renewable resources leading to the reduction of emissions is believed to be crucial for the future. The conventional transport of goods and people using fossil fuel powered vehicles produces approximately 15-20 % of all emissions released into the air caused by human activity. It is not the majority, however it is evident that transport is a significant sector. Moreover, it directly affects most of the population of developed countries. Increasing concentration of greenhouse gases not only causes the greenhouse effect, which leads to the global warming, but also it leads to smog in densely populated areas. The development of electric vehicles seems to be one of the most effective solutions to prevent pollution by reducing usage of fossil fuels for personal and public transport [10]–[12].

Another important aspect to consider switching from internal combustion engines to alternatives is the threat of oil reserves depletion. Transport sector is responsible for up to about 70 % of annual oil consumption. According to Statistical Review of World Energy [13] the total proved reserves of oil were approximately 1,73 trillion barrels in 2020. Recent estimates suggest that the global annual oil consumption is around 35,6 billion barrels. If oil consumption is expected to be similar in following years, the reserves will last for upcoming 47 years at most considering all known oil deposits. However, the estimation may be affected either by increased consumption or on the contrary by discovering new oil deposits. Either way, automotive industry is forced to search alternative fuels. According to Statistical Review of World Energy, between 2019 and 2021, the amount of renewable energy increased by more than 8 EJ. On the other hand, the consumption of primary energy remained essentially unchanged [14].

3.1.1 Challenges

As was mentioned the main reason for encouraging the development of electromobility is its zero CO2 emissions. To be precise electric vehicles (EV) do not burn any fuel, so EV do not emit any pollutants into the air. Hence local CO2 emissions of EV are truly zero unlike combustion engine cars. Despite all the advantages that electromobility can offer, it has its weaknesses that need to be targeted. This chapter is focused on CO2 emissions caused by production of the electricity needed to power an EV and life-time cycle of batteries.

Graph 1 – USA Annual Emissions for different types of vehicles



Source: U.S. Department of Energy [15], custom editing

Encouraging electrification of personal vehicles and public transport should be global consensus as a positive step towards lowering emissions in cities. To be able to claim that electromobility reduces CO2 emissions, it is necessary to focus on the energy mix used for electricity as a power resource. Electric cars seemingly produce zero exhaust emissions compared to conventional vehicles. However, there are another aspect that need to be considered. Total carbon footprint of different types of vehicle propulsion systems depends on number of factors. These factors are extraction, refining, production and transportation of the fossil fuel or electricity. Furthermore, the emissions caused by the manufacturing process of the vehicle propulsion system itself and its later disposal or scrapping which are referred as Cradle-to-grave emissions. Comparison of carbon footprints for different car types in the USA as of 2021 is shown in Graph 1 [15].

According to U.S. department of Energy, this bar chart clearly demonstrates the emission benefit of using electric power. The results are dependent on electricity fuel mix in 2021. differences between values may vary based on the energy mix according to the each observed country or territory [16].

Another challenge of EV is the limited lifetime of batteries. Estimated capacity decrease of Li-ion battery is 4-5% per year. So, it takes 6-7 years to reach the 70% capacity, which is usually the limit for reliable usage in EV. With the increasing expansion of electromobility the question about effective chain of recycling and battery disposal is considered to be one of the main weaknesses. The main component of the batteries is lithium, which can be recycled from used batteries. In addition to lithium, other metals such as cobalt, nickel and iron can be recovered. The problem here is, that recycling of all mentioned metals is currently more expensive than acquiring them by mining. Specially to obtain lithium by mining is much more economically feasible than recycling it. Used batteries therefore often end up in landfills. In addition to battery recycling there is the option of reusing old batteries further in various energy storage devices. However, this seems not to be a solution but only a postponement of the problem. The solution for effective recycling and following battery disposal problems depends on technological advancement. One of the leading EV companies working on a new recycling battery system is for example Tesla [10], [17].

Another possible issue connected with batteries is depletion of the precious metals used for battery production. Lithium is currently available in sufficient quantities and its deposits are found in many places including the Czech Republic. The problematic metal used in battery production is cobalt. Two thirds of its deposits are located in Democratic Republic of Congo. Due to the general instability of this African region and persisting issues of working conditions and child labour abuse Tesla continuously refuses to source cobalt mined in Congo. This decision caused battery shortage in recent years. For this reason, Tesla has developed a new battery chemistry, which is cobalt and nickel free [8], [18].

Another very discussed and problematic challenge is fire hazard. difficult battery extinguishing in case of a fire. If an electric car burst into flames, it is necessary to immerse it into a container full of water or covers it with a fireproof blanket. Some producers use special fire extinguishing holes to allow better access to the burning battery [19].

3.2 Technical Aspect of Electromobility

Electromobility is a clean and efficient form of transport with the use of electric power. It can be defined as utilization of electrically propelled vehicles for the transportation of people and or cargo. While all possible types of means of transport can utilize electric propulsion, in this thesis we focus mainly on road cars.

3.2.1 History of Technical Development

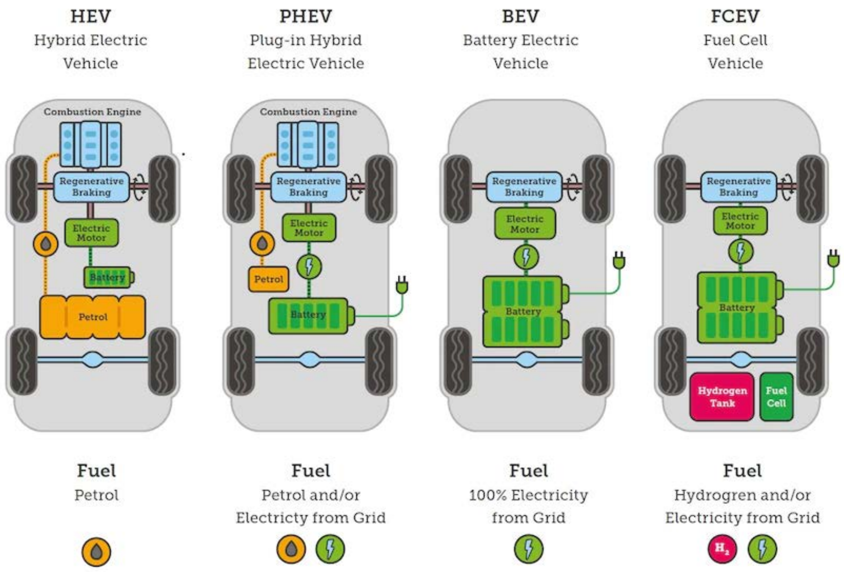
The evolution of electromobility has started at the end of 19th century and USA became a leader of electromobility. In the beginning of 20th century electric vehicles were at their peak in USA. Current internal combustion engine vehicles accounted for only 22 % of total transport, while electric cars accounted for 38 %, the rest of the market was represented by steam-power transport. The turning point was in infrastructure expansion and technical development, when compared to electric motor, the internal combustion engine was faster and more efficient [20] [21].

In last decades electromobility resonates with population mainly due to the environmental crisis. So, another breakthrough came with the introduction of the hybrid vehicle (HEV) in 1997 by Toyota and fully electrified Tesla car in 2008. Nowadays, most of the world´s car makers are progressively moving towards electrification. For example, Skoda Auto plans to stop the production of cars with internal combustion engines by 2035. Even so, the market and range of electric motorcycles or lightweight vehicles such as motor scooters, bicycles and scooters powered by an electric motor has grown. These transportation alternatives can in certain cases provide an feasible substitute to the car and e-cars as well [22].

3.2.2 Types of Electric Vehicles

Despite innovative advances, such as the battery improvement which has made EV affordable to a wider population, all EV models generally deal with the same problems of convenience as electric vehicles of the 19th century – charging time, density of charging stations and battery capacity. The current market offers four types of cars with an electric engine at different level of integration as shown in Figure 4.

Figure 4 - Types of electric vehicles



Source: The Climate Council website [23]

Battery Electric Vehicle (BEV) is the only type without an internal combustion engine. So, this type of cars has zero exhaust (local) emissions. What is the biggest advantage of this type of car. The propulsion is handled by one or more electric motors which are powered by a battery. The battery can be recharged primarily with power from the network. BEV is constructed by a smaller number of components and is generally less complex, therefore it is simpler to maintain. The disadvantages are the large weight of vehicle, caused by a need for a high-capacity battery, relatively low range and recharging options. According to a test conducted by the Norwegian Automobile Federation, the maximal range of current passenger electric cars can be up to 654 km, depending on the model and other factors such as average speed or outside temperature [24], [25].

Hybrid Electric Vehicles (HEV) combine propulsion by combustion engine with an assisting electric motor. The main purpose of this type of EV is to be able to operate in both modes – electric motor and internal combustion engine. This function allows a significant reduction of local emissions in urban areas, where the concentration is at the highest level and reduce fuel consumption. Meanwhile, combustion engine allows you long distance journeys. The battery has usually much lower capacity than in BEV and can be charged only by the internal combustion engine or by recovering energy from braking, which is called recuperation. HEVs are characteristic by their lower fuel consumption and air pollution compared to conventional combustion engine cars. From the study in 2020, the average fuel and corresponding emissions savings for a hybrid version of the same car model is around 35 % [16].

General HEV can be powered by either an internal combustion engine only, an electric motor only or by combination of both motors. However, in recent years manufacturers are developing so-called mild hybrids or battery-assisted hybrid vehicles – BAHVs. These vehicles lack the ability to drive in fully electric mode, and the electric motor is used only to assist the combustion engine and increase the efficiency of the powertrain as a whole.

Plug-in Hybrid Electric Vehicle (PHEV) share most of the advantages of HEVs, however in contrast to HEVs have larger batteries that can be charged also from the electricity grid. Another difference is that the use of the combustion engine is optimized to be minimal and when it is running it is used for recharging the battery. Therefore, the vehicle can be driven primarily by the electric motor, which increases efficiency. The battery range of PHEV vehicles is between 50 and 150 km. Disadvantages of PHEVs are higher weight compared to standard hybrids due to larger batteries and generally higher price [26].

Fuel Cell Electric Vehicle (FCEV) is a vehicle with electric motor, fuel cell generator and hydrogen tank. Hydrogen is converted into electricity in fuel cells, which powers the electric motor. The main advantage compared to BEVs is short refilling time, which is equivalent with conventional fuels. Batteries are still needed to supply required electric current on demand, however as the batteries are not used as the primary energy storage, their capacity can be much lower and this type of vehicle than benefits from lower weight. Nonetheless, the biggest disadvantage is lack of filling stations. Moreover, current infrastructure for producing sufficient amount of hydrogen is weak [16].

3.2.3 Methods of Charging

The success of BEV adaptation is indeed linked to the development of charging infrastructure and the time requirements for recharging. The main difference from the user point of view between EVs and standard vehicles with internal combustion engine is in the long duration of recharging compared to refuelling. Charging an EV takes between dozen minutes and few hours, while refuelling regular car last approximately five minutes. Therefore, recharging is best to be done while the car is not in use. For this reason, chargers are not just intended to be a part of gas stations but are being built in places where people spend hours of time. For instance, parking spots by shopping centres, urban areas or sports facilities. Moreover, number of companies offer their own charging spots as an employee benefit. All this considered, majority of EV owners are still most likely to charge their cars during the night at home, which is the most economical option considering both time and the ever-increasing cost of public chargers. Although the duration of home charging is significantly longer due to lower connection capacity, it can be utilized optimally during the night, when the vehicle is not in use and the price of electricity is reduced [27], [28].

Nowadays, EV chargers can be divided into Slow chargers, Fast chargers and Rapid chargers. Each charging type differs in ty type of current, the type of charging connector and mainly by provided power limit, which has the main influence on the widely discussed time of charging. Electric chargers can be outputting either Alternating Current (AC) or Direct Current (DC). During AC charging the current goes through on-board rectifier where it is rectified to DC, which the battery is able to store. The power capability of the on-board rectifier determines the possible maximum power that can be used for charging the battery. Thus it is a key component during AC type charging because it determines the time of charging. While DC charging does not pass through on-board rectifier, and it is directly saved into battery. For this reason, the time spent charging can be significantly lower. On the other hand, slow AC charging is generally recommended as a primary charging mode because it better conserves the lifespan of the batteries [29].

Slow Chargers are one of the easiest ways to charge EV, the charging power ranging from 2.3 kW to 6 kW. The most common used type of Slow chargers is 3.6 kW at 16 A alternating current, when the conditions of a conventional home socket are met. Charging duration is between 8 and 12 hours to fully charged EV. This is this type of charging mainly used in households where EV can be charged overnight.

Fast Chargers are the most widely used method of public EV charging with power ranging from 7 kW to 22 kW. An EV can be charged in 2-5 hours with typical output of 22 kW and AC of 32 A.

Rapid Chargers are the current fastest method of charging EV. These chargers primarily use DC at power levels above 50 kW and are able to charge EV to 80% of battery capacity in tens of minutes (20-60 minutes) with DC as high as 125 A. That is why this type is usually found near motorways, where the priority is to recharged battery in the shortest possible time.

Recently a new charger category called the UltraRapid Chargers is emerging. These have a DC output of 100 kW to 150 kW or even 350 kW. Also, a new smart device for EV charging called WallBox is used frequently. It can be fixed on a garage wall or an outdoor stand and it is common for home and small business uses. Their usual output is 3.7 kW, but they are able to charge up to 22 kW, depending on the input voltage. The advantage here is the ability to connect remotely with user who can control and monitor the charging. Moreover, smart WallBoxes can communicate with power distributors and effectively utilize the fluctuations of the grid load [29], [30].

Speaking of the grid load, electromobility in general is expected to have high demand on the electrical grid, in densely built-up areas it is not often possible to reinforce the capacity of the electrical grid. The solution for this problem can be shifting production of electricity closer to consumption and use local renewable sources such as small solar power plants for charging at home. Moreover, the creation of CO2 emissions connected with electromobility will again be reduced when renewable energy sources are used to produce electricity.

3.2.4 Developing Methods of Charging

The future of EV charging will offer more options, which are already being tested. One of the possibilities is wireless charging by electromagnetic induction, resonance charging and radio wave charging. A version of the induction charging system is tested and already used by BMW. Their technology relies on a charging plate called the *GroundPad*, which is placed on the floor and generates a magnetic field that is converted into an electric current in a receiving plate called *CarPad* installed inside the car, which charges the high-voltage batteries. Another wireless charging option with the possibility to charge during driving is being researched at the Stanford University. The idea is that every 32 km of road there would be integrated inductive charging strip to charge EVs batteries while driving. To be able use this technology the maximum speed would have to be limited to 64 km per hour. Another solution to rapidly decrease charging time is to build stations for replacing empty batteries for fully charged ones. For this idea to work it would be necessary to standardise the size of the batteries, their electrical output and capacity. Elon Musk already introduced this system for Tesla vehicles, but it has not developed so far [31], [32].

3.3 Electromobility in the EU

The market share of electric vehicles is steadily growing, especially in developed Western countries. Within the EU the Nordic countries led by Norway have the largest share of the EV market. European Union provides strong encouragement using cars powered by alternative fuels, especially electricity, as can be observed by the enormous increase in imported electric cars on the European market. The value of imported EVs increased by 2400 % between the years 2017 to 2021 (11.4 billion euros in 2021 compared to 0.46 billion euros in 2017). For Plug-in hybrids the value of imports increased by almost 800 % (€5.9 billion versus €0.67 billion) in the same period under review. For standard non-plug-in hybrids there was a 165 % increase in 2021 compared to 2017 (€11.8 billion compared to €4.5 billion). These increases go hand in hand with the increasing number of passenger vehicles. The demand for transport in Europe continues to grow and according to statistical forecasts done by the European Commission, the amount of passenger transport will increase by 50 % in 2050 in comparison to 2013. Moreover, the EU economy is currently very vulnerable to fluctuations in crude oil supply costs, as 94 % of European transport is dependent on crude oil, 90 % of which is imported from all over the world. Due to all of these issues EU strongly supports the development of Alternative mobility [33]–[35].

