Master Thesis

Use patterns and climate impact of electric scooters under Danish conditions

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June 2nd, 2020
Esbjerg, Denmark

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Contains: 151,781 characters, 53 figures and 8 tables. Equivalent to 73.4 standard pages

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Abstract

After the first electric scooters were seen on the streets of Santa Monica in 2017 the rental business has spread to many bigger cities around the world. This paper explores the history of the electric scooter and examines the rental business model and the laws and regulations under which it operates in Denmark.

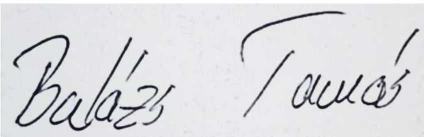
Transportation patterns of electric scooter users are explored using mobility data from the company VOI and questionnaires conducted with a community of electric scooter enthusiasts. The results indicate different use patterns for rented and privately owned electric scooters, where privately owned scooters are used mainly for commuting and rented scooter for rides in the evening and night-time.

A life cycle analysis from North Carolina State University was modified to reflect Danish conditions, showing emissions of 75.5 g and 33.2 g CO_2-eq per passenger kilometre for rented and privately owned electric scooters respectively. Manufacturing and collection/distribution are the two main determinants of the greenhouse gas emissions, while the results are highly sensitive to the lifespan of the electric scooter. Results are compared to the modes of transport being substituted by electric scooters and finally recommendations are given on how to improve the environmental performance of electric scooters in the future.

Solemn declaration

We hereby solemnly declare that we have personally and independently prepared this paper. All quotations in the text have been marked as such, and the paper or considerable parts of it have not previously been subject to any examination or assessment.

Bjarke Slater Christensen



Balázs Tamás

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1. Introduction

Researchers from North Carolina State University published a study in August 2019 that sparked headlines in both the US and Denmark. The study is believed to be the first peer reviewed life cycle analysis on rented electric scooters and it concludes that electric scooters have higher life cycle emissions than diesel buses per passenger mile. This triggered interest in the climate impact of this new mode of transport under Danish conditions.

The first electric scooters from the rental company Bird were seen on the streets of Santa Monica in September 2017 and have since then spread to many bigger cities around the world. In Denmark rental companies are present in Aalborg, Aarhus, Copenhagen, Herning, Odense and Vejle as of May 2020. However, not all Danish municipalities allow rental companies to operate in their cities, so privately owned electric scooters have also seen a rise across the country.

This paper explores the history of the electric scooter and examines the rental business model to figure out if the electric scooter is just a trend or a sustainable venture that will expand in the years to come. Laws and regulations in Denmark are also presented to understand the context in which the rental companies operate.

Using mobility data from the rental company VOI the paper examines the transportation patterns of electric scooter users in Odense from October 2019. More than 16,000 rides are examined to provide a solid statistical foundation for the study. Questionnaires are also conducted with a community of electric scooter enthusiasts to shed light on the differences between rented and privately owned scooters. Do they help solve the last mile problem of getting passengers the last stretch to their destination, when are they used and for what purpose? These questions will be part of the analysis of transportation patterns in Denmark.

To investigate the climate impact of electric scooters under Danish conditions, two life cycle analyses are conducted for rented and privately owned electric scooters. The analyses are based on the LCA from North Carolina and modified to reflect usage in Denmark. This includes transportation of goods from China to Europe, a different fleet of vehicles for collection and distribution, and battery changing with the Danish energy mix. The process of collection and distribution was removed completely for privately owned scooters and the functional unit of "1 passenger kilometre" is investigated using Monte Carlo analysis.

The LCA results are then coupled with the questionnaire findings that investigate what modes of transport are being substituted by the electric scooters. This forms the basis of a comparison between the greenhouse gas emissions per passenger kilometre of electric scooters and traditional modes of transport like cars, bikes, and public transportation in Denmark. Further, the Danish benchmark displacement is calculated and compared to the LCA results from Denmark and the US.

Finishing off, the paper discusses the main findings on transportation patterns and the subsequent climate impact of electric scooter usage in Denmark. A small list of recommendations is also included to help policy makers and companies reduce climate impacts in the future.

2. Problem statement

What effect does electric scooters have on transportation patterns and greenhouse gas emissions in Denmark?

- What forms of transportation do electric scooters substitute and does that make them an environmentally friendly choice?
- What happens to the environmental impact of an electric scooter if it is privately owned or used under Danish conditions?

3. Background

This section will start by describing the concept of micromobility, as well as providing a definition of electric scooters. It will present the history of electric scooters and the rise of electric scooter rental companies. Finally, a short analysis of the business model of rental companies will be described.

3.1. Micromobility

Micromobility is the combination of the words micro and mobility. Dediu (2019) says "micro" refers to minimal or small, while "mobility" is the ability to move or be moved in space freely, thus "the ability of movement through minimalistic means." Furthermore, Dediu (2019) challenged himself to find a better definition and reached the conclusion that for a device to be included into the micromobility category, it must have the purpose of moving a human being, allowing the occupant of the device to maximum freedom in mobility and propose that the device has to be below 500 kg in gross vehicle weight (U.S. Department of Transportation - National Highway Traffic Safety Administration 2002). Another approach to the concept of micromobility "refers to short-distance transport, usually less than 5 miles" (CBInsights 2020).

3.2. Definitions

The scooter itself (also called a kick scooter) is a human-powered "foot operated vehicle consisting of a narrow footboard mounted between two wheels tandem with an upright steering handle attached to the front wheel" (Merriam-Webster 2020). Whereas an electric scooter under the US5775452A patent (owned by Patmont Motor Werks, invented by Steven J. Patmont in 1996) is described as "an electric powered scooter having a tubular frame extending between a front steerable wheel and a rear electrically powered wheel". In attrition, an electric scooter "has the powering electric batteries mounted in a concealed under body position relative to the platform giving an electric scooter having a low centre of gravity with optimal riding profile" (Patmont 1996).

3.3. History of electric scooters

Electric scooters are becoming a day-by-day sight on the streets of big Danish cities and may become part of the future of transportation in Denmark. The following section will present how we arrived at today's scooters and will take a closer look at the emergence of rental companies in this sector.

3.3.1. The evolution of electric scooters

Three historic developments contributed to today's electric scooters. Firstly, electric scooters have a history and evolution coming from the desire to motorise vehicles in general and the use of electric motor in particular. Secondly, is the creation of the kick scooters and thirdly, is the development of battery technology in recent years.

3.3.1.1. Motorizing vehicles as part of the evolution of electric scooters

When observing electric scooters on the streets today it is probably hard to imagine that the concept of electric mobility has a history of more than 100 years old. Already at the end of the 19th century, Ogden Bolton Jr. had a patent for an electric motorcycle (Dedhia 2019), interestingly one year earlier than the first gas-powered motorbike was invented (Linden 2020).

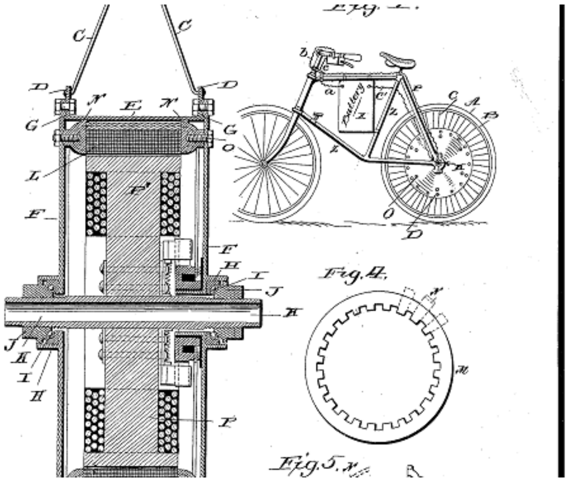


Figure 1. Ogden Bolton Jr.'s electric motorcycle patent from 1895 (Ebike portal 2020)

The inventor installed a direct current motor with 6 poles into the rear wheel's hub of the bicycle, while the battery was placed under the horizontal tube of the frame (Ebike portal 2020).
However, some concepts of electric mobility date back further, the earliest such example being Gutave Trouvé's electric tricycle from 1881 (Farrell 2018).

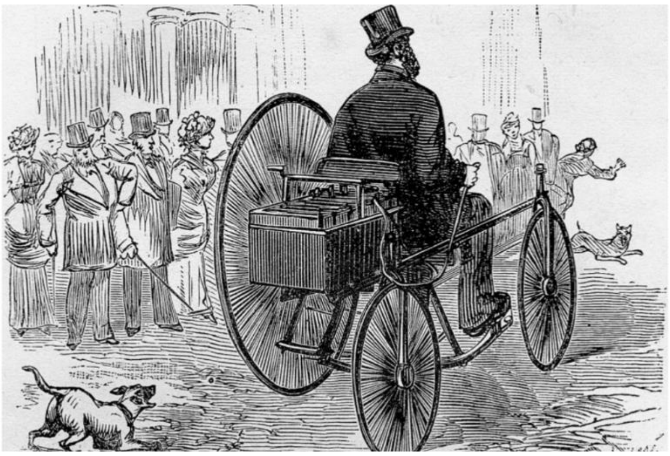


Figure 2. Gustave Trouvé's electric tricycle from 1881 driven in the streets of Paris (Farrell 2018)

Interestingly, Trouvé could not patent his creation since he did not invent the batteries or the vehicle, nor the motor, he just assembled some of the inventions of the age (Farrell 2018).
In 1897 a new electric bicycle concept and with it a new patent was registered in the United States by Hosea W. Libbey which is illustrated in figure 3.

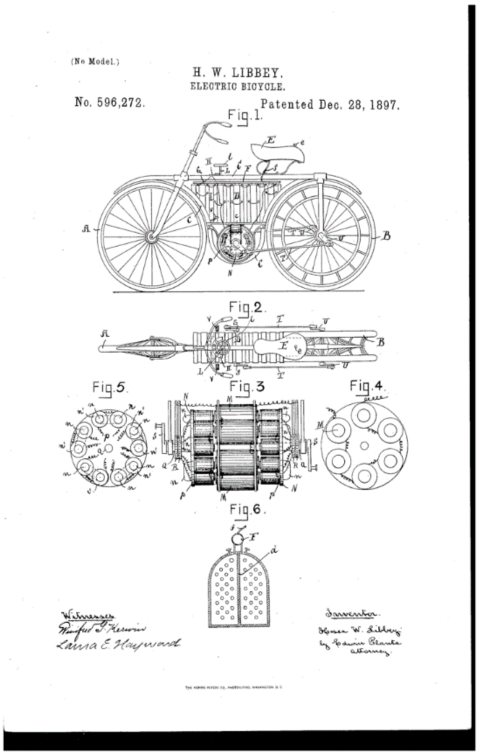


Figure 3. H. W. Libbey's Electric bicycle patent from 1897 (Libbey 1897)

Both the electric motor and the batteries were placed in the centre of the bike and the power output from the engine was connected to the rear wheel by two metal rods.

These historic inventions have little in common with today's electric scooters, however, they represented important breakthroughs in electric mobility in the early 19th century overshadowed by the rise of internal combustion engines until the end of the 20th century.

Although it did not have an electric motor, thus not relevant from the electrification of the vehicle, the Autoped had a very similar look to the modern electric scooter. It was created by the Autoped Company and was manufactured between 1915 and 1921, while a similar scooter called the Krupp-roller was manufactured between 1919 and 1922 by the company Krupp in Germany. The American Autoped was propelled by a 155 cubic centimetre (cc) gasoline engine producing 1.5 bhp with a top speed of 32 km/h. The German version had a bigger 191 cc engine with 1.7 bhp and a top speed of 35 km/h. These scooters were built with headlamps and tail lamps, as well as a toolbox and horn (Scooter Maniac 2020).

Figure 4. Long Island based Autoped company's stand-up scooter called Autoped from 1915 (Scooter Maniac 2020)

Peugeot started producing the Scoot'Elec in 1996, the first commercial electric moped with a 3 bhp direct current engine and 100 Ah nickel-cadmium batteries at 18v. It allowed the users to travel approximately 40 km on a single charge, and although it was heavy (around 115 kg) and the nickel-cadmium batteries were not very eco-friendly it sold around 3500 units from 1996 to 2006 (Dedhia 2019, Linden 2020, New Atlas 2010).

3.3.1.2. Kick scooter history

The second important factor to the evolution of electric scooters started with the invention of the kick scooter in Germany in 1817 which came to the United States from the 1920s, built by children relying on their imaginations (Hartman 2017). Early scooters were hand-made by attaching a handle to a wooden board, which in most cases were rolled on 7.5-10 centimetre wheels with steel bearing in the middle. These scooters could only be steered by leaning (Dungz 2020). Figure 5 shows an example of these early scooters.

