Usage patterns and environmental effect analysis of e-scooter sharing system: A case study in Gothenburg, Sweden

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SADIA ALI
GENTRINA PECI

DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING
Chalmers University of Technology
Gothenburg, Sweden 2022
www.chalmers.se

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SADIA ALI
GENTRINA PECI

CHALMERS
UNIVERSITY OF TECHNOLOGY

Department of Architecture and Civil Engineering
Division of Geology and Geotechnics
Chalmers University of Technology
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SADIA ALI
GENTRINA PECI

Supervisor: Kun Gao, Architecture and Civil Engineering
Examiner: Xiaobo Qu, Architecture and Civil Engineering

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Department of Architecture and Civil Engineering
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

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Abstract

Swedish cities are embracing shared micro-mobility systems (SMMS) such as e-scooters sharing systems to promote sustainable travel behaviour in urban contexts with corresponding infrastructure planning. SMMS are associated with various social, environmental, and economic benefits in terms of reducing greenhouse gases (GHG) emissions and noise pollution, preventing diseases (e.g., obesity), impairing traffic congestion, and providing solutions for the first- and the last-mile problem of using public transit. Even though many qualitative discussions about the positive effects of SMMS have been performed, quantitative assessments based on revealed massive usage data are lacking. The purpose of this thesis is thus to evaluate the environmental benefits of e-scooters based on massively big data from shared scooter systems.

This thesis is based on the scooter operation data of VOI company in Gothenburg. The used data cover the transaction data of two and half months and includes over 500 thousand valid trip records. On account that e-scooters from VOI companies are merely available in the centre areas of Gothenburg, so only trips using scooters in the central areas of Gothenburg are analysed and investigated.

This thesis firstly analyzes the spatial-temporal usage patterns of shared e-scooter systems in Gothenburg and the results showed that most trips last between 5-10 minutes with an average distance of 1793 m. It was also seen that most trips occur on the weekends and that the main peak hour is at six o'clock in the afternoon. Furthermore, it was also seen that the demand for shared e-scooters was much higher in the city center compared to areas located in the outskirts of the city center.

Nevertheless, this thesis quantifies the potential environmental benefits of shared e-scooter systems in Gothenburg in terms of reducing GHG emissions. The basic idea is to compare the emission of using e-scooters with those of using other transport modes for the same trips if e-scooters were not to exist. To realize such comparisons, we need to estimate the replaced transport models for every single trip using the scooter and corresponding GHG emissions of using different transport modes for the same trip. The statistics between the percentage of using different transport modes (e.g., walking, bike, public transport and car) and trip distance in Gothenburg are utilized to estimate the replaced transport mode. Simultaneously, the emission factors of using transport models for travelling based on life-cycle assessments are used for calculating emissions of using different transport modes for every single scooter trip. Combining the results about replaced transport modes and GHG emissions of using different transport modes for each trip, the reduced GHG emission due to using the scooter for each trip is quantified. The mean GHG emission reduction for the study area was estimated to be 10.71g CO_2. The mean GHG emission reduction was also calculated for different zones where the largest mean value was estimated to be 49.85 g CO_2 while the smallest was estimated to be -1.64 g CO_2. Furthermore, the greatest overall emission reduction was estimated to be 443594.04 g CO_2 in an area located in the suburbs.

The results showed that the use of e-scooters are environmentally friendly in some areas while they in other areas lead to higher GHG emissions. One of the main reasons is that e-scooters actually have a very high emission during the production phase if life-cycle emissions are considered. More importantly, the substituted transport by shared scooters matters in terms of reducing GHG emissions. If users use e-scooters for a trip instead of cars that have high emissions, it will generate GHG emission reduction. However, if a trip using a scooter replaces walking or transit with very low emission, it actually adds to emissions considering life-cycle emissions of scooter systems.

In conclusion for e-scooters to reach their full potential, the companies behind them must invest in sustainable production and thereby reduce the life-cycle emissions. Lastly, e-scooters may have shown even greater environmental benefits if they were available in the suburbs where the supply of public transport is not as large as they would probably replace car journeys.

Keywords: Micro-mobility, Shared micro-mobility, e-scooters, big data, GHG emissions, usage

patterns

Sammanfattning

Svenska städer implementerar allt mer delad mikromobilitetssystem (SMMS), så som elsparkcyklar, för att främja hållbart resebeteende i urbana sammanhang med motsvarande infrastrukturplanering. SMMS är förknippad med olika sociala, miljömässiga och ekonomiska fördelar, när det gäller att till exempel minska utsläppen av växthusgaser, bullerföroreningar, och trafikstockningar. Även om många kvalitativa diskussioner om de positiva effekterna av SMMS har genomförts, saknas kvantitativa bedömningar baserade på massiva användningsdata. Syftet med detta examensarbete är därför att utvärdera miljöfördelarna med elsparkcyklar baserat på massiva data från elsparkcyklar.

Detta examensarbete är baserad på elsparkcykeldata från företaget VOI i Göteborg. De använda uppgifterna täcker transaktionsdata för två och en halv månad och inkluderar över 500 tusen giltiga reseposter. På grund av att elsparkcyklar från företaget VOI endast finns tillgängliga i Göteborgs centrum, så analyseras och utres endast resor med elsparkcyklar i centrala Göteborg.

I detta examensarbete analyseras först de rumsliga och tidsmässiga användningsmönstren för elsparkcyklar i Göteborg. Resultaten visade att de flesta resor varar mellan 5–10 minuter, med medelresesträckan på 1793 m. Resultaten visade också att de flesta resor sker på helgerna och att den huvudsakliga rusningstiden är vid 18:00. Utöver det, konstaterades det också att efterfrågan på elsparkcyklar var mycket högre i stadskärnan jämfört med områden som ligger i utkanten av stadskärnan.

Dessutom, kvantifierar detta examensarbete de potentiella miljöfördelarna (när det gäller minskning av växthusgasutsläpp) med elsparkcyklar i Göteborg. Grundtanken är att jämföra utsläppen från användning av elsparkcyklar, med utsläppen från användning av andra transportmedel (t.ex. gång, cykel, kollektivtrafik och bil) för samma resor ifall elsparkcyklar inte ersätter den resan. För att göra sådana jämförelser uppskattas de ersatta transportmodellerna för varenda resa med elsparkcyklar och motsvarande växthusgasutsläpp vid användningen. Statistiken mellan andelen som använder olika transportmedel och reseavståndet i Göteborg, används för att uppskatta det ersatta transportmedel. Samtidigt används emissionsfaktorerna för att använda transportmodellerna för resor baserade på livscykelbedömningar, detta för att beräkna utsläppen från att använda olika transportsätt för varje enskild elsparkcykel resa. Genom att kombinera resultaten om ersatta transportsätt och utsläpp av växthusgaser vid användning av olika transportsätt för varje resa, kvantifieras det reducerade växthusgasutsläppet till följd av användning av elsparkcykel för varje resa. Den genomsnittliga reduceringen av växthusgasutsläppen för studieområdet uppskattades till 10.71 g CO2. Den genomsnittliga reducering av växthusgasutsläppen beräknades också för olika zoner där det största medelvärdet uppskattades till 49.85 g CO2 medan det minsta uppskattades -1.64 g CO2. Dessutom uppskattades den största total utsläppsminskningen till 443594.04 g CO2 i ett område beläget i förorten.

Resultaten visade att användningen av elsparkcyklar är miljövänliga i vissa områden medan de i andra områden leder till högre växthusgasutsläpp. En av huvudorsakerna är att elsparkcyklar släpper ut stora halter växthusgaser under produktionen. Däremot, bedömningen om elsparkcyklar är ett hållbart resealternativ eller inte beror på vilka transportmedel de ersätter. Ifall användare ersätter dess bilresor med elsparkcykelresor, resulterar det i minskat utsläpp av växthusgaser. Detta då elsparkcyklars totala CO2 utsläpp är lägre än bilars, enligt livscykelanalysbedömning. Däremot, ifall elsparkcyklar ersätter promenader eller kollektivtrafik, resulterar det istället till ökat växthusgasutsläpp.

Sammanfattningsvis, för att elsparkcyklar ska uppnå sin fulla potential måste elsparkcykel företag investera mer i hållbar produktion och för att minska dess växthusgasutsläpp under livscykeln. Slutligen, kan elsparkcyklar få en ökad miljövänlig inverkan ifall de blir mer tillgängliga i förorterna i Göteborg. Detta då utbudet av kollektivtrafik inte är lika stor och därmed kan en ökad tillgänglighet innebära att fler bilresor ersätts med elsparkcyklar.

Nyckelord: Mikromobilitet, delad mikromobilitet, elsparkcyklar, massiva data, växthusgasutsläpp, användningsmönster

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Sadia Ali and Gentrina Peci
Gothenburg, January 2022

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List of abbreviations

SMMS - Shared micro-mobility systems

SESS - Shared e-scooter systems

GHG - Greenhouse gases

VOI - A company that has developed the e-scooters analyzed in this thesis

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1 Introduction

Every year more than 100 million people are affected by climate catastrophes. According to the Red Cross (Röda korset, n.d.) up to 200 million people may need emergency aid by 2050 if the world does not act now. In connection with the climate changes that are currently taking place as a result of global warming, many countries around the world have decided to reduce their emissions. Sweden has a goal of achieving net-zero emissions of GHG into the atmosphere by 2045 (Naturvårdsverket, n.d.(b)). To achieve this, they must reduce their emissions from among other sectors, the transport sector, which accounts for one-third of all greenhouse gases emitted (Naturvårdsverket, n.d.(a)). According to a study conducted by traffic analysis (Trafa, 2021) the results showed that the majority of all journeys that take place in Sweden are carried out by car. This corresponds to 55% of all trips made in 2020. The remaining 45% were distributed rather evenly between public transport, walking, and cycling, see Figure 1.

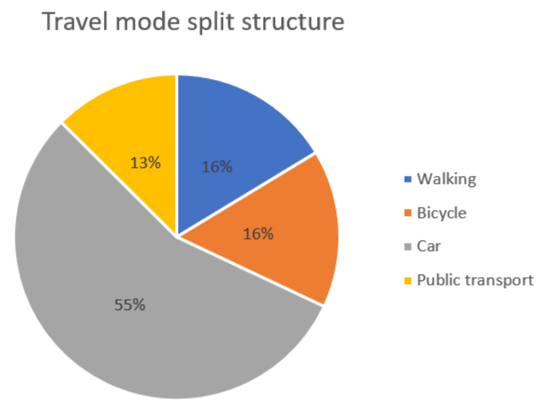


Figure 1: Travel mode split structure in Sweden 2020 (own illustration)

The Earth's environment is one of the main topics in public news and academic studies. The deteriorating greenhouse effect is one of the current issues. In the absence of the natural greenhouse effect, no organism would be able to survive on this planet. The reason is that the greenhouse effect keeps the planet warm by trapping the sun's rays (Oxford Reference, n.d.). However, fossil fuels consumption has surged rapidly since the industrial revolution. As fossil fuels contain hydrocarbon material, when they are consumed and burned for human purposes (e.g., transportation and industry), they release greenhouse gases (GHGs) such as carbon dioxide (i.e., CO2). By releasing large amounts of GHG emissions, it results in encouraging the natural greenhouse effect, which gradually increases the earth's average temperature. The increased average temperature on the planet caused by GHG emissions makes them the primary contributors to climate change and global warming. Figure 2 shows how the amount of CO2 has increased since the beginning of the industrial revolution.

As mentioned previously, human activities such as the consumption of fossil fuels in the transportation sector are responsible for a significant amount of GHG emissions. Figure 3 presents that the "Transportation" sector accounts for the largest part, which takes up 29% of the total GHG emissions in 2019. There are many different types of industries in the transportation section, including road and rail, transportation infrastructure, marine, airlines, air freight, and logistics (Hayes, 2021). According to the United States Environmental Protection Agency (2020), vehicles in the transportation sector such as cars, buses and trucks contribute to more than 70% of the total GHG emissions in Europe. Aside from the GHG emissions from the transportation sector, noise pollution is another major environmental issue (United States Environmental Protection Agency, 2020).

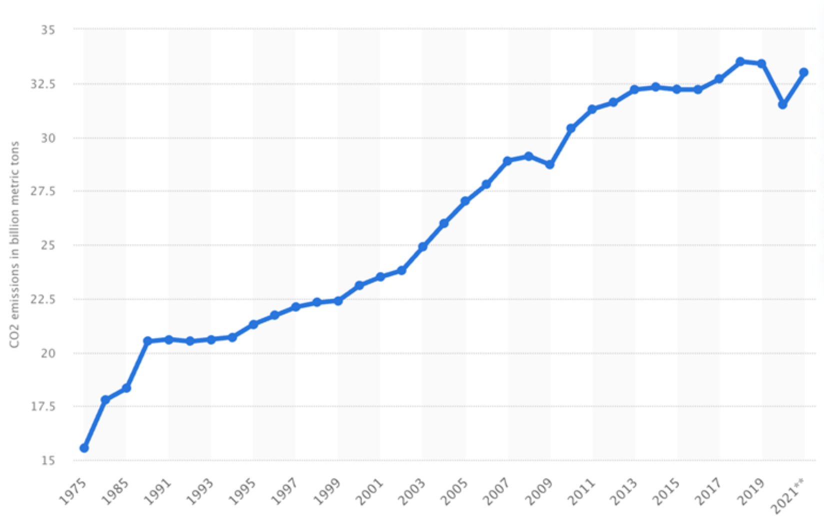


Figure 2: Worldwide description of carbon dioxide emissions from 1975 to 2021 (Statista, 2021).

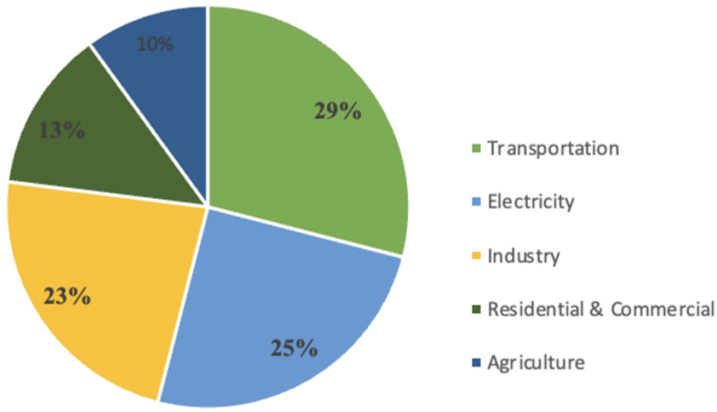


Figure 3: Greenhouse gas emissions worldwide in different sectors in 2019 (own illustration).

Furthermore, the transport sector currently accounts for 30% of all greenhouse gases emitted in Sweden, where most greenhouse gases consist of carbon dioxide. Methane and nitrogen oxide emissions are also present, but they have decreased significantly as the emission control technology has improved in recent years (Naturvårdsverket, n.d.(a)). The Swedish government has set a goal to reduce the greenhouse gas emissions from the transport sector by at least 70% in the year 2030 compared to 2010 (Sverigesmiljömål, 2021). Moreover, within the transport sector, it is the combustion of fossil fuels that accounts for the largest share of greenhouse gas emissions. The current Swedish transport system is still dependent on fossil substances. The use of fossil fuels does not only contribute to greenhouse gas emissions but also leads to acidification in watercourses and soil as well as deterioration of air quality (Roth & Lindén, 2016).

There are several different approaches available to reduce the use of cars which has a negative effect on the environment. One of them is the use of shared micro-mobility systems such as e-scooter sharing mobility. According to Mansky (2019), e-scooters already existed over 100 years ago but in recent years have the demand for these micro-mobility devices expanded, and the attention has increased radically. The modern-day e-scooters were first introduced in the United States in 2017 and have since spread rapidly around the world (Region Stockholm, 2019). In Sweden, the first electric scooters were available in 2018 when the Swedish company VOI launched their own electric scooters. Thanks to its flexibility, shared e-scooter systems (SESS) can provide convenient travel tools for users to reduce travel time or cost in many situations. The convenience and flexibility of shared scooter systems bring prosperity to implementing them in urban contexts, especially in the EU. Meanwhile, several comments and reports indicate that e-scooter sharing systems are environmentally-friendly, based on some reports from industrial companies such as VOI technology (2019). The intuitive judgement is that e-scooter merely use electricity and do not consume any fossil energy, which is beneficial for reducing GHG emissions and energy consumptions. However, such statements neglect the energy consumption and emission in the life cycles of e-scooter systems. There are actually notable emissions in the production, operations and disposal stages of e-scooter systems (Västsvenska paketet, 2017). By considering the associated GHG emissions on the e-scooter life cycle (i.e. production, operation and disposal), the emissions of an e-scooter system can be analysed and estimated.