3.3.1 European Legislative

A European union´s core document for overcoming the environmental challenges is the Green Deal, which prescribes a goal to lead the EU to climate neutrality by 2050 with the condition, that all EU Member States must participate and act proactively. Neighbouring regions across the continent have also been involved in the plan. Green Deal brings major changes in many sectors at all levels [36], [37].

As part of the Green Deal, the European Commission presented a Sustainable and Smart Mobility Strategy with an action plan for the next four years. This strategy lays the groundwork for the transformation of the EU's transport system, which should result in a 90 % reduction in emissions by 2050 through. Milestones of the Strategy by 2030 are: at least 30 million zero-emission cars operating on European roads; 100 European climate neutral cities; high-speed rail traffic doubles across Europe continent; Public transport planed for journeys of less than 500 km should be carbon neutral; automated mobility will be implemented on a large scale and zero-emission marine craft will be prepared for launch. In next 5 years, by 2035 is goal to have ready zero-emission aircraft for the market. Targets by 2050 are: zero-emissions cars, vans, buses and also new heavy trucks; doubled rail transport and new Trans-European Transport Network (TEN-T) as smart and sustainable way of high-speed rail. To fulfil all mentioned objectives, Sustainable and Smart Mobility Strategy consist of 82 initiatives in 10 key action areas with specific measures. For instance, the goal is to boost the number of zero-emission cars and the corresponding concreate action is to build and install 3 million public chargers by 2030 to ensure more accessible and practical using of EVs [36], [38], [39].

To succeed in reducing emissions in the EU enough to reach carbon neutrality in 2050, the European Commission put forward the most extensive set of proposals on climate and energy in mid-2021, as an intermediate step following the Green Deal called the "FIT FOR 55" package. The aim of the package is to reduce greenhouse gas emissions by at least 55 % by 2030 compared to 1990 levels. The package also included a directive on renewable sources. It will be necessary to increase the share of energy production by renewable sources from the current 20 % to 32 % by 2030. However, the European Commission is considering raising this goal to 38-40 % [40].

3.3.2 European Emission Standards

Since 1992 the Commission has regularly introduced Euro Standards to cut pollutant emissions from internal combustion engine vehicles and improve air quality. However, the strict limits are applicable only to new vehicles on the market in the entire European Economic Area. The latest standard Euro 6 was implemented in 2014 and has been updated twice since then. European Commission already realised a proposal for new Euro 7 standards. In 2035, new standards will reduce NO_x emissions from vehicles and vans by 35 % in comparison to actual Euro 6 and by 56 % for buses and trucks. At the same time particulate emissions from vehicles must be reduced by 27 % [41].

3.3.3 International Climate Agreements

Europe is not the only continent that has been suffering from climate changes during the last century. The current situation is affecting the whole world and threatening the environment across continents. That is why international organisations and institutions are dealing with various measures and regulations on a global scale.

United Nations Framework Convention on Climate change was adopted in 1992 in Rio de Janeiro as a multilateral treaty to protect climate and limit global warming. Paris agreement as a subsequent treaty on climate change was set and approved by 196 parties in 2015. The main goal is not to exceed global warming by more than 2 degrees Celsius in comparison to pre-industrial times and ideally keep it even lower than 1,5 degrees Celsius [42].

3.3.4 Subsidies in EU countries

New technologies always require significant financial investments, not just for developing or testing, but also for making technologies available for commercial uses and the general population. European market has had to react and create an environment, where automotive companies are motivated to develop new technologies and are willing to change their business strategies as well.

In general, electromobility across Europe is more developed in countries with higher living standards. 13 of the 28 EU Member States also provide subsidies available to individuals. The amount of the subsidy for the purchase of an electric vehicle differs from country to country. Some of the most generous are Germany, France or the Scandinavian countries. In Germany the subsidy for the purchase of an electric car is €4,000 in 2023, while it was €2,000 higher last year. According to a new directive Germany has decided to lower the subsidy for the EVs purchase and the subsidy for the purchase of plug-in hybrids was stopped at the end of 2022. In France the "Bonus-malus" scheme supports the purchase of an electric vehicle with €7,000 and moreover, the purchase of a car with high emissions is penalised. As a result of these measures, the average CO2 emissions produced by cars are falling. In addition to subsidies there are other ways to support the development of electromobility. For instance, Norway supports EV mobility with various financial incentives such as VAT exemptions, which make some EVs even cheaper than similar cars with internal combustion engines. They also benefit from other tax reliefs, such as they do not have to pay import duties, tolls, parking or they can use bus lanes. In contrast, the Norwegians do not support the purchase of EVs themselves with subsidies [43]–[45].

3.4 Electromobility in the Czech Republic

As a member of the European Union the Czech Republic has made commitments to reduce emissions of transport as well. Compared to the situation in the EU countries, the level of support is much worse. While almost half of the EU countries support personal usage of EVs. in the Czech Republic subsidies for electric vehicles are only available for selected types of companies and public institutions. Despite the non-ideal conditions, the number of EVs in the

Czech Republic is steadily growing. According to the Czech Statistical Office, in 2017 electric cars accounted for only 0.03 % of all registered cars, which was only 1525 EVs. In mid-2022 there were 12,325 passenger electric vehicles registered, which is roughly 2 % of newly registered cars in the Czech Republic. Together with Croatia and Slovakia we belong among the most conservative EU countries in the number of EVs. Low number of EVs in the Czech Republic is probably due to the higher price of EVs and the lack of state support for private individuals [46]–[48].

3.4.1 Measures and Legislation

The Ministry of the Environment along with the Ministries of Transport and Industry and Trade has issued a National Clean Mobility Action Plan in 2015. This document is based on the Directive of the European Parliament and of the Council (2014/94/EU) concerning the introduction of infrastructure for alternative fuels. The aim is to formulate national development targets for the year 2030. Regular updates of the National Clean Mobility Action plan are published every 3 years. They contain a recapitulation of the past years and shows the current development of clean mobility. The Paris Agreement and the Green Deal, which regulate the greenhouse gas emissions and move the EU towards climate neutrality, have made the biggest change in the development of National Action Plan for Clean Mobility. The latest update, released in 2019, is linked together with the mentioned EU energy and climate plans.

The strategic goal of the Czech Republic is to develop electromobility to reach 250,000 electric vehicles in operation by 2030. In order to achieve this goal, investment support for the development of public and non-public charging infrastructure, a uniform procedure for approving the building of charging stations and the introduction of quotas for developers are proposed. Infrastructure expansion is directly relying on to electricity distribution grid. The simultaneous charging of large numbers of vehicles can lead to blackouts, especially during peak consumption hours. The plan is to introduce Smart Grids to cover the fluctuations between minimum and maximum electricity consumption during the day, thus ensuring a stable power supply. At the same time, one of the proposed action steps is to increase the share of renewable energy sources in the transport sector specifically to mitigate the increasing electrical energy demands [49].

3.4.2 Program for Subsidies

The Ministry of Industry and Trade of the Czech Republic has published the National Recovery Plan, which describes the possibility of fundings of clean mobility from the European Union. For this purpose, there has been 4 884 million CZK earmarked by the Ministry. Investments for accelerating the development of public and non-public charging infrastructure will be prioritised. Another part of the investments is planned to be allocated to support municipalities, regions, state administration and business purposes. The amount of financial support is based on the price difference between an electric car and a car with an internal combustion engine. Large companies can receive up to 40 % of the difference up to a maximum of 225,000 CZK, state-owned enterprises up to 50 % of the difference and a maximum of 281,000 CZK, and small enterprises up to 60 % up to a maximum of 337,000 CZK. The Ministry of the Environment has also allocated 600 million CZK for the purchase of vehicles with alternative propulsion – EVs, vehicles with hydrogen propulsion and also charging points. The support is limited to a maximum percentage threshold of 50 %. As far as commercial companies are concerned, co-ownership by a public body is a requirement. Currently, a total of 200 million CZK has been drawn from the fund for vehicles of the N1 category up to 3.5 tonnes, M2 and M3 which are trucks up to 7.5 tonnes, N2 which is referred to as a medium-duty vehicle up to 12 tonnes and SS, which is a self-propelled working machine. Other vehicle categories are still eligible for subsidies until 15.12.2023) [50].

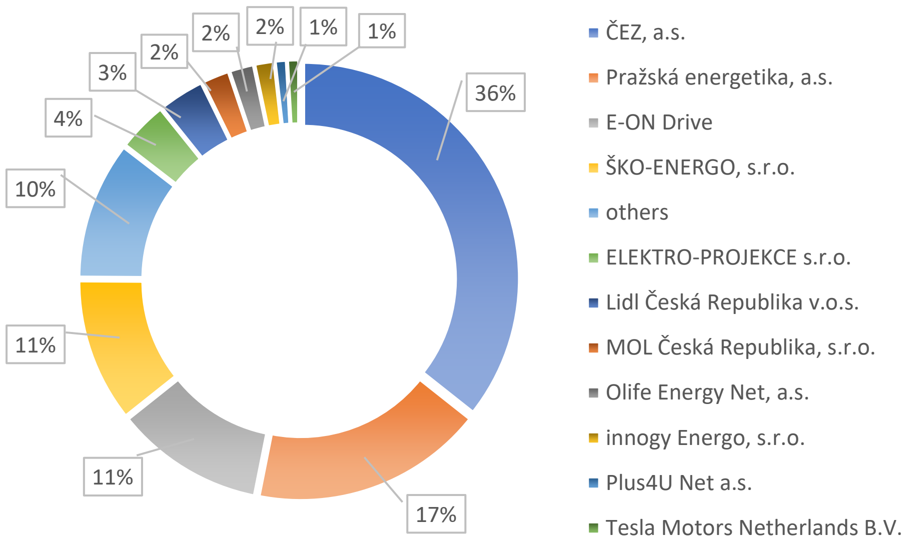
Although the Czech Republic has not allocated direct subsidies to individuals for the purchase of an electric car, it has at least introduced benefits such as free use of public car parks and dedicated spaces such as blue zones or free use of motorways. In the future, the Ministry is also considering allowing the use of bus and taxi lanes as in Norway [49], [51]. Moreover, the Ministry of the Environment provides subsidies of up to 45,000 CZK for the purchase and installation of charging stations in households under the New Green Savings Programme in order to expand electromobility in the Czech Republic and make it more accessible [52].

3.4.3 Charging Station Density in the Czech Republic

In an effort to unify the internal market and accelerate the adoption of alternative fuels across countries, the European Union has a directive that sets out requirements for the development of infrastructure of charging stations for electric vehicles as well as refuelling stations for natural gas and hydrogen fuels. In the Czech Republic this directive is implemented in several laws and programmes, for example in the above-mentioned National Action Plan for

Clean Mobility. In the Czech Republic there are 2642 public charging stations with 5286 charging points registered as of 31.12.2022. Located throughout the Czech territory there are 745 of these stations capable of DC Rapid charging technology. It is noticeable that there are more stations in the more densely populated areas such as the capital city of Prague, Central Bohemia, South Moravia.

Graph 2 – Top 10 charging station providers in the Czech Republic



Source: Transport Research Centre [53], custom editing

Among the largest operators of charging stations in the Czech Republic belongs ČEZ a.s., followed by Pražská Energetika a.s. and E.on Drive in third place. The Graph 2 shows the top 10 charging operators in country [53]. The most common type of chargers is combination of AC and DC at one place or just AC technology. The DC-only chargers are very rare and in most cases they are the Tesla superchargers [54], [55].

3.5 Electromobility and Last Mile Delivery

Every household, business, school, or institution is becoming a potential last-mile delivery point, as the percentage of sales of goods shifts more towards online every year. This is reflected in the increasing number of delivery trucks moving in cities, where greenhouse gas concentrations tend to be the highest. In the context of growing awareness of climate change there is a demand to consider not only economic but also environmental and social impacts. This is why EVs are often referred as the as the most suitable alternative to combustion engine cars in terms of reducing the negative externalities produced by combustion engines in city centres [56].

3.5.1 Last Mile Delivery

Last mile delivery is referred to as the last stage of delivery process to the customer. It is a complex process that involves a number of logistical activities and processes related to delivery from the last point of transit to the end point of the supply chain. Even though this is the final part of the supply chain, which has the shortest distance of the total supply chain, it is often considered the most expensive stage of the delivery process with plenty of room for optimisation still.

Last mile delivery can be used for parcels delivered to customer's door or collection point, which is which is referred to as the Business-to-Customer segment (B2C). Additionally, when the customer is a company itself it is referred to as the Business-to-Business delivery, or B2B segment for short. Both of these terms are closely linked to e-commerce. E-commerce is defined by many definitions from different perspectives. From our point of view, e-commerce can be characterized as realized purchases and sales of goods and services over the Internet. Generally, it may be said that the trend of e-commerce is steadily growing and is one of the commonly available services. This is confirmed by the statistics on online sales revenues, which grew by 21 % globally in monitored period between 2016 and 2021, with a significant increase in 2020 driven by the Covid-19 pandemic [57]–[60].

3.5.2 Aspect of Electromobility Implementation

Efficient last mile delivery is so becoming a crucial aspect for many companies to maintain their competitiveness in the market. All the costs of delivery are reflected in the price per order, which logistics companies are trying to keep as low as possible in this highly competitive environment. Many logistics companies choose to operate with internal combustion engine cars for the last mile, in the belief that it is more economical. Their purchase price is in most cases lower than that of an EV of the same category, but the savings of EVs are mainly reflected in running costs which are generally lower as the maintenance costs for combustion engines such as oil changes, spark plugs, pumps, etc. are eliminated with the adoption of an EV. Moreover, with current government support the costs can be compensated by tax bonuses for businesses [56], [61], [62].

As mentioned earlier, electromobility has local zero emissions which is crucial benefit in urban aeras and has positive impact for the environment. Another negative externality that can be limited by using electromobility is noise pollution as an important social aspect. However, in order to qualify electromobility as an effective solution for last mile delivery, the economic aspect must be fulfilled as well. Research confirms that fuel consumption of internal combustion engines, especially diesel ones, is significantly increased in urban environments, which demand low speed manoeuvring and frequent acceleration. These aspects do not affect the electric car's consumption to such an extent. For these reasons, choosing an electric car for last mile operation can be economically advantageous. A survey also confirmed that the selection of location is essential for effective last mile delivery. In a densely populated area, mileage per order drops significantly compared to a less populated area and the frequency of transfers between locations increases. This is crucial for EVs to achieve optimal efficiency considering their limited range. [63], [64]. Moreover, cars manufacturers must meet EU mandated fleet fuel consumption limits, as well as the limits set for CO_2 emissions per car sold, which was 120.8 g/km in 2021. Skoda Auto even met this target with a 3 g/km reserve. Thousands of electric cars and plug-in hybrids sold significantly helped to achieve this target, also because cars with CO_2 emissions below 50 g/km are accounted for 1.67 times to lower the overall average even more. Contracts between car manufacturers and logistics companies are often concluded with larger car volumes, obliging them to purchase a certain number of conventional combustion cars as well as a certain number of electric cars to keep them within the set limit. This creates a lot of pressure on companies to buy vehicles with zero local emissions, regardless of their strategies and targets [65].

4 Practical Part

The practical part focuses on the transition to an electric vehicle fleet in a logistics company of the last mile delivery segment. The development concept is carried out in cooperation with the logistics company, which provided all the input data and documents necessary for this thesis. The company focuses on last mile transport in many segments such as e-commerce, express delivery, or groceries. For this thesis a demonstrative example of a partner focusing on the groceries segment was selected. This segment carries certain specificities for the choice of an electric vehicle. The branch is located in the capital city of Prague, in the Prague 9 district. In this case, the location of the branch within Prague is not so important because the whole city is considered as one big zone of potential customers. We can therefore say that the population density aspect of the zone, which is an important requirement for the optimization of electric vehicle fleet effectivity, is fulfilled. The selected partner has committed to be carbon neutral by 2030, and in other countries the transformation to the electric fleet has already begun. The scheme is no longer owning a fleet of cars, but it has switched to an operational leasing strategy, where contracts with car dealers are mostly for 36 months. The cars that are dedicated to our partner end their lease period in March and July 2024. Existing cars are no longer leased due to high mileage and new contracts are always concluded for new cars. This provides an ideal opportunity to make changes in the operation and replace the fleet with electric cars.