Figure 5. Early kick scooter (Dungz 2020)

The kick-scooters of today (Figure 6) have an aluminium body, steering-handles and often a collapsible design. This was the idea of Wim Ouboter, who on a night in 1990 was headed out to a bar but first wanted to grab a hot dog at a place about 1 km from his house. His problem was that the distance was too long to walk but too close to take the car or get his bike out of the garage (Holder 2018). In 1996 Wim created his kick scooter, which was collapsible, with aluminium body and in-line skate wheels (Dungz 2020). Wim then started a collaboration with the sports brand K2 and started commercializing a three-wheeled scooter, and later in 1997 established his own company the Micro Mobility Systems AG (Micro Mobility Systems AG 2020).

Figure 6. Foldable kick-scooter (Dungz 2020)

Today a large range of kick-scooters are available on the global market from two-wheelers to three- and four-wheelers, even special so-called stunt scooters which are stronger and can be used for doing tricks on a half-pipe (Dungz 2020).

3.3.1.3. Evolution of battery technology

The last factor in the evolution of electric scooters was the advancements in battery technology. Batteries consist of an anode, a cathode and an electrolyte which separates the two and can be either disposable batteries or rechargeable. In the case of disposable batteries, the anode is losing electrons during the discharge while the cathode is accepting this electron and the process cannot be reversed. The rechargeable batteries use the same principle; however, the process can be reversed (Alarco and Talbot 2015). The word "battery" was first mentioned in 1749 by Benjamin Franklin, but the true invention is linked to Alessandro Volta (after whom the electric potential is named), who in 1800 created a battery cell using copper, zinc, and salt water, which was generating 0.76 volts and the electric potential could be increased by connecting multiple cells (Alarco and Talbot 2015). The next major step was made in 1859 when Gaston Planté invented the lead-acid battery. This type of battery is still widely used and almost all cars use this technology, especially for starting internal combustion engines (Alarco and Talbot 2015). Nickel cadmium (NiCd) batteries were one of the first rechargeable batteries invented in 1899 by Waldemar Jungner. Experiments with batteries continued to reach higher electric potential and capacity as well as longer life and in 1989 the NiMH (nickel-metal-hydrogen) batteries replaced the NiCd ones (Alarco and Talbot 2015). Further development was driven by technological advancements which produced high potential, long lasting batteries, and most importantly compact sizes. These initiatives led us to the invention of the lithium-ion batteries in 1980 by John Goodenough. In the early lithium-ion batteries thermal runaway was common, however Goodenough introduced the lithium iron phosphate nano-scale cathode in 1990, which made the battery cells more stable and allowed fast charge and discharge (Hoong 2016, Battery Association of Japan 2015, Alarco and Talbot 2015). This started a new chapter in electric advancements of many technologies relying on batteries and made the rise of the modern electric scooter possible. The stand-on electric scooters breakthrough to its modern form with a foldable body is dated back to 2009, when the former Myway turned into Inokim and started producing foldable electric scooters (Linden 2020). Nowadays, after a short search in online stores, one can find at least 25 different kinds of stand-on electric scooters sold on the Danish market.

3.3.2. Rise of rental companies

Urbanization and traffic congestion in areas are on the rise and this creates problems for citizens. Ridesharing and carpooling companies are somewhat a solution to the problem, but people are always looking for improvements. Data suggests that out of all trips in U.S. cities around 60% have a length shorter than 8 km, in which case cars are not the ideal choice (Smith 2018, CBInsights 2020). The shift to micromobility transport could be strengthened by the prediction that in 2050 up to 2.5 billion more people will live in urban areas, increasing the already high pollution levels and traffic congestion in certain cities. Moreover, micromobility services can allow people to access public transportation hubs or in some cases replace other modes of transport (CBInsights 2020).

The rise of the rental companies started in September 2017 when 10 Bird scooters were deployed on the streets of Santa Monica, California. A couple of days later, the streets were invaded by these electric scooters when hundreds more were deployed. The release of the scooters was done similarly to the start of Uber, who started operations without authorization and only asked for them later (Yakowicz 2020, Hawkins 2018).

What makes electric scooters popular compared to other modes of transport is that they can be cheaper than public transportation or owning a car and, in some cases, also faster. They are more flexible and have a greater distance potential from 1 kWh of energy, where normal ICE cars have around 1.3 kilometres, electric cars around 7 kilometres, while electric scooters about 85 kilometres (CBInsights 2020).

Bird was the first company to step into the micromobility market with electric scooters and in a very short time earned the so-called unicorn title, which refers to start-ups reaching $1 billion in value. In 2018, Bird also reached the $2 billion valuation, while Lime, another micromobility company renting out electric scooters and bikes, reached $2.4 billion in January 2019. Bird's and Lime's popularity at launch and their achievement of reaching millions of rides in just a couple of months was making the companies an attractive place for investors. These two companies raised more than $750 million combined in funds in their first couple of months (CBInsights 2020, Smith 2018). After Bird and Lime, several companies joined the dockless rental market of electric scooters like Jump, Lyft, Spin, Scoot. Future predictions estimate the electric scooter market to be worth around $300 – 500 billion by 2030, where the U.S. alone will be worth $200 – 300 billion and Europe around $100 – 150 billion (CBInsights 2020).

3.4. Business model of electric scooter rental companies

This analysis will allow the reader to understand the business model of electric scooter rental companies. For the first sight, one can say that the business model of these kinds of companies is simply getting users, who rent their scooters. For a deeper understanding of how these companies can create value, some analysis will be presented.

3.4.1. Business Model Canvas

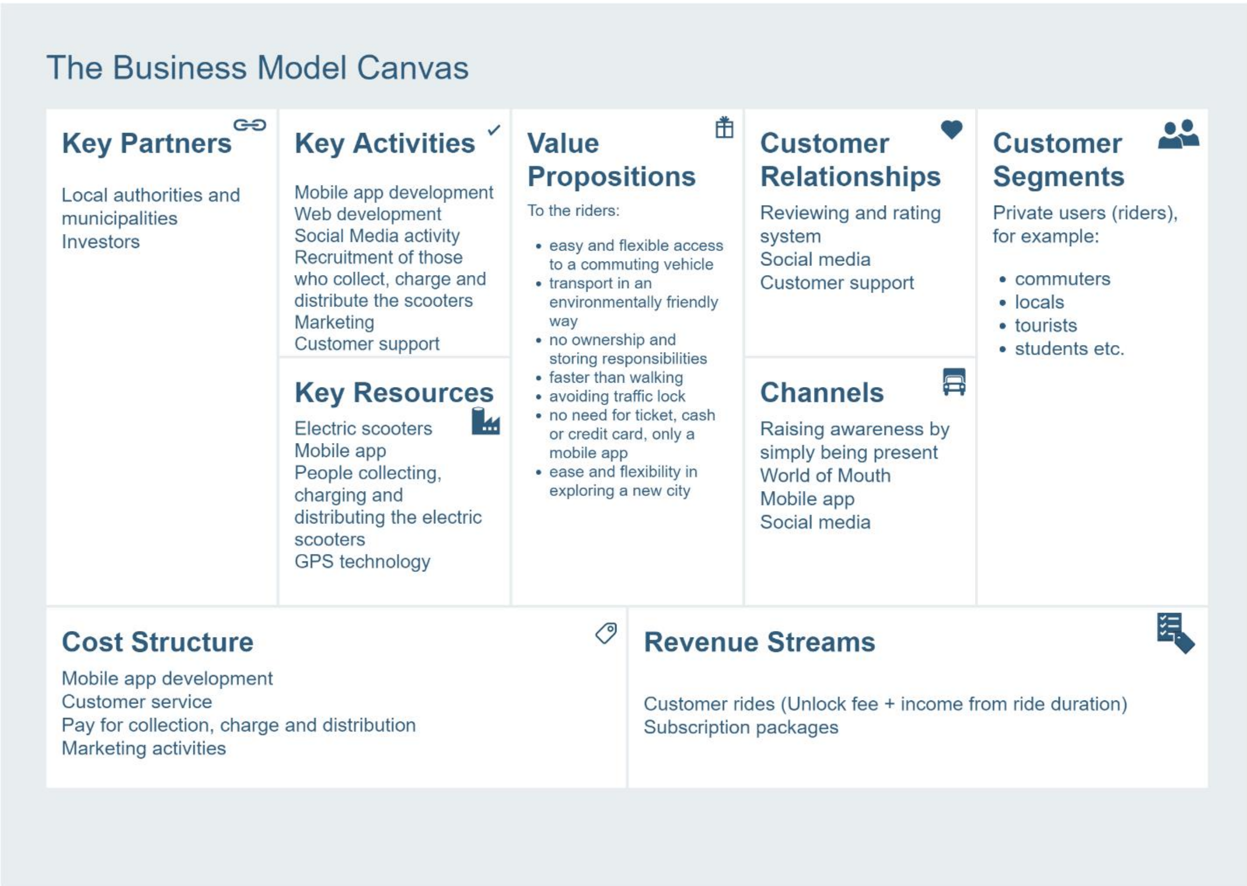


Figure 7. Business Model Canvas for electric scooter rental companies (own work)

As a first step to build the Business Model Canvas for an electric scooter rental company the Customer Segment was defined. Here the company has all the people to whom they want to create value. In this case, private users who want to commute, want to have fun or want to explore the city. The second step is describing the Value Proposition, more exactly what kind of value is created to the customer segment. As described in the canvas, the electric scooter rental companies offer easy and flexible access to a commuting vehicle for their riders and a way to avoid traffic jams. The next step is defining how the value is delivered to the Customer Segment, namely the Channels of communication they use. Electric scooter rental companies use Channels like social media, mobile apps, word of mouth and brand recognition based on their presence in Danish cities. The category of Customer Relationship is addressed through activities such as customer support. Revenue Streams are gained through customer rides and some subscription packages, these are price mechanism that companies use to capture value.

The next step is defining the Key Resources the company needs to be able to deliver the value they want to their customers. In this case, electric scooters and the mobile app are the most important. Key Activities show endeavours that the company needs to undertake in order to create value, in their case mobile app development, social media activity, marketing and more. The Key Partners are those who can help the company, like local authorities and investors. The final step is the Cost Structure, where electric scooter rental companies will have expenses related to mobile app development, and paying for the collection, charging and distribution of the scooters.

From the Business Model Canvas, it can be seen that electric scooter rental companies are dependent on very few key resources, thus the cost of running a business is relatively low, however, from the other end the revenue stream is also limited and it is based on customer rides.

3.4.2. SWOT analysis

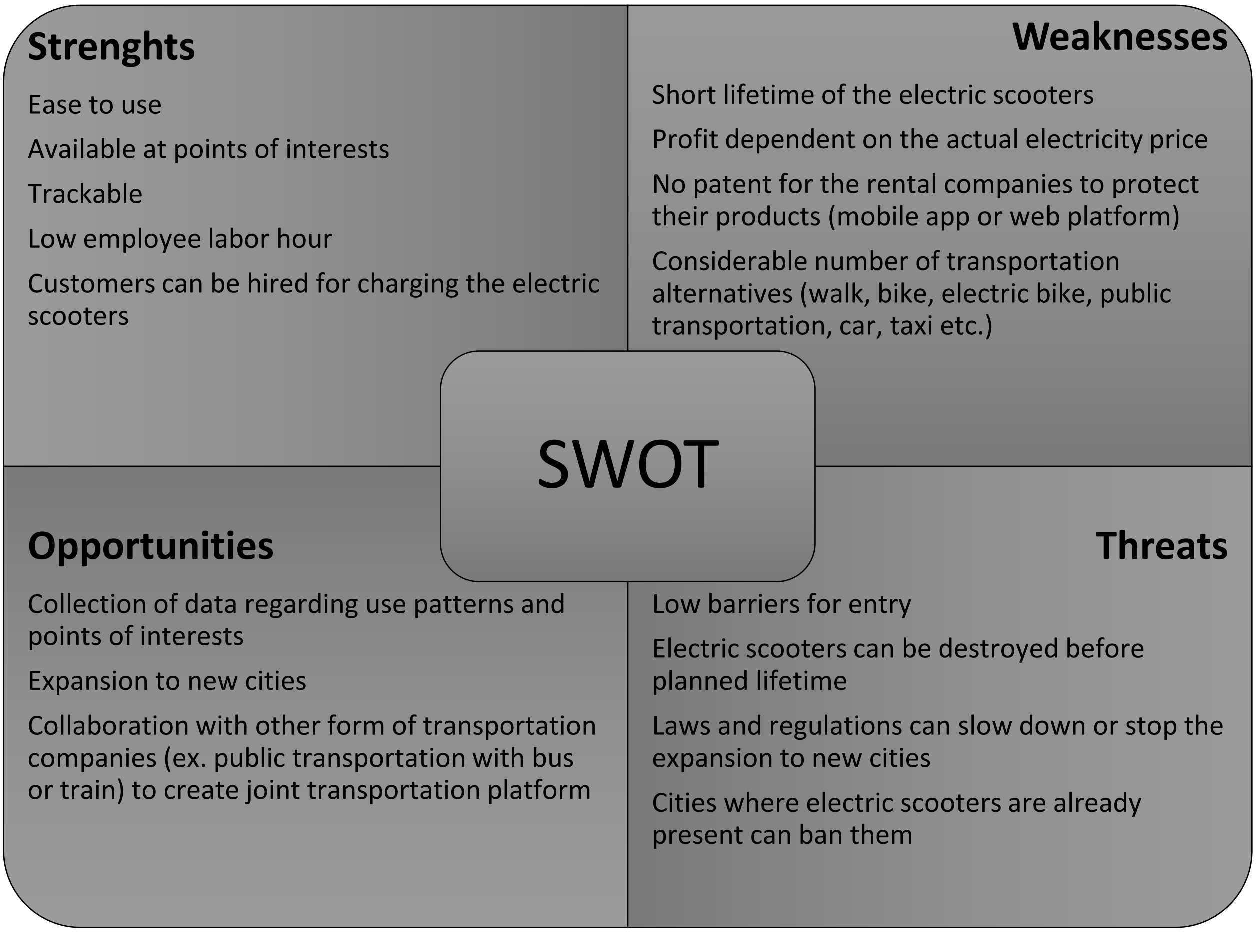


Figure 8. SWOT analysis for electric scooter rental companies (own work)

The figure above describes the SWOT analysis for the electric scooter rental companies. Among the strengths are the access and ease of use for riders as well as the company requiring few employee labour hours. Some of the weaknesses rental companies must face are the short lifetime of the scooters and the high number of transport alternatives. Companies in this segment could gain advantages if some of the opportunities materialise, such as better understanding of points of interests and demand, collaboration with other companies for joint ventures and expansion to new cities. However, they might face threats because the industry has low barriers of entry, electric scooters might have even lower lifetime if they are destroyed prematurely, and governments or municipalities can decide to ban their activity.