Moreover, whether (or how much) SESS produce environmental benefits depends on the transport mode substituted by SESS and travel characteristics (e.g., distance). If a traveller uses SESS for a trip instead of a taxi or private car, it is, without a doubt, beneficial for reducing energy consumption and GHG emissions for the trip. However, a bike-sharing trip replacing walking does not create an extra environmental benefit on account of the energy consumption and emissions in manufacturing the bikes and operating the system (Li et al., 2021). Although, the potential environmental benefit is one of the most critical motivations of developing SESS in the era of climate change. Very few studies have quantitatively evaluated the environmental benefits of SESS. However, quantitative assessments on the potential benefits derived from SESS are crucial evidence and supports urban managers to make development decisions concerning SESS.

1.1 Research questions

1. What are the usage patterns in Gothenburg?
2. What are the differences of usage patterns in different urban areas?
3. What travel modes does e-scooter sharing system replace and how beneficial is this replacement from an environmental perspective?

1.2 Aim

The aims of this thesis are to answer the abovementioned research questions based on massive real usage data of SESS. We get access to the transaction data of e-scooter systems in Gothenburg from the open API of the VOI company. Based on the unique data, we firstly investigate the spatio-temporal usage patterns of SESS in Gothenburg. Particularly, this study reveals the potential differences in the usage patterns in different urban areas with different built environments. Moreover, this study quantitatively estimates the environmental effects of the e-scooter sharing system on GHG emissions based on real usage data. The core of evaluating the benefits of e-scooters is to compare the emissions from e-scooters to those of using other transport modes for the same trips if an e-scooter sharing system was not to exist. To realize this aim, we first estimate the replaced transport mode for each SESS trip. The GHG emissions using different transport modes for a trip are estimated based on life-cycle analysis. Finally, the aggregated environmental influences of SESS are estimated based on aforenoted contents.

2 Literature review

2.1 Micro-mobility

As urban areas throughout the world continue to expand rapidly and the demand for the existing transportation network is increasing, micro-mobility is gaining attention as a possible alternative. Micro mobility is defined as a short-distance transport and can be described as “Personal transportation using devices and vehicles weighting up to 350 kg and whose power supply, if any, is gradually reduced and cut off at a given speed limit which is no higher than 45 km/h” (International Transport Forum, 2020). In micro mobility, human-powered vehicles are used exclusively, such as bikes, e-scooters, skateboards, e-rickshaws etc. Micro mobility is offering attractive solutions for “first and last-mile connectivity”, as well as assisting in the reduction of traffic (Bhagyalaxmi, Madangopal & Chandrashekar, 2020).

Moreover, the term “micro-mobility” gained popularity around the year 2016 when Dediu, an American analyst, connected the term to sharing vehicles such as bicycles and scooters. The term “micro”, according to Dediu (International Transport Forum, 2020) refers to either the short distances that are travelled by such vehicles or the vehicle itself. In the past few years, the use of micro vehicles has increased drastically in connection with the introduction of electric scooters. Many micro vehicles are owned by private individuals who use them for daily trips. Besides the privately owned vehicles, it is also common to find mainly electric scooters and bicycles on the streets in the city that are available to rent (International Transport Forum, 2020). This concept of renting a vehicle when needed is called shared micro-mobility and will be described in more detail in chapter 2.1.1.

2.1.1 Shared micro-mobility systems (SMMS)

Shared micro-mobility (SMMS), is the system of sharing using low-speed modes such as electric scooters (e-scooters) and electric bikes (e-bikes). This innovative transportation system provides users temporary access to small modes of transportation to satisfy short-distance travel demands (Shaheen & Cohan, 2019) and thus has an impact on users’ travel behavior and decision making. Shared bike-sharing can be divided into station-based (docked), dockless and hybrid bike-sharing systems. Scooter sharing, on the other hand, can be divided into standing electric scooter sharing and moped-style scooter sharing. The main difference between docked and dockless sharing systems is that docked sharing system provides one-way station-based service, while dockless sharing system enables checking out the sharing mode and returning in any locations within a predefined geographic region (Shaheen & Cohan, 2019).

Furthermore, Bielinski and Wazna (2020) conducted that availability of shared micro mobility is an important requirement that needs to be considered and improved to provide the shared micro mobility services to as many social groups as possible. Urban areas are increasingly affected by different issues such as traffic congestion, car accidents, space occupied by cars, air pollution and, external transportation costs. Accordingly, Bielinski and Wazna (2020) state that increasing the availability of these services will support municipal administrations in addressing the challenges associated with urbanised areas.

E-scooter sharing system

Shared e-scooters are now available almost worldwide, according to 6T-Research office (2019). There were approximately 20 different companies established on the market in the year 2019 (Figure 4). Since e-scooters are relatively new and developing very fast, the figure may not be up to date as it is likely that there are more companies that have entered the market as well as more countries that have access to shared e-scooters.

Since e-scooters are relatively new on the market, so the relevant research is very limited, and

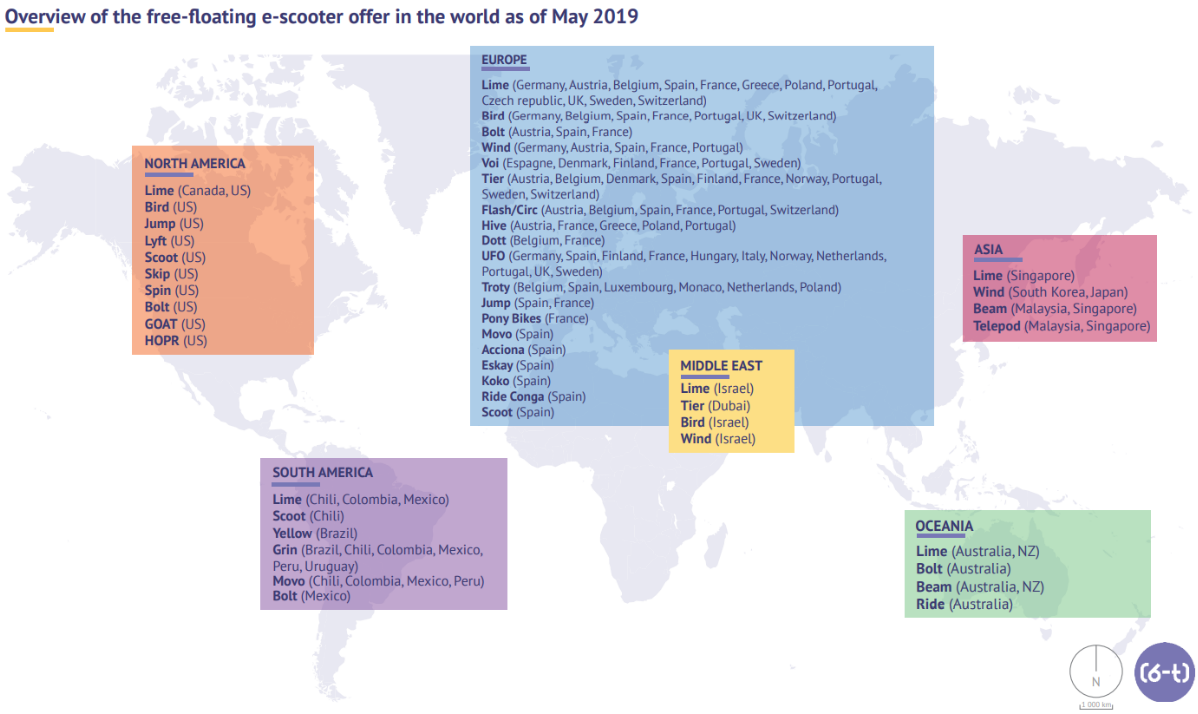


Figure 4: Overview of the free-floating e-scooter offer in the world during 2019 (6T-Research office, 2019).

there aren't many reports that describe how they are used or who the ones that use this service are. However, there are some studies that have been conducted in Europe and in the US. The results in these different studies have shown similar trends when it comes to usage patterns. A study conducted in Oslo, Norway, showed that 62% of the users are men and that 67% of the users are in their 20s (Berge, 2019). Another study conducted in Paris, France, showed roughly the same results where 66% of all users are men and more than 50% of the users are under 35 years old (6T-Research office, 2019). About the same results have been seen across the Atlantic in the US where at least 60% of the users are men in both New York (Lime, 2018) and Seattle (Movmi, 2018) as well as most of the users being in their 20's.

The use of e-scooters means that the use of other transportation modes is reduced, but it is difficult to say with certainty what transport modes e-scooters replace. There are some studies that have been conducted, specifically in Norway, Spain and France, where the results have shown that the use of e-scooters mainly replace walks and shorter trips that would otherwise have been made with public transport (Berge, 2019; Palau, 2019; 6T research office, 2019).

Moreover, when analysing how e-scooters are used in Sweden, Andersson (2019) conducted that Sweden follows roughly the same trends as international results have shown. According to the study, 66% of all people who use e-scooters in Stockholm are men, and most users are also under the age of 30. Most of the respondents were also students, and they accounted for 40% of all responses. Moreover, the results also showed that 68% of the trips were pleasure/leisure trips and that the e-scooters are used more frequently during the weekends compared to weekdays. When it comes to the replaced transport modes by e-scooters, 60% of the respondents replied that they would have walked instead, 24% replied that they would have used public transport, 8% replied that they would have used their private bike, and 8% answered that the trip would not occur at all (Andersson, 2019).

Laws and regulations for e-scooter sharing systems

The widespread use of e-scooters has unfortunately generated a growing trend for accidents due to factors such as parking in inappropriate areas and using sidewalks improperly. In order to counteract this trend, there are countries around the world developing policies and guidelines that could alleviate these issues. For instance, by developing different frameworks during the operation phase, such as helmet requirements and minimum age for use. The study conducted by Stigson Klingegård (n.d.) showed that most of the local authorities have not yet developed a regulatory framework for effectively integrating e-scooters into urban areas.

Meanwhile, in Sweden, e-scooters are constantly being processed, and policies are being developed to govern the usage of this micro-mobility device. In Sweden, an e-scooter can be considered as a bike if it does not exceed the speed of 20 km/h and has a maximum engine power of 250 $Watts$, according to the Swedish Transportation Agency (Transportstyrelsen, 2021b). For an e-scooter to meet the bike requirements, a helmet is required to be worn by users younger than 15 years old, and it is prohibited to bring others from riding the same e-scooter. Furthermore, riders are required to have front -and rear lights as well as reflectors when riding in the dark. They are allowed to ride on the bike path but sometimes also on the roads. When operating an e-scooter, the Swedish Transportation Agency has issued several recommendations, including driving carefully when passing fellow road users and adjusting the speed depending on the situation. Additionally, it is important to park the e-scooter in an appropriate location to avoid becoming an obstacle for fellow road users (especially children, the elderly, and the disabled). It is also not permitted to ride an e-scooter while intoxicated or tired. If the e-scooter does not meet the requirements of a bike, it will be classified as another class depending on the speed and the engine power, leading to that other requirement needs to be followed (Transportstyrelsen, 2021b).

Government and public views on e-scooter sharing systems

Despite laws and regulations, one research by an insurance company shows a sharp increasing trend of accidents involving e-scooters since 2019. During the period of April to August 2019, 14% of those who examined hospitals in Stockholm were injured in traffic accidents involving e-scooters (Stigson & Klinegård, n.d.). The number of users of scooter systems still represents a relatively small portion of all road users. In contrast, the number of accidents caused by e-scooters is disproportionate. This indicates that e-scooter users are more likely to be injured than other road users. Additionally, in May 2019, the first accident involving a shared e-scooter was reported in Sweden. Since then, the number of accidents involving e-scooters has increased. Due to the rapidly growing trend of accidents by e-scooters, there is a growing concern among authorities around the world about the safety of e-scooters (Stigson & Klingegård, n.d.).

Moreover, the statistics from the Swedish Transport Agency (Transportstyrelsen, 2021a) indicate that most accidents involving e-scooters occur in large cities in Sweden, such as Stockholm, Gothenburg, and Malmö. In Gothenburg, there are daily discussions about how e-scooters should be handled. There have been discussions within Gothenburg's community about banning e-scooters from the city. The argument for this statement is, for instance, that e-scooters lead to huge costs on the welfare system. Beyond this statement, there are discussions about introducing requirements such as reducing the speed when riding the e-scooter in the center part of Gothenburg, the maximum number of e-scooters, and land lease fee (Storm, 2021; Transportstyrelsen, 2021c).

Furthermore, Insurance Soved Blog (2020) reports that 31% of the pedestrians in the Australian city Adelaide are uncomfortable when sharing the sidewalk with e-scooters, with a proportion increasing with the pedestrian's age. Moreover, the study shows that 29% of pedestrians have been forced to move quickly to avoid colliding with e-scooters. The study does also state that up to 40% of the e-scooters were not parked as per the instructions of the operator, which poses a potential safety risk to pedestrians (Insurance Soved Blog, 2020). According to Swedish Transport Agency (Transportstyrelsen, 2021b), the number of accidents with e-scooters has risen to 1000 accidents in the past year. In 2016-2018, approximately 20 personal injury accidents occurred per year with an e-scooter involved. In the following years, the number of injury accidents increased, and 1 056 accidents involving e-scooters happened from August 2021 (Transportstyrelsen, 2021a).

From July 2020, local areas in England, Wales and Scotland have been able to undertake 12 months of e-scooter trials, provided they meet the requirements of DfTs (Department for Transport). The main purpose of this trial is to examine if e-scooters have a positive or negative effect on society (The Guardian, 2020). The views from stakeholders differ on potential benefits and problems presented by e-scooters. Some believe that e-scooters offer solutions to a wide range of transport policy goals, such as reducing congestion and pollution in urban areas. However, some are concerned that e-scooters have substituted and are substituting trips that would have been walked and biked instead of replacing cars. This could result in increased negative health impacts through reduced physical activity but also would negate the supposed congestion-alleviating (Hirst, 2021). Further, the UK parliament (Hirst, 2021) explain that safety concerns and "tackling" climate change are other issues that need to be handled. When coming to concerns about the safety of e-scooters, the UK parliament (Hirst, 2021) explain that stakeholders are worried if e-scooters are safety designed and whether users have the skills to use them safely. Besides, there are also discussions about how e-scooters interact with other vehicles, road and pedestrians and how liability is handled when accidents occur. When speaking about reducing the environmental impact, proponents of e-scooters explain that these micro mobility devices can help reduce the everyday CO2 emissions by getting people out of their cars. Contrarily, several studies suggest that the short lifespan of e-scooters means these carbon savings may be minimal, if achieved at all. The end date of the trial in the UK has been extended to May 2022, and the latest city to trial e-scooters is London (BBC, 2021). The city of London tested these micro mobility devices in June 2021. Since then, the police service (i.e., Metropolitan police) has reported that the number of accidents with e-scooters has been increasing sharply. The Met police have also reported that "there's concern that e-scooters are being used by criminal gangs." (BBC, 2021).

In Europe, e-scooter is legally allowed in the public spaces in most of the European countries except Greece and the Netherlands where these devices are not allowed yet (Kamphuis & van Schagen, 2020). However, e-scooters are still existing in these countries where several Greek respondents have been reporting seeing e-scooters in Greece on a regular basis and claiming that they have become more common. The road users/vehicle category that e-scooters legally belong to differs in different countries in Europe. In most European countries (such as Czech Republic, all Scandinavian countries, Poland and Italy), e-scooters are legal and are categorized as bikes. However, in Finland, e-scooters are defined as a bicycle if the device travels faster than 15 km/h. Otherwise, they are defined as a pedestrian. In Germany, Austria, Spain, Belgium and France, e-scooters are classified in a separate category. For instance, in Germany, e-scooters are "a new category of vehicles that is similar to light mopeds and bicycles" (Kamphuis & van Schagen, 2020). In most European countries, e-scooters users can use bike facilities if possible. If the bike facilities are not available, e-scooters are expected to use road lanes, in Switzerland, Germany, France, Australia, Portugal as well as Sweden. However, in Finland, Belgium and Sweden, the e-scooters are also allowed to use the pavement but with criteria. For instance, in Finland, are you get to use the pavement if you have a walking speed with a maximum speed of 15 km/h while in Sweden and Belgium, you are required to not travel faster than the pedestrians (Kamphuis & van Schagen, 2020).

Towards parking e-scooters in public spaces, almost all countries regarded it as a serious problem (Kamphuis & van Schagen, 2020). E-scooters are considered a safety issue for general pedestrians but especially for blind, disabled, and senior pedestrians. Netherland is the only country where the study result shows that the parking of e-scooters is not being considered a problem, and the reason is that e-scooters are rarely seen (Kamphuis & van Schagen, 2020). Furthermore, Nikiforiadis et al. (2021) showed that e-scooters tend to replace environmentally friendly modes (e.g., walking and public transport), which result in that the environmental impact of e-scooters may not be as great as it was initially envisioned".