4.1 Current Operation Analysis

First, a brief description of the current operation processes of logistics for the selected grocery partner example is carried out. Timewise, the first loadings of orders take place as early as 6am and the last loading is usually around 7pm. The selected branch serves not only as a logistics point, but also as a supermarket open to the general public during its opening hours. The depot, a warehouse from which the orders are dispatched, also serves as a place for workers, so called pickers, who complete orders made by customers online. The pickers prepare the orders on the loading dock, which is the last link in the processing of each order. Orders are already from the depot stacked and prepared in thermo-boxes to meet the temperature chain requirements. The couriers then collect the orders at designated parking spaces and load them into their cars. Finally, the orders are distributed to the end customers at their doorstep.

The branch is currently serviced by 10 combustion engine vehicles of a panel van type, specifically Volkswagen Caddy Maxi model with a 1600 cc diesel engine. The delivery system operates on a time slot management basis, usually consisting of 2-3 routes per day. The slot system is typical for the groceries segment, and it differs significantly from for example parcel services. For the mentioned parcel services, it is typical that the courier has all the orders he has to deliver for the day loaded in his car and has the most efficient route planned accordingly. The customer therefore cannot choose the time of delivery and in many cases not even the day. In contrast, time slot management involves delivering a purchase within a set time window based on the customer's preferences, who can choose the desired date and time of delivery. The courier therefore runs so-called scheduled routes during the day, in between which it returns to the depot for a new load. This requires efficient route planning, for which the company uses its own software and regards it as its know-how. The selected grocery delivery partner branch only offers fixed hourly slots, thus slightly lagging compared to its largest competitor, which offers its time slots within 15-minute windows. But regarding the transition of the branch to EVs, the wider hourly slots give an advantage. Narrower time slots reduce the possibilities of route planning and complicate the required optimization of delivery routes. Transfers between customers are thus often longer, which would be an inconvenient aspect for EVs that have limited range.

4.1.1 Statistical Analysis of Internal Logistics Data

In this section internal data provided by the logistics company are described. An examined monthly period of January 2023 is selected as a representative example. During this period, a total of 6 626 orders were delivered from the selected branch to the customer's doors, distributed over total of 841 individual routes. Statistics per route are summarized in Table 1 below.

Table 1 – Statistics of internal logistics data for the examined monthly period of January 2023

Route Statistics							
	Mean $\bar{x}$	Std σ	Max	Min	Median $\tilde{x}$	Modus $\hat{x}$	Sum Σ
Distance [km]	57,46	33,93	178,72	8,24	50,56	106,34	47632
Duration [hours]	3,82	0,88	6,97	1,42	3,83	3,02	3213
Number of orders	7,88	2,25	16	3	8	7	6626
Cumulative weight [kg]	251,63	87,26	559	68	241	234	103421

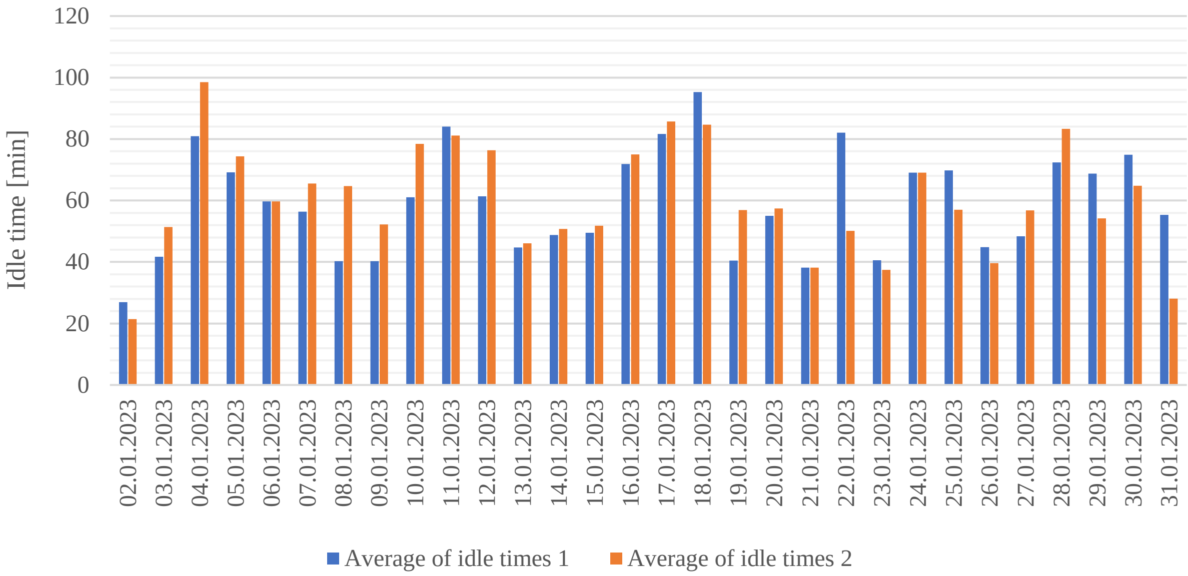
Source: Company internal data

There were 28 routs per day on average for all 10 cars. The real-world data show that in rare cases, all 10 cars were in operation at the same time. The tenth car serves mostly as a guarantee in cases of extreme load or in case of breakdown. Thus, in the vast majority of cases, 9 cars are actively serving the branch at the same time. On days of lower order volume, only 7 cars were in service. In these cases, when there is a smaller order backlog, the transfers between customers tend to be longer and the optimization of the routes is not ideal. This could be a potential problem for the introduction of EVs due to their limited range. On average one courier delivers an order to 7,9 customers per one route. The number of orders per roulette is mainly limited by the capacity of the vehicle’s cargo space and by the ability to fulfil the temperature chain requirements, where it is challenging to maintain strict temperature values especially for chilled products such as dairy products or fresh or frozen meat, especially during hot summer days. For these two reasons, the number of orders per route should not exceed 18 by rule. which was never reached during the period under review. The highest number of orders per route was 16 and the most frequent number was 8 orders. If the branch is served by all 10 cars and each car is scheduled for 3 routes, the maximum possible number of served customers is 540 per day in chosen branch, whereas the average number of served customers is 220 per day in the period under review. It is therefore clear that the operation is far from being utilized to the maximum possible optimum of orders. The turnover approaches this number only during the so-called high season, such as Christmas and the period around it in the Czech Republic, and then the next major holiday, Easter.

4.1.2 Idle Time Analysis

Between each rotation courier returns to the depot, where a new loading takes place, and the courier has a break. Therefore, there is theoretically room for recharging the electric vehicles batteries during these idle times to manage the daily mileage. In the vast majority of days, there are two idle times for each car per day. These are extracted from the provided data by comparing start and end times of each driver´s route for each day. The bar chart in the Graph 3 shows the average idle times of all cars in operation per day in a period of one month. The idle times are adjusted for the time allocated for loading, which cannot exceed 5 minutes by rule and each time is therefore reduced by 5 minutes. Idle time 1 is the pause between the first and second route, idle time 2 demonstrates the pause between the second and third route. The shortest pause for the entire observation period for this vehicle was recorded at 2 minutes.

Graph 3 – Average of idle times for all 10 vehicles for each day during the month under review.



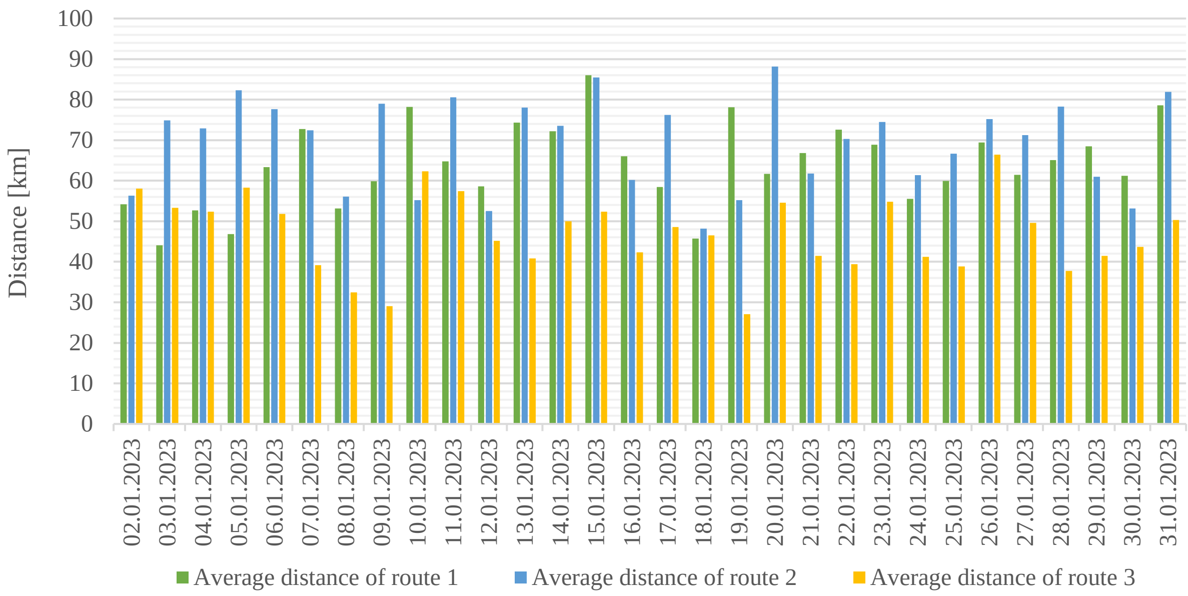
Source: Company internal data

On the other hand, the longest pause in the sample period lasted 273 minutes, which is rather an isolated exception due to the low order flow on that day. The days with less order flow were mainly on Mondays and Wednesdays. Conversely, the shortest pauses were recorded on days such as Thursday, Friday and Sunday. On average the car stayed at the branch parking space for 65 minutes between the first and second routes, with a median of 61 minutes. Between the second and third routes the average is 56 minutes, with a median of 32 minutes. In total the cars stay at the branch for a total of 122 minutes on average throughout the day, which is a period that can be used for possible recharging of the electric vehicle batteries. The breaks between the first and second routes, which tend to be around midday, are generally longer than the breaks between the second and third routes. This may be due to the afternoon increase in traffic in the capital city and the overall load of the delivery chain.

4.1.3 Route Distance Analysis

The average distance covered per route during the period under review is 57.46 km. The highest daily mileage is recorded as 178.72 km, while the lowest daily mileage for all routes is 8.24 km. The shortest distances recorded are usually the third routes, when due to a low load of orders the courier carries, for example, only one order in the neighbourhood of the depot. This means a 169.76 km variance between the shortest and longest daily mileage. On average, transfers between customers were 6.43 km long per order. This average is distorted by long journeys on non-busy days and journeys to customers in adjacent villages around Prague. With higher order volume days 0.9 km was recorded as the lowest average transfer length between customers per route in the month under review.

Graph 4 – Daily average mileage of the 10 cars for each route for the period under review.



Source: Company internal data

The bar chart in the Graph 4 above shows the daily distance average over the 10 cars for each route for the period under review. It is the daily mileage that will be the key element for the implementation of electric vehicles at the selected branch. The chart shows that the longest distances tend to be during the second route, while the routes with the shortest distance tend to be during the last third route. The average mileage during the first route was 64.30 km, during the second route 71.72 km and the third route has an average mileage of 47.51 km. Confirming the trend of the longest middle routes, which may be influenced by the busiest and most preferred times of customers returning home from work during the afternoon. Conversely, orders delivered on the first routes are most commonly delivered in the morning to parents on maternity leave or pensioners.

4.1.4 Other Factors

The range of a fully electric vehicle can be influenced by speed, driving style, weather conditions, elevation of route and by weight of the load for the route. With an average number of 7.9 orders per route and the average weight of the customer orders 15.57 kg, the average weight of full load per route is approximately 122.97 kg. The highest recorded load per route during the period was 559 kg. Renault, for example, reports that its Kangoo Van E-tech electric L1, which has the technical characteristics to meet the needs of the traffic, has a range of 332 km on a fully charged battery under ideal conditions. Ideal conditions are considered to be an outside temperature of 35 degrees with the air conditioning off and an average speed of 30 km/h with zero load weight.

Table 2 – Estimates of the real mileage by Renault for Kangoo Van E-tech electric model.

Temperature (°C)	heat/AC	Load (kg)	Real range estimation		
			City	Combination	Highway
35	OFF	0	308	265	205
	ON	0	276	246	198
20	-	0	274	244	185
5	OFF	0	258	227	166
	ON	0	238	215	161
35	OFF	122.97	286	259	203
	ON	122.97	256	241	195
20	-	122.97	268	239	183
5	OFF	122.97	252	222	164
	ON	122.97	232	210	159
35	OFF	559	259	239	249
	ON	559	244	231	190
20	-	559	255	230	178
5	OFF	559	240	213	160
	ON	559	221	202	156

Source: Renault car manufacturer [66], custom editing

It is already obvious from these ideal conditions that in real operation the claimed range of 332 km on a fully charged battery is impossible to achieve. Table 2 shows an estimate of the real mileage affected by outside air temperature, load weight and heating or air conditioning running. The weather factor is divided into three categories, 35 degrees, 20 degrees which is given as the ideal temperature to use an electric car because it is assumed that neither air conditioning nor heating needs to be turned on at that temperature, and the last category is 5 degrees. The load capacities are also shown in the table in three categories. No load, which is shown to give an idea of how much this factor affects the range of a fully charged electric car, then a weight of 122.97 which represents the average weight of loading per route and 559 kg which was the maximum weight of loading per route in the month under review. The range is then estimated for 3 driving styles, urban traffic, highway driving and a combination of the two.

In urban traffic, where the average vehicle speed is assumed to be 50 km/h, the realistic range is estimated to be the highest. This confirms that the choice of an electric vehicle for urban traffic is logical. For highway cruising, the average driving speed is assumed to be 110 km/h. In the case of a combination, it is assumed that, for example, an urban ring road or a section of highway is also used and the average speed of the electric vehicle is set at 70 km/h. The lowest range is given by the manufacturer for highway driving, where, with an air temperature of 5 degrees and the heater on, the range is reduced by 46 % to 156 km compared to the stated maximum range. In the operation in which the EVs will be applied, the use of the highway is uncommon, and the couriers primarily move around the city centre of Prague. Therefore, the style of driving on the highway, where the range is rapidly reduced, does not affect the current operation. With an average load of 122.97 kg, the best EV range of 286 km was achieved when the temperature was 35 degrees and the air-conditioning was turned off in urban traffic, which represents unbearable conditions for couriers. When the air conditioning is switched on, the battery range is reduced by 10,5 % to 256 km. Thus, factoring in air conditioning on at 35 degrees, a better result is estimated for real-world range in 20-degree weather, assuming no need to use the car's air conditioning or heater, yielding a gain in range of 12 km. With occasional highway use, the average range under those conditions is reduced by 20 km. Conversely, at the extremes of 35 and 5 degrees, the range between urban driving and highway use is increased by having the heater or air conditioning on. At an outside temperature of 35 degrees, with the air conditioning off, the range is reduced by 103 km when changing from urban to highway style. Conversely, when the air conditioning is on, the difference is less, by 75 km. At an extreme temperature of 5 degrees, there is a range difference of 80 km with the heater off and 65 km with the heater on. Ultimately, for both examples, the overall range is still lower with the AC/heater on.

The most realistic conditions that will be most common in the operation and need to be considered are the lower extremes of air temperature and when the heating or air conditioning is on as needed. For the purposes of the thesis, the closest approximation to the estimated real-world mileage is achieved by calculating a real-world coefficient by dividing the realistic and ideal ranges provided. Considering all above, the range decrease is estimated at 35 %. Thus, in the following chapters, the coefficient value of 1.35 will be used to decrease the range and increase consumption parameters needed for subsequent analysis.