3.4.3. PEST analysis

Political	Economic	Social	Technologic
• Municipalities can make their own regulations • Denmark is member of NATO since 4th of April 1949 • Denmark is member of the European Union since 1st of January 1973 • The prime minsiter is the head of government and the monarch is the head of state	• Denmark's GDP per capita in 2019 was $59.135 • Household disposable income has growth with 1,2% from 2017 to 2018 and the indlation rate was only 0.8% in the same period • Employment rate among the highest in Europe, only 5.02% unemployed in 2019 • Consumer confidence index was 100.78% in January 2020 showing an optimistic approach of households toward the development of the economy	• The country shows a very low income distribution inequality between the average of the top 20% and the average income of the bottom 20% with a ratio of 3.7, while among other OECD countries the best performer has a ratio of 3.6 and the worst 37.6 • Gender equality is one of the best among OECD countries by having more than 40% female ministers, while 37.4% of the total parliamentarians are woman	• In 2018 Denmark spent 3.042% of its GDP on R&D, well above the OECD average of 2.372%, creating a favorable environment for the technological development

Figure 9. PEST analysis (own work based on OECD 2020a, OECD 2020b, OECD 2020c)

The PEST analysis reveals that from a macro perspective the Danish market creates a favourable environment for the rental companies especially looking to political, economic, and technological forces. The income level of the population favours non-essential consumption, while political and economic stability support investments. The technological factor reveals that Denmark is keeping up with the technological development and even focuses on leading technological advancements.

3.4.4. Conclusion

From the perspective of the PEST analysis, SWOT analysis and Business Model Canvas, the electric scooter rental companies base their business models on some simple principles. The first one is the transportation itself, where this mode of transport is convenient, fast, cheap, and relieves the user from ownership obligations and traffic jams. The other is the accounting, where on the cost side they only have the mobile platform, the electric scooter itself, the collection and charging, and the customer support, while the revenue is generated from the use of electric scooters. These simple principles make the rental companies viable, while some of the weaknesses and threats listed in the SWOT analysis include multiple transport alternatives, short lifespan of the electric scooters and possible ban from cities that question their long-term success.

4. Laws and regulations

4.1. Changes to the traffic act

The introduction of electric scooters to the Danish roads is made possible by a change to the road traffic act in late 2017 when the Danish parliament passed bill "L 28 Forslag til lov om ændring af færdselsloven (Bemyndigelse til at fastsætte regler om små motoriserede køretøjer)". The bill was introduced by the Minister of Transport, Building and Housing - Ole Birk Olesen on the October 4th 2017 and finally passed on December 12th 2017 by a unanimous vote in parliament (Folketinget 2017a).

The law allowed the Minister of Transport, Building and Housing to lay down regulations for the use of small motorised vehicles, such as provisions on vehicle speed, position on the road, loading, use of signals and signs, lighting and directions for traffic. It also allowed the minister to set regulations on age requirements, driving license requirements, drunk-driving and driving under the influence of drugs, etc.

In the written introduction by the minister (Folketinget 2017b), he explains that the purpose of the bill was to create a better framework for the regulation of small motorized vehicles. Before there was no regulation in the road traffic act on small motorised vehicles and many of these e.g. electric scooters were not allowed in traffic. In recent years, as a result of technological developments in the field of motor and battery technology, there has been an increase in the number of new types of small motorized vehicles. The bill sought to follow this market trend and the growing interest in the population in new flexible means of transportation. But because the vehicle types are still very new in traffic, the bill proposed an initial legalization through a pilot scheme. The minister would be authorised to lay down regulations on small motorised vehicles, giving due regard to road safety.

In the report given by the Committee on Transport, Building and Housing on November 30th 2017 two parties commented on the bill (Committee on Transport, Building and Housing 2017). The Social Democrats said they were very open and curious when it comes to new technology and new modes of transport. They were especially positive if the new vehicles could contribute to greater flexibility and mobility, a cleaner environment and less congestion on the roads. But they were also worried that many of these new vehicles would make it harder for bikes to get around.

The Red–Green Alliance also welcomed new modes of transport if it meant that more people would leave the car, motorcycle or moped at home. But they were concerned about how the bill would affect the development of traffic related injuries and how the proposal would affect road safety on bike paths. They called for a closer examination of the impact on existing traffic patterns and the likelihood of accidents or injuries. However, they also felt that the minister had met their concerns and the Committee on Transport, Building and Housing recommended the proposed bill for adoption unchanged (Committee on Transport, Building and Housing 2017).

4.2. Pilot scheme for motorized scooters

The bill was adopted and created changes to the road traffic act, meaning the minister could now create a pilot scheme for small motorised vehicles, which he did with a ministerial order on January 14th 2019. The ministerial order took effect on January 17th 2019 and allowed people to use electric scooters in public with certain requirements and limitations.

4.3. Regulation of use

The rules for using electric scooters are set out in Order no. 40 of 14/01/2019 -"Bekendtgørelse om forsøgsordning for motoriseret løbehjul" with later changes and amendments set out in Order No. 665 of 01/07/2019 – "Bekendtgørelse om ændring af bekendtgørelse om forsøgsordning for motoriseret løbehjul". The following section summarises the requirements on scooter and driver which are valid for the duration of the pilot scheme.

Requirements for the scooter

Speed – The engine must not be able to propel the vehicle at more than a maximum speed of 20 km per hour.

Lights – Must be equipped with at least one headlight that emits white or yellow light and at least one taillight that emits red light. The front and rear lamp must emit light that is clearly visible at least 300 meters away.

Reflexes - An electric scooter must be provided with at least one white reflective device visible from the front, at least one red reflective device visible from the rear, and at least one yellow or white reflective device visible from both sides.

Labelling – An electric scooter must be CE marked.

Weight and size - An electric scooter must have a maximum weight of 25 kg, a maximum length of 2 meters, and a width of 0.7 meters measured at the widest point on the vehicle.

Equipment – Must not be equipped with a seat or pedals or be connected to a trailer or sidecar.

Requirements for the diver

Age - An electric scooter may only be driven by a person over the age of 15 unless the driving is accompanied by and supervised by a person of age.

Road Traffic Act – The driver must follow the rules of the Road Traffic Act, which apply to bicycles and cyclists including the use of bike lanes, hand signals and bike traffic lights.

Limits - The driver must obey the speed limits and the blood alcohol content limit of 0.5.

Liability – Rental companies must obtain liability insurance for their vehicles and the driver must be able to document the insurance to the police.

Single user - No persons other than the driver may be carried on an electric scooter.

Failure to comply with these regulations might result in a fine in the order of 700 DKK to 2,000 DKK depending on the offence (Rådet for Sikker Trafik 2020).

4.4. Taxation

All rental companies operating in Denmark have Danish branches that are registered for VAT and thus pay taxes in Denmark. All companies are however so new that they have not yet filled their first annual report to the tax authorities. Consequently, a study of their taxation has not been possible.

4.5. Environmental regulation

To sell an electric scooter in the European Economic Area the producer must obtain CE marking for the product to ensures that European requirements are met regarding safety, health and environmental protection (European Commission 2020). The rules are set out in the various EU directives on everything from machinery to electromagnetic compatibility, and the following applies specifically to the environmental protection requirements for electric scooters according to Segway-Ninebot (appendix 1):

Restriction of Hazardous Substances Directive (RoHS) restricts the use of hazardous material used in electrical and electronic equipment. It bans the use of lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE) to protect human health and the environment (European Commission 2015).

Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) moved the responsibility from authorities having to demonstrate that a chemical was unsafe for it to be banned, to placing the responsibility on industry to document the safety of their chemicals. The process of registration, evaluation and authorisation ensures better and earlier identification of the properties of chemical substances. All documented in a central European database that allows consumers and industry to find and use this information for enhanced safety and innovation (European Commission 2019b). The "no data no market" motto is a clear example of the precautionary principle in the European Union.

Waste Electrical and Electronic Equipment Directive (WEEE) aims at prevention, recovery and safe disposal of waste. It requires producers to put the crossed-out wheelie bin symbol on their products and for all member countries to introduce rules for collection, treatment and recovery of waste (European Commission 2019c; Dansk Producent Ansvar 2018).

The EU Battery Directive was adopted to minimise the negative impact of batteries and harmonise requirements in the European market. It forbids the sale of batteries with hazardous substances, it sets targets for collection and recycling as well as producer requirements for labelling of batteries and their removability from equipment (European Commission 2019a).

4.6. Municipal rules

The legalisation of electric scooters has meant that a number of electronics stores, departments stores, and web shops have started selling electric scooters to the Danish consumers. But at the same time, there have been several rental companies popping up in Danish cities offering electric scooters for on-the-spot rental via a mobile app. The electric scooters are scattered all around the cities and can be found on a map, created using built-in GPS in each of the electric scooters. The rental companies must obtain permits by the local City Council to operate their business like this because it is considered commercial activity on municipal land (Københavns Kommune 2019b). The cities that have allowed for this, as of February 2020, are Aalborg, Aarhus, Copenhagen, Herning, Odense and Vejle but it varies between cities how many companies they have allowed and how many scooters they have allowed each of them to place on the streets.

In Aalborg, Aarhus, Vejle and Herning they have allowed for one rental company – VOI or Donkey Republic, with the maximum number of electric scooters set between 100 to 150 (Aalborg Kommune 2020; Aarhus Kommune 2019; Vejle Kommune 2020; TV Midtvest 2019). In Odense, they have allowed two rental companies VOI and TIER, with a maximum of 1,000 electric scooters (Odense Kommune 2020) but in Copenhagen, the rental companies have started their businesses without obtaining proper authorisation first. As of May 2020, at least 6 rental companies including VOI, Tier, Lime, Circ, Wind and Bird are present in Copenhagen (Viatrafik 2020), but the municipality has yet to permit them to operate in the city. Copenhagen Municipality is working on a decision that will allow for 200 scooters in the inner city and 3000 in the surrounding neighbourhoods. 11 rental companies have applied for permission to operate in 2019 but no permits have yet been given (Københavns Kommune 2019a).

Some cities have chosen not to allow rental companies on municipal land and are awaiting experiences from other cities first. In the city of Esbjerg, the council is sceptical because of traffic accidents that have happened after the pilot scheme was introduced. The chairman of the Engineering and Construction Committee says that the municipality is ”Reflecting on the chaos, that other cities have experienced” (JydskeVestkysten 2019) but doesn't dismiss the possibility of rental companies being allowed in the future. He also explains that electric scooters are not part of the municipality’s new mobility plan, which is based on cycling because of health considerations.

For municipalities, it is hard to make considerations for health, mobility, road safety and environment come together, and they have had to work out some of the teething troubles of the rental scheme together with the rental companies. Some cities have now introduced Non-Parking Zones and Incentivised Parking Zones in a stick-and-carrot approach to try and keep people from leaving the electric scooters in unwanted areas and help make city streets look tidier (VOI 2020b).

Slow Zones have also been introduced in pedestrian streets to minimise the risk of collision. The electric scooters were not allowed on pedestrian streets in the first place, but people disobeyed the rules and drove there anyway to great frustration for many. The geo-fencing technology slows down the scooters when they're in a Slow Zone restricting them to only 2-5 kilometres per hour - equivalent to walking pace (Politiken 2019). These are all initiatives taken to combat the negative press coverage that many of the rental companies have had throughout 2019, but the companies also provide useful data to the local municipalities helping them to plan for better transportation.

4.6.1. Transport planning and data

Rental companies provide very detailed information on when and where their electric scooters are used which they deliver to the local municipality. The municipality can then use that information to make important decisions on transportation planning and city development. The companies do this to help local government plan better, but also to demonstrate the value they bring to a city (VOI 2020a).