2.2 GHG emission from e-scooter sharing system

An effective way to reduce GHG emissions is by reducing the number of fossil-fuel-based transports. This can be done in several different ways, such as encouraging the use of public transport and promoting using bicycles or walking for shorter journeys. Another alternative transport mode is the e-scooter. As previously mentioned, shared e-scooter systems have been operated in many parts of the world, and the operators of shared e-scooter systems describe e-scooters as sustainable transport modes. Moreover, many of the e-scooter companies argue that they reduce the use of cars and thus contribute to a greener environment. According to VOI (2020), their own study showed that 19% of all trips of using VOI scooters performed in 2020 replaced a car journey. This indicates that the e-scooters indeed replaced some car-travels. However, the fact that they replace some car journeys does not necessarily mean that they are completely environmentally friendly on account of their life cycle energy consumption and emissions.

To determine the e-scooters environmental benefits, the GHG emission reduction of a trip using an e-scooter compared to other means of transport can be analysed. Additionally, the type of transport mode that is replaced with an e-scooter also has a major impact on how much or whether it will even lead to a reduction in GHG emissions. Other important factors are the nature of the journey, such as distance and duration. Therefore, to be able to assess what environmental benefit e-scooters have, it is necessary to first estimate which transport modes e-scooter replaces such as cars, public transport, bicycle or walking under different conditions and contexts. Depending on the transport mode that the e-scooter replaces the benefit will vary. For example, if an e-scooter replaces a trip that would have taken place with a car, the environmental benefit will be high compared to if it instead replaces a trip that would have taken place on foot. A walk being replaced with an e-scooter does not only lead to no environmental benefit rather it results in an increase in GHG emission because of the high emissions emitted during the production phase of the e-scooter (Li et al., 2021).

Furthermore, there are several aspects that affect which means of transport e-scooter replaces. Aspects such as the time of day, where in the city the traveler is located (city or suburb), the distance between origin and destination and whether there are other travel options available all play a big role in what means of transport the e-scooter replaces. In mode choice, the traveler chooses the option that has the highest utility i.e., the one that costs the least and takes the shortest time among the available options. This, in turn, means that the traveler chooses the option that goes from its origin to the destination without taking detours. This also means that two e-scooter trips with the same travel distance, aim and taking place during the same time during the day can replace two different modes of transport. One e-scooter trip might replace a public transport trip because it has its origin in the city center while the other replaces a car journey because it has its origin in the suburbs instead (Li et al., 2021).

2.2.1 Life-cycle analysis

The released emissions can be divided into different parts of the vehicle's life-cycle such as production, operation and disposal, see Figure 5. The production phase can be introduced after the validation of the design and production process have been done. This phase includes the manufacture of products and the way the product is manufactured by. During the production phase, many samples are being invested and tested before the complete finished product is sent to the customer. The next phase in the life-cycle is called the operation phase which is about the usage of the product by the customers into the field. When the product for different reasons is no longer worth utilizing or repairing the product, the disposal phase begins which is the ending phase of a product's life cycle (Open textbook, 2016).

The GHG emission factor is of interest when analyzing product's life-cycle. From a study, based on micro mobility system in London, Cottell, Connelly and Harding (2021) stated the CO2 emissions for selected transport modes, per passenger kilometer. In the paper (Cottell, Connelly & Harding, 2021, p. 26) the different transport modes are showing the CO2 emissions from different phases,

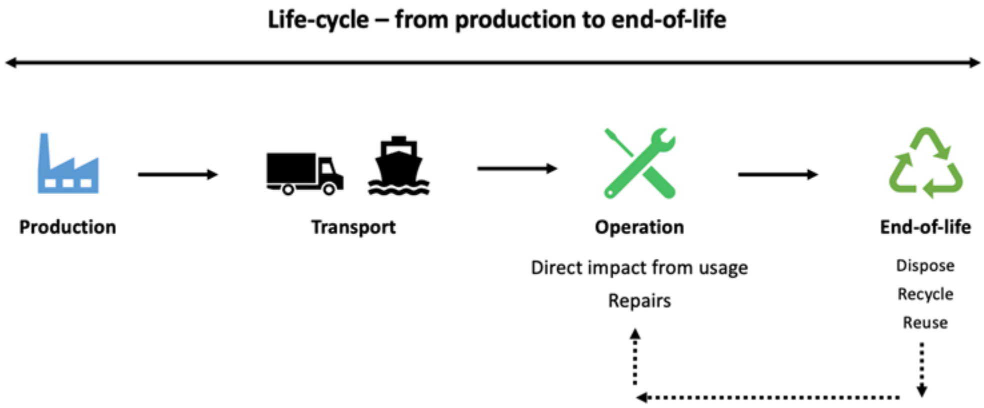


Figure 5: General life-cycle of a product, from the production phase to end of life.

which is divided into "Vehicle component", "Infrastructure component", "Fuel component" and "Operational services". For the production phase, the "Vehicle component" and "Fuel component" are represented in Table 2, while the "Operational services" are presented for the operational phase. The disposal phase is not presented in Table 2 due to the lack of emission factor data for each transport mode in this phase.

When analysing the environmental impact from e-scooters, it is necessary to analyse the life-cycle of these micro mobility devices. The life-cycle begins with manufacturing and production of the e-scooters. Then, as described earlier, the next phase is the operation of the vehicles and lastly the end of life (i.e., disposal phase). In the production phase, all the energy consumption to extract the raw material, transform them, assemble them etc. needs to be considered. The battery is of highly interest when analysing the environmental impacts from the production phase, due to that the battery is considered to be very polluting. Previously, when the e-scooters reached end of life the whole device was replaced but now more e-scooters companies (e.g., VOI) are designing their devices so that most parts of the device can be reused and only the battery needs to be replaced. Another factor that matters when analysing the GHG emissions from e-scooters is what kind of energy source (i.e., ecological -or fossil fuel energy sources) is used when producing the energy for the e-scooters. If the energy is produced from fossil fuels burning (such as oil) the GHG emissions increase which lead to increasing impact on the environment. During the operation phase, on the other hand, recent studies shows that the e-scooters can be considered to have advantage (Fournier, 2019). The reason is that they do not contribute to any pollution when being used, but only particles being released when braking during the trips. The recent study shows that longer e-scooter trips are connected to more environmental benefits. However, e-scooters need to be transported to charging station, which is usually handled by trucks, which also have an important impact on the environment. As mentioned before, during the production phase the material to produce an e-scooter have an environmental impact. It is therefore of great importance to develop the recycle industry, especially with regard to e-scooters' batteries (Fournier, 2019).

2.2.2 Noise pollution

Noise pollution is described as repetitive exposure to extreme sound levels that can cause harm to both humans and other living organisms (Environmental pollution centers, 2021). How much damage these sound levels causes varies from person to person as well as to what extent one is exposed to it. It is mainly all types of traffic that causes noise pollution in Sweden where road traffic constitutes the largest part, followed by railway and airport traffic. Other common sources for noise pollution are construction and industrial sites. (European commission, n.d.). According to the Swedish Work Environment Authority (Arbetsmiljö verket, 2020) there is a risk of permanent hearing damage if one is exposed to noise levels that exceeds 85 dB for a longer period.

Furthermore, there are several other health issues that are connected to high sound levels such as hypertension, sleep disturbance, child development, cardiovascular and psychological dysfunctions (Environmental pollutions center, 2021).

To protect the residents of today's societies and reduce the risks of diseases and poor quality of life, there are several different measures that have been introduced to urban environments around Europe. The measures are aimed to reduce the noise levels and the European Environment Agency (2021) has compiled a list of solutions that have been applied which are:

- Replace old asphalt with smoother asphalt
- Reduce speed limit for cars
- Running waterfalls in the city center
- Quiet areas in form of parks (Green areas)
- Educate residents and encourage them to use vehicles that causes lower sound levels such as bicycling, or using electric vehicles

3 Study area and data

3.1 Gothenburg

The area examined in this thesis is Gothenburg which is located in the western part of Sweden. Gothenburg is the second largest city, with an area of 448 km^2 and a population of 580,000 inhabitants (Regionfakta, 2021). The city of Gothenburg is rapidly growing, and the population is expected to increase to 700,000 inhabitants by 2035. As the number of inhabitants increases, the city also needs to keep up with development and thus expand. Therefore, there are several major projects that are taking underway right now in both construction and infrastructure to meet the upcoming demand (Göteborgs stad, n.d.(b)).

Gothenburg is a big city and is divided into different districts. There are four major urban areas consisting of Northeast, Centrum, Southwest and Hisingen, as shown by Figure 6. Moreover, each urban area is made up of several smaller areas shown in Table 1 below (Göteborgs stad, n.d.(c)).

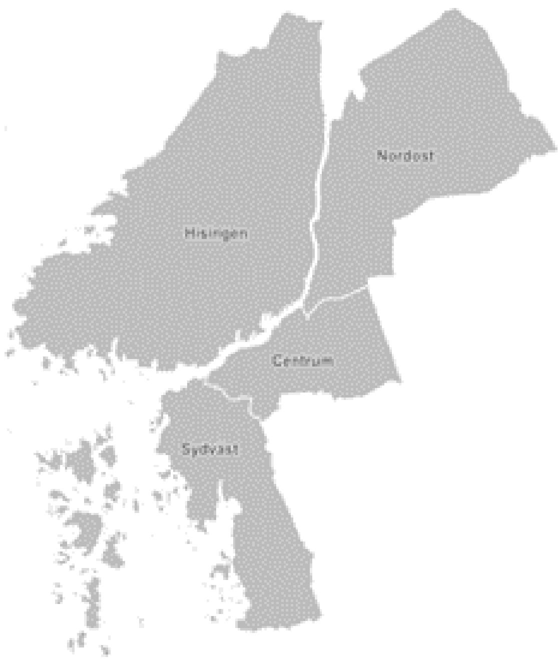


Figure 6: Districts of Gothenburg (Göteborgs stad, n.d.(a))

Table 1: Urban areas within Gothenburg

Urban areas	Smaller areas within the urban areas
Nordost	Östra Angered, Bergsjön, Gamlestaden-utby, Kortedala, Södra Angered, Centrala Angered, Norra Angered
Centrum	Kålltorp-Torpa-Björkekärr,Kallebäck-Skår-Kärralund, Krokslätt-Johanneberg, Guldheden-Landala, Olivedal-Haga-Annedal-Änggården, Kungsladugård-Sanna, Majorna-Stigberget-Masthugget, Norra Centrum, Lunden- Härlanda-Överås, Olskroken-Redbergslid-Bagaregården.
Sydväst	Stora Högsbo, Askim-Hovås, Billdal, Södra Skärgården, Bratthammar-Näset-Önnered, Centrala Tynnered, Älvsborg
Hisingen	Kärra-Rödbo, Backa, Kvillebäcken, Kyrkbyn-Rambergsstaden, Norra Älvstranden, Södra Torslanda, Björlanda, Tuve-Säve, Kärrdalen-Slättadamm, Östra Biskopsgården, Västra Biskopsgården

3.2 Operation areas of VOI shared e-scooter systems

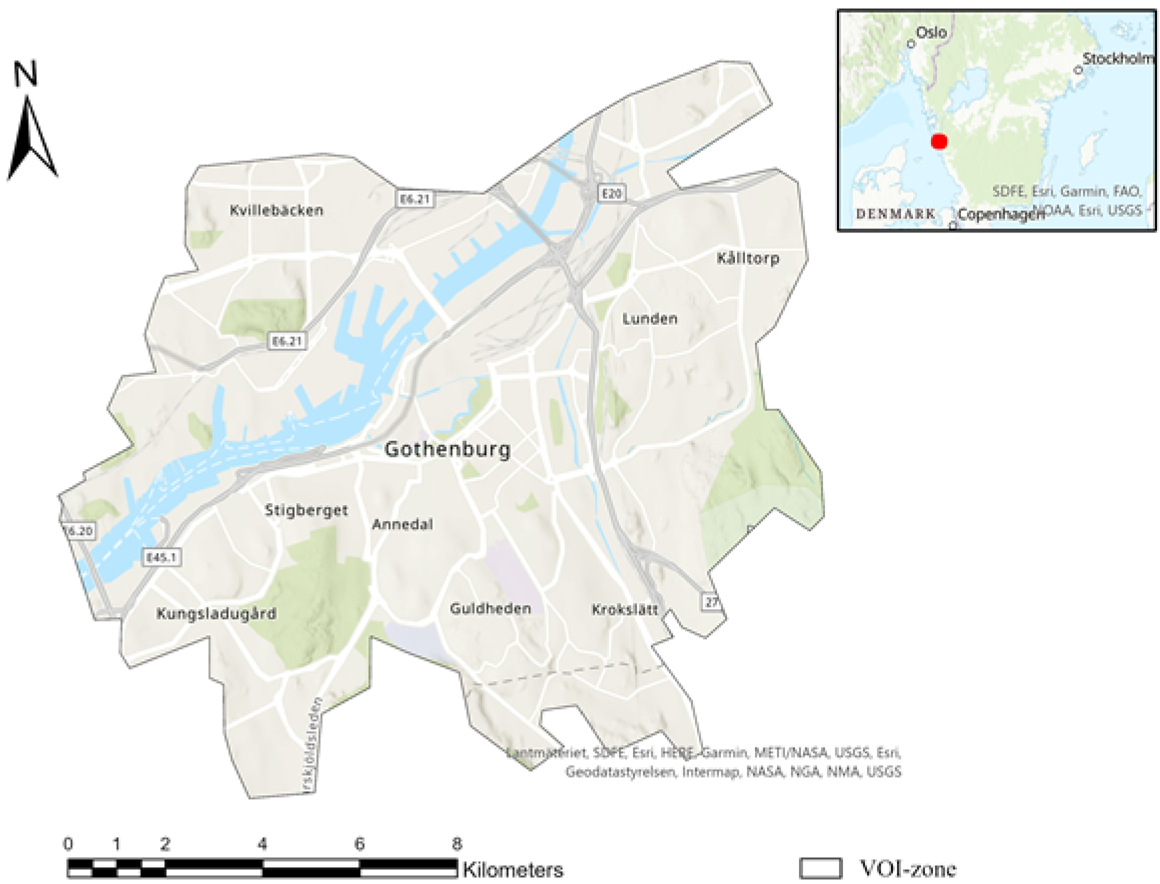


Figure 7: Map of the study area.

Since the purpose of this thesis is to investigate how VOI's electric scooters are used in Gothenburg compared to other means of transport the focus area will be VOI's own zone which can be seen in figure 7. VOI has limited the use of its e-scooters to Gothenburg's inner city as well as some other adjacent areas. This area will hence-forth be referred to as the "VOI zone". From the figure it can be seen that the zone lies within major roads such as E20, E6 E45. The zone also contains all the major districts that lie within Gothenburg's inner city.

The zone has an area of 152.2 km^2 and a circumference of 71 km. VOI's own e-scooters are placed all over the zone for easy accessibility. Since the zone occupy large parts of the inner city, it becomes natural that the users share the land with other means of transport and pedestrians. To reduce accidents and ensure that there is some type of order VOI have together with the city of Gothenburg divided the large zone into several smaller zones with different purposes. The developed zones are (VOI, n.d.):

- **Great parking space:** Users get a discount on their trip if they park within this zone.
- **Parking space:** Good parking space however, parking in this zone does not give any discounts on the trip. In some cities the users are only allowed to end their trip within this zone. However, this does not apply to Gothenburg.
- **Parking prohibited:** Although the main idea is that one should be able to park anywhere within the 27 different zones in Gothenburg there are certain exceptions where it is unsuitable to park the e-scooters on. In these areas, parking is prohibited, and the user can not end their journey within this zone.
- **Restricted speed zone:** This applies to areas where a lot of pedestrians, cars and other means of transport are present. When an e-scooter enters this zone, the speed is automatically reduced until they exit the zone.
- **Riding prohibited:** There are a few areas where it is forbidden to ride the e-scooter even though they lie within the zone presented in Figure 7. If the users enter this area the e-scooter will automatically shut down.

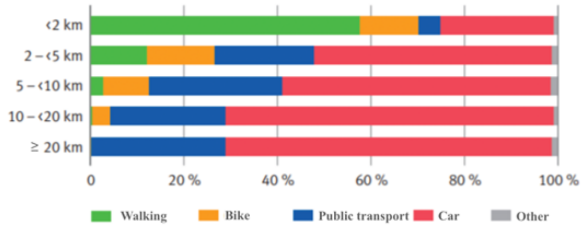
3.2.1 Demography

Since Gothenburg is a big city, the demographic differs in different parts of the city. In this report the demographic will only be presented in relation to the population, gender, and age within the 27 different zones in Gothenburg. The data presented here was obtained from the city of Gothenburg during 2021, however data could not be found for all the districts that lie within VOI's zone since some of them are industrial or commercial areas as well as areas that no longer exist in connection with the districts being remade this year (Göteborgs stad, n.d.(d)).