4.2 EV Operation Requirements

For the successful implementation of electric vehicles in operation, it will be necessary to select a suitable EV model that will match its technical parameters to the requirements of the current operation. In addition, the daily mileage of each car over the period of interest needs to be analysed and an assessment made as to whether EVs will be able to fulfil daily milage requirements under current conditions.

4.2.1 E-utility Vehicle Market Analysis

The current car operating at the selected branch is a Caddy Maxi model from the German manufacturer Volkswagen with a diesel engine of 1600 cc capacity. Its parameters fall into the category of small utility vehicles, also called panel vans. Survey of the market in this category of available electric vehicles will be made. Table 3 shows the technical parameters of the vehicle.

Table 3 – Current ICEV vehicle parameters specified by the manufacturer.

Caddy Maxi 1.6 TDI	
Fuel type	Diesel
Engine power	75 kW
Consumption l/100 km	5,9
Range	650
Max speed km/h	150
Cargo capacity (m^3)	4,2
Cargo capacity (kg)	700

Source: Volkswagen car manufacturer, custom editing

Among the main technical criteria that will determine the choice of an electric car will be the size of the cargo space. However, cars with a smaller cargo space of at least 3.9 m^3 have also been selected, which is still sufficient under current operating conditions and the allocated number of transportation thermo-boxes. For the current model the capacity is 4.2 m^3 with a maximum weight of 700 kg. For each electric car the most significant factors will then be price, range and the possibility of charging with both alternating current (AC) and direct current (DC) with higher power for to the fast recharging of the car. The range of all electric vehicles compared is given according to Worldwide Harmonised Light Vehicles Test Procedure (WLTP) standards. Multiple-criteria decision analysis (MCDA) weighted sum method is used for EV selection shown in Table 4. The best EV variant with the highest weighted sum score will be selected based on the identified criteria C1 to C9 - purchase price excluding VAT, consumption, battery capacity, AC and DC charging, theoretical range on full battery charge, maximum speed, volume and weight capacity of the cargo space. All the values of these parameters were sourced directly from the manufacturers.

Table 4 – Multiple-criteria decision analysis for EV models comparison.

		Renault Kangoo Van E-tech	**VW ID.Buzz Cargo**	**Toyota Proace city EV L2**	**Citroen e-jumpy**		**Maxus eDeliver3**	**Opel Vivaro Electric M - L1**	**Peugeot e-Expert L2**		**Fiat e-Scudo L2**		**MCDA Parameters**	
		EV1	**EV2**	**EV3**	**EV4**	**EV5**	**EV6**	**EV7**	**EV8**	**EV9**	**EV10**	**EV11**	Type	Weight
Price without VAT [CZK]	**C1**	821 000	1 236 741	860 000	1 139 900	1 299 900	**890 000**	1 029 900	1 119 900	1 279 900	1 096 900	1 256 900	**MIN**	**0,30**
Consumption [kWh/100 km]	**C2**	18,4	20,4	**18**	24,1	25,6	23,6	21,3	21,7	24,4	24,1	28,9	**MIN**	**0,15**
Usable battery capacity [kWh]	**C3**	45	**77**	50	50	75	53	50	50	75	50	75	**MAX**	**0,10**
Charge power (AC) [kW]	**C4**	11	11	11	11	11	6,6	11	11	11	11	11	**MAX**	**0,05**
Fast charge Power (DC) [kW]	**C5**	80	**170**	100	100	100	100	100	100	100	100	100	**MAX**	**0,09**
Range [Km]	**C6**	300	**394**	275	231	329	240	231	231	329	229	329	**MAX**	**0,20**
Max speed [km/h]	**C7**	130	**145**	135	130	130	120	130	130	130	130	130	**MAX**	**0,01**
Cargo capacity [m³]	**C8**	3,9	3,9	4,3	4,6	4,6	4,8	**5,3**	**5,3**	**5,3**	**5,3**	**5,3**	**MAX**	**0,05**
Cargo capacity [Kg]	**C9**	612	750	751	925	925	905	925	**981**	960	926	925	**MAX**	**0,05**
MCDA Results		**0,828**	**0,859**	**0,834**	**0,714**	**0,764**	**0,766**	**0,759**	**0,740**	**0,781**	**0,729**	**0,765**		

Source: Car manufacturers, own calculations, custom editing

A weight and type of criterion was assigned to each observed parameter. The sum of the weights gives a value of 1. For the company, the amount of investment in the implementation of electric vehicles will be decisive, for this reason the most important criterion is the price with a weight of 0.30 followed by another very important parameter with a weight of 0.20 which is the range of the electric vehicle. Then a weight of 0.15 is assigned to the parameter consumption in kWh/100 km, a weight of 0.10 applies to the criterion battery capacity. The criterion DC charging speed is weighted with a value of 0.09 and slightly smaller weight is given to the AC charging speed, with a value of 0.05. Cargo capacity criteria were evaluated low at 0.05 each, because the cargo spaces of all selected EVs are sufficient and the actual capacity is not a significant benefit for the current operation. Finally, the maximum speed parameter was evaluated with the smallest priority of 0.01 due to the operation taking place primarily in the city centre and city ring road or tunnels, where the speed is limited to 70-80 km/h with only occasional use of the highway, therefore high speed being the lowest priority.

According to the selected weights, the best rating was achieved by an electric vehicle from the German brand Volkswagen with its ID.Buzz Cargo model, which significantly stands out above its competitors in crucial parameters such as range, battery capacity, power during DC charging, and its maximum speed could also compete with personal electric cars. On the other hand, it does not dominate the cargo capacity as well as consumption parameters. The Toyota Proace city EV in L2 version is evaluated as the second-best variant, dominating with the lowest overall consumption at 18 kWh/100 km in comparison with its competitors. The imaginary third place goes to the Renault Kangoo Van e-tech, which stands out for its lowest price and decent range.

It should be noted that all the top places were taken by vans with the smallest possible cargo space for the current operation. The e-Jumpy model with a 50kWh battery capacity from the French brand Citroen is considered the least suitable choice. This is mainly due to the relatively high price and low range on a fully charged battery. The same model in a version with a 75 kWh battery capacity and thus a higher range, which increases the range, was better positioned. Generally speaking, for all models that are on the market with the standard 50 kWh charger capacity and the increased 75 kWh capacity, the trend is that the models with the higher battery capacity are always more advantageous according to the selected weights. The price/range ratio on a full battery charge is therefore more favourable here. On The other hand, the higher capacity 75 kWh battery takes approximately 15 minutes longer to charge, which is a factor to consider as well. The Maxus eDelivery model used by the largest competitor on the market came in an imaginary fifth place. Overtaken by the Peugeot e-Expert L2 with a 75 kWh battery capacity, which dominates with the highest m^3 cargo space capacity.

4.2.2 Selection of Appropriate EV Model

In this section, the 3 best evaluated variants will be compared in detail, namely the ID.Buzz Cargo, the Toyota Proace city EV L2, the Volkswagen ID.Buzz Cargo and the Renault Kangoo Van E-tech. The ID.Buzz outperforms the other competitors with its parameters such as DC charging power, battery capacity, and most importantly range. Despite a battery capacity of 77 kWh, it doesn't take hours to charge, with DC charging power it can be charged to 80 % in 30 minutes. On a slow AC charger at 11 kWh, the car will charge in 7 hours 30 minutes, which fits the idea of charging the car primarily overnight. The carmaker ID.Buzz describes the car as a breakthrough model in the utility vehicle category in terms of innovation and design, its dimensions and small turning diameter (11.9 m) make it an ideal choice for operation in large cities where there are many small streets. In urban traffic, the model should have a respectable range of up to 425 km on a fully charged battery. The ID.Buzz Cargo thus appears to be an ideal choice of electric vehicle, the only minus that the model has is the relatively high price the capacity of the cargo area, which with its 3.9 m3 is the smallest acceptable option for the current operation conditions.

Figure 5 - Toyota Proace city EV (L2) on the left, Volkswagen ID.Buzz cargo on the right.

Source: car manufactures official webpages

On the other hand, the Toyota Proace model has the largest cargo space with a capacity of 4.3 m^3 out of the 3 winning models selected. It also has the lowest fuel consumption, despite having the lowest range. However, compared to all the models, it is still one of the best with a range of 275 km. However, compared to all the models, it is still only of the largest range and that is 275 km. Charging the car with its 50 kWh battery to 80% takes 30 minutes with DC at 100 kW charging power. With AC charging via an 11 kWh on-board charger, it takes about 4.5 hours to charge. When it comes to top speed, Toyota is not far behind here either, with 135 km/h. In the third place is the Kangoo Van E-tech, which again has a smaller cargo space of 3.9 m^3 but has the lowest price, which is 34 % cheaper than the ID.Buzz Cargo. In terms of battery capacity, it has the worst in the entire group of cars studied with a capacity of 45 kWh. This with a consumption of 18.4 kWh/100 km corresponds to a range of 300 km.

Despite the results of the multi-criteria analysis, where Volkswagen's ID.Buzz Cargo was the highest rated vehicle, the Toyota Proace City EV in the extended L2 version is recommended for the current requirements of the operation and the client. The main reasons for this recommendation include lower purchase price and the 0.4 m^3 more cargo space. The ID.Buzz is significantly more expensive compared to models with the same cargo capacity, with purchase prices below 1 million CZK. All this considered the main reason for choosing only the second-best rated vehicle, are the conditions set by the company's car fleet provider. The car dealer from whom the company has been provided with cars will deliver the required number of new diesel vehicles for the necessary fleet expansion for the next season only on the condition of purchasing a certain number of electric cars. The ID.Buzz Cargo model is not available in the dealer's range of light commercial vehicles with pure electric drive, whereas the Toyota Proace city EV is available from the dealer. The Table 5 below shows the charging options for the recommended car in service.

Table 5 – Charging options for the recommended car in service.

	Power	Type	Minutes to charge	Capacity
AC charge	11 kW	type 2 mode 3	300-450	100%
DC charge	100 kW	CCS Combo	30	80%
Home charging	3,6 kW	type 2 mode 2	1800	100%

Source: Toyota car manufacturer [67]

In 2023 manufacturer Nissan is set to introduce an extended version (L2) of its Nissan Townstar model, which will be the main competitor to the Proace city EV. In particular, a more powerful on-board charger is expected, which is already standard in the short version. Nissan's short version competes with the L1 version of the Proace city EV mainly on lower fuel consumption and longer range. In contrast, the Toyota model has better specifications on battery capacity, cargo space capacity, top speed, and most importantly, more DC charging power. So it is to be seen how well the Nissan Townstar L2 will compete with the recommended Toyota Proace city EV L2.

4.3 Simulation of EV Operation

In this section the capability of the selected EV model will be evaluated on current operation real-world data. The data used for this simulation is already mentioned in the chapter 4.1 - Current Operation Analysis.

Figure 6 - Example of a query result obtained from the company database system.

route_id	code	total length	cumulative weight	start_time	end_time	route duratio	agent name	vehicle id	model	num of order	start date
1901631	2P	25,92	449	2023-01-05 13:40:12	2023-01-05 17:16:35	3,6	Řidič 1	10582	Caddy	13	05.01.2023
1927476	1K	88,76	321	2023-01-19 08:59:03	2023-01-19 12:28:57	3,48	Řidič 1	10582	Caddy	10	19.01.2023
1927998	2K	33,58	195	2023-01-19 13:33:43	2023-01-19 16:33:00	3	Řidič 1	-1	Caddy	7	19.01.2023
1928511	3C	35,28	103	2023-01-19 17:32:05	2023-01-19 19:58:08	2,43	Řidič 1	10582	Caddy	5	19.01.2023
1929496	1K	39,4	444	2023-01-20 09:00:01	2023-01-20 11:56:37	2,93	Řidič 1	10582	Caddy	12	20.01.2023
1930066	2G	37,56	501	2023-01-20 13:30:41	2023-01-20 17:32:17	4,03	Řidič 1	10582	Caddy	15	20.01.2023
1930518	3G	37,33	174	2023-01-20 18:10:49	2023-01-20 20:56:32	2,77	Řidič 1	10582	Caddy	8	20.01.2023
1931359	1K	33,83	506	2023-01-21 09:34:57	2023-01-21 13:05:24	3,52	Řidič 1	10582	Caddy	13	21.01.2023
1931954	2K	26,67	559	2023-01-21 13:52:25	2023-01-21 16:51:14	2,98	Řidič 1	10582	Caddy	14	21.01.2023
1932431	3K	9,25	120	2023-01-21 17:33:43	2023-01-21 19:27:59	1,9	Řidič 1	10582	Caddy	4	21.01.2023
1933139	1K	20,74	435	2023-01-22 08:46:06	2023-01-22 11:48:27	3,03	Řidič 1	10582	Caddy	15	22.01.2023
1933595	2K	53,94	394	2023-01-22 13:48:15	2023-01-22 17:13:30	3,42	Řidič 1	10582	Caddy	12	22.01.2023
1936316	1K	36,11	234	2023-01-24 08:46:35	2023-01-24 11:29:59	2,72	Řidič 1	10582	Caddy	9	24.01.2023
1936859	2K	25,93	178	2023-01-24 13:33:05	2023-01-24 16:01:28	2,47	Řidič 1	10582	Caddy	7	24.01.2023
1937249	3K	11,01	129	2023-01-24 17:07:28	2023-01-24 18:49:00	1,7	Řidič 1	10582	Caddy	5	24.01.2023
1938129	1K	0	216	2023-01-25 09:04:43	2023-01-25 10:40:02	1,6	Řidič 1	10582	Caddy	8	25.01.2023

Source: Company internal data

During the examined monthly period of January, a total of 6 626 orders were delivered from the selected branch to the customer's door, distributed over total of 841 individual routes. There were 28 routs per day on average for all 10 cars. For these routes data are stored in the company internal system. Example of a query result obtained from said system, which is 841 rows long in total, is shown in the Figure 6.

4.3.1 Idle Time Charging Simulation

When pairing corresponding routes of one driver for each day together, it is possible to extract the idle times between the routes as well as the distances the vehicle had to travel. These extracted data then can be organised together and used to calculate if the vehicle is capable of successfully completing all of its routes. Moreover, it is possible to determine how much can the vehicle be charged between the routes during the idle times, and how does that affect the success rate. The inputs needed for these calculations are summarized in the Table 6 and shown in orange colour. The usable capacity is said to be 96 % of the total battery capacity and the real world consumption and total range are obtained using the Real world coefficient as

$$C_{rw} = C_s \cdot r \quad [kWh/100\ km], \tag{10}$$

$$R_t = \frac{B_{uc}}{C_{rw}} \cdot 100 \quad [km]. \tag{11}$$

Table 6 – Input parameters for the idle time charging simulation.

Input Parameters			
Toyota Proace city EV L2			
B_c	Battery capacity	50	kWh
B_{uc}	Usable capacity	48	kWh
CS_{AC}	AC Charging speed	11	kW
CS_{DC}	DC Charging speed	100	kW
C_s	Specified consumption	18	kWh/100 km
r	Real world coefficient	1,28	-
C_{rw}	Real world consumption	23,0	kWh/100 km
R_t	Range	208	Km

Source: Toyota car manufacturer [67], own calculations

When considering the distance of the first route as D_1 and second route D_2, then an estimated range before the departure of the routes R_2 and R_3 is calculated for each row as

$$R_2 = R_t - D_1 \quad [km], \tag{12}$$

$$R_3 = R_2 - D_2 \quad [km]. \tag{13}$$

When taking into consideration the possibility to recharge the EV during the idle time, when denoting the idle time between routes 1 and 2 as T_1 and between the routes 2 and 3 as T_2 a new estimate of range before the departure of the routes can be calculated as

$$R_{2AC} = R_t - D_1 + \frac{T_1}{60} \cdot CS_{AC} \cdot \frac{100}{C_{rw}} \quad [km], \tag{14}$$

$$R_{3AC} = R_{2AC} - D_2 + \frac{T_2}{60} \cdot CS_{AC} \cdot \frac{100}{C_{rw}} \quad [km], \tag{15}$$

where the results are obtained for using the slow AC charger and the fast DC charger similarly by using the appropriate charging speed

$$R_{2DC} = R_t - D_1 + \frac{T_1}{60} \cdot CS_{DC} \cdot \frac{100}{C_{rw}} \quad [km], \tag{16}$$

$$R_{3DC} = R_{2AC} - D_2 + \frac{T_2}{60} \cdot CS_{DC} \cdot \frac{100}{C_{rw}} \quad [km]. \tag{17}$$

It is important to note that the resulting theoretical ranges obtained before the departure need to be constrained up to the maximal range of the EV. This can be easily achieved using a conditional statement. The resulting ranges are then compared to the according route distance. If the range is higher than the required distance it is marked as successful - green and when it is lower it is marked as unsuccessful – red. There is also a range reserve of 15 km taken into consideration and the range is marked yellow when it does not surpass the route distance with this reserve added. The results of these calculations are shown in the Table 7 below for the first 10 rows of the whole dataset.