A quick phone survey was conducted with three Danish municipalities asking them how they used the data they got from rental companies. All said they were still in the initial phase of looking at the data but hoped to use it for transportation planning in the near future. Aalborg municipality had already identified that a large amount of scooter trips start at public transportation hubs, like train stations and bus terminals, and finishes spread out across the city. This information is going to be used when making decisions on where to place the electric scooters or allowing more electric scooters in the city. All municipalities said that working with this data is new to them and finding a way of processing the raw data is the first priority.

Odense municipality has granted access to some of their VOI data from October 2019, and a close analysis of this done in chapter 6. Mobility data.

4.7. Evaluation of the pilot scheme

An evaluation plan was made with the introduction of the pilot scheme for small motorised vehicles. The Danish Road Traffic Authority is in charge of the evaluations that will be conducted yearly with no end date because it is hard to estimate how long the process of data collection is going to take, to ensure a sufficient basis for decision making (Danish Road Traffic Authority 2017). The evaluations draw available data from traditional sources such as the Police, the Road Directorate, and the emergency rooms but other sources like insurance companies or pension funds are also included for the sake of injury statistics.

The first evaluation report was published on February 27th, 2020 and created the first official inside into electric scooters in Denmark (Danish Road Traffic Authority 2020). It is focused on scooter distribution, rider behaviour, accident statistics, carbon footprint, and recommendations for policymakers. Most interesting for this paper is the section on carbon footprint that is based on Hollingsworth, Copeland and Johnson (2019a). The Danish Road Traffic Authority does not produce a specific life cycle analysis for Denmark, but they evaluate the assumptions and premises of the North American analysis and came up with an estimate of the life cycle emissions of a rented electric scooter in Denmark. These considerations have been included in the design of our own life cycle analysis (see chapter 14. LCA design).

Danish Road Traffic Authority (2020) also included a survey of the modes of transport that electric scooters substitute. This included interviews with 208 users in Aarhus and Copenhagen, and online

questionnaires with 427 respondents. The results of these are compared to our own questionnaire findings in chapter 11. Questionnaire comparison.
Finally, the evaluation report included an emission comparison with other modes of transport. Danish Road Traffic Authority (2020) uses Danish emission factors for cars with ICE and public transport from The Danish Council on Climate Change and the Danish bus company - Fynbus. Those same emission factors have been used in our own calculations on benchmark displacement (see chapter 16. Benchmark displacement).

5. Stated and revealed preference

According to Kroes and Sheldon (1988), stated preference methods refer to techniques that assess individual's statements with the purpose of estimating a preference, while revealed preference methods are techniques which evaluate data directly from observation of an event.
Abdullah, Markandya and Nunes (2011) compared the revealed and stated preference methods and observed that while stated preferences describe hypothetical or virtual alternatives, the revealed preference method is describing an actual situation. Revealed preference provides a more realistic picture of preference because it is based on people's actions and not just statements of intent.
However, revealed preference can only investigate already existing alternatives, whereas stated preference can tackle additionally proposed and generic choice alternatives as well. This allows researchers higher flexibility and a wider range of choices, for example evaluating the demand for a good or service with conditions that do not yet exist.
This paper uses revealed preference when looking at mobility data from rental users in Odense, but the stated preference method is also used with a questionnaire survey on members of a Facebook community. This was the only way to obtain data on users of privately owned electric scooters, but also to answer the question "*Out of the trips you ride on electric scooters, what modes of transport would you have chosen to use instead?*".

6. Mobility data

6.1. Kepler.gl

Kepler.gl is an open-source visualisation software that will be used to uncover the revealed preference of the electric scooter riders in Denmark.
It was developed by Uber's visualisation team in 2018 as part of the first project hosted by the Urban Computing Foundation. The foundation was created as a non-profit organisation and works to improve mobility, safety and energy consumption in cities through the use of open-source software. The members include research institutes, mobility companies like Uber and big tech giants like Google and Facebook (PR Newswire 2019).
Kepler.gl is designed to handle large amounts of geolocated data easily. What sets Kepler.gl apart from other geographic information systems (GIS) is the low amount of data manipulation and data modelling required to create the visual output. Kepler.gl is browser-based and allows users to drag and drop data files straight into the program and automatically extracts the variables of interest like time, location and other attributes. This allows for quick visualisation and overview of a dataset (Uber Engineering 2019).
Kepler.gl supports traditional GIS layers like point, line and polygon but also other layers catered more specifically to transport mapping like arc, trip and icon layers amongst others. It includes time filtering of data, allowing the user to play forwards and backwards through a dataset to observe developments and patterns. It also includes a brush feature that allows investigation of smaller regions or sections of a map. This is particularly interesting when looking at directions of travel and connectivity between places (Uber Engineering 2019).
Our phone survey (see section 4.6.1. Transport planning and data) showed that at least one Danish municipality uses Kepler.gl to visualise the data they get from electric scooter rental companies. This indicates that these geographic information systems are already part of the foundation for decision making amongst policy makers in Denmark.
The software is however relatively new, but Uber is working on developments to give Kepler.gl better performance, advanced analytics, improved usability and more data integration in the future (He 2019). Kepler.gl version 2.0.1 was used for the visualisations in this paper.
As mentioned previously, rental companies provide detailed data to local municipalities on the use patterns of their electric scooters. We have asked two rental companies that operate with municipal authorisation in Denmark: TIER and VOI, if we could access some of this data for use in this paper, but none of our requests has been successful. VOI's Regional operations manager said that the company is too busy to help sufficiently, and TIER has not responded to numerous inquiries. However, Odense municipality has granted access to the data they received from VOI for October 2019. This is data they were already using for city planning.

6.2. Mobility data

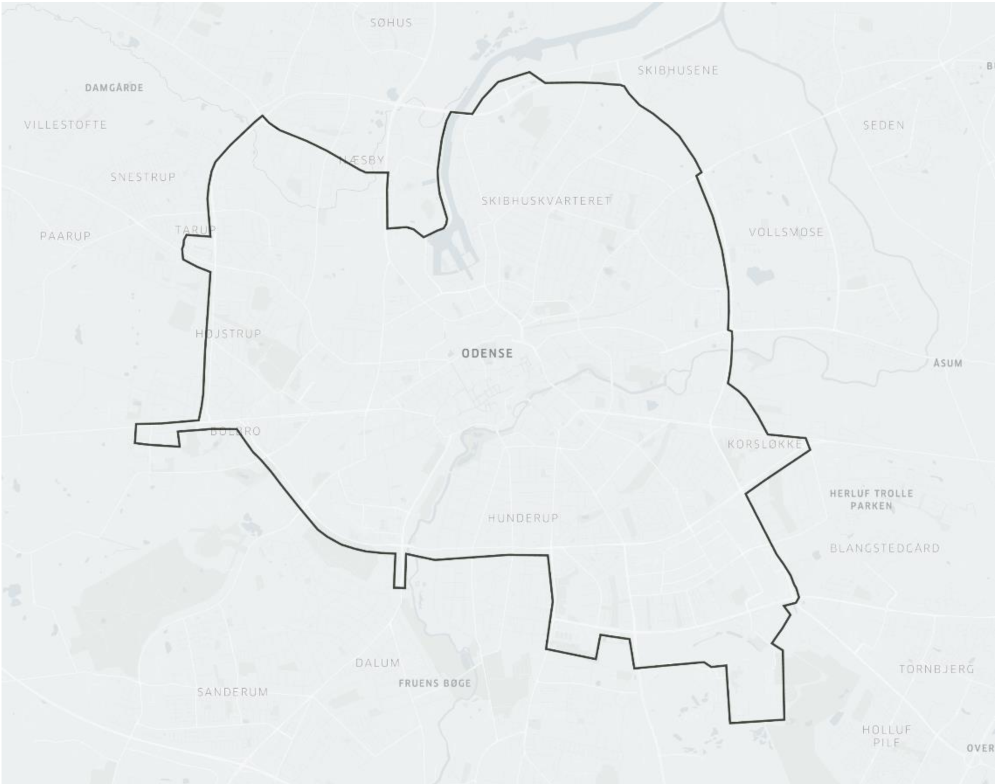


Figure 10. Geographic coverage of dataset (own work)

Our analysis of the Danish use patterns is based on this VOI dataset that spans from October 1st to 31st 2019 and covers the city of Odense in a radius of roughly 3,5 km from the centre, see Figure 10. The dataset consists of 26 variables and 16,479 objects (or trips) of which 164 has been removed as outliers for statistics on duration. The 26 variables are described below:

Table 1. Description of variables from VOI dataset (own work)

Variable	Description
start_lon	Longitude at starting point of ride
start_lat	Latitude at starting point of ride
end_lon	Longitude at ending point of ride
end_lat	Latitude at ending point of ride
is_weekday	Whether ride was taken on a weekday
city	City
country	Country
start_time	Starting time in GMT
end_time	Ending time in GMT
start_time_local	Local starting time, including daylight saving

end_time_local	Local ending time, including daylight saving
revenue_eur	Revenue as number without commas
free_fraction	Unknown
stripe_revenue_eur	Revenue in euros
manual_ended	Whether ride was manually ended by VOI
is_collected_revenue_stripe	Whether revenue was collected
ride_duration_mins	Ride duration in minutes
time_of_day	What time interval the trip was in (00-06, 06-09, 09-12, 12-15, 15-18 and 18-24)
ride_hour	Which hour the ride was started
ride_date	Full date of ride
day_of_week	Day of the week
day_of_month	Day of the month
week_monday	Week number
month	First day of month
quarter	First day of quarter
year	Year

6.3. Manipulation and outliers

6.3.1. Ride duration

For statistics on ride duration, we excluded the 164 objects that were manually ended by VOI (where variable "manual_ended" was equal to "true"). 46 of these had a ride duration of 0 minutes and 71 had a duration of exactly 96, 120 or 160 minutes. As it is unlikely that so many trips had the exact same duration, we believe they were manually ended after hitting a time limit. For this reason, they do not give accurate information on ride duration and were therefore excluded from calculations.

6.3.2. Time of day

During the data review, the variable "ride_hour" was found not to match the local Danish time or GMT. The values were consistently four hours behind the local time for the daylight savings period (October 1st to 26th) and two hours behind the local time for the standard time period (October 27th to 31st). This was problematic because the time intervals in the variable "time_of_day" were assigned according to the "ride_hour" variable. Many rides were consequently attributed to the wrong time periods and were misleading.

To correct this, a new variable "real_ride_hour" was created and assigned an hour-value corresponding to the local time at the start of the rides. This was used again to create the variable "real_time_of_day" where time periods now reflected the actual local time. The reason for the mismatch between the time variables is unknown, but it is believed that "ride_hour" is the flawed variable because the two others (local time and GMT) match up.

6.3.3. Week number

The variable "week_monday" contained the weeks 39-43 although the month of October 2019 covers the weeks 40-44. Dates had been assigned the wrong week category by 6 days making week change occur between Saturday and Sunday. For statistics on week numbers, a new variable "real_week_monday" was created with the dates placed in the correct week category.

7. Analysis of mobility data

The following section presents and visualizes the analysis of mobility data is in five categories: date, time, duration, travel, and revenue. Charts and maps have been created to help get an understanding of the use pattern of the rental users in Odense.

7.1. Date

VOI users took 16,479 trips on electric scooters in Odense in the month of October 2019 and represent half of electric scooter traffic in the city. As the data is anonymous it is unknown how many users account for the total number of rides, but it is assumed that many users have taken multiple trips in the period.

Figure 11 presents the number of rides per date in October and ranges between 327 trips on October 28th and 966 trips on October 4th. The rounded average is 532 trips per day and is shown with the orange line, with a statistically significant 95% confidence interval of 471-592 trips. The number of rides develops in a wave pattern with a duration of seven days suggesting that the weekday is an important factor for ride frequency.