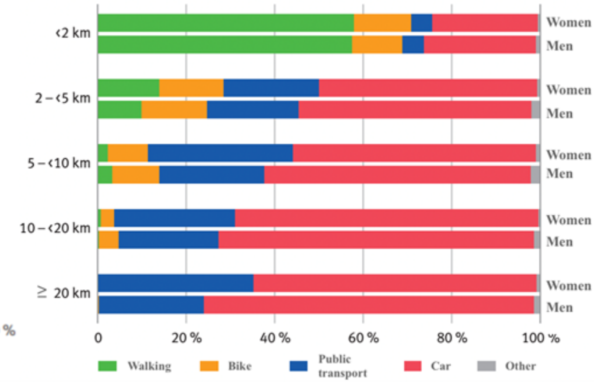
In total, there are 168 229 people who are registered in this zone. Most live in Brämaregården, which accounts for 13% of the total population for the area. Other large areas are Olivedal, Haga, Krokslätt and Kvillebäcken. There are slightly more men than women within this zone where men account for 50,4% of the total population while women account for 49,6%. The age group varies from 20–69-year-olds in the different zones, however the most common age group is 30–39 year-olds followed by the age group 20-29 which is slightly smaller (Göteborgs stad, n.d.(d)). For more detailed information regarding all the areas see appendix 1 in chapter 10.1.

3.2.2 Travel mode split structure in Gothenburg

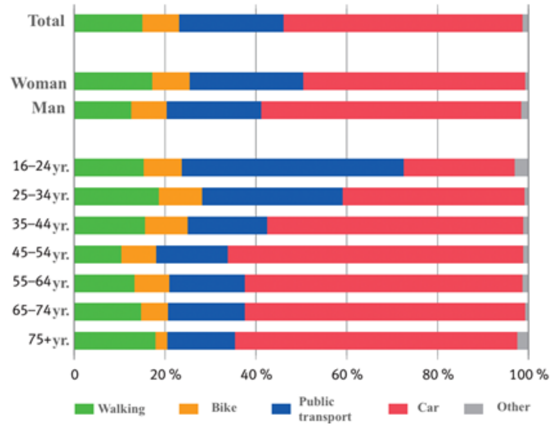
The most common way to travel within Gothenburg is to travel by public transport, car, bicycle, electric scooter or on foot (Göteborgs stad, 2018). In connection with the coronavirus breaking out at the turn of the year 2019/2020 data from 2017 will be presented to show what the travel habits looked like under normal conditions, i.e., before the pandemic.



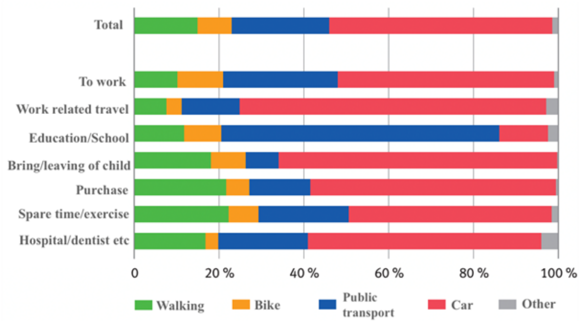
(a) Distribution of transport modes per travel distance on weekdays



(b) Distribution of transport modes per km on weekdays for men and women



(c) Distribution of transport modes for travel on weekdays for demographic groups



(d) Distribution of means of transport for travel on weekdays with different purposes

Figure 8: Travel habit distributions (Västsvenska paketet, 2017)

Distribution of transport modes per travel distance on weekdays: Often one chooses to use different modes of transport based on the traveled distance. Figure 8 (a) below shows that the most common way to travel when it comes to distances that are shorter than 2 km is to walk while distances that are above 20 km the most used mode is the car. Furthermore, the figure also establishes the fact that walking and biking are mostly used when the distance is less than 2 km while public transport and car are mostly used for distances that are above 2 km. In addition to that Figure 8 (b) also shows that women walk, bike, and use public transport to a greater extent than men.

Distribution of transport modes for travel on weekdays for demographic groups: Figure 8 (c) shows that the majority of all the travels performed in Gothenburg during the weekdays are done by car which accounts for approximately 56% of all the travels. The second most common way to travel is by public transport which accounts for approximately 20% of all the travels. Gothenburg's public transport consists mainly of trams and buses but there are also boats and trains. The least common way to travel is by biking and walking where biking accounts for circa 6% of all the travels and walking accounts for circa 17% of them. Moreover, it can also be seen that traveling by car is most common travel mode for the age group 45-54 years old while public transport is mainly used by 16-24 years old. Walking and biking are more or less the same for all age groups with the exception of the age group 75 +.

Distribution of means of transport for travel on weekdays with different purposes: The purpose of one's journey also determines which mode of transportation that is used. Figure 8 (d) shows that public transport dominates when it comes to travel for education while cars dominate when it comes to travel for work and travels performed during work. For recreational trips the most common mode is traveling by car followed by walking and public transport.

3.2.3 Land use

The different zones in Gothenburg includes the inner city and the middle city. The inner city is the most central part of Gothenburg and constitutes most of our study area while the middle city does not belong to the city center but is directly adjacent to it. These areas are mainly mixed urban developments which means that these areas hold housing, workplaces, offices, trade, facilities, and various public services. In addition to buildings, mixed urban areas also include local streets, pedestrian, and bicycle paths, as well as public places such as squares and parks (Göteborgs stad, n.d.(d)). Furthermore, it can be seen from Figure 9 that there are several important public transport hubs which are marked as red dots within the zone. Other areas of interest are parks and sport areas which are marked in green as well as university campuses which are marked with many small red dots. Moreover, it can also be seen that the southern part of the zone has a greater housing density than the city center. Even though there are residentials/housing in all the areas the proportion of households is much smaller in the city center compared to the rest of the zone as there is a greater focus on, for example, trade in this area (Göteborgs stad, n.d.(e)).

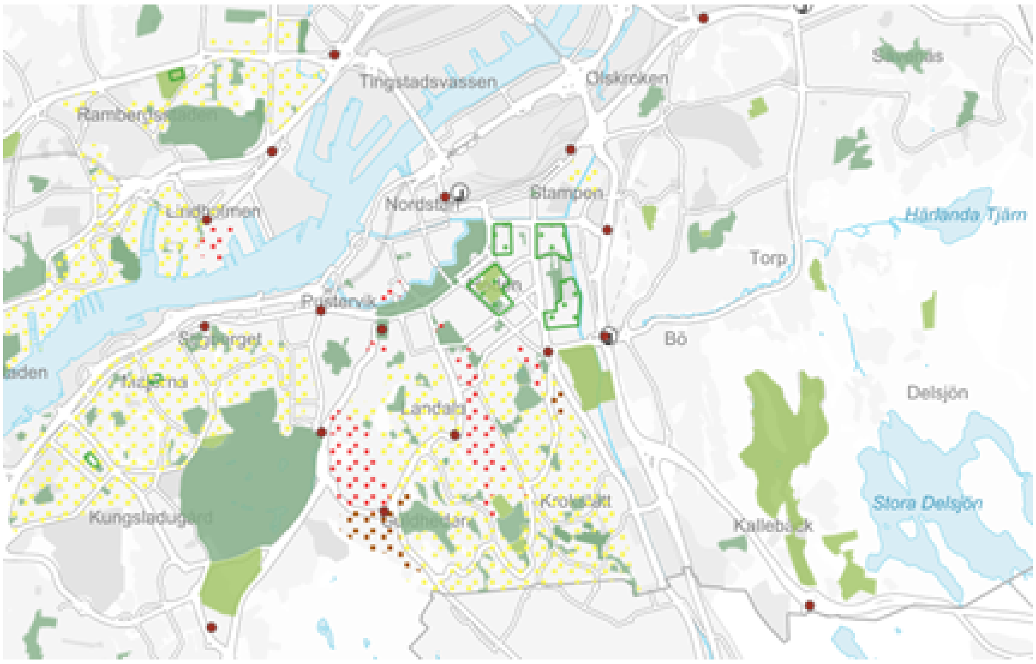


Figure 9: Land use in central Gothenburg (Göteborgs stad, n.d.(e))

4 Methodology

The application Jupyter Notebook and the software ArcGIS Pro are used for data analysis.

It was mainly two different programs that were used during the analysis phase of this thesis. The first program is the application Jupyter Notebook which is a web-based application used to create and share documents that contain equations, codes, visualizations, and descriptions. The application can be used to sort and transform large amounts of data, perform numerical simulations and static models. It can also be used for data visualization and machine learning, among other things (Jupyter, 2021). The application was used in this thesis to manage the large amount of data provided by VOI.The second program is the ArcGIS Pro application which is a feature-packed software that supports data visualization and comprehensive analysis (Esri, n.d.). ArcGIS Pro can be used to transform data into maps and actionable information, which was of interest in this thesis.

Figure 10 demonstrates the steps taken in the proposed framework. The three main steps of the proposed framework are: the information about the recorded e-scooter trip, estimation of substituting the transport modes by the recorded e-scooter trip and determining GHG emission reduction of the recorded trips.

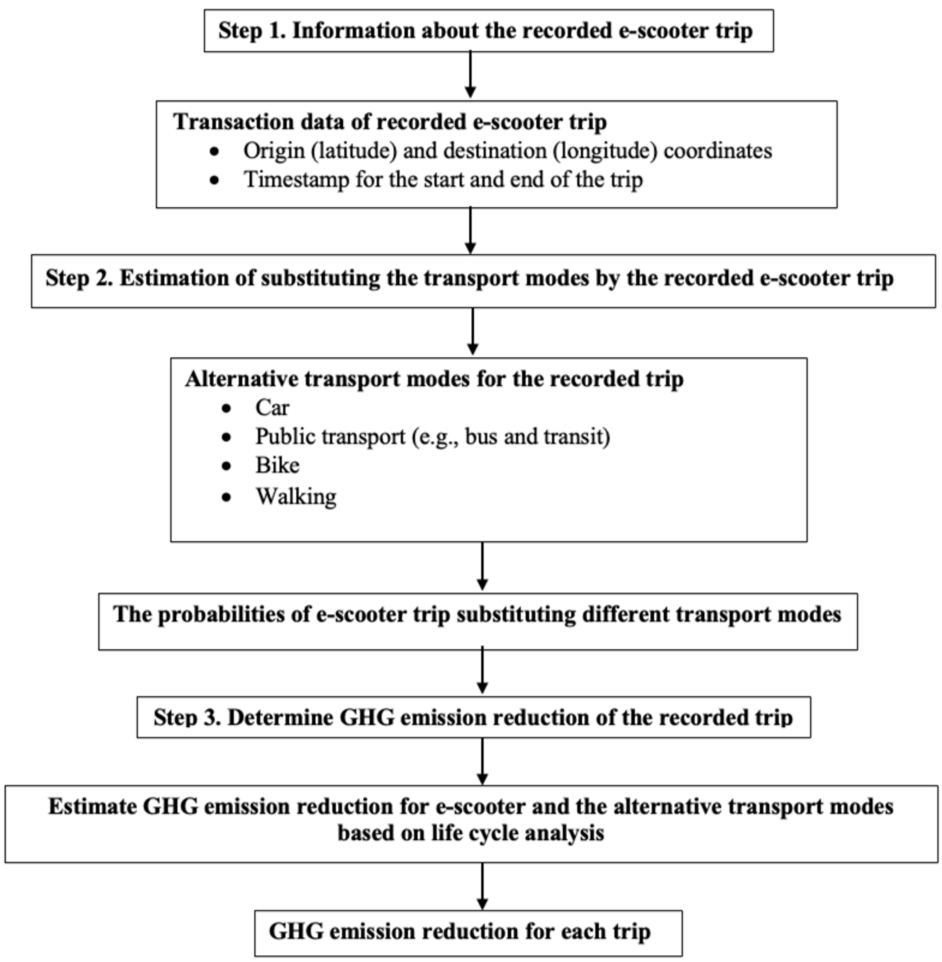


Figure 10: Framework for assessing e-scooters environmental benefits.

4.1 Extracting trip transactions from position data

The raw data that was provided by VOI was downloaded from open API data. The downloaded data was in form of positioning data and only contained the GPS information about the e-scooters that were not in use meaning that once the e-scooter was in use it was not included in the list. Moreover, the data was downloaded at a frequency of 10-15 seconds making it possible to record many trips to give a fair representation of the situation. By downloading the data at such a high frequency, it was ensured that the start and end coordinates of each trip were included in the data, which was then analysed. It also made it possible to extract the distance based on the position data. Lastly, by knowing the download frequency the start/end time of each trip could also be extracted. In total approximately two months' worth of positioning data was transformed into transaction data which was then used to perform the different analysis.

The data provided contained 762 565 trips. Some trips were however abnormal which indicated that some outliers needed to be cleared of the transaction data. This was done by limiting the travel distance, duration, and speed. According to VOI's terms of service, one can only travel for 45 minutes continuously, thus setting the maximum duration to 45 minutes. Furthermore, the speed was limited to 20 km/h which is the maximum permitted speed, and the distance was limited to 10 km. Once all the outliers were cleared out of the transaction data the number of trips went down from 762 565 to 532 938. The analysis was then performed using the data that had been cleared.

4.2 Estimating substituted transport mode for each trip using e-scooter

When analysing the substituted transport mode for each trip using e-scooter, the statistics about the probability of using different transport modes with the trip distance. The trip distance is presented in the transaction data and by analysing the relationship between the probability of using different transport modes (see Figure 11) and the trip distance, the substituted transport mode for each trip using e-scooter could be estimated.

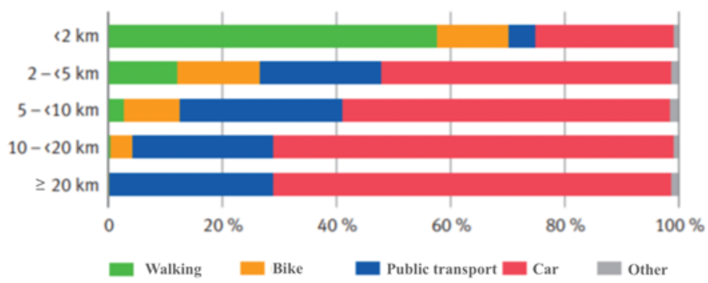


Figure 11: Distribution of transport modes per travel distance on weekdays (Västsvenska paketet, 2017)

4.3 Environmental influences analysis

4.3.1 GHG calculations

When analyzing the difference between the GHG emissions of using e-scooters and using the substituted transport mode for a specific trip is a result of GHG emission reduction from using e-scooter for the trip. The GHG emission reduction of the trip is calculated by using eq. 1.

$$P_{walk} \times GHG_{walk} + P_{bike} \times GHG_{bike} + P_{pub.transp.} \times GHG_{pub.transp.} + P_{car} \times GHG_{car} - GHG_{e-scooter} \tag{1}$$

Where: P_j is the probability of each transport mode j (see Figure 8 (a))
GHG_j the green house gases for each transport mode j (see eq. 2)

The probability for using transport mode j for different trip distances in Gothenburg. By using Figure 8 (a), the probability of using the transport mode j depending on the trip distance could be determined. While the GHG emission factors of using transport mode j were calculated by using equation 2.

$$GHG_j = E_j \times Distance_j \tag{2}$$

Where: $Distance_j$ is the travel distance of using a transport mode j of a trip
E_j is the final emission factor for each transport mode j (see eq. 3).

$$E_j = E_{pj} + E_{oj} \tag{3}$$

Where: E_{pj} is the emission factor during the production phase for each transport mode j
E_{oj} is the emission factor during the operation phase for each transport mode j

From Table 2, the emission factors (E_{pj} and E_{oj}) during production and operation phases for the different transport modes can be observed. The different transport modes can be described in more detailed what there are representing (Cottell, Connelly & Harding, 2021). Car in the table is representing the mean CO2 emission values of BEV (Battery electric vehicle) and ICE (Internal combustion engine) cars were calculated. The bike category is divided into private and shared e-bike while public transport is a combination of bus and tram. The GHG emissions during production and operation phases of different transport modes are presented in Table 2. The emission of walking is zero in the production and operation periods because no energy is consumed during these phases.

Table 2: Mean CO2 - emission factors for respective transport mode (Cottell, Connelly & Harding, 2021).