Table 7 – First 10 rows of the theoretical range before departure calculations

								Range before departure of route					
								No charging		**AC charging**		**DC charging**	
Index	**agent name**	**date**	**idle time 1 [min]**	**idle time 2 [min]**	**distance route 1 [km]**	**distance route 2 [km]**	**distance route 3 [km]**	R_2 [km]	R_3 [km]	R_{2AC} [km]	R_{3AC} [km]	R_{2DC} [km]	R_{3DC} [km]
0	Driver 17	23.01.2023	33,95	1393,28	63,01	74,78	41,15	145,32	70,54	172,34	208,33	208,33	208,33
1	Driver 17	27.01.2023	3,82	17,87	72,12	129,94	65,07	136,21	6,27	139,25	23,53	163,82	163,13
2	Driver 6	15.01.2023	27,83		43,58	90,63		164,75	74,12	186,90	96,27	208,33	117,70
3	Driver 6	16.01.2023	115,62		21,51	131,64		186,82	55,18	208,33	76,69	208,33	76,69
4	Driver 6	19.01.2023	29,25		65,74	26,34		142,59	116,25	165,87	139,53	208,33	181,99
5	Driver 6	22.01.2023	78,55		116,73	103,29		91,60	-11,69	154,11	50,82	208,33	105,04
6	Driver 6	24.01.2023	18,80	17,93	78,83	51,14	47,48	129,50	78,36	144,46	107,59	208,33	208,33
7	Driver 6	25.01.2023	107,10	3,97	29,65	52,75	16,61	178,68	125,93	208,33	158,74	208,33	184,28
8	Driver 6	26.01.2023	12,38	5,73	65,84	141,1	28,43	142,49	1,39	152,35	15,81	208,33	108,71
9	Driver 6	29.01.2023	21,97	100,72	20,69	46,39	17,75	187,64	141,25	205,12	208,33	208,33	208,33
10	Driver 6	30.01.2023	43,33	2,28	33,37	0	23,92	174,96	174,96	208,33	208,33	208,33	208,33
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

Source: Company internal data, own calculations

The individual unsuccessful instances (in red) are counted and divided by the total number of instances to give the success rate for each route and charging type. The results are shown in Table 8.

Table 8 – Success rates for the according routes and charging types.

No charging		AC charging		DC charging	
R_2	R_3	R_{2AC}	R_{3AC}	R_{2DC}	R_{3DC}
94,96 %	**77,31 %**	**98,32 %**	**87,39 %**	**100 %**	**100 %**
86,13 %		**92,86 %**		**100 %**	

Source: own calculations

The results show that for the selected EV and its parameters the current operation would fail in 13,87 % cases when not charging during the day. When using the AC charger, the success rate does not improve substantially, and the current operation would still fail in 7,14 % cases. When using the DC fast charger during the idle times, the current operation would not fail in a single case during the period under review. This resulting success rate can then be analysed for different input parameters using so called sensitivity analysis. It is shown in Table 9 for different EV battery capacities and charging speeds.

Table 9 – Sensitivity analysis of success rate for different EV battery capacities and charging speeds.

Success rate			Battery capacity - kWh								
			40	45	50	55	60	65	70	75	80
Charging speed - kW	AC	3,6	80,7%	86,1%	89,9%	92,4%	94,5%	96,2%	99,2%	99,6%	99,6%
		7,5	84,5%	88,7%	92,4%	94,1%	95,8%	99,2%	99,6%	99,6%	99,6%
		11	87,0%	91,2%	92,9%	97,1%	98,7%	99,2%	99,6%	99,6%	100,0%
		22	93,7%	95,8%	97,5%	98,7%	99,6%	99,6%	100,0%	100,0%	100,0%
	DC	24	94,5%	96,2%	97,5%	98,7%	99,6%	100,0%	100,0%	100,0%	100,0%
		50	97,1%	98,7%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%
		75	98,7%	99,6%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%
		100	99,2%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%
		150	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%

Source: own calculations

The results show that EVs with higher capacities of the battery can achieve sufficient success rates even with very low charging speeds, supposedly even without charging at all. However, the added weight of the larger battery is not accounted for. On the other hand, even smaller battery capacities, as low as 45 kW can still achieve perfect success rate when using the fast 100 kW charging speed. Similar sensitivity analysis is shown in Table 10 for different consumption input parameters.

Table 10 – Sensitivity analysis of success rate for different EV consumptions and charging speeds.

Success rate			Specified consumption - kWh/100 km								
			18	19	20	21	22	23	24	25	26
Charging speed – kWh	AC	3,6	89,9%	87,0%	84,9%	82,8%	81,1%	79,0%	76,5%	73,1%	71,8%
		7,5	92,4%	90,3%	88,7%	85,7%	84,5%	82,4%	81,1%	77,3%	74,4%
		11	92,9%	92,0%	90,3%	87,8%	86,6%	84,5%	83,2%	81,1%	80,3%
		22	97,5%	96,6%	95,4%	94,1%	91,6%	90,3%	88,2%	87,4%	86,1%
	DC	24	97,5%	96,6%	95,4%	94,5%	93,3%	91,2%	89,9%	87,4%	86,1%
		50	100,0%	99,6%	98,7%	97,1%	97,1%	95,8%	95,4%	95,0%	93,7%
		75	100,0%	100,0%	99,6%	99,2%	98,3%	98,3%	95,8%	95,4%	94,5%
		100	100,0%	100,0%	99,6%	99,6%	99,2%	98,7%	98,7%	97,9%	95,4%
		150	100,0%	100,0%	100,0%	100,0%	99,6%	99,2%	99,2%	98,3%	97,5%

Source: Own calculations

It is clear that the consumption of the EV plays a key role in the success rate. Similar effect to the consumption parameter has the mentioned real world coefficient, which basically increases the consumption artificially. But when using the fast DC charging during the idle times, the success rate does not drop significantly even for some of the higher consumption rates. Based on the results of these analysis, it is therefore very beneficial and to some degree necessary to include the fast DC charging capabilities in the proposed solution.

4.3.2 Charging Resources Simulation

Next, a similar analysis can be made to calculate the charging resources needed per each route to achieve the desired route distances. The DC charging speed of 100 kW is taken into account here. The ranges remaining without charging R_2 and R_3 are calculated again the same way. When the range remaining is lower than the distance of next route plus the mentioned reserve of 15 km a recharging requirement E_2 and E_3 in kWh is calculated as follows

$$E_2 = (D_2 - R_2 + 15\,) \cdot \frac{C_{rw}}{100} \;\; [kWh], \tag{18}$$

$$E_3 = (D_3 - R_3 + 15\,) \cdot \frac{C_{rw}}{100} \;\; [kWh]. \tag{19}$$

When the range remaining is enough to cover the distance of the following route with the 15 km reserve, the charge requirement is set to zero. These requirements are then calculated for each row of the whole dataset in Table 11.

Table 11 – First 10 rows of the charging resources needed calculations.

						Range remaining without charging		DC Charging needed for successful route		Time needed using DC charger	
Index	**agent name**	**date**	**distance route 1 [km]**	**distance route 2 [km]**	**distance route 3 [km]**	R_2 [km]	R_3 [km]	E_2 [kWh]	E_3 [kWh]	t_2 [min]	t_3 [min]
0	Driver 23	02.01.2023	53,38	84,78	63,03	154,95	70,17	0,0	1,8	0,0	1,1
1	Driver 23	10.01.2023	18,12			190,21	190,21	0,0	0,0	0,0	0,0
2	Driver 23	22.01.2023	12,41			195,92	195,92	0,0	0,0	0,0	0,0
3	Driver 23	28.01.2023	68,09	64,88		140,24	75,36	0,0	0,0	0,0	0,0
4	Driver 17	02.01.2023	33,73	32,74	26,05	174,60	141,86	0,0	0,0	0,0	0,0
5	Driver 17	03.01.2023	21,2	40,54	52,94	187,13	146,59	0,0	0,0	0,0	0,0
6	Driver 17	04.01.2023	68,01	134,38	89,54	140,32	5,94	2,1	22,7	1,3	13,6
7	Driver 17	06.01.2023	54,54	134,16	80,59	153,79	19,63	0,0	17,5	0,0	10,5
8	Driver 17	07.01.2023	50,75	0	16,8	157,58	157,58	0,0	0,0	0,0	0,0
9	Driver 17	09.01.2023	58,04	41,18	46,77	150,29	109,11	0,0	0,0	0,0	0,0
10	Driver 17	10.01.2023	30,2	91,95		178,13	86,18	0,0	0,0	0,0	0,0
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

Source: Company internal data, own calculations

Another view of the recharging resources is the time spent at the fast DC charger during the day. The times needed to recharge the required amount of energy to successfully complete all routes can be calculated as

$$t_2 = \frac{E_2}{CS_{AC}} \cdot 60 \quad [min], \tag{20}$$

$$t_3 = \frac{E_3}{CS_{AC}} \cdot 60 \quad [min]. \tag{21}$$

The results for each row are then again summarized, resulting in a total DC recharging requirements for the period under review, and are shown in the Table 12 below.

Table 12 – Results of DC charging resources needed per month under review.

E_2 [kWh]	E_3 [kWh]	t_2 [min]	t_3 [min]
230,9	**1246,9**	**138,6**	**748,1**
1477,9		**886,7**	

Source: Own calculations

The charging times can then be subjected to another sensitivity analysis, when accounting for different battery capacities and consumptions. The results are shown in Table 13 below.

Table 13 – Sensitivity analysis for total DC charging time required to successfully complete all routes or different EV battery capacities and consumption.

Total DC charging time [min]		Battery capacity - kWh								
		40	45	50	55	60	65	70	75	80
Consumption - kWh/100 km	16	1168	748	458	275	151	76	35	17	6
	17	1503	1012	653	407	249	136	71	35	17
	18	1878	1314	887	575	367	227	125	67	34
	19	2285	1647	1156	784	516	336	207	116	64
	20	2720	2014	1460	1026	700	468	309	189	109
	21	3189	2415	1791	1301	919	631	429	286	174
	22	3684	2836	2152	1606	1167	828	575	397	264
	23	4194	3291	2548	1935	1445	1054	749	528	370
	24	4722	3771	2960	2292	1752	1309	958	687	490

Source: own calculations

As the results indicate, the times spent at DC chargers vary substantially depending on the parameters of EV used. When the battery capacity is large enough, the DC charging times are almost negligible. This is an aspect to consider when possibly upgrading to a new EV model.

4.4 Requirements for Electrification Infrastructure

For the successful implementation of electric vehicles into operation, it is necessary to build the charging station. The chargers will be built on the partner's property and the investment is going to be substantial. Charging stations of private companies are often built as publicly available for a fee to help with the prospect of a faster return on investment. However, in our operation the chargers will be used for private purposes only. While it would be possible to provide charging stations for public use, this would complicate and lengthen the construction process. The process of building charging stations for private use involves less legislative steps and without certain obligations for the operator. In addition, it would not be appropriate to have strangers' cars using public charging stations on a partner's private property where it is very busy around vehicle loading. Mainly, this practice would intensify the main problem, the risk of the charging point being occupied at the time when the car will need to charge to drive the next route.

4.4.1 Process of Charging Stations Construction

There are not as many technical obligations and preparations for the construction of slow AC electric charging stations as for the construction of powerful DC charging stations. If all the construction work and modifications are sorted out, the actual installation of the charging stations takes just two weeks in both AC and DC charging. The whole process starts with finding out the total capacity of the electrical network from the provider that operates in the location. Because the depot is located near the shopping mall area, there should not be a problem and there should be sufficient network amperage capacity. If this were not the case and the consumption of the charging stations exceeded the capacity of the transformer station, it would be necessary to consult the electricity network provider for an increase in the maximum capacity and in any case for permission to connect to the connection. If these steps were agreed with the energy provider at the depot site, the second step would be to start the building permit process. Currently, there is not an established law in the Czech Republic that defines the rules and conditions for the construction of a charging station, so each building authority may have different procedures and conditions. As a rule, however, the entire building permit process will be accelerated and simplified if the construction does not interfere with the supporting structures of the building, doesn't change the appearance of the building, or doesn't require the modification of the electricity connection. After these initial most challenging steps, comes the actual construction work, which is further estimated to require just two weeks.

4.4.2 Selection of Charging Stations

The company fleet of EVs will primarily be primarily charged overnight at AC charging stations, as this type of charging is more battery life considerate than DC charging as well as the purchase price of an AC station being significantly lower. Charging station with a minimum capacity of 11 kW needs to be available for each car, so that it is ready for the upcoming day. In the previous chapter 4.2 EV Operation Requirements it is shown that 94.96 % of the cars would complete the first two routes out of three without needing a recharge, and only 77.31 % of the cars would make it through a full day's mileage without a charge. This implies the need to build fast charging stations as well, so that the cars can recharge the required mileage in the least possible time during idle time. Due to the fact that each car has differently long routes and different number of customers, cars return to the depot continuously at different times. For this reason, it is recommended to build only 1 DC charger, as their cost is significant. In addition, between the second and third routes the need to charge an EV will be higher, and not every car will drive all three routes in a day. Most couriers will end their shift on the second route and so the charging capacity will split into fewer cars to charge at the DC chargers in the most needed time window. In spite of the very low probability of the event that 2 cars have to be charged at the same time, a single DC charger with a power of 150 kW and two charging connectors is proposed. In the case that multiple cars arrive at the charger, it can simultaneously charge 2 cars while splitting its power to 75 kW each.

For overnight charging column AC charging stations with 2x 22 kW are recommended. Although the current recommended car can only receive 11 kW of power via the on-board charger, the technology is rather progressive in this direction and for passenger electric cars the 22 kW on-board charger is a new standard. It is therefore likely that this development will also apply to commercial vehicles and the charging stations will be already prepared for this. It is recommended to purchase 4 such charging stations in total. Four AC charging stations are able to charge up to 8 cars at a time. The total number of charging stations is therefore 5 with a total of 10 charging points. A fleet consisting of a total 10 cars can thus be comfortably charged for the next day. The proposed recharging scheme would be such that the cars that finish their shift after the second route would be recharged at the AC charging stations while the remaining cars are being utilised for the third route. When the last cars from the third rotation return, the charged cars would be parked in conventional parking spaces and the remaining cars would be connected to AC charging. In the case that no car is 100 % charged when the rest of the fleet returns to storage, there is the option to use the free stands at DC charges. Even though DC charging is less battery-life friendly, it would be economically inefficient to acquire the extra 5th AC charging station, as it would sit unoccupied and unused most of the time. The argument of possible scaling of operations for a larger volume of orders and thus the potential need for more cars and more charging stations for charging is very unlikely, because the branch itself and its warehouse have a limited capacity, which is therefore the determining factor of the scalability. Moreover, not even all 10 cars are currently utilized to their full potential. Not all of them are running 3 routes per day and the cargo space of the cars is far from being used fully, as discussed in chapter 4.1 - Current Operation Analysis.