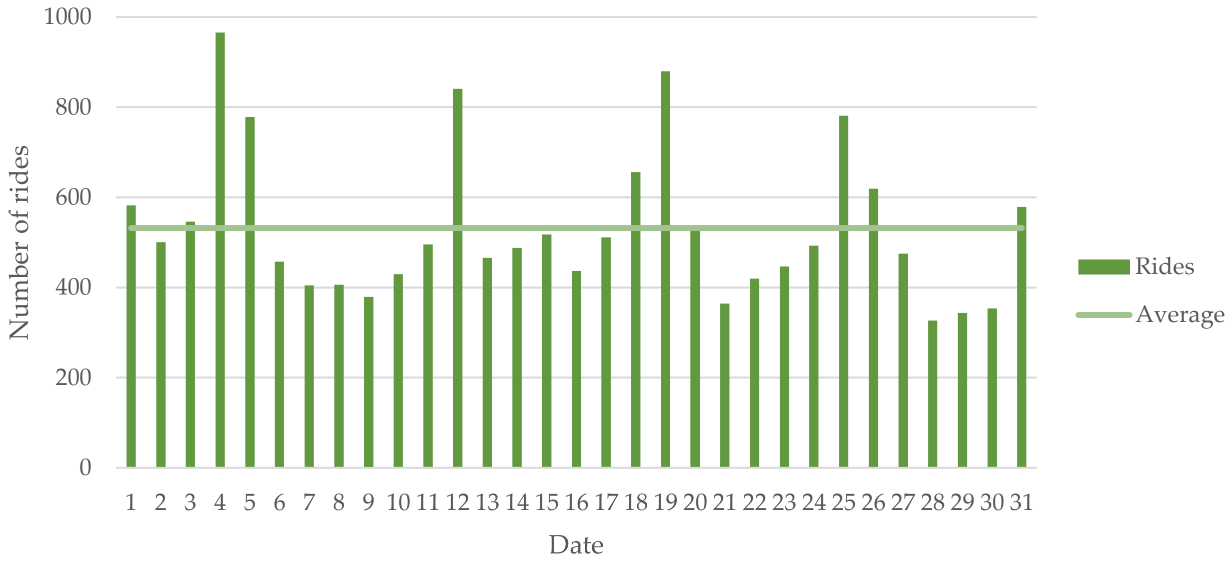


Figure 11. Rides per date in October (own work)

The number of rides per average weekday is displayed in figure 12 with error bars showing 95% confidence interval, all with p-value <0.01. The average frequency is used because October does not have an equal number of each weekday. Monday shows the lowest average frequency of 396 rides and Saturday almost double with 780 rides. There seems to be a trend of a build up over the week from Monday to Saturday with a drop down to Sunday and Monday, where the build-up starts over again. Both Friday and Saturday have an average ride frequency over 700 whereas the rest of the days have a frequency roughly between 400 and 500 rides. This suggests that people use electric scooters much more on Fridays and Saturdays.

However, the confidence interval for Friday is very wide so we cannot conclude that it has a greater ride frequency than Monday, Tuesday, Wednesday, Thursday and Sunday. Only Saturday shows a confidence interval above the five others. Initially it was hypothesised that people used rented electric scooters significantly more on the weekend because they were travelling out of town, but the ride frequency for Sundays says otherwise.

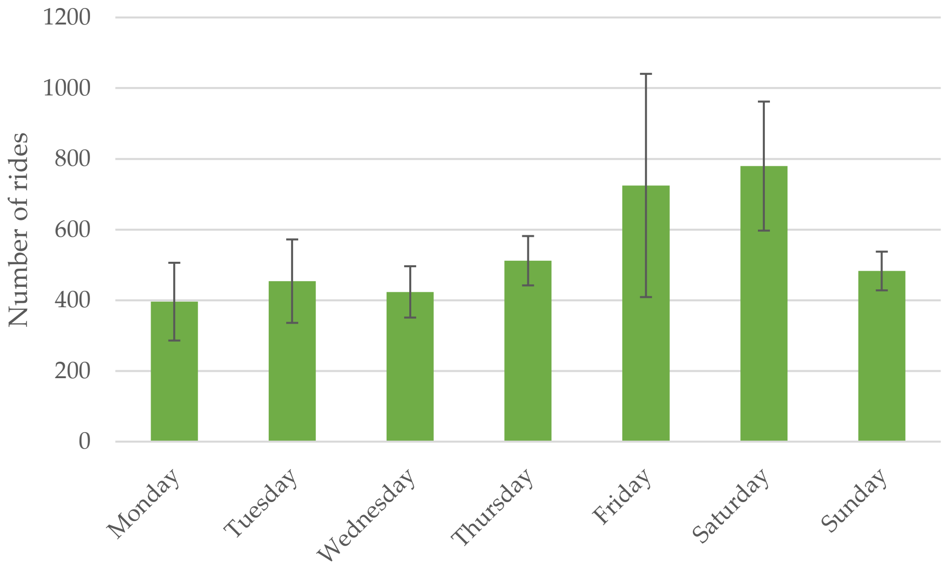


Figure 12. Rides per average weekday (own work)

Frequency per week number was also investigated despite the low number of weeks. Only weeks 41 to 43 were documented in their entirety in the data sets, so weeks 40 and 44 were excluded from figure 13. The chart shows a relatively low difference of 18% between the weeks with most rides occurring in week 42. This also happens to be autumn holidays in Denmark and given the fact that weather and other factors might influence ride frequency, we cannot say much about weekly differences with only 3 objects.

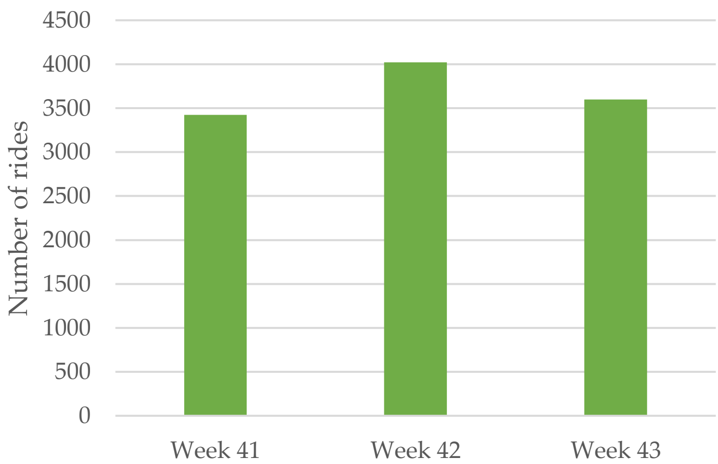


Figure 13. Rides per week number (own work)

7.2. Time

When looking at the number of started rides over the day in figure 14, it is evident that there are big differences over the 24 hours. Afternoons and evenings have the largest number of rides by far and the usage seems to continue into the late hours of the night. The early morning then sees a major drop in usage followed by a build-up before midday. Only 200-400 rides were taken per hour between 6:00 and 9:00 in the morning whereas the hourly number of rides between 17:00 and 19:00 was over 1,100. This suggests that people don't use rented electric scooters to get to work in the morning but rather to get around town during the day and especially after work hours.

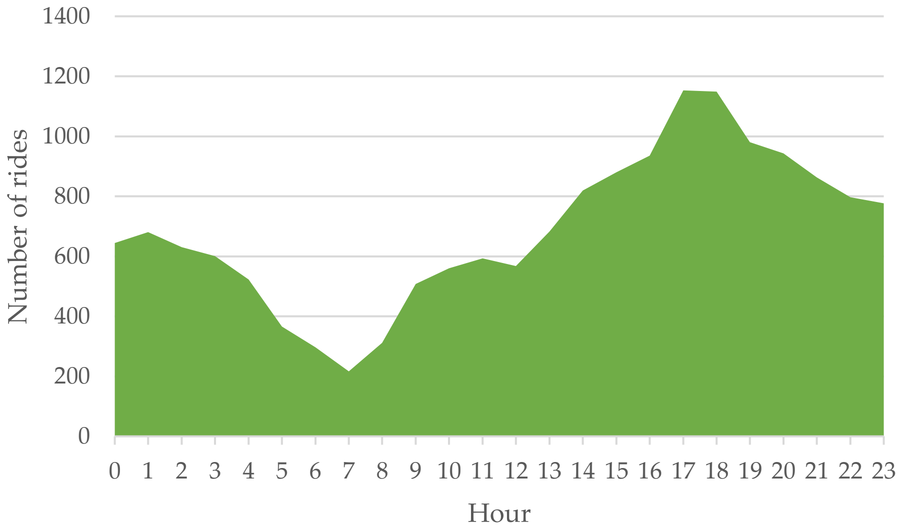


Figure 14. Number of started rides over the day (own work)

Figure 15 shows the number of started rides over the day in the intervals VOI has specified. They are divided into four 3-hour periods between 6:00 in the morning and 18:00 in the evening and two 6-hour periods from 18:00 in the evening till 6:00 in the morning. On the intervals we see the same clear trend as in figure 14, with low numbers in the morning, growing bigger over the day and becoming greatest in the afternoon and evening. Be aware that the evening and night periods cover twice as many hours as the other day-intervals and thus appear relatively larger. However, there is still a substantial number of rides in the evening and night. The high number of rides between midnight and the early morning suggests that people use rented electric scooters as an alternative to public transport when the buses stop running in Odense from about midnight till 5:00 in the morning. Coupled with the high number of rides on Fridays and Saturdays this suggests that people could be using rented electric scooters to get home from parties and nights out.

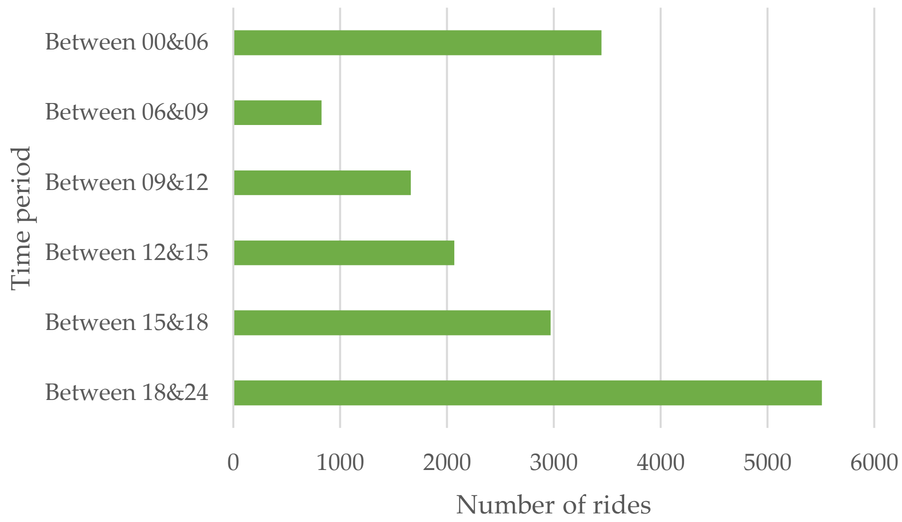


Figure 15. Number of started rides in intervals (own work)

7.3. Duration

Ride duration is presented in five-minute intervals in figure 16 below. This shows a predominant use of rented electric scooters for shorter rides up to five minutes. The frequency drops by 38% to the 6-10-minute interval and again by 58% to the 11-15-minute interval compared to the previous. The last two intervals contain less than 1,600 rides combined and thus makes up less than 10% of the total rides. The numbers indicate that rented electric scooters are a popular mode of transport for short trips.

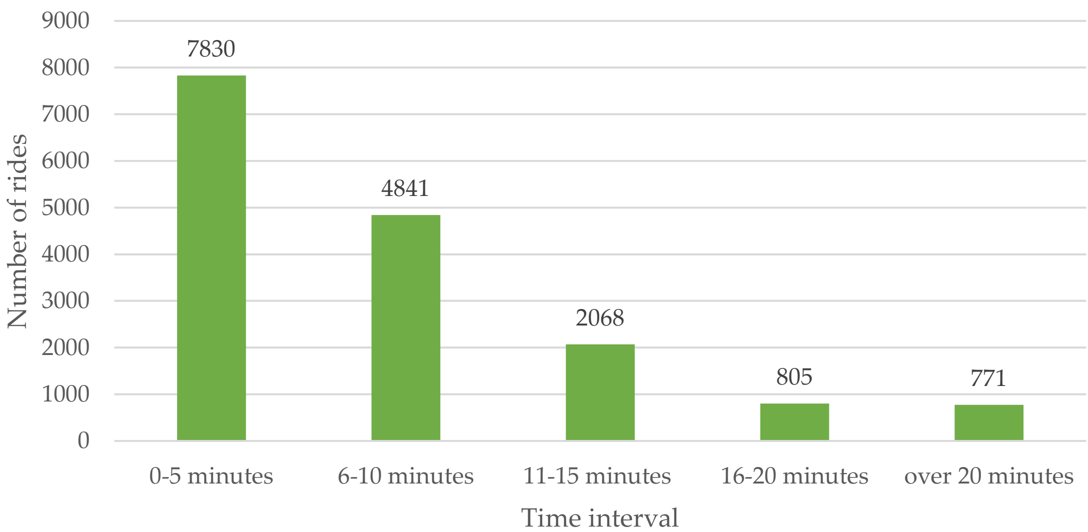


Figure 16. Ride duration in intervals (own work)

As described in section 6.3. Manipulation and outliers, objects have been excluded from statistics on ride duration if they were manually ended by VOI. The differences are illustrated in table 2 showing average ride duration with and without the excluded objects. If the manually ended rides are included, they drag up the average ride duration by almost half a minute and therefore do not present a true picture of the actual electric scooter use.

Table 2. Average ride duration with and without manually ended (own work)

	Average ride duration <u>without</u> manually ended	Average ride duration <u>with</u> manually ended
Mean	7.54 min	7.99 min
95% confidence interval	7.40-7.67 min	7.82-8.16
P-value	$2.2e^{-16}$	$2.2e^{-16}$

As the top speed of electric scooters in Denmark is 20 km per hour, the maximum theoretical distance that can be covered on a ride of average duration is 2.47-2.56 km. This indicates that rented electric scooters help solve travellers last or first-mile problem. Although the maximum theoretical distance is longer than a mile (1.609 km), the actual distance travelled is likely to be shorter because of city traffic, acceleration and so forth.