Emission factors (g CO2-eq/pkm)	**Car**	**Bike**	**Public transport**	**Shared e-scooter**	**Walking**
Production [E_p]	29.45	18.75	7.14	35	0
Operation [E_o]	131.25	18.3	8.9	32.1	0
Total emission [E]	160.7	37.05	16.04	67.1	0

4.3.2 Analysis of emission reduction in different areas

Since both emission per trip and emission reduction per trip were known, the emission reduction for each area could be calculated for each zone. This made it possible to calculate the overall emission reduction (see eq.4) and the overall emission reduction weekly (see eq.5, where the division by 9 represents 9 weeks of collected data).

$$Overall\ emission\ reduction = Mean\ value\ emission\ reduction \times nr\ of\ trips \tag{4}$$

$$Overall\ emission\ reduction\ (weekly) = \frac{Mean\ value\ emission\ reduction}{9} \tag{5}$$

Once all the necessary calculations were performed the overall emission reduction and overall emission reduction weekly could be visualized by adding it as an attribute in ArcGIS.

4.4 Usage pattern analysis

The transaction data handled in the application Jupyter Notebook was used as input data in ArcGIS Pro but before running the data in the software the topography of Gothenburg was selected. From the VOI-app the Gothenburg was delimited within VOI's own zone and was then divided into different zones, more specifically 27 zones, for a better understanding.

The boundaries of the different zones were mainly determined by the districts in which Gothenburg is already divided in. However, some special considerations were still taken into account when defining the boundaries such as motorways and other major roads that naturally divides the land into different areas. Furthermore, the Göta River also constituted a barrier since e-scooters that are in the water is not of interest. Since VOI's area of use is the inner city and the middle city, there were no major natural barriers to consider other than the Göta River. When choosing the zones, it was also considered how the zones are built i.e., land use such as industries, companies, stores etc.

4.4.1 Spatial and temporal analysis

Spatial analysis: The first step in the spatial analysis was to download the transaction data into ArcGIS Pro. The transaction data was downloaded for each zone and this by choosing "select by location" where the transaction data was selected in the "input feature" and the zone of interest was selected in the "selecting features". In order to analyse the spatial distribution of the study are, the "XY to line" was used. According to ArcGIS Pro own website (n.d.(b)) the tool "XY to line" is described as the tool that "creates a feature class containing geodetic line features constructed based on the values in a start x-coordinate field, start y-coordinate field, end x-coordinate field, and end y-coordinate field of a table". In this study, the table that are used for this analysis is the attributes from the transaction data. After running the "XY to line" for each zone, the "Merge (Data Management)"-tool was used. The "Merge (Data Management)" has the function to "Combines multiple input datasets into a single, new output dataset. This tool can combine point, line, or polygon feature classes or tables."

By performing this analysis in ArcGIS Pro, a visual representation of how the trips are distributed across the city could be presented. Furthermore, it was also investigated how long the trips are in terms of distance. This was done by calculating the distributions and analyzing the statistical data for all trips occurring in Gothenburg in the application Jupyter notebook

Temporal analysis: For the temporal distribution three different aspects were analysed which were:

- What is the duration of the trips?
- On what day do most trips take place?
- What time do most trips take place?

Like the spatial analysis this was also done in Jupyter notebook by calculating distributions and analyzing the statistical data for each of the questions posed above.

4.4.2 Geofencing

Geofencing is according to Smart city Sweden (n.d.) described as a virtual fence that controls the movement of vehicles within a geographical area. VOI has created several geofencing, as mentioned in chapter 3.2, which purpose is to navigate users where VOI's geographical boundaries are in the 27 different zones in Gothenburg. According to the VOI app, users can get a discount on their VOI-trip if they park the e-scooter at the "great parking lots" that are visualized with green zone on the app. An analysis of how many e-scooters were parked on these parking lots was done by creating a new shapefile named "parking lots" in ArcGIS Pro. After creating the parking lots on the 27 different zones in ArcGIS Pro, the transaction data was merged with the parking lots and the number of e-scooters in each "great parking lot" could be analysed.

5 Results

5.1 Spatial usage patterns

We firstly investigate the spatial usage patterns in different parts of the city. We divided the studied area into 27 zones based on land use and municipal boundaries, as shown in Figure 12.

Figure 12: Overview image of the 27 different zones in Gothenburg.

5.1.1 Number of trips in each zone

The results are based on VOI data that begins on the 14th of May and ends on the 20th of July. Figure 13 and 14 show the number of VOI trips that have taken place in each zone. The map is marked with different colors to demonstrate how the demand varies. The dark red color indicates that there is a high demand for e-scooters in those specific areas while yellow indicates that the demand is low. The exact intervals can be seen in Figure 13. From the figure and the diagram, it is clear that Olivedal-Haga, Inom Vallgraven and Johanneberg are the areas with the greatest demand. On the other hand the areas with the smallest demand are Skår, Delsjöområdet and Tingstadsvassen-Hisingsbron.

Moreover, a clear pattern can be distinguished from Figure 13 of how the demand is at its highest in the inner city and decreases gradually the further away the areas are located from the inner city. Furthermore, there is one area that is an exception to this pattern which is Kvillebäcken. Kvillebäcken has a high demand despite being at the edge of the zone and being surrounded by zones that have a low demand.

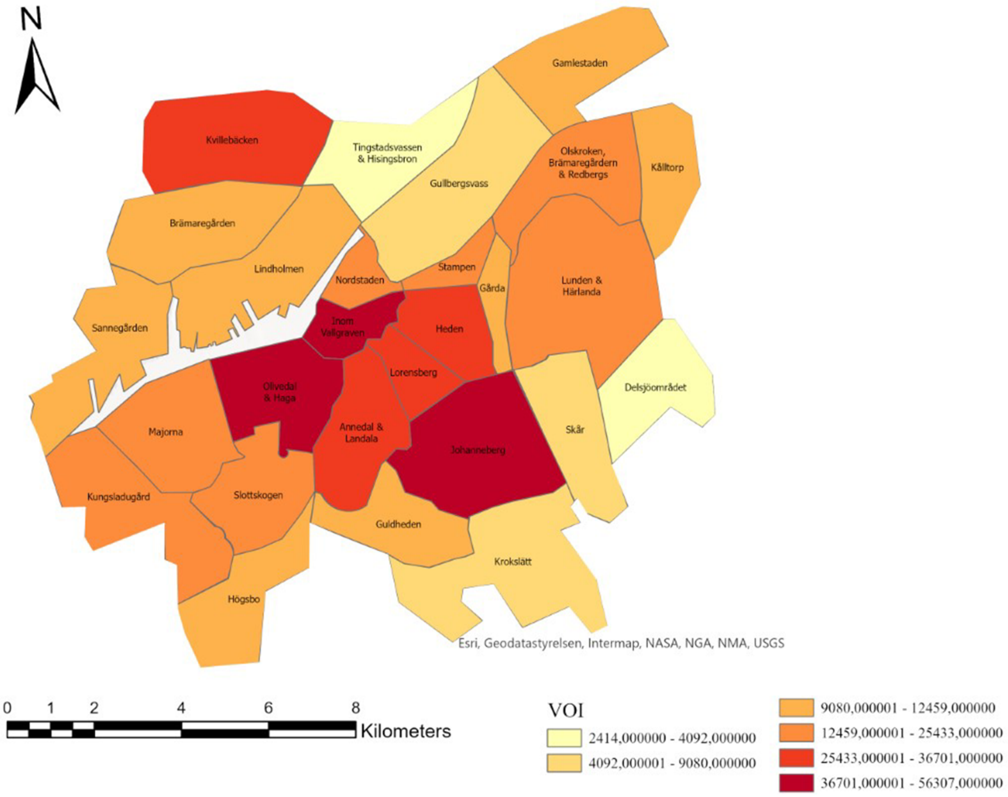


Figure 13: Number of VOI trips for different zones.

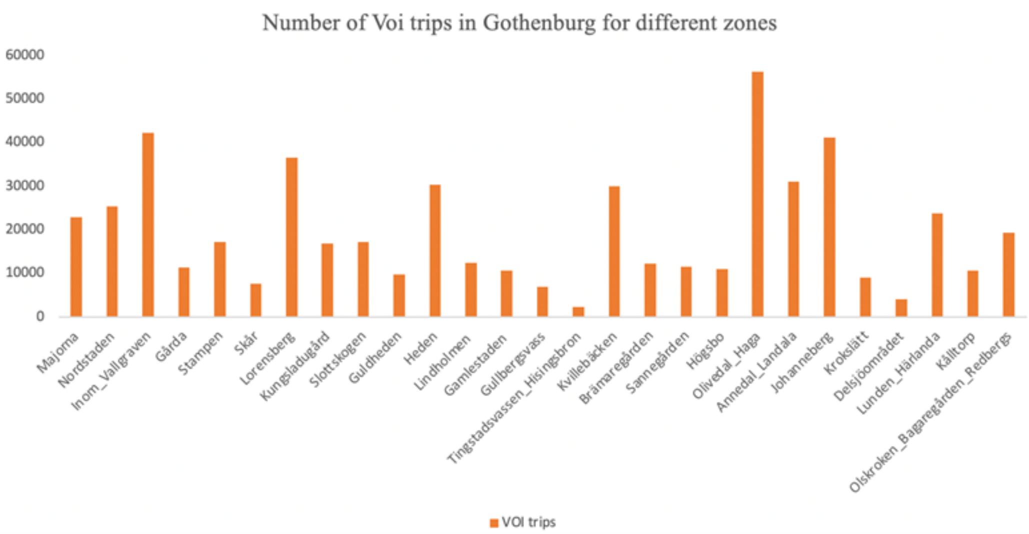


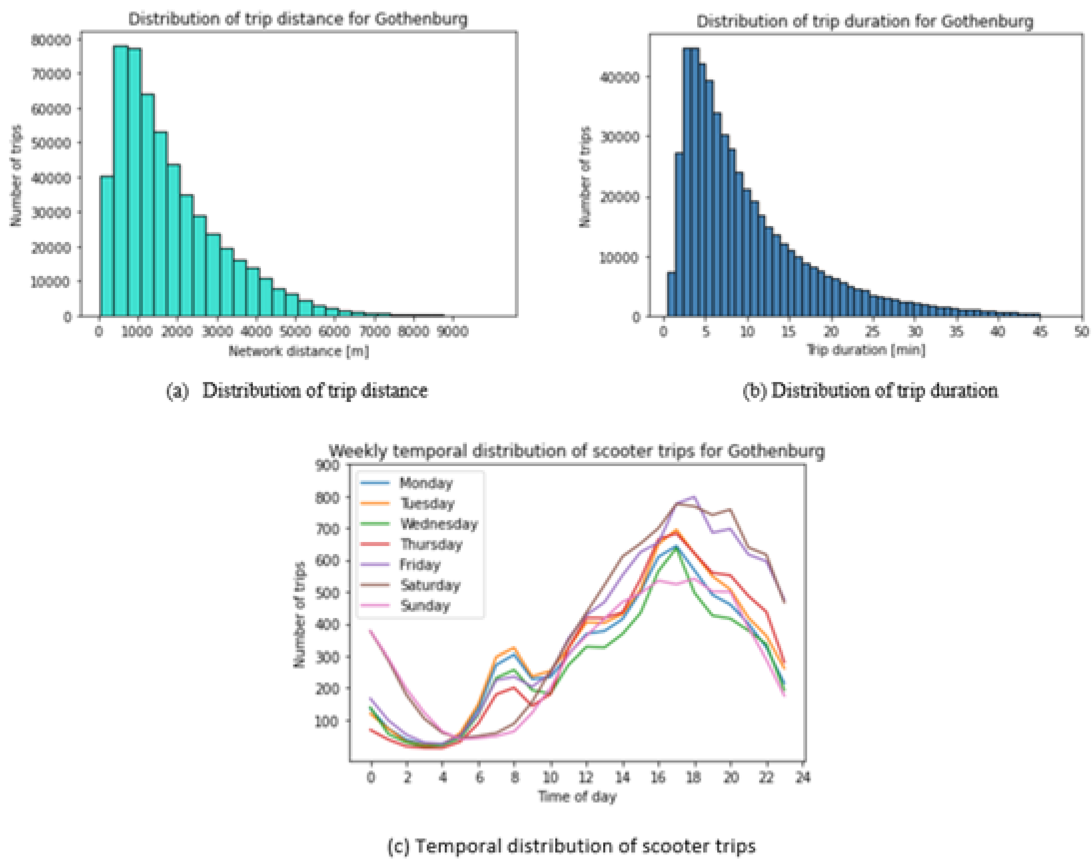
Figure 14: Number of VOI trips in Gothenburg for different zones based on transaction data.

5.1.2 Trip characteristics of using SESS in Gothenburg

Based on the approximately two months' worth of data the distribution of trip distance and duration was calculated as well as the temporal distribution for all the zones in the the VOI zone. Figure 15 shows the results from each of those calculations.

From Figure 15 (a) it can be seen that most trips travel a distance between 0.5-1.8 *km* and the number of trips gradually decreases as the distance increases. Furthermore, most trips have a duration between 4-7 min. Like previously it is clear that most of the trips are shorter rides and when the duration increases the number of trips decreases.

Lastly the temporal distribution shows during what day of the week and what time of the day most of the users ride the e-scooters. From Figure 15 (c) it can be seen that the most popular days are Fridays and Saturdays where the number of trips are around 800 while the least popular day is Sundays and the number of trips decreases with about 60% compared to Fridays and Saturdays. Furthermore,the graph also shows that the number of trips increases during the day. The least amount of trips occur in the morning between 06.00-09.00 with about 200-300 trips. During noon, the number of trips have increased by about 150% to around 500 trips. The maximum peak hour occurs in the afternoon between 15.00-19.00 with around 600-800 trips where the number of trips has increased by 300-350% compared to the morning peak hour. Furthermore, it can also be seen that the afternoon peak hour has a longer duration during the weekends (Friday and Saturday nights) and last until 22.00.



(a) Distribution of trip distance

(b) Distribution of trip duration

(c) Temporal distribution of scooter trips

Figure 15: Spatial and temporal distributions for the entire VOI zone

Table 3: Statiscal parameters regarding trip distance and trip duration for the entire VOI zone

All 27 different zones	**Nr of trips**	**Mean**	**Mode**	**Std**	**Min**	**25 %**	**50 %**	**75 %**	**Max**
Trip distance [m]	532 938	1793	714	1334	47	778	1425	2480	10000
Trip duration [min]	532 938	10	2	8	1	4	8	13	45

5.1.3 Trip characteristics in different urban areas of Gothenburg

Trip distance: Figure 16 shows that all areas have a distribution that is skewed to the right except Delsjöområdet which has a distribution that is somewhat right-skewed because of the shape but at the same time deviates from the traditional shape because of the one bar that stands out to the left. The distribution being skewed to the right indicates that the number of trips decreases as the distance increases.

A clear difference regarding the travel distances can be seen between the areas that have a high demand compared to the areas with a low demand (top three and bottom three). Areas with a high demand travel very short distances between 0.8-1.5 *km*. In Figure 16 (b), for example, it can be seen that more than 40% of all trips that take place in Olivedal Haga travel a distance between 0.8-1.2 *km*. Similar values can also be seen for Inom Vallgraven and Johanneberg, see Table 4.

Trips that take place in the three smallest areas tend to travel slightly longer distances where most of the trips are between 1-2.5 *km* apart from the Delsjöområdet, see figure 16 (e). In this area, most trips are about 1.5 *km* or between 3-4 *km*. In addition, the number of trips in these areas are significantly less than the number of trips that take place in the areas mentioned above. For these three areas, it can be seen from Figure 16 (d-f) that the area Tingstadsvassen has the highest number of trips occuring for distances between 0.8-1.5 *km* where the number of trips amount to approximately 1400. For the other two areas the number of trips amount to approximately 500 respectively. This means that there are almost 8 times more trips occurring in the three larger areas compared to the three smaller areas. Moreover, VOI have limited the trips to a max distance of 10 *km* however, the results show that the longest distance in these areas was 9.2 *km* which was once again in the Delsjöområdet.