The recommended models of both types of charging stations are from the Czech supplier ChargeUp. The selected type of AC charging station is the Post eVolveT model, which can simultaneously charge 2 cars with a maximum power input of 44 kW, the purchase price of one of these stations is 98 000 CZK excluding VAT. The DC charging model selected is called Raption 150 and can charge 1 car with a maximum power input of up to 150 kW or two cars simultaneously with a power output of 75 kW. The purchase price of this powerful charging station is 985 000 CZK excluding VAT. Furthermore, due to the location of the charging stations, it would be advisable to acquire a dynamic control system for the charging stations, which can distribute the available network power among the actively used chargers. At the same time, it monitors the current consumption to avoid overloading the reserved maximum of the network and a possible subsequent outage.

Figure 7 – Proposed charging stations, AC station on the left and DC station on the right

Source: ChargeUp Services CZ s.r.o. website

The investment in the stand-alone purchase of charging stations for the company's partner amounts to 1,377,000 CZK, excluding VAT. The necessary cables for conducting the electric current then amount to 100 CZK per metre for AC charging and 600 CZK per metre for DC charging. The number of metres required will depend on the distance between the charging station and the transformer station. Because of the significant difference in price per metre, the DC charging station is recommended to be placed as close as possible to the grid connection. In addition, the cost of construction work will be significant and must be taken into account, however it is beyond the scope of this thesis to quantify precisely, as there is vast number of factors that need to be considered.

4.4.3 Public Charging Station Infrastructure

During the period when the AC charging stations at the branch will be built and installed and the DC fast charging stations will still be under construction, the network of publicly available DC charging stations will be used when it is necessary to use fast charging of the electric vehicle between the routes. This alternative solution is proposed mainly for the purpose of implementing EVs in real operation as soon as possible. Due to the longer construction time of fast charging stations and the more complicated process, implementation could be significantly delayed. Because the DC stations are not planned to be the primary source of energy for the EVs, but only as a backup source when the daily milage is longer than the range of a fully charged EV, the use of the public grid should not create significant inconvenience or compromise for the operation. In addition, the area around the selected branch is densely populated with public charging stations, and there is a possibility to charge anywhere around the city on the return to the depot. There is a total of 27 charging points within few km of the branch.

The battery charge status and remaining range would be monitored by dispatchers via the smart MyT app, through which driving data, battery status or the entire car can be monitored remotely from the company's facilities and by the couriers themselves during their shift. This allows dispatchers to efficiently schedule mandatory EV charging breaks while manually intervening in scheduled routes using the software and inserting the break manually. With a volume of 10 cars and one branch, this is manageable manually by a team of dispatchers. In the case of implementing EVs at multiple branches with higher order volumes and car counts, investment would be required to develop software that would schedule the necessary EV charging brakes automatically regardless of the charging location.

The option of using public charging stations runs the risk that the charging points will be occupied at the time of need. According to the vehicle register there were 12,325 passenger electric vehicles registered in 2022, which is roughly 2 % of newly registered cars in the Czech Republic. Currently the percentage of EVs in the CZ is not significant and together with a fairly robust infrastructure of public charging stations the probability of all charging points being occupied is currently very low. Moreover, the locations with charging stations are often located in the shopping centre area. The times at which cars will need to be recharged is between 11am and 1pm, when the majority of the population is at work during the weekdays and not spending time at the malls. Thus, this makes the option of occupied stations even more very unlikely. On the other hand, on weekends when people spend their leisure time in shopping malls the risk of charging points being occupied will be higher. According to [68], people most frequently spend around 90 minutes in shopping malls. Thus, it would be expected that people would be more likely to use AC charging stations at shopping centres, which are primarily designed for these occasions. On the other hand, DC charging stations are mainly used in places like petrol stations where people do not spend too much time. Therefore, it can be expected that AC charging points will be occupied primarily, which would not interfere with our operation, which will exclusively use DC chargers to recharge EVs between routes.

Next, a wider area around the depot, where car loading takes place, is mapped. Table 14 below shows an overview of the charging points mainly with fast charging stations up to 4 km from the depot, where the time to reach the charging point from the depot is about 8 minutes. Public charging points with only the slow AC charging option are not considered here. There are approximately 27 additional public charging locations with only the Type 2 slow charging option in the wider vicinity of the depot.

Table 14 – Overview of the charging points near the depot

Operator	Distance from branch (m)	Type of charger	Maximum input power	Charge points	operating hours
ČEZ	50	Type 2 (Mennekes)	22 kW	9	non-stop
ČEZ	50	CCS Combo	50 kW	8	non-stop
ČEZ	50	CHAdeMO	50 kW	8	non-stop
ČEZ	50	CCS Combo	150 kW	2	non-stop
ČEZ	80	Type 2 (Mennekes)	22 kW	6	09:00-21:00
Transfer Energy	2100	Type 2 (Mennekes)	22 kW	1	non-stop
Transfer Energy	2100	CHAdeMO	63 kW	1	non-stop
Transfer Energy	2100	CCS Combo	75 kW	1	non-stop
E.ON	2700	Type 2 (Mennekes)	43 kW	1	non-stop
E.ON	2700	CHAdeMO	50 kW	1	non-stop
E.ON	2700	CCS Combo	50 kW	1	non-stop
ČEZ	3200	Type 2 (Mennekes)	22 kW	2	non-stop
ČEZ	3200	CHAdeMO	50 kW	2	non-stop
ČEZ	3200	CCS Combo	50 kW	2	non-stop
E.ON	3600	Type 2 (Mennekes)	43 kW	1	non-stop
E.ON	3600	CHAdeMO	50 kW	1	non-stop
E.ON	3600	CCS Combo	50 kW	1	non-stop
PRE	3700	Type 2 (Mennekes)	22 kW	1	non-stop
PRE	3700	CHAdeMO	50 kW	1	non-stop
PRE	3700	CCS Combo	75 kW	1	non-stop
PRE	3900	CCS Combo	75 kW	2	07:00-21:00
PRE	3900	CCS Combo	300 kW	2	07:00-21:00
PRE	3900	CHAdeMO	50 kW	2	07:00-21:00
PRE	3900	Type 2 (Mennekes)	22 kW	1	07:00-21:00
ČEZ	3900	Type 2 (Mennekes)	22 kW	3	non-stop
ČEZ	3900	CHAdeMO	50 kW	3	non-stop
ČEZ	3900	CCS Combo	50 kW	3	non-stop
ČEZ	3900	CCS Combo	150 kW	1	non-stop
ČEZ	3900	CCS Combo	300 kW	1	non-stop

Source: Map of charging stations [69]

In the immediate vicinity of the mall area, there are 10 CCS Combo fast-charging points next to the depot, which support the selected Toyota model. There are also 8 DC charging points of the CHAdeMO type and 9 slow charging points of the Type 2 type in the same location. In addition, 6 of Type 2 slow charging points are reserved in the underground parking garage. These chargers are not restricted by any opening hours and are therefore accessible non-stop without the need for staff. Additional Type 2 AC chargers located in the underground garage are limited to use during mall opening hours. The operator of the charging stations at the depot site is ČEZ, s.r.o.. There is a total of 69 additional charging points in 9 locations within a 4 km radius of the depot, of which 25 are for slow type 2 charging and 44 for DC fast charging. Of the 44 total points, the recommended Proace city EV is only compatible with CCS Combo charging points, which are more common around the depot, so it is capable of charging at 25 charging points. Despite the fact that superchargers of up to 300 kW can be found in the area, thus charging a car in a matter of minutes comparable to refuelling a car with an internal combustion engine, the selected model is only capable of receiving 100 kW of power. There are 2 DC charging points capable of 150kW in the mall area, which can charge the Toyota Proace city EV to 80 % in 30 minutes. If these charging points were occupied, it would depend on the current order load whether the vehicle could afford to charge on a 50 kW DC charger, which would take approximately 50 minutes to charge to 80 %. If the car had to be back available as soon as possible it is preferable to find another DC charger with a minimum 100 kW capacity nearby.

4.4.4 Price of Charging at Public Stations

In the shopping mall area where our partner's depot is located, there are charging stations from the supplier ČEZ, which is the largest distributor of charging stations in the Czech Republic. This supplier together with others is increasingly utilizing the term roaming charging station This means that if you hold a chip from one of the suppliers, you can charge your car at a station operated by another company. So all you need is one chip and you can charge your car anywhere, plus the billing is simpler because you only pay to one supplier. Of course, there are advantages and disadvantages to everything, and there is a price to pay for simplicity. It costs more to charge at foreign station other than the suppliers home station as the rate per kW is higher. For this reason, most electric vehicle owners are registered with multiple suppliers and thus own multiple chips in order to charge the car at the most affordable price possible. Roaming charging is therefore used in extreme situations as an emergency solution, which customers can use with the three largest charging station providers - CEZ, PRE and E.ON, as it tends to be at the highest rate. The tables below compare the 3 dominant distributors in the Czech Republic. HPC (High Power Charging) prices are for charging with a capacity greater than 150 kW and are with the most expensive tariff. The prices are without VAT. At the charging stations, one can pay with the mentioned chip, a conventional credit card and in some cases via a mobile app.

Table 15 – Overview of the ČEZ distributor pricing.

ČEZ				
type of charging	Type of station	CZK/kWh Without VAT	Number of free minutes	CZK/minute Without VAT
AC	own and partner station - Kaufland	4,88	480	1,65
	own and partner station	6,61	480	1,65
	NON-registered costumer	8,26	480	1,65
	Roaming station	9,09	480	1,65
DC	own and partner station	10,74	90	1,65
	NON-registered costumer	12,4	90	1,65
	Roaming station	13,22	90	1,65
HPC	own and partner station	14,88	45	1,65
	NON-registered costumer	16,53	45	1,65
	Roaming station	18,18	45	1,65

Source: ČEZ website [70]

The ČEZ distributor has the best prices at Kaufland partner stations and is the only one with a single roaming tariff, so as a registered customer with CEZ, you pay one price at other stations. In contrast, the distributor E.ON has different roaming tariffs for each distributor it has signed contracts with.

Table 16 – Overview of the E.ON distributor pricing.

E.ON				
type of charging	Type of station	CZK/kWh Without VAT	Number of free minutes	CZK/minute Without VAT
AC	Registered costumer	8,26	480	1,65
	NON-registered costumer	9,92	480	1,65
DC	Registered costumer	10,33	90	1,65
	NON-registered costumer	12,39	90	1,65
HPC	Registered costumer	14,05	45	1,65
	NON-registered costumer	15,7	45	1,65

Source: E.ON website [71]

ČEZ and E.ON have a similar system of tariffs compared to PRE. Depending on the type of AC/DC/HPC charging, you have a certain number of free minutes during which the customer pays only the kWh rate. After these minutes, which are more than sufficient for a full charge, are exhausted, the customer starts paying the second rate for each additional minute at the charging station. These tariffs serve to keep people from blocking spots for other customers once they have charged their car.

Table 17 – Overview of the PRE distributor pricing

** Tariff 1 CZK/minute charged after first 240 minutes free*

PRE			
type of charging	Type of station	CZK/kWh Without VAT	CZK/minute Without VAT
AC	partner station - ČSOB	4,44	-
	PRE customer	6,61	0,41
	non-PRE customer	7,44	0,83
DC	partner station - ČSOB	4,44	1*
	PRE customer	9,09	0,83
	non-PRE customer	9,91	1,65
HPC	PRE customer	10,74	1,65
	non-PRE customer	11,57	1,65

Source: PRE website [72]

In contrast, at PRE distributor charging stations, the customer pays both the kWh rate and the per-minute rate from the beginning, with the exception of ČSOB partner charging stations, where AC charging is unlimited and DC charging is charged at the per-minute rate only after 240 minutes, while DC charging takes only tens of minutes to recharge the electric vehicle.

The following table compares rates for charging the Toyota Proace City EV at public charging stations. It is proposed to use the public network until the company builds its own charging station facilities and fast charging capability. Primarily DC chargers will be used, the construction process of which is more complex and time-consuming, but comparisons are calculated for all charging options. The number of minutes is the estimated time required to recharge an electric car to 80 %. The battery capacity is therefore reduced to 40 kWh and divided by the power of the charging station. The minutes expressed here are needed to quantify the cost of the PRE distributor, which price for recharging the electric car is of two components, the price per kW and the price for each minute of charging the car. The ČEZ and E.ON distributors offer free minutes and only after they have expired, the tariff per minute is added to the fixed component per kW. The time required to charge a car to 80 % at public stations is such that for these two suppliers only the rate per kW is charged. The rates per kW considered are for registered customers without discounted tariffs at partner sites.

Table 18 – Prices for 80 % battery charge of selected EV model using public chargers.

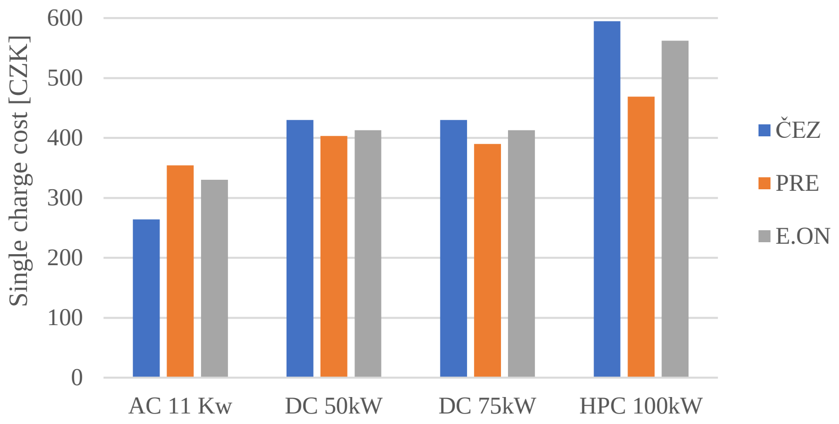
			ČEZ	**PRE**	**E.ON**
Charging type		Time (minutes)	Price (CZK)		
AC	11 kW	218	**264**	354	330
DC	50 kW	48	430	403	413
	75 kW	32		**390**	
HPC	150 kW	24	595	**469**	562
	300 kW	24			

Source: own calculations

The selected duration for AC charging is the time it takes to charge the car to 80 % with an on-board charger with power of 11 kW. For DC charging stations, the time is calculated for 50 kW and 75 kW. For HCP charging stations that are up to 300 kW in the immediate vicinity of the depot, the charging time is estimated according to the maximum possible battery power, which is 100 kW for the recommended model, regardless of the more powerful charging station. Despite the fact that Toyota states that the Proace City EV will charge to 80 % on DC charging in 30 minutes, the calculated estimate of time is 24 minutes using the charging speed and battery capacity. The values given by the manufacturer therefore vary slightly, probably due to possible thermal throttling and other factors, that may prolong the charging cycle. The times are only indicative because the customer will not arrive at the stand with a 0 % discharged EV, so this is considered the most pessimistic scenario with the maximum possible time spent at the charging station. The 80 % threshold is chosen because it is not possible to charge the EV at maximum power to the full capacity. In order to maximize the battery lifetime and limit battery heating, the power is gradually reduced along the so-called charging curve. The charging efficiency starts to drop rapidly when 80 % is reached and the remaining 20 % takes a very long time to charge due to the lowering charging power.

As shown in Table 18 as well as in Graph 5 PRE appears to be the most economically feasible electricity distributor for charging an electric vehicle at a public station. With the exception of AC charging, for which CEZ has the most favourable prices, PRE has the most favourable rates for other types of charging. The result may be surprising in that PRE is the only company that also charges for the time spent at the charging point when charging an EV, so at first glance this company appeared to be the least favourable, but the opposite is true. CEZ as the largest representative in the number of charging stations across the Czech Republic has the highest rates per kW except for AC charging. E.ON as the third largest distributor of charging stations is between CEZ and PRE with its prices. When recharging an electric car to 80 % at an HCP charging station from PRE, it costs 4690, while at E.ON the customer pays 930 more and at CEZ even 1260 more.