7.4. Revenue

The next category of mobility data examines VOI´s revenue from the rental business. Figure 17 shows the frequency of revenue from trips in October below 12 €. Only 11,852 trips contained data on revenue and are thus included. Most trips produced a revenue of 2-3 € and 75% of the trips produce revenue between 2-5 €. Some trips gave VOI a much higher revenue up to 80 €, but these are not included in figure 17. This produces an average of 4.06 € with a 95% confidence interval between 4.00-4.11 €, P-value =<0.01.

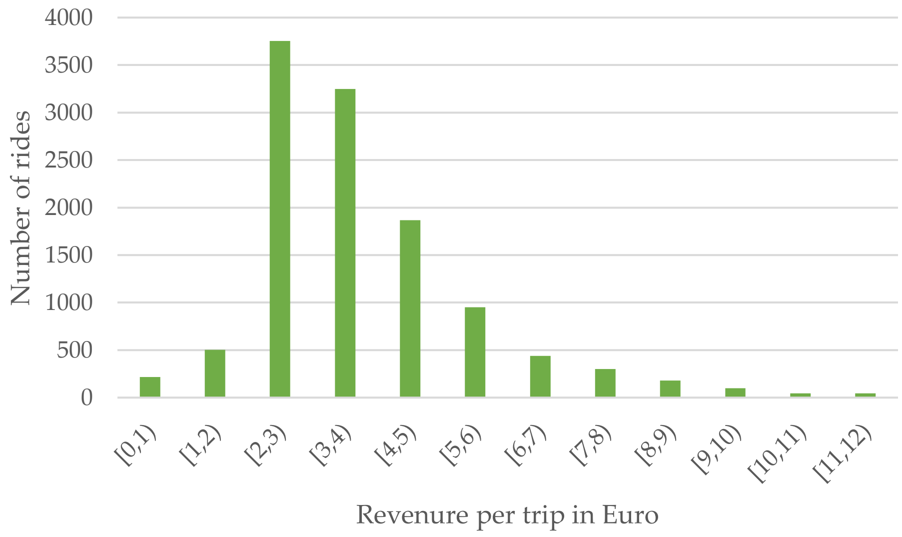


Figure 17. Frequency of revenue (own work)

7.5. Travel

As VOI had more than 16,000 electric scooter trips in October they are impossible to visualise in a single map. Figure 18 shows a 2D snapshot of electric scooter travel in Odense on Saturday, October 12th, 2019 with 841 rides. Each trip is visualised with a yellow arch from starting point to finish point showing the trip in a direct line. The map indicates that traffic is heaviest in the inner city and that outer part of town sees more scattered usage.

Figure 18. 2D map of electric scooter travel in Odense on October 12th, 2019 (own work)

The same rides are also presented in a 3D map from a southwestern angle in figure 19 below. This reveals that there are many short trips in the city centre, but also in the outer parts of town where riders only travel a handful of streets. Longer trips largely start or finish in the city centre, but almost all the trips keep to the limits of the designated riding area. Only three trips can be spotted in the foreground of the map breaking this boundary.

Figure 19. 3D map of electric scooter travel in Odense on October 12th, 2019 (own work)

Figure 20 and 21 shows heat maps of starting points and ending points for the entire month of October. A comparison shows similar geographical locations where rides start and stop, but there seems to be a difference in density between the two maps. The starts seem to be slightly denser, than the finishes in the city centre and in reverse the endpoints seem slightly denser in the outer parts of town.

Figure 20. Heatmap - starting points October (own work)

Figure 21. Heatmap - ending points October (own work)

Differences can be hard to see on the overall heatmap, so investigations were continued onto smaller sections of the map. Figure 22 and 23 shows starts and finishes in the area around Odense station, where the clusters of starting points look slightly denser than the end clusters on the right.

Figure 22. Heatmap - starting points Odense station (own work)

Figure 23. Heatmap - ending points Odense station (own work)

In the western outskirts of town, we have a section of the neighbourhood Bolbro displayed in figure 24 and 25. The outer sections show a slightly denser pattern of endpoints than starting points suggesting that more people might ride from the city centre to the outskirts than the other way around.

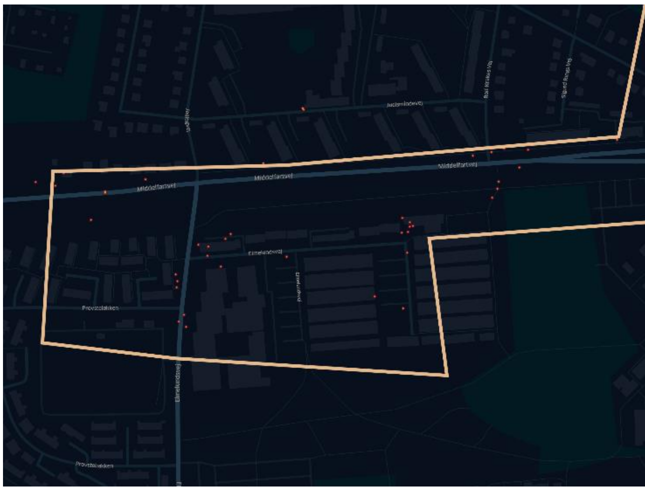


Figure 24. Heatmap - starting points Bolbro (own work)

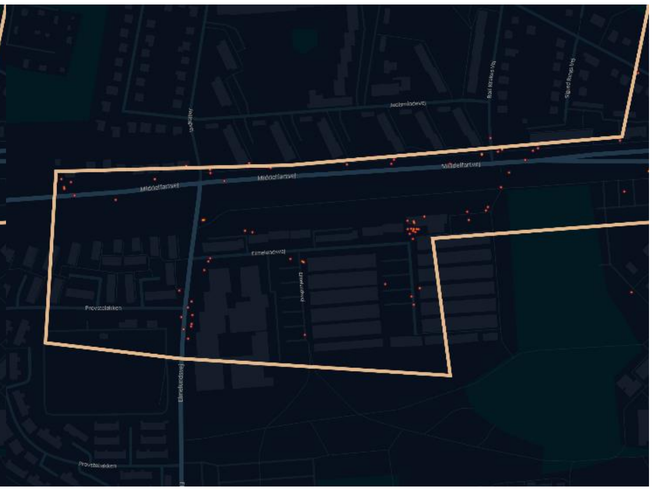


Figure 25. Heatmap - ending points Bolbro (own work)

The routes of travel are also investigated using the brush feature in Kepler, showing all rides to and from a small section of the map. The brush covers a circular area with a radius of 0.5 kilometres and could be moved around the map to show the direction of travel from any point. Six brushes from around the city edges are mapped and shown in figure 26 below. This makes it very clear that the predominant direction of travel is to and from the city centre. Some trips do go across town, but the trend is very clearly centre oriented.

Figure 26. Six brushes of travel direction from the city edges (own work)

This is even more evident when looking at the brush from the city centre in figure 27. The visualization looks like a sun with the rays shining out in all directions. The middle is so dense that we can't make out the individual trips from one another, but they spread out to cover all the rest of the city, showing the clear trend in travel direction.

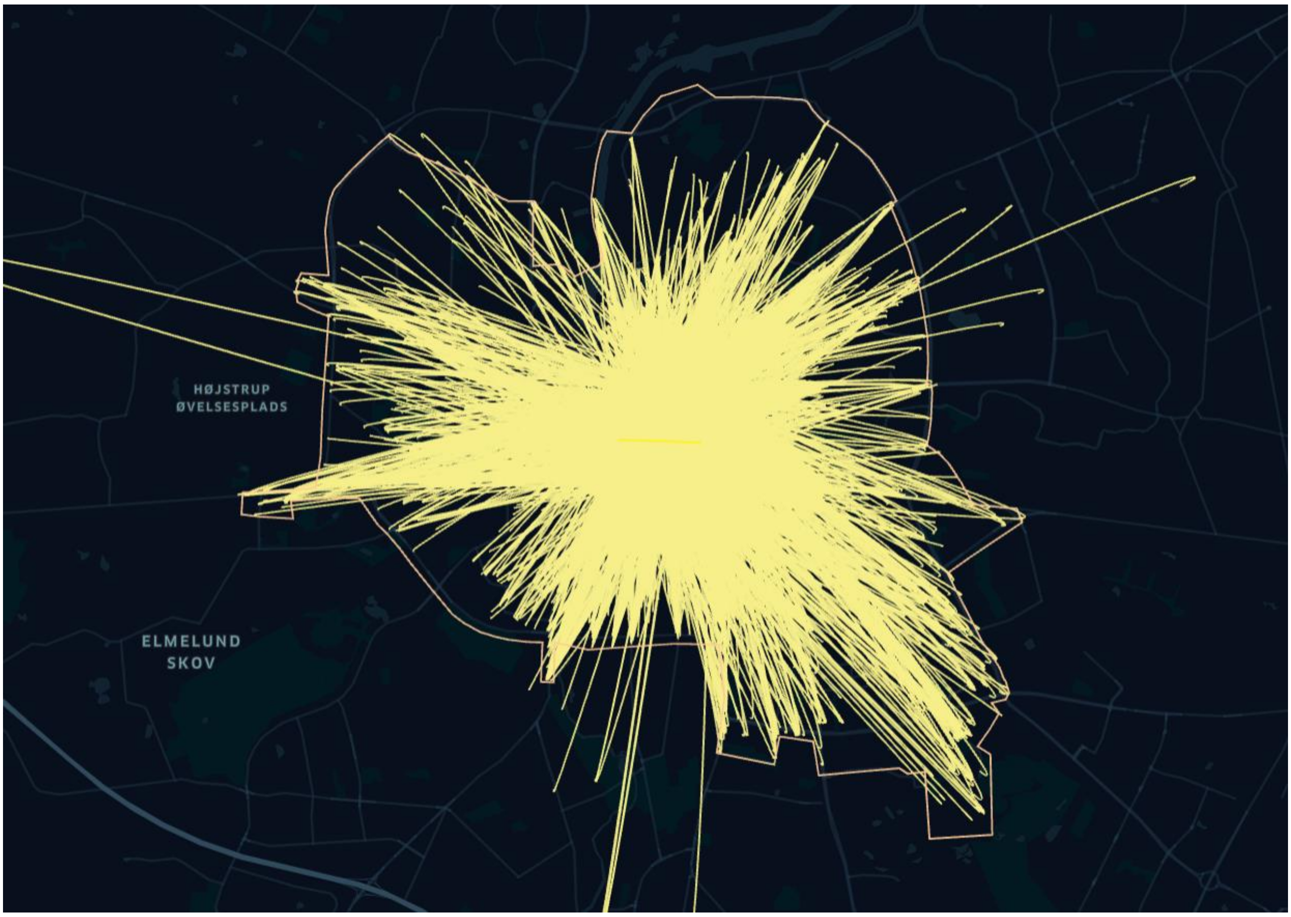


Figure 27. Brushes of travel direction from the city centre (own work)

8. Theory on questionnaires

Questionnaires are a research instrument consisting of a series of written questions and it is a means to collect data regarding people's belief, attitude, behaviour and knowledge (Boynton and Greenhalgh 2004). Questionnaire surveys are a quick and cheap research tool in general. Because of these characteristics, they are often viewed as something anybody can construct and use without learning too much about it, sometimes jeopardizing their value (Eaden, Mayberry and Mayberry 1999, Regmi, et al. 2016). However, Saris and Gallhofer (2014, 4) argue that questionnaires are a rather complex way of getting data and they propose some steps for building a questionnaire.
Several studies in the field of research are advising researchers to take their time and decide on some important aspects of the method. Saris and Gallhofer (2014, 4) recommend starting with the decision on **choice of topic**, where they propose that researchers decide on the use of a descriptive or explanatory (can be either experimental or nonexperimental) study into the research problem. Boynton and Greenhalgh (2004) prioritize the decision on what type of information is desired to be generated and align the tools for reaching that goal. They further advice on the decision on the length of the questionnaire as well as the method.

8.1. Choices of variables

The next step is deciding on all the variables to measure in the study. In this phase, the researchers have another responsibility to look up whether there already is a questionnaire design that could be used (Boynton and Greenhalgh 2004, Setia 2017a). Some questionnaires are open and can be freely used when correctly referenced, others require the consent of the authors. Either way, an already existing questionnaire can be useful even if it is not used directly because it can be an effective guide to find all the relevant variables (Setia 2017a).