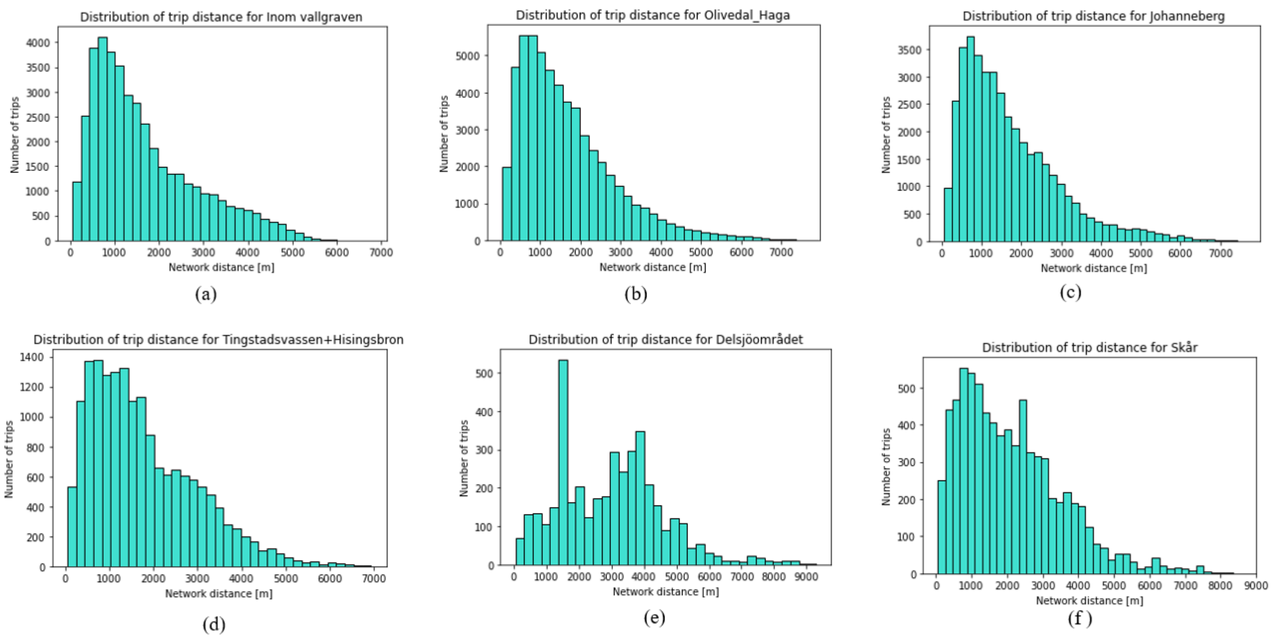


Figure 16: Trip distance for the three areas with the biggest and smallest demand.

Table 4: Statistical parameters for trip distance.

Area	Nr of trips	Mean	Mode	Std	Min	25 %	50 %	75 %	Max
Inom Vallgraven	42 274	1676	800	1178	52	770	1343	2344	6778
Olivedal-Haga	56 307	1649	1000	1172	49	760	1374	2232	7568
Johanneberg	41 251	1701	800	1215	51	779	1391	2334	7614
Tingstadsvassen	17 330	1763	800	1187	49	830	1491	2511	6931
Delsjöområdet	4092	2978	1500	1597	54	1591	3066	3951	9289
Skår	7738	2107	600	1431	53	961	1864	2950	8349

Trip duration: The distributions for trip duration, see Figure 17 looks almost the same as the distribution for trip distance in terms of shape. They are all right skewed and, as before, Delsjöområdet deviates slightly from the traditional positive skewed distribution. The figures show that most trips have a duration between 5-10 min except for the Delsjöområdet where most trips either last 5 min or 15 min.

Table 5 shows different statistical parameters about the duration. The results show that all areas except Delsjöområdet have an average duration of about 10 min, while Delsjöområdet has an average duration of 16 min. The median values are very similar to the mean values which means that both the mean and the median values give a fair representation of the dataset. Moreover, like the limitation with the distance, the duration has also been limited to a maximum of 45 min and the results show that all areas have at least one trip that reaches the maximum duration.

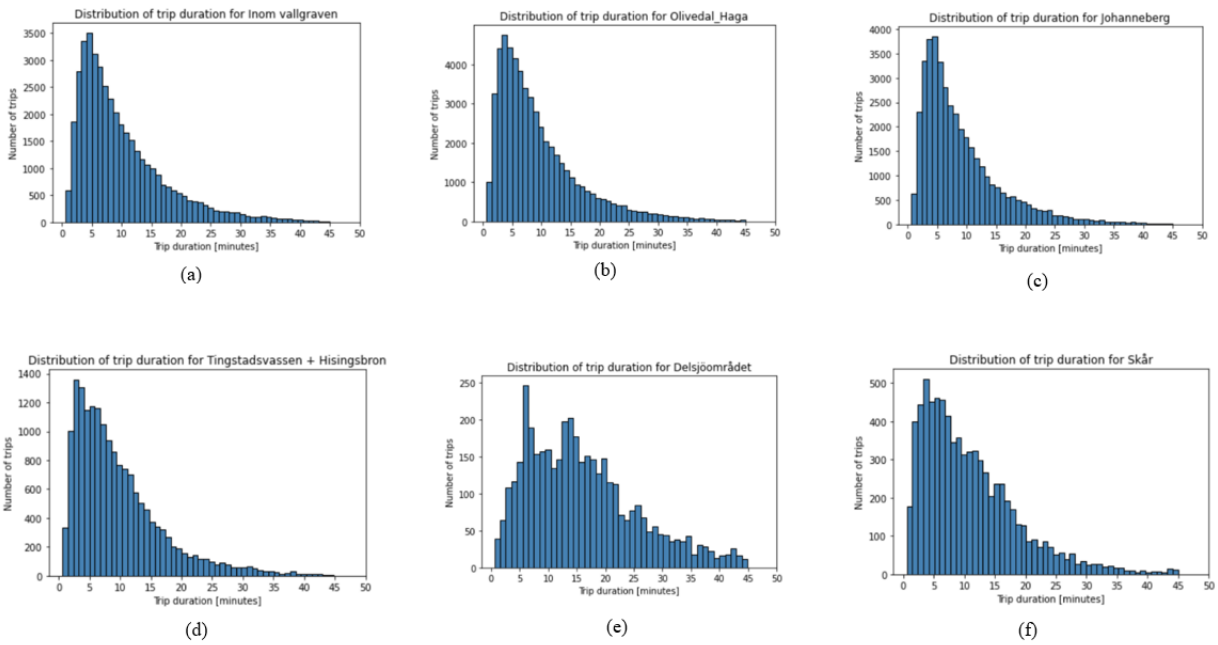


Figure 17: Trip duration for the three areas with the biggest and smallest demand.

Table 5: Statistical parameters for trip duration

Area	Nr of trips	Mean	Mode	Std	Min	25 %	50 %	75 %	Max
Inom Vallgraven	42 274	10	5	8	1	5	8	13	45
Olivedal-Haga	56 307	10	5	7	1	4	7	12	45
Johanneberg	41 251	9	5	7	1	4	7	12	45
Tingstadsvassen	17 330	10	3	7	1	4	8	13	45
Delsjöområdet	4092	16	6	10	1	8	14	21	45
Skår	7738	11	5	8	1	5	9	15	45

Mean, median and mode: Since all the distributions have a positive skew, the average value is a little larger than the median value. By comparing the different values with the figures for both trip distance and duration, it can be seen that the median is more representative than the mean. For example,the average trip distance for Johannberg is 1701m m while the median is 1391 m and Figure 16 (c) shows that there are more trips occurring at 1400 m compared to 1700 m. Nevertheless, the most accurate parameter is the mode which describes which distance that has the most trips. The modes for the different areas can be seen in Table 4 which shows that trips in Delsjöområdet have the longest travel distance of 1500 m while Skår has the shortest travel distance of 600 m. Similar argument can also be made for the trip durations i.e that the mode is the most representative parameter. For example, the mean duration for Inom Vallgraven is 10 min, however most of the trips have a duration about 5 min as seen in Figure 17 (a).

Standard deviation: Small values of standard deviation indicate that the dispersion of the data from the mean value is small while high values indicate that the data has a great variance which obtain more uncertain results. The standard deviation for both the trip distance and duration is high for all areas, thus indicating that the data has a large dispersion. The area with the lowest value for standard deviation is Skår since most of the values are on the left side of the data while Delsjöområdet has the highest standard deviation which is expected since its data is very dispersed.

Percentiles: Percentiles show how the data is distributed within different intervals. In this report, it has been chosen to report for the 25th, 50th and 75th percentiles. For trip distance, it appears that 25% of all trips for the three largest areas travel a distance that is less than about 800 m while 50% of all trips are shorter than about 2000 m and lastly 75% of all trips are shorter than 2350 m. For the three smallest areas, there are slightly larger differences between the different areas due to Delsjöområdet which as previously mentioned deviates from the traditional right skewed distribution. Nevertheless, in general it can be said that about 25% of all trips are shorter than 1130 m while 50% of all trips are shorter than 2140 m and lastly 75% of all trips are shorter than 3140 m.

Trip duration has a more even distribution for all areas compared to trip distance where there was a difference between the three largest and smallest areas. However, Delsjöområdet deviates slightly and because of this all areas except Delsjöområdet will be presented first and after that will Delsjöområdet be presented on its own. The distribution here is that 25% of all trips are shorter than approximately 5 minutes, 50% of all trips are shorter than approximately 8 minutes and 75% of all trips are shorter than 14 min. For Delsjöområdet, 25% of all trips are shorter than 8 min, 50% of all trips are shorter than 14 min and finally 75% of all trips are shorter than 21 min.

5.1.4 Temporal usage patterns in different areas of Gothenburg

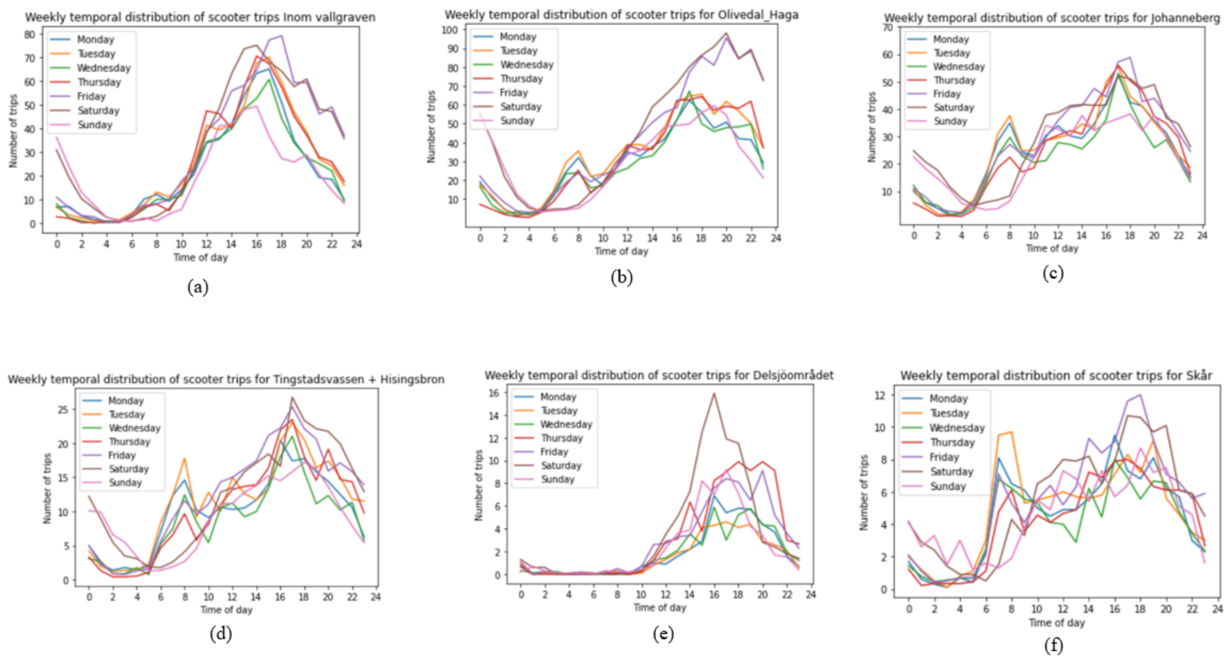


Figure 18: Temporal usage patterns.

Figure 18 shows how the e-scooters are used in a given week. By comparing the figures to each other, it can be seen that the usage of e-scooters increases during where the maximum peak takes place during the afternoon. All distributions have an afternoon peak but only four out of six areas have a morning peak Where two out of those areas have university campuses located nearby. The areas with a morning peak are:

- Olivedal-Haga
- Johanneberg
- Tingstadsvassen
- Skår

The peaks occur approximately around the same time for all the distributions; however, a small difference can be seen between weekdays and weekends. The afternoon peak for weekdays (Monday-Thursday night) takes place between 16.00-20.00 where most trips occur around 18.00. The morning peak on the other hand takes place between 06.00-09.00 where most trips occur at 08.00. For weekends (Friday night – Saturday night) the afternoon peak lasts a little further into the evening approximately until 22.00. There are no morning peaks during the weekend.

For those areas that have two peaks over a 24-hour period, the usage rate is much higher during the afternoon compared to the morning. There are some variations where some areas have an increase of more than 100% such as Olivedal-Haga while others only increase by 20% such as Skår.

Generally, Fridays and Saturdays seem to be the most popular days to ride e-scooters on where they amount to almost 100 trips in the more popular areas (see Figure 18 (a)-(c)) while they only amount to a maximum of 26 trips in those areas that are not as popular (see Figure 18 (d)-(f)). For Delsjöområdet, Thursdays are also a very popular day. For the remaining days, the use seems to be even, and no special day stands out to be the least popular.

5.1.5 Geofencing

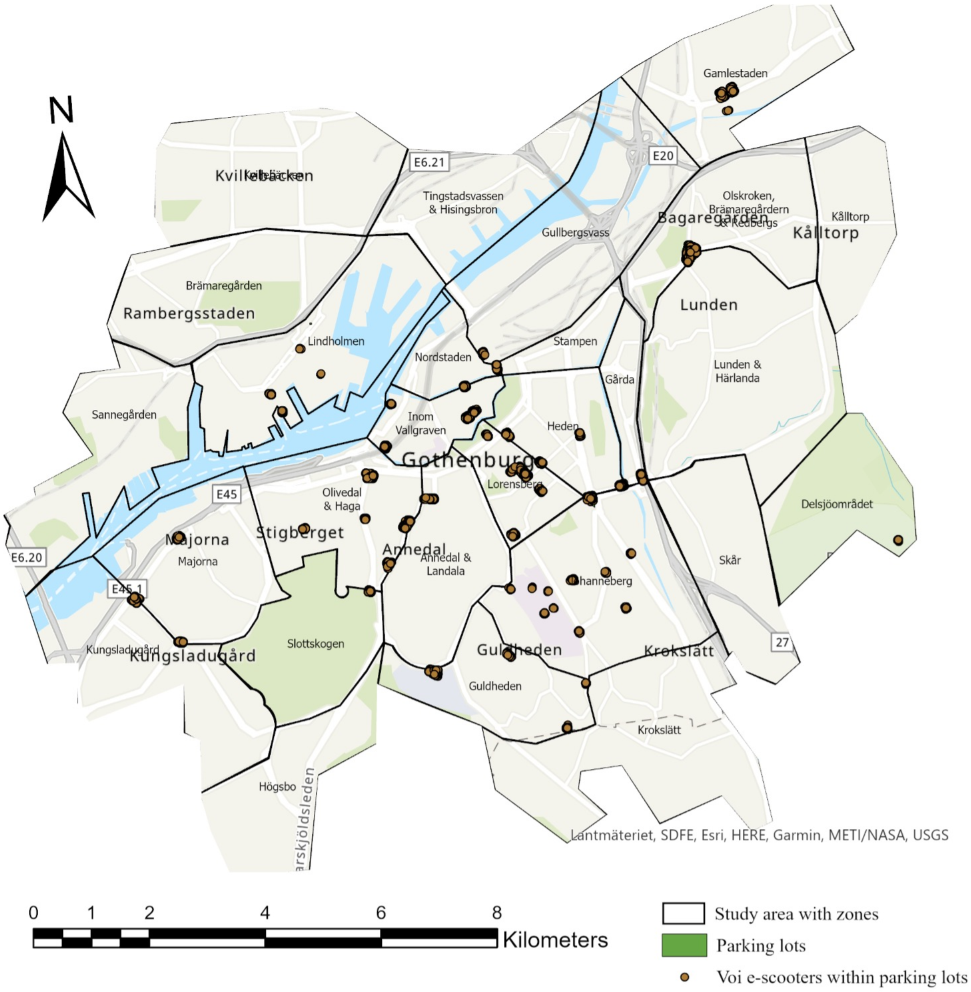


Figure 19: Distribution of parking lots in the VOI zone.

The company VOI has developed different parking lots on their app where “great parking lots” helps users to navigate where the optimal parking lots can be found. These parking lots are visualized with green on the VOI zone and if users park their e-scooters there they will be rewarded with a discount on their trip. The parking lots are mainly located on the center parts of the VOI zone (see Figure 19). When analysing which zone that have the majority and minority of these parking lots, the results showed that the area of Johanneberg has most of the parking lots with 11 of them while Gullbergsvass, Olskroken Bagaregården, Gårda, Delsjöområdet, Slottskogen and Kungsladugård have only one parking lot for each respective zone. However, when analysing the number of e-scooters that were parked on these parking lots in each zone, Lorensberg has the majority while a minority were parked in Kungsladugård (see Figure 19).