Graph 5 – Comparison of single charge cost for different distributors and charging modes.



Source: websites of electricity supplliers, custom editing

Because EVs will use the public charging infrastructure primarily for fast charging at HCP stations, it would be advisable to charge the car on the way from the last customer and not primarily near the warehouse where the charging stations from the CEZ provider are. With EVs being driven all over Prague there is a high chance of recharging at a better rate. PRE, the company with the most favourable HCP charging tariff, has a total of up to 242 charging stations throughout Prague, including 37 charging stations with a capacity greater than 50 kW and 9 HCP charging stations with a capacity of 150 kW or more. E.ON has a total of 32 charging stations throughout Prague, none of which have a capacity of more than 100 kW. ČEZ has a total of 127 charging stations throughout Prague, of which 83 are DC chargers with a capacity of more than 50 kW and 7 charging stations with a capacity of 150 kW or more. Despite the fact that ČEZ has the largest network of electric chargers in the capital city, PRE dominates with up to 2 times the number of stations in the Czech Republic.

4.4.5 Transformation Phases Plan

The transition from the current fleet to an EV fleet is planned in two phases, depending on the termination of the lease contracts of the current diesel cars. The lease contracts are concluded for 36 months, with the first 6 cars expiring in March 2024, and the next 4 cars four months later, in July 2024. The planned implementation of the electric fleet is therefore based on March 2024. Earlier implementation does not make economic sense, because the early termination of the lease contracts involves a financial penalty. In addition, the partner gets enough time for the building permit process and the construction of the charging stations. Estimated construction of AC charging stations including building permits is between 3-6 months. For DC charging stations, the entire process can take up to one year. For this reason, it is necessary to take into account the use of the public charging station network, which was considered for this purpose in the previous chapter. The Gantt chart below shows the detailed timetable for each activity.

Figure 8 – Gantt chart for the transformation phases plan.

Transition to Green Mobility

ACTIVITY	START	DURATION (months)	PERIOD																		
			03/23	04/23	05/23	06/23	07/23	08/23	09/23	10/23	11/23	12/23	01/24	02/24	03/24	04/24	05/24	06/24	07/24	08/24	09/24
Cooperation with Energy Supplier	03/23	7																			
Cooperation with the Charging Stations Provider	04/23	7																			
Construction Permition AC	05/23	6																			
Construction Permition DC	05/23	13																			
Construction work AC	11/23	3																			
Construction work DC	06/24	2																			
Installing AC Chargers	01/24	2																			
Installing DC Chargers	07/24	2																			
Phase 1 Ordering Electric Cars	10/23	1																			
Phase 2 Ordering Electric Cars	02/24	1																			
EVs Delivery	03/24	2																			
Fully Electrified Branch	07/24	-																			

Source: custom editing

The first step in the whole process is a business meeting with the energy supplier at the location of the charging stations. The aim of the meeting is to establish the maximum capacity of the network and, if necessary, to facilitate an increase. Also, the location of the connection where all the cables will be routed must be clarified and therefore this information is needed for the subsequent building permit. At the same time, during the ongoing negotiations with the energy supplier, meetings with the supplier of the charging stations will also begin, discussing the technical needs of the selected stations and the wattage needed for operation. Once all the needs have been determined, the building permit process and necessary legislative steps can begin. In the case of AC chargers, the average processing time for construction permits is around 3 months, the Gantt chart shows a time of 6 months, so there is sufficient room in case of complications or possible delays. In the case of DC charging stations, the time can be significantly longer, up to one year.

The construction work itself is divided into two phases, the first for the preparation of the AC charging stations and the second for the DC charging. In the case of AC chargers, the construction work is longer for two reasons. AC charging stations are built at a greater distance than DC charging due to the cost of cables. It is also due to the larger number of AC charging stations. The actual construction work is mainly running cables to the power station and constructing parking spaces at the pole stations. For DC charging, the construction work will be on a smaller scale and, for example, the parking space and the preparation for connecting the station will be pre-prepared from the previous phase. The actual installation of the charging stations takes within two weeks. The ordering of electric cars is also being carried out in two phases, the time required for the leasing company is half a year. For the first existing cars at the branch, whose contract expires in March 2024, the first wave of cars needs to be ordered in October 2022. Ordering cars earlier is economically disadvantageous, as the cars would accumulate at the depot and the company would pay the lease for both the existing fleet of cars and the newly ordered electric cars. The lease for the second phase of cars expires in July 2024. The leasing company is bound by the delivery time and therefore if it fails to meet it, the Company would not pay penalties for exceeding the contracted miles on the existing fleet or for extending the contract. As the Gant Charter shows, complete electrification from a vehicle perspective will take place before the installation of DC charging stations. This should not jeopardize the operation as it is crucial for logistical reasons to have its own AC chargers. It all depends on the length of the building permit process, which is shown in the graph with a pessimistic view and assumes a large time margin. In the event of construction issues, or the building permit itself, where the whole process will be extended despite the projected margins, cars will be charged at public charging stations even for overnight AC charging. Also for this case a cost model is calculated in the following chapter. In case there is no problem and the building permit process goes smoothly, construction work will start earlier and the private charging station infrastructure will be ready by the time of the transition. This step is very difficult to estimate, because the Czech Republic does not have clearly defined legislative procedures and rules for such cases.

4.5 Financial Aspect of EV Operation

The motivation to switch to electromobility at the selected branch is on both sides. The partner has committed to carbon-neutral transport by 2030 in its annual reports, and the logistics company, as a major player on the Czech market in last-mile logistics, has to adapt to the needs of partners who increasingly demand clean mobility. The investment in the electrification of the branch is therefore split between the two parties. The partner investing in the construction of a private network of charging stations on the property of the depot, where the warehouse and loading takes place, whereas the logistics company will provide the electric cars and their operation. The costs analysis of charging infrastructure was outlined in the previous chapter, and in this chapter the focus is switched to the costs of the EV operation itself.

4.5.1 Comparison of Monthly Operating Costs

The monthly cost consists of a fixed part, which is a monthly payment per vehicle referred to as the leasing, and a variable part, which is derived from the running costs of the vehicle. Monthly costs of the ICEV diesel vehicles are compared with three EV operation scenarios. First, utilisation of EVs fully dependant on the public charging stations, utilisation of EVs charged overnight at private AC chargers and during the day using public DC chargers, utilisation of EVs charged only using private charging stations.

The inputs for this comparison are shown in Table 19. For the EV case 1 the prices for kWh are deducted from the chapter 4.4.4 Price of Charging at Public Stations as the lowest prices offered by the PRE supplier. For the EV case the DC charging price stays the same, however the AC charging price is now obtained from the price list of the electricity suppliers. For this application the suppliers offer a special tariff called C27d, which is specifically designed for the use of EV overnight slow charging. Again, the lowest offer is considered, which is offered by ČEZ supplier. Finally, for the third EV case the DC charging price is then obtained similarly using the supplier’s pricelist, however the reduced tariff cannot be used for DC charging anymore. It is important to note that these prices for the private charging are only an estimate, as the exact numbers are defined based on the negotiated contract with the supplier, which accounts for many factors.

Table 19 – Input parameters for the operation cost analysis

Input Parameters			
EV CASE 1 - Public Charging Infrastructure			
P_{1AC}	AC charging price	6,61	CZK/kWh
P_{1DC}	DC charging price	10,74	CZK/kWh
C_{EV}	Consumption	23	kWh/100km
L_{EV}	Leasing	26 392	CZK/month
EV CASE 2 - Private AC Charging and DC Public Charging			
P_{2AC}	AC charging price	5,32	CZK/kWh
P_{2AC}	DC charging price	10,74	CZK/kWh
C_{EV}	Consumption	23	kWh/100km
L_{EV}	Leasing	26 392	CZK/month
EV CASE 3 - Private Charging Infrastructure			
P_{3AC}	AC charging price	5,32	CZK/kWh
P_{3AC}	DC charging price	6,88	CZK/kWh
C_{EV}	Consumption	23	kWh/100km
L_{EV}	Leasing	26 392	CZK/month
ICEV CASE			
P_{ICEV}	Diesel price	28,84	CZK/litre
C_{ICEV}	Consumption	7,5	litre/100km
L_{ICEV}	Leasing	23 664	CZK/month

R_t	Milage per the whole fleet	47632	km / month
R_{DC}	Milage needed on DC charge per the whole fleet	9396	km / month
n_C	Number of cars	10	

Source: Company internal data

For the ICEV case, the inputs are derived from the current operation averages acquired from data available for the period of January 2023 used previously. The seemingly low diesel price is due to a long-term contract with the supplier as well as the price not including VAT. On the other hand, the consumption of diesel is relatively high, much higher than the manufacturer specifies. This is mostly caused by its ineffective operation in city traffic as well as by the winter season, which not only implies the use of winter tires, but the frequent cold starts of the diesel engines deteriorate the consumption average significantly. Another key parameter is the monthly milage, which is obtained from the same period, and finally the milage needed to be covered on DC charge is calculated based on the simulation analysis performed in the chapter 4.3 Simulation of EV Operation.

The input parameters and subsequent calculations do not include the couriers' pay and working time, due to the fact that the charging takes place between routes during idle times, which are already included in the couriers' financial rewards for the whole shift. Therefore, with the electrification of the branch, there is no need to intervene in the extension of shifts and the associated increase in courier rewards.

The total cost of EV operation is calculated for all cases as

$$TC_{EV1} = \left(L_{EV} + \frac{P_{1AC} \cdot C_{EV} \cdot (R_t - R_{DC})}{100} + \frac{P_{1DC} \cdot C_{EV} \cdot R_{DC}}{100}\right) \cdot n_C \quad [CZK], \tag{22}$$

$$TC_{EV2} = \left(L_{EV} + \frac{P_{2AC} \cdot C_{EV} \cdot (R_t - R_{DC})}{100} + \frac{P_{2DC} \cdot C_{EV} \cdot R_{DC}}{100}\right) \cdot n_C \quad [CZK], \tag{23}$$

$$TC_{EV3} = \left(L_{EV} + \frac{P_{3AC} \cdot C_{EV} \cdot (R_t - R_{DC})}{100} + \frac{P_{3DC} \cdot C_{EV} \cdot R_{DC}}{100}\right) \cdot n_C \quad [CZK], \tag{24}$$

And the total cost of current ICEV operation is calculated as

$$TC_{ICEV} = \left(L_{ICEV} + \frac{P_{ICEV} \cdot C_{ICEV} \cdot R_t}{100}\right) \cdot n_C \quad [CZK]. \tag{25}$$

The results are then shown in the Table 20 as well as the total cost savings, which are calculated by comparing each EV case to the original ICEV case.

Table 20 – Results of the operation cost analysis

	Total cost CZK/month		**Total cost saving CZK/month**	
ICEV Case	TC_{ICEV}	339 669		
EV Case 1	TC_{EV1}	345 261	$TC_{ICEV} - TC_{EV1}$	-5 592
EV Case 2	TC_{EV2}	333 929	$TC_{ICEV} - TC_{EV2}$	5 740
EV Case 3	TC_{EV3}	325 586	$TC_{ICEV} - TC_{EV3}$	14 083

Source: own calculations

For set input parameters, the first EV case costs are actually higher than the for the ICEV case. However as shown in the Gantt chart in Figure 8, this case is not likely to occur. The EV case 2, which is likely to take place for the first couple months of the transition, exhibits slight positive savings. This scenario should take place from the beginning of the implementation of the EVs, when AC chargers are already built and used and DC charging is provided by the public charging infrastructure, since the approval process for building permits for chargers of this capacity is expected to take longer. The final EV case 3 demonstrates the ideal situation where cars are only charged at private charging stations. Even though leasing electric cars are more expensive, the actual operation of the electric car is more economical, making case 3 exhibit substantial savings, which amount to 168 996 CZK per year. This is significant cost saving in context of the branch size and its profits. This is a very important conclusion for the company, showing the operation of EVs is economically viable and sensible.

4.5.2 Sensitivity Analysis of Monthly Costs

The total monthly savings for the final EV transformation case are subjected to sensitivity analysis for different diesel and electricity prices as shown in Table 21. The electricity prices are considered as for the C27d tariff used for AC charging, and so the DC prices are adjusted accordingly to give the final results.

Table 21 – Sensitivity analysis of monthly savings for different diesel and electricity prices.

EV CASE 3 Savings CZK/month		Diesel prices - CZK/litre (without VAT)								
		26	28	30	32	34	36	38	40	42
Electricity prices - CZK/kWh (without VAT)	1	54 014	61 159	68 304	75 449	82 593	89 738	96 883	104 028	111 173
	2	42 425	49 570	56 715	63 859	71 004	78 149	85 294	92 439	99 584
	3	30 836	37 981	45 125	52 270	59 415	66 560	73 705	80 850	87 995
	4	19 247	26 391	33 536	40 681	47 826	54 971	62 116	69 261	76 405
	5	7 657	14 802	21 947	29 092	36 237	43 382	50 527	57 671	64 816
	6	-3 932	3 213	10 358	17 503	24 648	31 793	38 937	46 082	53 227
	7	-15 521	-8 376	-1 231	5 914	13 058	20 203	27 348	34 493	41 638
	8	-27 110	-19 965	-12 820	-5 676	1 469	8 614	15 759	22 904	30 049
	9	-38 699	-31 554	-24 410	-17 265	-10 120	-2 975	4 170	11 315	18 460
	10	-50 288	-43 144	-35 999	-28 854	-21 709	-14 564	-7 419	-274	6 870
	11	-61 878	-54 733	-47 588	-40 443	-33 298	-26 153	-19 008	-11 864	-4 719
	12	-73 467	-66 322	-59 177	-52 032	-44 887	-37 742	-30 598	-23 453	-16 308
	13	-85 056	-77 911	-70 766	-63 621	-56 476	-49 332	-42 187	-35 042	-27 897

Source: own calculations

The result for example shows, that if the price of diesel were to be reduced to 26 CZK/litre at current electricity prices, with the rate of 5.32 CZK/kWh for AC charging, it would make the operation of the EVs still profitable. However, the opposite is rather expected in the future, due to the limited oil supplies, indicating seemingly good prospects for the EV case.

4.5.3 Comparison of Operating Costs per Kilometre

A frequently used metric used to evaluate operation costs is cost per km. This can be obtained by dividing the total costs by the number of cars and by the monthly milage. For the EV cases it is thus determined as

$$KC_{EV1} = \frac{TC_{EV2}}{n_C \cdot R_t} \; [CZK/km] \, , \tag{26}$$

$$KC_{EV2} = \frac{TC_{EV2}}{n_C \cdot R_t} \; [CZK/km] \, , \tag{27}$$

$$KC_{EV3} = \frac{TC_{EV3}}{n_C \cdot R_t} \; [CZK/km] \, , \tag{28}$$

while for the ICEV case as

$$KC_{ICEV} = \frac{TC_{ICEV}}{n_C \cdot R_t} \; [CZK/km] \, . \tag{29}$$

The results again summarised and shown in Table 22.

Table 22 – Results of the operation cost per kilometre analysis.