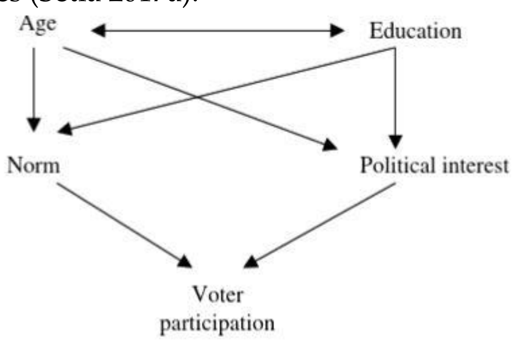


Figure 28. A model explaining voter participation in elections (Saris and Gallhofer 2014, 5)

The choice of variable can be simple, for instance in the case of a descriptive study where the purpose of the study directly determines the choice. For example, if the purpose is to determine the satisfaction with a specific product or service the researcher simply asks, "how satisfied are you with the service/product?". Things get more complicated if we want to study indirect effects on things like *voter participation* as the example in figure 28. It shows that *political interest* and *norm* has a direct effect on *voter participation*, but two other variables *age* and *education* have an indirect effect on it. This means that a voter's *age* and *education* affect their *political interest* and *norm*, and that will determine *participation*. If the *age* and *education* are not addressed in a survey, the effects of *norm* and *political interest* could be overestimated (Saris and Gallhofer 2014, 5).

8.2. Data collection method

Questionnaire surveys can be distributed either online or in some of the more conventional ways like face-to-face, over the phone or by post (Regmi, et al. 2016).
Online distributed surveys provide some convenience for both the people administering the questionnaire and for the respondents. Besides the benefits of fast distribution and economic benefit, the data collectors can get in contact with hard-to-reach populations (ex. specific focus groups or people with disabilities) and avoid the mistakes that can appear when written data is transferred into a computer. The online survey also creates some comfort for the respondents with regard to the time they answer the questionnaire, how much time they take to answer it and where they want to answer it, as well as the chance to complete the questionnaire in multiple sessions (Regmi, et al. 2016).

8.2.1. Choice of operationalisation

Operationalisation in this context refers to putting into effect or realising the questionnaire itself. Designing optimal questions is a challenge in many aspects. First, the researchers must decide on the depth of the study and create questions accordingly (Saris and Gallhofer 2014, 7). For example, we can ask "do you ride electric scooters?". Here we have the subject riding an electric scooter and the dimension is superficial or general. But we can go down in dimension and keep the same subject, like "do you ride privately owned electric scooters?" or "How often do you ride electric scooters per month?" and so on.
Second, the questions can be open- or closed-ended. In an open-ended question, the researcher does not provide answers for the respondent, but they must express themselves in their own words (Setia 2017a). This type of question allows the respondent creative freedom to answer in longer sentences and capture responses that the researcher might not be thinking of. However, these types of questions can take longer to complete which in return can discourage people from responding. It is also harder for researchers to analyse the data and might require more resources. In hand-written surveys, the readability might create loss of some data (Boynton and Greenhalgh 2004). In case of the closed-ended questions, the researcher provides options for the respondents and asks them to choose one or multiple answers from a list (Setia 2017a). Closed-ended questions are easier to complete than open-ended because people do not have to think about the answers, and this could encourage completing the questionnaire. Furthermore, it is easier for researchers to standardise and analyse the data and it is more suitable for online surveys, where people are administering the questionnaire themselves (Boynton and Greenhalgh 2004). Closed-ended questions also have some drawbacks like not allowing the respondents to express their view on the topic. The participants

might just randomly tick one of the options and so the completion is dependent on the respondents understanding of what is required from them (Boynton and Greenhalgh 2004). Further, researchers might not have thought of all possible answers to their questions. To counteract these drawbacks, it might be good to include an "other" or "please specify" option for the closed-ended questions, where the respondents can define other answers (Setia 2017a).

Further aspects a researcher must address when designing a questionnaire include the title and introduction, language, the time period, instructions in the questionnaire, the layout, demographic information, closing comments and accompanying materials (Setia 2017a, Boynton and Greenhalgh 2004).

The title of the questionnaire must indicate clearly what the study is about. It is important to try to avoid misleading wording and distressing the participants. Further, the title should provide an outline of the study and the purpose of the research. The introduction should say approximately the time required for the completion of the questionnaire, whether the research is anonymous or not and how confidential the answers will be processed (Boynton and Greenhalgh 2004).

Setia (2017a) suggests that the language of a questionnaire survey should be simple and easy to understand, especially in cases where data is collected regarding the participant's knowledge, attitude, experiences, behaviour and practices, while trying to avoid a negative or threatening tone, especially toward the end of the questionnaire.

Regarding time, there are two aspects that a researcher must consider. One is the data collection period. For example, a question like "how worried are you that COVID-19 virus will affect your life?" for a European citizen would give different outcomes if it was asked at the beginning of February 2020 or late March 2020. The other aspect of time in a questionnaire is more centred around question formulation (Setia 2017a). For example, "how many times did you use Rejseplanen.dk to plan your journey?" will not necessarily provide researcher information on the usefulness of the site today, but if the question included a period like "how many times did you use Rejseplanen.dk to plan a journey in the last month?" it would give a more accurate answer.

Inclusion of instructions is also a very important element of questionnaire surveys and will help the respondent to understand what to do and how they should approach different questions. For example, if the respondent should pick one or multiple answers or when the answer is a scale from 1 to 10, whether rating 1 is the best or the worst (Setia 2017a, Saris and Gallhofer 2014, 8).

Determining the layout of a questionnaire includes decisions on the font size (it is important that researchers make sure that the respondents can read the questions easily), graphics and illustrations (must provide clear and professional overall effect, while easily understandable) and skip patterns (avoiding data collection which is not relevant or errored, while keeping the questionnaire efficient). Researchers must also ensure mutually exclusive response categories (for example, if the question is "how old are you?" and the answers are 18-25; 25-40; 40-60, it is unclear where to place a 25-year-old. In this case, answers like 18-25; 26-40; 41-60 are preferred). Researchers must also avoid double-barrelled questions (trying to avoid addressing more than one issue in a question). Finally, researchers must examine if any variable is unnecessary or repetitive if the length of the

questionnaire is appropriate and if the order of questions can lead to bias (Setia 2017a, Boynton and Greenhalgh 2004).
Demographic information is another important aspect a researcher must consider in a questionnaire survey. In the phase of variable choice, researchers have to determine and be careful that the demographic information gathered is enough to profile the participants, but does not contain any item that could be irrelevant (Boynton and Greenhalgh 2004).
According to Boynton and Greenhalgh (2004), researchers often forget about expressing thanks to the participants at the end of the survey.

8.2.2. Piloting

Piloting is used to prevent questionnaires from failing to deliver by addressing issues regarding the understanding of the questions and the ability of respondents to complete them all. Piloting can reveal if respondents are being offended or bored by the questions, or if they dislike the way the survey was constructed (Boynton 2004). Boynton (2004) suggests close observation of the test person's reaction to both the format of the questionnaire and the time they spend understanding and answering it. Researchers should look at how respondents arrive at the given answers, if they are confused or surprised by the question or any of the listed answers (in case of a quantitative survey especially), and if they give short or abrupt answers (especially in case of a qualitative survey) because it could indicate that the question itself was short or abrupt.
Every questionnaire survey must report on a specific population, being that either a county's population or a subgroup thereof. The relevance is indisputable because it will ultimately influence the sampling phase and without knowledge of the population, a sampling design would not be possible. Sample refers to a part of the studied population the research is based on. The researchers must not influence the sample at any phase of the study; thus, random sampling is preferred. It is only possible to generalise results from a random sample to the population if the sample design is known (Saris and Gallhofer 2014, 9).

8.2.3. Validity and reliability

Heale and Twycross (2015) define validity as the "extent to which a concept is accurately measured in a… study", while a questionnaire is reliable if it produces the same outcome over time even if it's administered by different researchers (Setia 2017b).
For a simple example demonstrating validity and reliability we can use the example of an alarm clock from Heale and Twycross (2015). If the alarm clock is set to 5 am every day and the alarm clock is ringing at 5 am every single day, we can say the alarm clock is valid and reliable. However, if the alarm clock is set to 5 am but rings at 5:30 am every single day instead, the alarm clock is reliable because it rings at the same time every day, but it is not valid.

9. Questionnaire Creation

A questionnaire was designed to examine what modes of transport electric scooters substitute and to supplement and compare the findings on Danish mobility patterns with those from the VOI data in the previous chapter. This section describes the choices made on questionnaire design from creation until launch. The survey is part of this descriptive nonexperimental study.

9.1. Choice of variables

The process started with research into what other questionnaires were conducted on this topic and found one questionnaire conducted in Denmark and two conducted in the United States (the evaluation report by the Danish Road Traffic Authority was not published at the time and so that survey was not included in the design process).

The carsharing company GreenMobility conducted a Danish survey in 2019 with 3800 respondents of which 325 said that they used electric scooters as their primary or secondary transport. They were then asked what mode of transport they used before electric scooters were a possibility, and the respondent's had 8 different categories to choose from including: bike, walk, carsharing, bus, metro, train, car and "don't know" (Berlingske 2019).

The LCA from North Carolina State University included a survey with 61 respondents that were asked, "if e-scooters were not available, what percentage of the time would you use these alternatives?" (Hollingsworth, Copeland and Johnson 2019a, 8). The respondents had six different response categories including bike, walk, taxi/Uber/Lyft, bus, drive or "would not have gone". The survey also included two questions on riders' reason to ride with response categories related to money and time savings, environmental focus, or recreational reasons.

The second American survey was more comprehensive and was conducted in Portland, Oregon by Portland Bureau of Transportation in 2018. It contains 50 questions on electric scooter use, including frequency, connections, reason to ride, knowledge of traffic laws and substituted modes of transport. The last question was asked in the following four ways (Portland Bureau of Transportation 2018):

- *If an e-scooter had not been available for your last trip, how would you have made that trip?*
- *Before using e-scooters, I....*
- *Since first using shared e-scooters, how has your use of the following options changed?*
- *Think about your last ride on an e-scooter in Portland. If a shared e-scooter had not been available, how would you have gotten around?*

But the survey also included a large amount of questions asking background information on electric scooter users, such as health status, income, education, postal code and many more.

With inspiration from these previous surveys, a number of overall research questions that were then formulated based on the problem statement. These questions or variables below outline the main focus of the survey.

Research questions:

- *What other modes of transport do electric scooters replace?*
- *Are they privately owned or rented?*
- *How often do people use them?*
- *How do people use them?*
    - *Time of day?*
    - *In connection with other modes of transport?*
    - *How far do they ride?*
- *Why do people use them?*

To study some of the indirect effects on these variables, three background questions were also included: gender, age and income. The number of background questions is small because a deeper inquiry into the background effects is outside the scope of this paper.

9.2. Data collection method

The questionnaires were distributed online via a Facebook community for electric scooter riders in Denmark. The group is called "El løbehjul Danmark :)" and contained 784 members as of March 24th, 2020.

9.3. Operationalisation

The questionnaire was created in the SurveyXact software because University of Southern Denmark provides students with free access to this tool. The full questionnaire can be seen with background questions in appendix 2 in its English form, but the questionnaire was available to respondents in both Danish and English.

The questions were formulated to be very general in the beginning to establish whether the respondent ever rode privately owned or rented scooters. Skip patterns were put in place so that respondents would skip over questions that were not relevant to them. This made sure that respondents didn't get questions related to privately owned or rented scooters if they hadn't indicated that they used them.

The next question was very specific on the monthly average of rides and the following questions were all related to the riders overall average transportation on electric scooters.

Questions were all closed-ended giving the respondent two or more answers to choose from. Some include the category "other" and in those cases, an optional "specify box" was placed at the bottom of the list to give a bit of freedom and flexibility. But the closed-ended structure made it possible to get a standard set of results that compare easily.

The response categories were also specifically chosen to make comparison with mobility data and other surveys easy. An example is a question where respondents were asked to specify when they ride electric scooters. Here the categories were made using the same timespans as the ones VOI uses in their data set. Similarly, the question on ride duration was made with categories based on the results of the mobility data.

For categories on the modes of transport that electric scooters substitute, attention was drawn towards the Danish and American surveys done previously. However, these used broader categories that would make calculations on climate footprint hard, so a more precise set of categories was chosen for this questionnaire. The category “car” was split to two options as “Electric car” and “Car/Taxi with internal combustion engine”, and a new category was made that included “Other electrical transport” such as electric bikes, hoverboards and segways. Many modifications were made to make sure the categories included most of the conceivable modes of transport in Denmark anno 2020. The total number of categories to this question became 10, including the answers “Other” and “I wouldn't have taken the trip”. The total list can be seen in appendix 2.

Formulating response categories also included efforts to ensure answers were mutually exclusive. This was especially important for the background question on age where one year could be significant to the results. However, for the question on when the electric scooters where ridden, the answers were made from one full hour to another, making them overlap. This was done because one minute is far less significant to the results and to insure quick readability. Unfortunately, a mistake was found in the transport categories after the questionnaire was carried out because a bike could be placed in both the bike category as well as in the category for nonelectrical transport. But due to the order of the questions, and the examples placed in brackets after the category, it is estimated not to have a significant impact on the results.

Avoiding double-barrelled questions was also a priority and became evident in the question of why people ride electric scooters. The first version of the questionnaire included the response category “it's cheaper and easier than the car” but this was later changed to two questions when the mistake was spotted in the pilot phase.