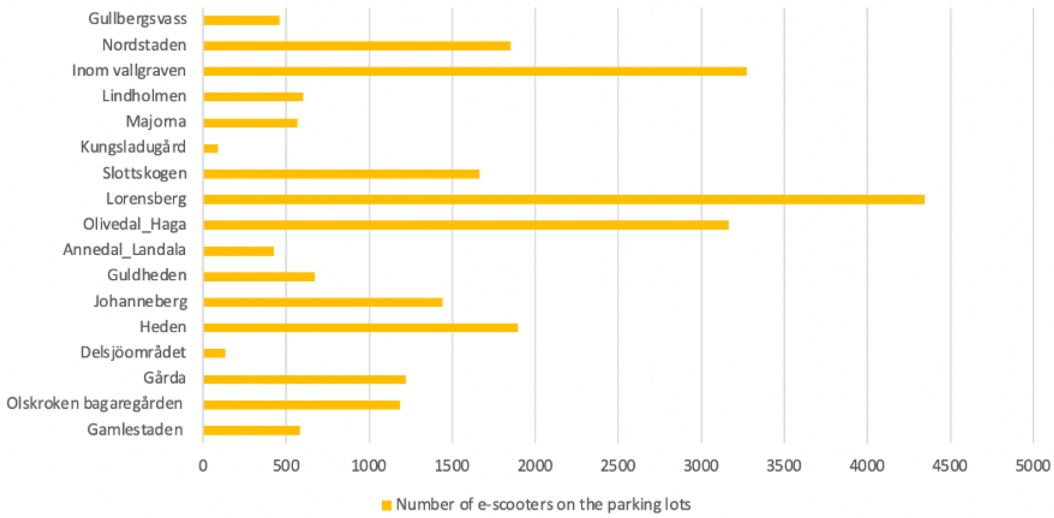


Figure 20: Number of e-scooters that were parked on the “very good parking lots” in the different zones.

5.2 Environmental effects of SESS

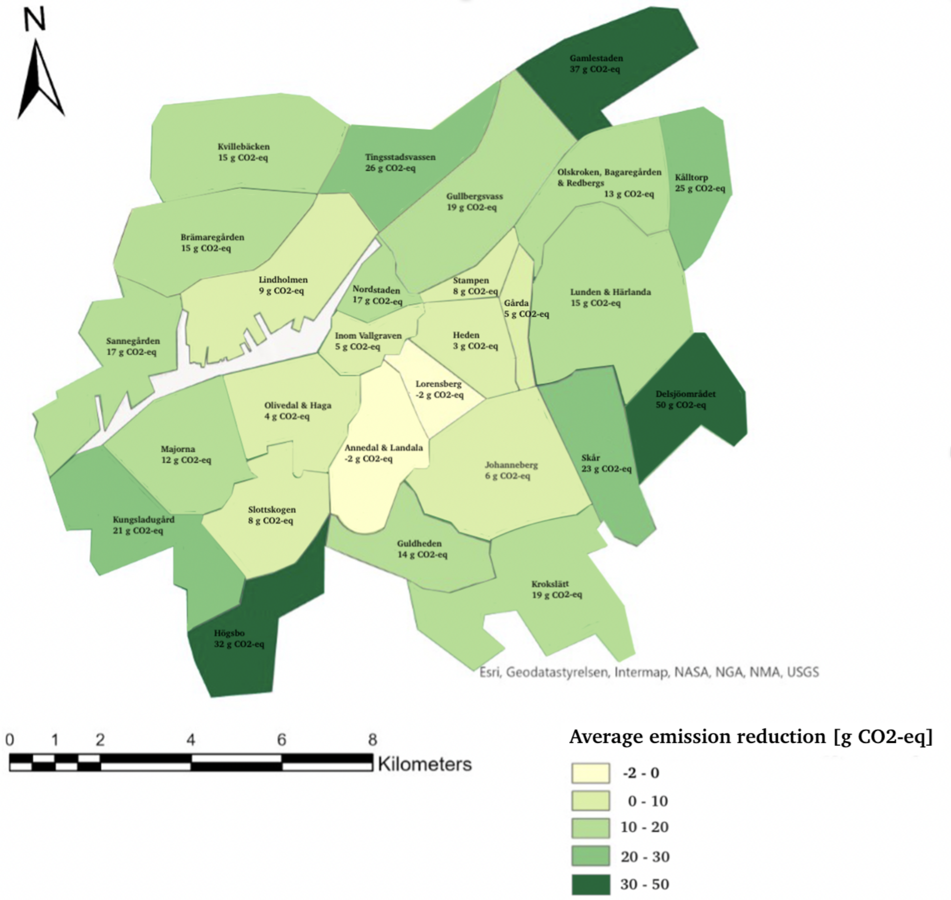


Figure 21: A map of the average GHG emission reduction per trip in the different zones.

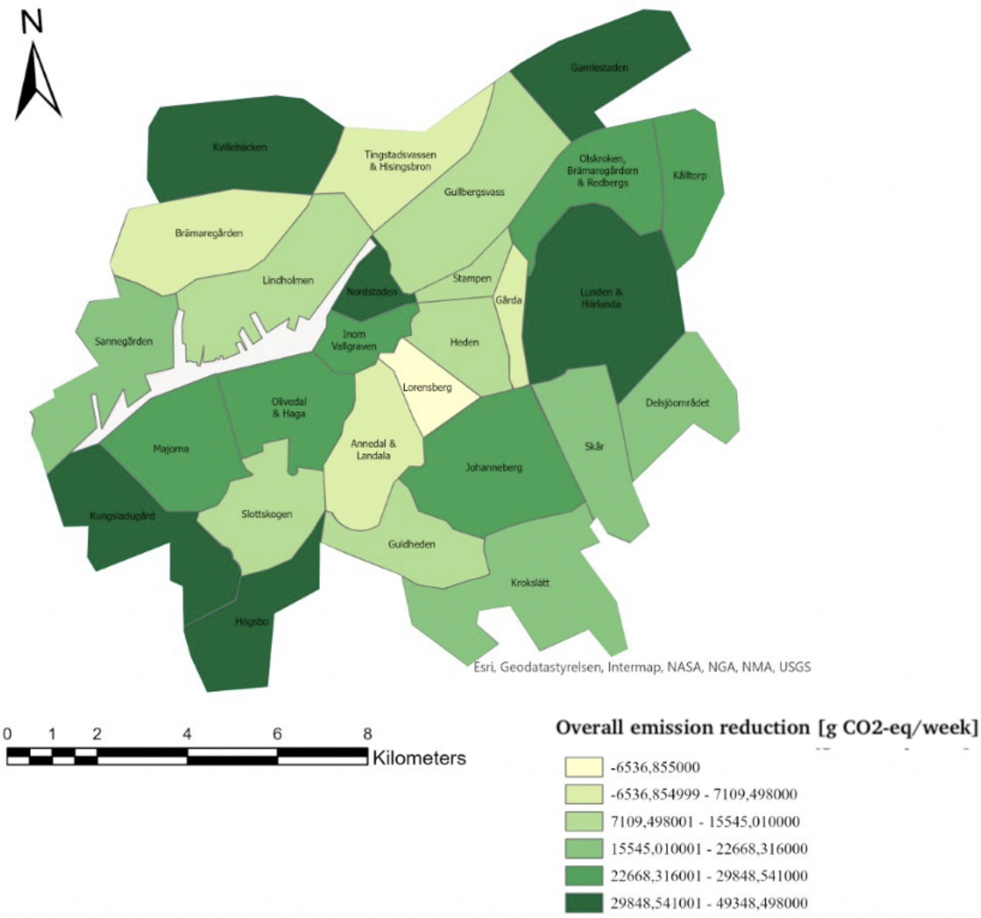


Figure 22: A map of overall GHG emission reduction in the study area.

Figure 21 shows which zones have the largest respectively the smallest GHG emission reductions when substituting the trip by a e-scooter instead of using other transport modes (i.e., car, public transport, bike and walking). From Figure 21 it can be observed that the largest GHG emission reductions are shown in Gamlestaden, Högsbo and Delsjöområdet. It can also be observed that the closer to the center of Gothenburg, the more does the values of GHG emission reduction decrease. Figure 21 further presents that the zones Annedal Landala and Lorensberg are showing the lowest GHG emission reduction, with -2 g CO2. Low GHG emission reduction values means that in these areas of Gothenburg does the e-scooter devices have a negative impact when replacing the transport modes that are used if not being substituted.

Furthermore, the statistical parameters regarding the emission reduction can be analysed. From Table 6 it can be observed that the mean emission reduction in the entire VOI zone is 10.47 i.e. positive GHG emission reduction, while the maximum value is approximately 440. Table 7, on the other hand, presents the statistical parameters for the average emission reduction in the 3 smallest and the 3 largest areas in terms of demand. The figure show that 2 of 27 zones (i.e. Lorensberg and Annedal-Landala) have negative GHG emission reduction in terms of the mean value and also the most number of trips are conducted in these 2 zones. Moreover, the Table 7 shows that from the green areas (Gamlestaden, Högsbo and Delsjöområdet) that have respresents positive environmental effects, Delsjöområdet among these 3 areas shows the largest GHG emission reduction. From Table 8 it can be observed that Lorensberg has the smallest overall emission reduction while the rest of the areas shows the areas with largest results.

Table 6: Statistical parameters regarding emission reduction for the entire VOI zone

Area	Nr of trips	mean	std	min	25%	50%	75%	max
Entire Voi zone	531392	10,47	52,25	-47,4	-27,38	-13,6	54,22	439,499

Table 7: Statistical parameters for the average emission reduction

Area	Nr of trips	mean	std	min	25%	50%	75%	max
Lorensberg	36664	-1,5	43,98	-47,39	-30,23	-18,73	-3,78	188,7
Annedal-Landala	31095	-1,64	43,52	-47,4	-29,74	-18,14	-3,67	209,61
Gamlestaden	10761	36,8	65,55	-47,4	-14,55	-9	84,05	436,12
Högsbo	11007	32,11	61,96	-47,4	-18,31	-2,6	73,05	286,82
Delsjöområdet	4068	49,85	66,84	-47,39	-21,2	67,12	86,45	271,69

Table 8: Overall emission reduction for different areas

Area	Nr of trips	overall emission reduction
Lorensberg	36664	-56519,84
Gamlestaden	10761	396110,01
Högsbo	11007	353403,17
Kungsladugård	16922	362530,91
Kvillebäcken	30049	438538,99
Lunden_Härlända	23763	348902,65
Nordstan	2504	443594,04

5.2.1 Sensitivity analysis

Table 9: Emission reduction sensitivity

Increase of mean value	Scenario 1	Scenario 2	Scenario 3	Scenario 4
VOI zone	10%	20%	20%	30%
Inom Vallgraven	20%	20%	60%	60%
Olivedal-Haga	25%	50%	75%	75%
Johanneberg	17%	33%	50%	50%
Tingstadsvassen	2%	2%	9%	6%
Delsjöområdet	2%	4%	4%	4%
Skår	1%	6%	10%	6%

Table 9 shows how much the mean value for GHG emission reduction has increased based on the different scenarios presented in Table 11 found in the appendix, chapter 10.2. The table has been color-coded with red, yellow, and green to make it easier to see where the biggest changes have occurred. Red indicates that the increase in GHG emission reduction is very small and the interval has been set to be between 1-9%. Yellow indicates that there has been an increase however the impact it has may not be very great, thus the interval for yellow has been set to be between 10-20%. Lastly, green indicates that the GHG emission reduction has increased by at least 20% which has been interpreted as an increase that results in a relatively large impact. The results show that all four scenarios led to an increase in GHG emission reduction for all areas. The areas with a high demand (Inom vallgraven, Olivedal-Haga and Johannberg) have a high increase while the increase in emission reduction for the areas with a low demand (Tingstadsvassen, Delsjöområdet and Skår) are extremely small.

The results show that the entire zone does not increase very much between the different scenarios. The biggest difference is found between scenario 1 and 4 where the mean value increases by 20%. The mean value for GHG emission reduction for the three largest areas in terms of demand have an increase between 10-75% while the three smallest areas have a small increase between 1-9%.

The area with the smallest increase is Skår for scenario 1 while the area with the largest increase is Olivedal-Haga for scenario 3 and 4.

6 Discussion

6.1 Travel distribution across the VOI zone

The results shows that the majority of all trips taking place in Gothenburg occur in Olivedal-Haga, Inom Vallgraven and Johanneberg, while the least number of trips take place in Tingstadsvassen, Delsjöområdet and Skår. The reason why the map looks the way it does can be explained from three different aspects which are location, land use and demographics. By looking at these three aspects, several similarities and differences can be found between the areas with a high and low demand.

6.1.1 Location

Location is one of the most important aspects because it is well known that the central part of a city always has higher demand. This can also be seen in Figure 13 where the areas located in the city center have the greatest number of trips while the areas located towards the edges have a smaller number of trips. It can also be noted that the number of trips decreases gradually for the areas located further away from the center and out towards the edges of the zone.

The fact that the number of trips is much fewer in the zones that are located around the edges may be because e-scooters are not as accessible there as they are in the inner city. This may be because most people travel shorter distances and thus both start and end their trip in the inner city. This can be seen in Figure 15 where the average duration and distance for trips within Gothenburg is 10 min and 1.7 km respectively. This means that a trip that starts in Olivedal, for example, can with 1.7 km travel to Lorensberg in the east, Majorna in the west and Slottsskogen in the south. This in turn means that the positions of the e-scooters are still quite central and the number of e-scooters available decreases the further away one gets from the city center. This, combined with the fact that most parking spaces for e-scooters are in the city center, makes them less accessible outside the city center.

Another important aspect linked to location is whether these areas are in close proximity to important public transportation hubs since it is more likely that users then will use the e-scooter for the last mile before reaching their destination. Areas that are close to public transportation hubs will therefore also have more trips. This is also consistent with the results that have been presented. For the three largest areas it is two out of three that are near important public transportation hubs while for the three smallest areas there are no important public transportation hubs nearby.

6.1.2 Land use

Another factor that affects the usage pattern is land use. There is a major difference in how the land is used in central Gothenburg compared to areas located outside the city center. The inner city has large commercial areas, park spaces, campuses for both university and high school and office areas. On the other hand areas located outside the city center have large areas for households and slightly smaller areas for trade and other public places. This means that most people must travel into the city center in order to get to work/school and perform other everyday errands. As the average trip distance for e-scooters is less than 2 km, the probability of people using e-scooters to travel into the city is very small.Instead, they are much more likely to use the e-scooters once they are in the city center.

6.1.3 Demography

The third aspect that also have an impact is the demographics of the different areas. According to the literature study, it is mainly young adults and men who use e-scooters. Chapter 3.2.1 and Table 10 in Appendix 10.2 show the number of inhabitants and the most common age group for each area. Using this data, an estimation of what types of people that use e-scooters can be made. However, this is only an approximation and there are many factors other than the most common age group per area that affects who the travelers may be.

When observing the demographics of the three largest and smallest areas, it can be seen that the areas with a high demand are areas where there are more men than women registered and an age group that previous studies mentioned in Chapter 2.1.1 have shown use e-scooters. For the smallest areas there is no data for Tingstadsvassen but for the other two areas most of the inhabitants are women where the most common age group for Delsjöområdet is 30-39 and 50-59 for Skår. Although Skår have an older population that according to previous studies does not use e-scooters, the demand is higher in this are compared to Delsjöområdet that has the "right" age group. This can be due to several factors. To begin with, Delsjöområdet is a little located further away from the city center than Skår which means it takes longer to travel there. Skår on the other hand, is adjacent to Johanneberg which is an area that is among the three largest areas, which may further explain why Skår have higher demand than Delsjöområdet despite the high average age.

6.2 How does the distribution differ for the different areas

The distribution can be analysed from two different angles. One is to look at the entire VOI zone as one single area and the other is to look at individual areas which in this case are the three largest and smallest areas in terms of demand that are of interest.

6.2.1 The 27 different zones in Gothenburg

The results presented in chapter 5.1.2 is considered reasonable. The fact that most trips are on the shorter side is consistent with the results that have been presented from previous studies mentioned in chapter 2.1.1. There are several possible reasons to why the trips are on the shorter end. One reason may be that since most trips take place in the inner city the different public services needed are in close proximity to each other meaning that people wont have to travel very long distances to get to their destination. Moreover, multiple studies around the world have shown that most trips when using e-scooters are leisure trips rather than commuting trips. This in turn results in the trip distance not being as long as a commute distance. Besides,it can be noted from Figure 15 that most trips take place on Friday/Saturday evenings, which strengthens the argument that the majority of all trips are leisure trips rather than commuting trips.