	Cost per kilometre CZK/km		**Kilometre cost saving CZK/km**	
ICEV Case	KC_{ICEV}	7.13		
EV Case 1	KC_{EV1}	7.25	$KC_{ICEV} - KC_{EV1}$	-0,117
EV Case 2	KC_{EV2}	7.01	$KC_{ICEV} - KC_{EV2}$	0,120
EV Case 3	KC_{EV3}	6.84	$KC_{ICEV} - KC_{EV3}$	0,296

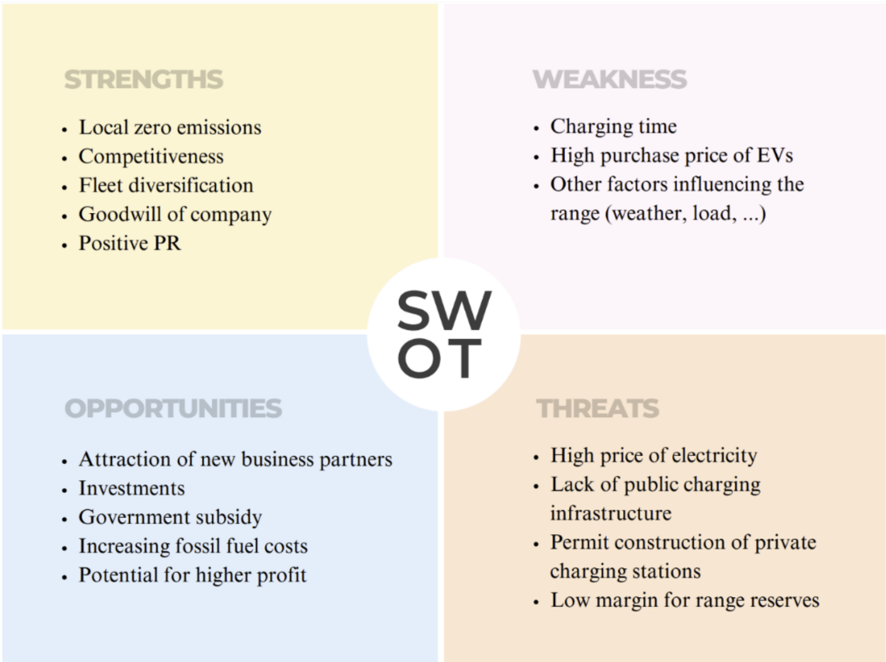
Source: own calculations

In the case 1, an electric car costs 0.117 CZK more to run than a diesel car. From this we can conclude that investing in your own charging stations is essential. In the case of private charging stations, the situation is reversed and the price per kilometre for an electric car is more favourable compared to a diesel car.

4.6 SWOT Analysis

A SWOT analysis for the transformation of the current ICEV fleet to EVs is shown and described below. From an environmental point of view, the biggest strength is considered to be zero CO2 production in the location of vehicle utilisation, i.e. the city centre, where the situation regarding the concentration of pollutants is the worst, and a growing integration of electric vehicles into traffic should improve the situation.

Figure 9 – SWOT Analysis of EV operation



Source: custom editing

Another strength of the transition to electromobility is that the company continues to be competitive. The largest competitor has had fully electrified cars in its operations for some time. Some partners have asked about the possibilities of emission-free transport during meetings, so this step forward seems inevitable for the firm's survival. The company experienced the importance of fleet diversification in early 2022, when fuel prices, particularly CNG, skyrocketed as a result of the Russian invasion of Ukraine. At that time, most of the fleet was CNG-powered, including the partner used to demonstrate the transition to electromobility. For this reason, a large percentage of the fleet switched to diesel cars because the cost of diesel, despite its astronomical prices, was not as high as CNG. Because of this uncertainty of future fuel prices, it is worth investing in fleet diversification. Goodwill of the company with a clear sign of environmental concern will strengthen the company's position in the market. Closely related to this is positive PR, thanks to which the company can attract not only new potential customers but also, for example, investors and build reputations.

Among the new opportunities thanks to the implementation of electromobility are, for example, appealing to new partners, customers or investors. It also opens up the possibility of support from the government, which by its commitments to the European Union will have to support the development of electromobility not only among private individuals. Among the opportunities there is as well the volatile market with fuel prices and further rapid increases, making electromobility more favourable in the future.

One of the weaknesses of electromobility is the time spent at charging stations. Despite all the technological developments and the expansion of the network and super chargers that can charge a car in minutes, this is still the most perceived downside of electromobility by the general public. This is because despite powerful superchargers, most cars cannot handle such power. The maximum battery capacity of personal electric cars is significantly higher than that of, for example, light commercial vehicles. Another downside of electro-mobility is the purchase price of the vehicles, which in turn is reflected in the operational leasing that the company prefers. Even though the difference between the purchase price of an electric car and an internal combustion engine car of the same class has narrowed in recent years, the difference is still more than not insignificant. This is despite the fact that some car companies receive subsidies from the government for the production of electric cars, such as in Germany. Furthermore, a widely speculated disadvantage of electromobility is the range on a fully charged battery. Thanks to the uniform WLT methodology, the ranges presented by the automotive manufacturers are realistic, but still assuming ideal conditions. It is variable factors such as weather, driving style or altitude difference that can significantly affect the battery range, by as much as half.

The biggest threat to the whole transformation to electromobility for the operation itself is the high price of electricity per kWh or translated into a higher price per kilometre than diesel or petrol. At that point, costs would increase and thus profits would decrease. Another threat is the lack of charging station infrastructure. The Czech Republic has plans to invest in expanding the infrastructure, especially fast charging stations, but such construction will take several years. Although the operation is planned to use private charging stations, the public network will initially need to be connected, especially DC chargers between routes during the day. There is therefore some risk of inadequate infrastructure and hence charging station occupancy.

Closely related to this problem is the threat of a long duration of construction permits for the construction of a private charging network. For AC charging stations, planning permission should not be an issue given their capacity. Whereas for DC chargers, it will be a more complicated process that may bring a lot of roadblocks and thus delay the building permit significantly. Fortunately, a situation where cars would have to charge at public charging stations should not be cost threatening to operations, rather it is logistically unsustainable in the long run. Finally, there is a threat of running out of range during operation, which is much higher for EVs due to generally lower margins of range reserves, with which the vehicles return for charging. If frequent shutdowns are experienced, it would certainly damage the company's reputation.

5 Results and Discussion

The conducted research shows that the use of electric vehicles is less damaging to the environment than the operation of cars with internal combustion engines, when including all life cycle factors (life cycle emissions). In the case of electric vehicles, emissions are mainly generated by the production, disposal or recycling of batteries and the proportion of the energy mix used to generate electricity. A survey was carried out in the USA during which the share of renewables in the energy mix was 19.65 %. Despite this, the annual carbon footprint of an electric car is almost 5 times smaller than that of an internal combustion engine. In the Czech Republic, the share of renewables was 17.7 % in 2021, meaning that EVs certainly meet the objective of reducing emissions and can be a step towards a solution of the environmental crisis. State support for the construction of photovoltaic power plants could further improve the situation. Overall, the state is trying to encourage the expansion of electromobility to meet its commitments, although not through direct subsidies for the purchase of a car as in other EU countries. The Czech Republic has allocated subsidies for the expansion of fast charging stations in the public infrastructure and has also set aside funds for individuals to receive subsidies for the construction of home charging stations. A proposal has also been submitted to unify the procedure and rules for the construction of electric charging stations, which the Czech Republic currently does not have. This presents one of the biggest risks for all companies, as each building authority has different procedures and requirements for granting a building permit. For this reason, a large percentage of companies may delay their transition to electromobility. Given the number of EVs in the Czech Republic, the infrastructure is currently oversized and sufficient. The state foresees up to a quarter of a million electric cars on the road by 2030, despite this, it seems that the infrastructure of charging stations is not and will not be an obstacle to the development of electromobility in the Czech Republic. Also, thanks to technological advances in supercharging, the time it takes to recharge an electric car is approaching the same time spent refuelling. This phenomenon is confirmed in the McKinsey company investigation [73], where the Tesla's network of superchargers is discussed. In the USA it covers 99.96 % of the area with their stations, where their models are charged in minutes. Furthermore, the types of alternative propulsion systems offered by the current market were presented in the research. To meet the partner's requirements, the only type that entirely eliminates the use of an internal combustion engine, the battery electric vehicle, was selected. This is because it is the only model that guarantees and fulfils the condition of zero direct (local) emissions, which is so much in demand in city centres. The range of electric light commercial vehicles on the current market is already quite wide. Based on the results of the multi-criteria analysis, a Toyota ProAce city EV was recommended for the needs of the current operation. Price was identified as the parameter with the greatest weight, followed by range and consumption, which were one of the best for this model.

Furthermore, baseline statistical analysis of real-world data from the operation of the selected partner in the e-grocery segment was performed. Range seems to be the most discussed topic regarding EVs. The longest route during the period under review was 178.72 km, which was more of an exception on days with lower order volume and less efficient route planning. The most frequent length of a single route was 106 km and the average length was only 57.46 km. Even when considering the maximum, the selected EV model with very pessimistically adjusted range of 208 km will have no need to recharge the car during routes. This baseline analysis therefore demonstrated the feasibility of electromobility at the selected branch, as there is no need for investment on the part of the logistics company to develop software that would have to create pauses during the routes. In addition, given the segment in which the EVs will be implemented, such a solution would also cause considerable difficulties for the operation itself, where there would be a risk of non-compliance with the temperature chain due to pauses to recharge the EV, especially in the summer months.

However, recharging EVs after the end of routes would be necessary to reliably cover all the daily mileage. A simulation using selected EV model was performed on the current operation data and showed, that nearly 95 % of the cars in the study period would have completed the first and second route without the need for charging in between, However, only 77.3 % of the cars in the study period would complete all three routes throughout the day successfully without charging. It is therefore necessary to incorporate charging into the idle times of the vehicles. In the case of using AC charging in the times between the routes 98.3 % of cars would have completed the second route and less than 87.4 % would have completed all three routes. If a fast 100 kW DC charger is used for the idle time charging, 100 % of the cars in the studied monthly period would successfully complete all three routes. This clearly shows the importance and of a powerful DC charging system, while being much more expensive. There is of course the question of what each company is willing to invest in the EV transition. Benefits such as competitive ability, increased prestige and reaching even more demanding customers are among the harder to quantify parameters. The partner decided to go down the route of building its own charging infrastructure for the selected branch, which means a significantly higher investment due to the purchase price of a DC charger compared to AC charging stations. But as demonstrated, it is essential for the seamless transition.

In its January 2023 survey [73], McKinsey company reports that nearly 50 % of logistics companies confirmed the use public charging infrastructure to accelerate the transition to electromobility. This option was also considered and public charging infrastructure in the near vicinity of the selected branch was mapped. Multiple cost models were evaluated regarding the costs associated with recharging on public and private charging stations. A cost model with full use of the public network of charging stations, including night-time AC charging and DC charging during the day, was the only one with a higher total cost per month compared to cars with an internal combustion engine. This result is obtained using the lowest electricity rates offered at public charging stations. For slow AC charging, it is most profitable to recharge at ČEZ supplier's stands, while the tariffs for fast charging of DC and HPC stands are the most favourable for PRE supplier. Its rates per kWh are lower by 5.8 CZK/kWh than for ČEZ. The overall costs for electric operation are 5,592 CZK per month higher for the whole fleet of 10 cars in comparison to current diesel cars. However, it is important to mention that the partner has currently contracted for lower prices for fuel than the general public at affiliated gas stations. This option is not out of the question even for usage of public charging stations, so there is potential for more favourable prices per kWh. How much, if at all, suppliers would be willing to discuss the kWh rate at public charging stations, when there is a steady and certain uptake of a certain number of cars, could influence the results of financial analysis and the whole perception of the need for the construction of own private charging stations could be revised.

In the second cost model case, when using publicly available stations only for DC charging and using private AC chargers during overnight charging, the EV operation shows savings of CZK 5,740 per month compared to ICEVs in terms of operating costs. This saving is mainly achieved thanks to the special D27d program, which allows cheap overnight charging at a discounted rate for up to 8 hours, which is sufficient to recharge the EV via the on-board charger for the next day. For this case the cost per kilometre differs by 0.120 CZK/km in favour of the electric cars. This result is confirmed by the McKinsey study, which claims that a light electric commercial vehicle has 13 % lower costs than a diesel competitor. With today's electricity and diesel prices, charging at full private charging stations comes out as the most optimal option. For this case, electric vehicles are more profitable on total operating costs by 14 083 CZK per month for the fleet of 10 cars at the selected branch. This would mean an increase in profit in one year by 168,996 CZK.

However, the whole cost model is based on currently unstable variables, with fuel prices fluctuating not only as a result of the Russian invasion, but also due to the covid-19 pandemic. The price of electricity has also risen significantly in recent years due to increased global demand following the end of the lockdowns associated with the pandemic. Among the fastest rising commodity prices is gas, the price of which has risen by an average of 30 %, representing an important input commodity for electricity generation. It is therefore clear that these fluctuations are bound to have an impact on the final price per kW, and the world is thus experiencing an energy crisis. On the other hand, oil is facing a major setback these days thanks to the drive towards carbon neutrality that many countries have committed to under the Green Deal. The trend in fleets going electric is confirmed by the McKinsey study, which states that more than 50 % of companies surveyed plan to fully decarbonise their fleets by 2027. Moreover, oil prices are expected to rise in the future due to thinning oil reserves and more costly extraction. Thus, oil is expected to grow faster than electricity in the future. As shown in the sensitivity analysis, the savings for operating electric vehicles could be much more significant in this scenario. In addition to the economic benefits, the market research carried out by the McKinsey study of light commercial vehicle utilisation confirms the improved brand value and environmental benefits.

6 Conclusion

The research shows, that when the correct energy mix and modern battery technologies are used, electric vehicles produce less CO_2 emissions over their entire life cycle than cars with internal combustion engines, and therefore appear to be a good step towards environmental sustainability of transportation. Considerable negatives such as the lack of charging station infrastructure, the length of recharging and the range on full charge, which are associated with electric mobility, have been refuted for this example of electric vehicle deployment. The Czech Republic has a dense network of public charging stations, yet it is one of the worst countries in terms of the number of registered EVs compared to EU Member States. This may be due to the lack of support for the development of electromobility and indirect subsidies for the acquisition of electric vehicles, except for state-owned enterprises. Thanks to advancing technologies, EVs are able to charge within a few tens of minutes at ultra-fast charging stations. At the same time, the range of the vehicles is nowadays sufficient to maintain the set processes in the selected operation without any adjustments or significant interventions. This implies that electric operation is feasible in the current workload condition and proves the relevance of using electric vehicles not only in the last mail delivery segment, but in urban traffic in general, where CO_2 concentrations are highest. The results of studies performed in the practical part clearly demonstrate not only the viability of EVs at the selected branch but also the significant savings in operating costs assuming the use of private charging stations. The increased profit enables the repayment of costly investments in the construction of charging stations. However, in this specific case, the investment associated with the construction of the charging stations will be very likely covered by the partner. The key outcome for the logistics company is that even if the public infrastructure has to be used, the operating costs of EV operation are negligibly higher, which could be balanced by increasing the price per order so as not to reduce profit. Moreover, the zero-carbon trend is more than expected to attract more customers, which are invaluable benefits for both the logistics company and the partner. With oil prices expected to rise due to thinning reserves and more costly extraction in the coming years, strict EU measures limiting the entry of internal combustion cars into city centres and confirmation that electric operation is feasible in the current workload condition, the switch to electromobility is a very sensible step forward for the logistics company.

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8 List of Figures, Graphs, Tables and Abbreviations

8.1 List of Figures

8.2 List of Graphs

8.3 List of Tables

8.4 List of Abbreviations

MCDA	Multiple-criteria decision analysis
MCDM	Multiple-criteria decision-making
WSM	Weighted sum model
EJ	Exajoule (10^{18} joules)
EV	Electric vehicle
EU	European Union
USA	United States of America
CZK	Czech koruna / crown
CO2	Carbon dioxide
ICEV	Internal combustion engine vehicle
BEV	Battery Electric Vehicle
HEV	Hybrid Electric Vehicles
PHEV	Plug-in Hybrid Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
AC	Alternating current
DC	Direct current
NOx	Nitrogen oxides
VAT	Value-added tax
B2C	Business-to-Customer segment
B2B	Business-to-Business segment
cc	Cubic centimetres
HPC	High Power Charging

9 Appendix

The appendix of this thesis is in electronic form as excel xlsx spreadsheet file. It contains on separeate sheets all the data, tables, calculations and graphs used in this work.

File: Appendix_Diploma_Thesis_Sandra_Kustova.xlsx

Sheets:

1. Operation data from the period of January 2023
2. Statistics calculations
3. Graphs of idle times and distances
4. Simulation of idle time charging
5. Charging resources analysis
6. Financial analysis
7. Multiple criteria decision analysis
8. Gantt chart