For the temporal distribution there are two main peaks, one in the morning and one in the afternoon where the afternoon peak has many more trips than the morning peak. This may be due to several factors, but the main reason is probably because the input data that has been used ranges from mid-May to mid-July. This means that half of the input is during a period when most people went to school and work while the other half is during the summer holiday season. Because of this, the number of trips in the morning will be much less than those taking place in the afternoon which can also be seen in Figure 15 (c). Unlike the morning, most people still go out in the afternoon and evening, which results in the number of trips naturally increasing during these times. Furthermore, the results showed that the number of trips increases throughout the day. This can once again be explained by the fact that the data includes both a school/work period and a holiday period. During the holiday most people start their day a little later in the morning which explains why the usage increases until the evening and then decreases after 19.00 on weekdays and 22.00 on weekends.

If the input had covered Mars-May, for example, instead of May-July, the graph would probably look a little different. The main difference would be that the graph would have two clear peaks, one in the morning and one in the afternoon. In addition to that the number of trips in the morning would probably increase and be comparable to the number of trips that take place in the afternoon. Lastly, the number of trips would not increase during the day instead there would be quite few trips between 9.00-16.00 with perhaps a slight increase around noon due to lunch break.

6.2.2 The three largest and smallest areas

Distance and duration distribution: For the three largest areas, the distribution for trip distance and trip duration are almost identical. Figure 17 and Figure 16 show that most trips are around 5 min and travel about 1000 m. These values are once again considered to be reasonable and they are also similar to the results reported for the entire VOI zone. It was expected that they would show somewhat similar results since most of the analysed data is located in these areas. Unlike the similar results shown for the three largest areas, the results for the three smallest areas have some variations. The main difference is that the distribution of Delsjöområdet does not follow the trend of being skewed to the right like the other areas. The other difference is that the trip duration and distance are longer for these areas compared to the other three. In these areas most of the trips have a duration of about 6 min but there are also many trips that last around 15 min in Delsjöområdet. Like the trip duration, the trip distance is also much longer and is about 2 km which is twice as far as the distances observed for the three largest areas.

Temporal distribution: The result presented for the temporal distribution was not expected for these areas. It was expected that the three areas with the largest number of trips would have both a morning peak and an afternoon peak as they are within the city center and thus have a high demand. The results instead show that for the three largest areas it is only two out of three areas that have both a morning and afternoon peak. The third area that does not have a morning peak is Inom Vallgraven and this result is slightly surprising since it is within the city center and has a campus area nearby. However, since this area is adjacent to the central Station which is one of Gothenburg's most important public transport hubs many people may choose to travel by public transport from the central station to their destination instead of walking to this area and looking for e-scooters.

The results for the three least trafficked areas on the other hand is expected. Like before it is two out of three areas that have both a morning and an afternoon peak even though they are not very clear. The areas that have a morning peak is Skår and Tingstadsvassen and they are both adjacent to areas with a large number of trips, see Figure 13. They are also located near different campuses, which means that many students probably use e-scooters to travel to school in the morning.

Furthermore, even though the temporal distribution is unique for each area some similarities that can be distinguished is that:

- The number of trips increases during the day.
- They all have a peak in the afternoon around 18.00 for weekdays and 20.00 for weekends.
- The most popular days are Fridays and Saturdays.

6.2.3 Geofencing

One of the biggest reasons to why e-scooters are so popular is because their flexibility and accessibility. Users can pick up an e-scooter from anywhere within the Voi zone and end their trip when they reach their destination without having to think about parking. Since users are able to park the e-scooters anywhere within the zone, many complaints have been made about how the e-scooters are an obstacle to pedestrians and cyclists. These types of complaints have been made around the world and has been discussed in more detail in 2.1.1. In connection with this, VOI has introduced geofencing within their zone as described in chapter 3.2. By dividing the zone into smaller zones with different conditions, VOI believe that they reduce the number of accidents while ensuring that the streets are free of obstacles. One of the limits that has been analysed in this thesis is how many users that park within a "great parking zone". The result showed that approximately 4%

of all e-scooters were parked in a great parking lot, which is a very small percentage. Since this thesis has not analysed ordinary parking spaces it is difficult to estimate how many trips that end in a parking zone.

Enforcing users to end a journey within a parking zone has both advantages and disadvantages. Examples of some advantages are that they do not disturb or lie as an obstacle on the streets. It will be easier for those who collect the e-scooters and charge them to ride a predetermined route with their cars, which in turn contributes to less emissions. Another advantage is that the users know where to go in order to get a hold of an e-scooter. On the other hand, this also means that a part of the e-scooter's purpose disappears since they won't be as easily accessible as they are today.

6.3 GHG emission reduction

The environmental analysis focused on examining the impact that the use of e-scooters has on the environment when they replace other transport modes. The results from Figure 21-22 and also the statistical parameters (see Table 7-8) showed that the further away the zone is located from the central part of Gothenburg, the higher environmental benefits from e-scooters i.e., larger GHG emission reduction. On the other hand, the results represented in chapter 5.2, also presented that approximately 2 out of 27 zones have negative values in the GHG emission reductions, meaning that in these zones the e-scooter trips increase the emissions of GHG. The explanation for the negative values could be that some e-scooter trips would be substituted by walking if there were no e-scooters, and according to Table 2 walking emits zero GHG emission. Public transport (e.g., transits and buses) and public services (e.g., schools, stores, banks, restaurants and so on) are generally available around the center areas in Gothenburg. This results in that people who live near the central parts of Gothenburg (e.g., Nordstaden, Inom Vallgraven, Olivedal-Haga, Heden etc.) have more options to accomplish their needs since most of the services are nearby. In such cases, the e-scooter sharing trips are short-distance (see Figure 15b) and are likely to replace walking rather than transport modes such as cars. This will therefore result in fewer GHG emission reductions in the central zones which have higher commercial land use.

Furthermore, a reason to why the zones (e.g., Gamlestaden, Högsbo and Delsjöområdet) that are located further away from the central part of the city have a lower GHG impact than the city center could be because of that the supply of public services is not as large in these areas compared to the city center. This means that they still need to travel into the city center to get everyday errands done. Since these areas are not too far away from the city center (approximately 2-4 km), it means that using the e-scooter is a good travel option. Moreover, the trips made with an e-scooter from these areas most likely replace cars and some public transportation since these are the two most common travel modes for distances between 2-5 km. This in turns explains why the GHG emission reduction is high for these areas, since the use of cars have a much higher GHG emission compared to the use of e-scooters according to Table 2.

Additionally, the results for the zone Nordstaden can also be discussed. Nordstaden is centrally located, however, in this zone the GHG emission reduction is higher than for the rest of the zones nearby. This result indicates that the usage of the e-scooters in this area is most likely replacing trips of transport modes that have higher emissions (e.g., car) than e-scooters which in turn has a beneficial effect on the environment. One reason could be that since the availability of e-scooters is high which is presented in Figure 13, people who used to take the car all the way to Nordstaden for e.g., errands or jobs, park the car a little further away from the center and takes an e-scooter the last mile. Another argument could be that in Nordstaden the e-scooters are more accessible for users, which makes them easier to take use. Lorensberg and Annedal-Landala, on the other hand, showed low GHG emission reductions meaning that e-scooter trips are substituting most likely walking in these areas. This case could be explained by using the term convenience, because for instance the more available, trendy, and easy the usage of e-scooters is in an area the more the demand increases and substitute a transport mode.

Moreover, the zones with a higher education facility density have higher environmental benefit from e-scooters. The use of e-scooters is being more common way for students, especially college students, to access nearby services in Gothenburg. This can be observed for e.g., Johanneberg, where Chalmers University of Technology is located, which has a positive GHG emission reduction and can be a result of the e-scooter usage. This might therefore be the explanation for higher GHG emission reduction in zones such as Johanneberg with higher education facility density.

6.3.1 Sensitivity analysis

The sensitivity analysis was done mainly because the probability of people walking and the probability of people traveling with public transport for distances less than 2 km seemed unreasonable for central parts of Gothenburg. Figure 8 that was reported in chapter 3.2.2 is scenario zero, i.e., the starting scenario which applies to the entire VOI zone. This scenario is not representative for the central parts of the city since the supply of public transport is large and always available. Due to the high availability of public transports in the city center, many travelers are probably using public transport for short distance trips too. In addition, the study zone includes several important public transport hubs which indicates that the use of public transport is high. Furthermore, it is not very far between different stops in central Gothenburg and there can be up to three stops within a 1 km distance. Because of this, only 3% using public transport in central Gothenburg was considered to be too small. This in turn also affects the results of the GHG emission reduction. To get results, in terms of GHG emission reduction, that represent the situation somewhat better four different scenarios were established where the percentage that uses public transport was increased and the percentage that walks was decreased for distances shorter than 2 km. The results showed that the mean value for GHG emission reduction increased for all scenarios and areas.

As it can be seen in table 9, there is a big difference between the three largest areas and the three smallest areas. This can be due to several different factors, but an important factor is the network distance. It has previously been presented that the three largest areas have many but short trips in term of distance while the smaller areas travel longer distances. This in turn means that the change in probability for trips less than 2 km does not have a large impact on these areas as the average distance is more than 2 km. There are certainly trips that are less than 2 km, but since they are not a majority the increase in emission reduction is extremely small. Unlike the three smaller areas, the larger areas have a great increase up to 75%. This is because the larger areas generally travel shorter distances so when the probabilities changes for these areas the emission reduction increases for most of the trips which in turn results in a higher mean value.

Furthermore, it appears that the emission reduction generally increases with the scenarios. This is because in each scenario it is the same parameters that have been changed, i.e., the probability of walking was reduced and the probability of using public transport was increased gradually. Nonetheless, there are some deviations, for example, scenario 4 for Tingstadsvassen and Skår decreases compared to scenario 3. Additionally, the emission reduction increasing so much for the three largest areas indicates that the input probabilities are very sensitive to distances that are less than 2 km.

As mentioned earlier this sensitivity analysis was performed because the proportions did not seem accurate for the city center and out of the four scenarios scenario three seems to be the most accurate in our opinion. From the results it can be seen that the e-scooters are more useful in the outskirt areas compared to the city center since there is a greater chance that they replace car trips that have higher emission than e-scooters. However, from Figure 13 it can be seen that the demand in these areas is low. In summary, the following can be said; in the areas that the e-scooters are used frequently the environmental benefit is generally low while in the areas that the e-scooters are used very little the environmental benefit is high.

7 Conclusion

7.1 What are the usage patterns of e-scooter in Gothenburg?

The results show that e-scooters are used to varying degrees in the different areas of Gothenburg. As stated in chapter 5.1.1 e-scooters are used to a much higher extent in central Gothenburg compared to areas outside the city center. This can be due to several different reasons such as location, land use and accessibility. Moreover, it is well known that the central part of a city always has a higher demand compared to the areas that are on the outskirts which was also what our result showed. This is because most people must travel into the city center in order to get to work/school and perform other everyday errands

When e-scooters were first introduced they were described as a means to solve the problem of the first and last mile. The results however show that the e-scooters are not primarily used for commuting but rather for leisure. This can be seen in the average distance and duration of the entire zone as well as the temporal distribution. The average distance and duration for the entire zone is 1.8 km and 10 minutes, which means that it is mainly very short trips that occur. Furthermore, the e-scooter is used mainly during weekday afternoons and especially during late weekend evenings when there is not a great need for commuting.

7.2 What are the differences of usage patterns in different urban areas?

As mentioned previously the results show that the areas with the highest demand are located within the city center while the areas with a lower demand tend to be located outside of the city center, see Figure 13. The main difference between these areas is the trip distance. The areas with a higher demand tend to travel shorter distances about 800-1.5 km while areas with a smaller demand travel longer distances about 1-2.5 km. This is mainly because the city center is densely built which means that the everyday tasks that need to be performed are usually near each other. This in turn indicates that the journeys do not have to be that long. Furthermore, several studies pointed out that it is mainly college students who uses e-scooters, which can also be seen in the results as the areas with a high demand have university campuses nearby which may explain the high demand. Another factor is that they are all located near important public transportation hubs which makes it more likely that the e-scooters are used for the last mile before reaching the destination.

7.3 What travel modes can e-scooters replace and how beneficial is this replacement from an environmental perspective

In this study, the e-scooters replace mainly walking and public transportation i.e., environmentally friendly modes meaning that the environmental impact might not be as beneficial as it was originally proposed. The discussion shows, however, that e-scooters are used as a substitute for walking and public transportation mainly in the city center compared to the zones with a longer distance to the center of Gothenburg. While the longer the distance is from the center, the more environmental benefit do the result shows. The reason can be that in the outskirt zones, the most common transport mode that is used when traveling e.g., into the center are cars. If e-scooters are used in these areas, they mainly replace car trips with higher GHG emissions compared to e-scooters which have a positive environmental impact. However, the majority of the e-scooter devices are more accessible in the city center compared to the areas further away. The literature review conduct that from a life-cycle perspective of e-scooters, the longer the e-scooter journeys are with fewer decelerations, the more environmentally friendly they are observed. Therefore, it can be conducted that e-scooter operations need to allocate more devices in the zones with a long distance from the city and maybe then these micro mobility devices will replace the more car trips.

8 Limitations

This report will focus on SMMS which in general includes both bike-sharing and e-scooter sharing systems. However, this study will only focus on e-scooters. More specifically, the study will only focus on e-scooters run by the company VOI. Furthermore, the report has also been limited geographically to Gothenburg. From an environmental perspective, the work will focus on GHG emissions linked to electric scooters and other common means of transport. Lastly, another limitation on this thesis is the method of estimating replaced transport modes (walking, bike, public transportation, and car).

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10 Appendices

10.1 Appendix 1

Table 10: Population demographic

Area	Female	Male	Total population	Most common age group
Annedal-Landala	3586	3487	7073	20-29 .
Brämaregården	-	-	-	-
Delsjöområdet	-	-	-	-
Gamlestaden	4288	4316	8604	20-29 .
Guldheden	4275	4314	8589	30-39 .
Gullbergsvass	-	-	-	-
Gårda	-	-	-	-
Heden	2240	2350	4590	20-29 .
Högsbo	1684	1684	3368	30-39 .
Inom Vallgraven	1615	1760	3375	30-39 .
Johanneberg	3275	3640	6915	20-29 .
Krokslätt	6013	6768	12781	20-29 .
Kungsladugård	4797	4357	9154	30-39 .
Kvillebäcken	5352	5954	11306	30-39 .
Kålltorp	3933	3594	7527	20-29 .
Lindholmen	1894	1995	3889	20-29 .
Lorensberg	655	631	1286	60-69 .
Lunden	4698	4763	9461	20-29 .
Majorna	4308	4101	8409	30-39 .
Nordstaden	-	-	-	-
Olivedal-Haga	6145	5788	11933	30-39 .
Bagaregården	5039	4872	9911	30-39 .
Sannegården	3648	3686	7334	30-39 .
Skår	1844	1697	3541	50-59 .
Slottsskogen	-	-	-	-
Stampen	2761	3007	5768	30-39 .
Tingstadsvassen	-	-	-	-

10.2 Appendix 2

Table 11: Scenarios

Scenario 0	P (walking)	P (bike)	P (publ.tr.)	P (car)	P (other)
>2 km	55%	20%	3%	22%	0%
2-<5 km	10%	14%	20%	50%	6%
5-<10 km	2%	10%	25%	55%	8%
10-<20 km	0%	5%	30%	65%	0%
Scenario 1	P (walking)	P (bike)	P (publ.tr.)	P (car)	P (other)
<2 km	48%	20%	10%	22%	0%
2-<5 km	10%	14%	20%	50%	6%
5-<10 km	2%	10%	25%	55%	8%
10-<20 km	0%	5%	30%	65%	0%
Scenario 2	P (walking)	P (bike)	P (publ.tr.)	P (car)	P (other)
<2 km	43%	20%	15%	22%	0%
2-<5 km	10%	14%	20%	50%	6%
5-<10 km	2%	10%	25%	55%	8%
10-<20 km	0%	5%	30%	65%	0%
Scenario 3	P (walking)	P (bike)	P (publ.tr.)	P (car)	P (other)
<2 km	38%	20%	20%	22%	0%
2-<5 km	10%	14%	20%	50%	6%
5-<10 km	2%	10%	25%	55%	8%
10-<20 km	0%	5%	30%	65%	0%
Scenario 4	P (walking)	P (bike)	P (publ.tr.)	P (car)	P (other)
<2 km	33%	20%	25%	22%	0%
2-<5 km	10%	14%	20%	50%	6%
5-<10 km	2%	10%	25%	55%	8%
10-<20 km	0%	5%	30%	65%	0%