Instructions were given at the start of the questionnaire to ensure the respondent knew the purpose of the survey and to make sure they knew that answers are treated anonymously, as that could affect people's answers. After the background questions were answered, respondents were presented with another line of instructions that informed them that they should only include trips on electric scooters in Denmark in their answers. Subsequent instructions were given in brackets after each question specifying how the answer must be given e.g. as percentage of total trips. The questionnaire finishes off with a short thank you message to the respondent for contributing to the thesis.

Language has been kept neutral with the font Arial size 15 for easy readability on most screens. The graphical layout was done with the logo of University of Southern Denmark on a grey background and the questions in black letters in a white box. This ensures a professional and neutral look and keeps focus on the content of the question.

9.4. Testing the quality

A pilot test was done on the first version of the questionnaire to root out any mistakes in language, double barrelling, and general understandability. Three people participated and their feedback was incorporated into the second version of the questionnaire. This meant a number of corrections and the addition of more instructions after some of the questions. The second version was then presented to the main supervisor who had a few comments on background questions that were incorporated into the final version.

9.4.1. Population and sample

The survey focuses on the population of electric scooter riders in Denmark. The sample was taken from a Facebook community described in section 9.2 Data collection method. Initial plans had been to distribute the questionnaire to electric scooter riders via rental companies and retailer websites, but companies did not wish to participate so plans had to be dropped. Sampling from the Facebook community means that the sample might contain more private owners of electric scooters than would be representative of the population. This is a potential bias.

9.4.2. Validity and reliability

Validity is ensured by choosing variables that are similar to ones in other surveys on the subject. By doing pilot tests, corrections and getting expert opinions from the supervisor the authors have sought to guarantee the highest rate of validity. When it comes to reliability there is a concern that the time of year might have influenced the results. Especially the question on numbers of rides per month could be very dependent on the season in which it is asked. Or the question on substituted modes of transport that could be affected because people might be more likely to use open transport in the summertime.

10. Questionnaire analysis

The questionnaire was distributed on March 10th, 2020 and the link was deactivated two weeks later on March 24th, 2020. During this period, a total of 138 questionnaires were distributed and they are categorized after responses as: distributed, partially complete, and complete. Figure 29 shows the distribution between the three categories.

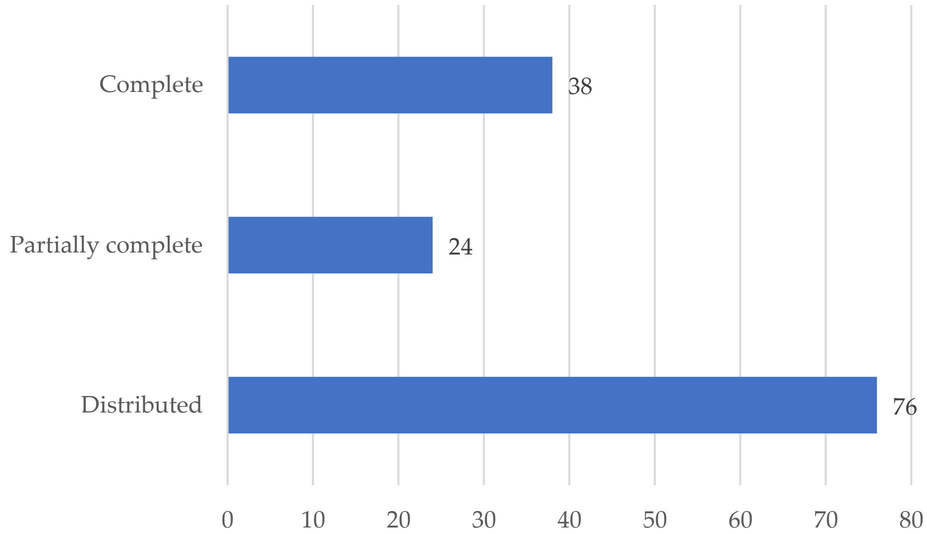


Figure 29. Overall status of respondents (own work)

Distributed, refers to those questionnaires for which the questionnaire's link was accessed, however, none of the questions were answered. In case of partially complete, the respondent completed at least one question and proceeded to the second question, while in case of complete all the questions were answered.

The researchers observed during the verification of partial complete surveys that 88% of those who have not completed the questionnaire abandoned when reaching the first question where they had to specify a percentage on different answers, while the rest of 12% abandoned at the second or third question of the same type. This may be because respondents found it too difficult to calculate the weight of the different options. This highlights a flaw in the design of the questionnaire which had not been observed during the validation or piloting of the survey.

This analysis will focus on the complete questionnaires, thus, the responses from 38 people will be analysed. Before the analysis got started the data was tested, which indicated that data manipulation was necessary. The first problem concerned the questions where respondents had to answer with a numeric value. All answers that were left blank did not automatically generate a 0 value in the dataset, and so the calculations on average did not produce the right result. To ensure correct results the researchers went through all the completed questionnaires one-by-one and added the 0 value in every blank field. Further, for the question on what other mode of transport the respondent would use if they were not riding an electric scooter, some of the respondents chose the option "other" but stated responses that were already listed in the given categories. In those cases, the answers were added to the existing categories.

10.1. Demographic characteristics of respondents

The biggest share of the respondents are male (95%) and only 5% are female, while in regard to their age 50% of respondents are in the age group 18 to 25 years, 42% of respondents are between 26 and 50 years, while only 8% of the respondents belong to the age group of above 50 years. Their income distribution can be observed in figure 30.

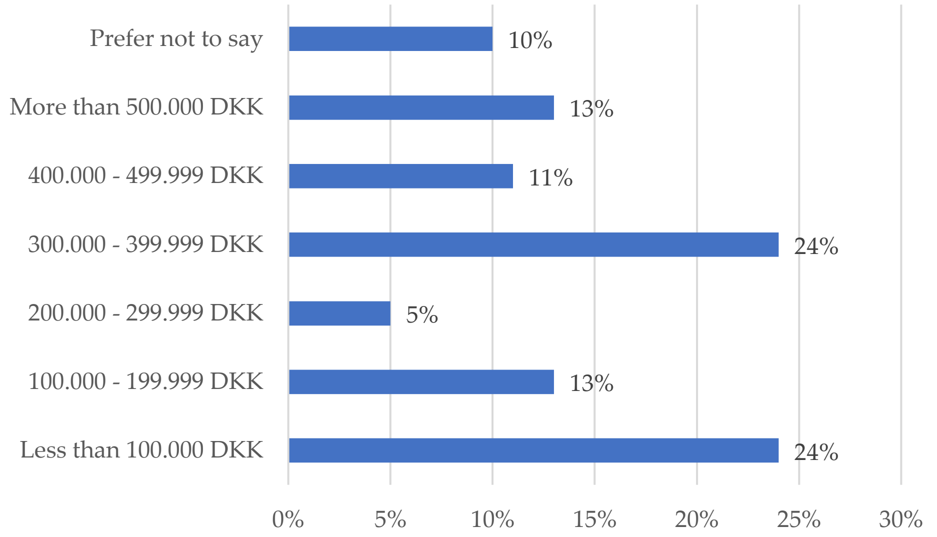


Figure 30. Income distribution of respondents (own work)

Responses to the question *"Do you sometimes ride privately owned electric scooters?"* were 89% yes and only 11% no, as can be seen in figure 31.

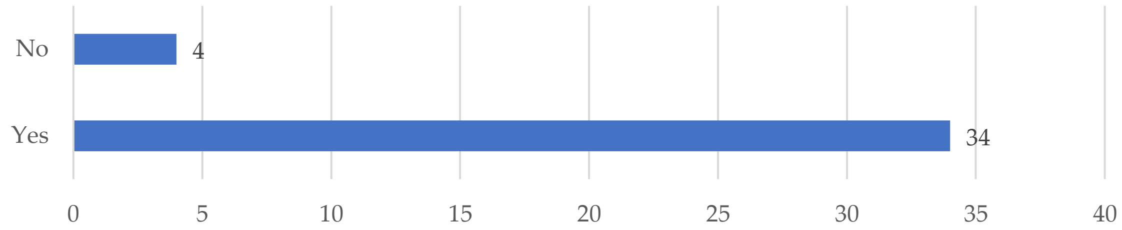


Figure 31. Respondents riding private electric scooters (own work)

To the same question concerning rented electric scooters (Figure 32) 29% answered yes and 71% no, meaning only 11 out of 38 participants who completed the questionnaire are riding rented electric scooters.

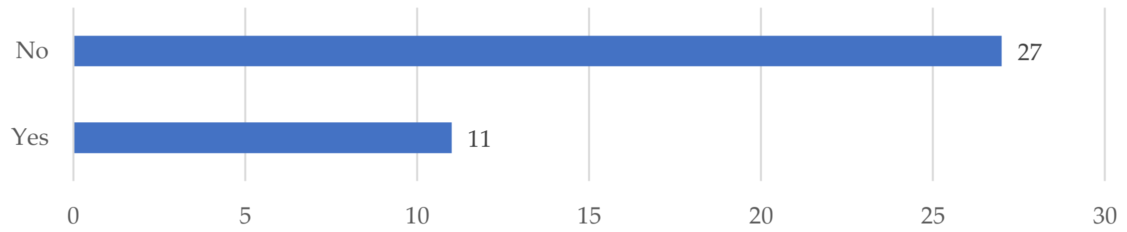
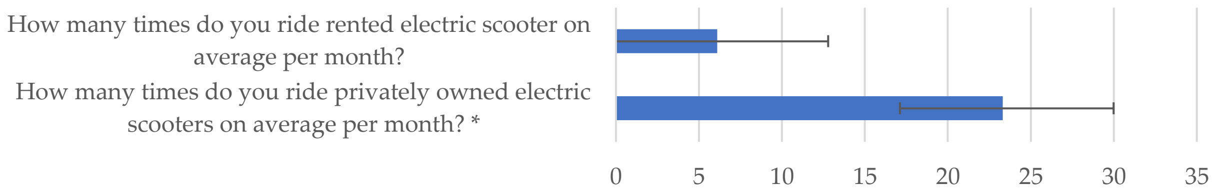


Figure 32. Respondents riding rented electric scooters (own work)

The analysis will proceed with 37 respondents because one respondent does not ride either privately owned or rented electric scooters.
Figure 33 shows a substantial difference in average use frequency between the privately owned and rented electric scooters.

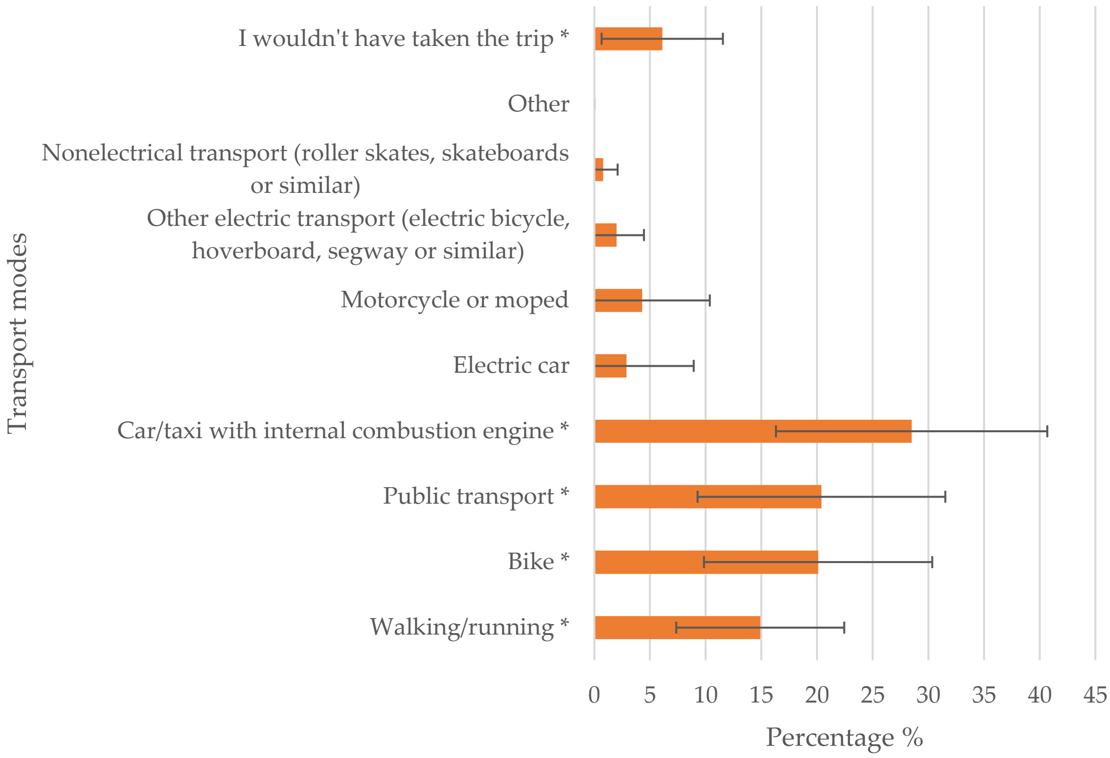


Error bars display the 95% confidence interval, while "*" show that results are significant with a p-value less than 0.05.
Figure 33. Use frequency of electric scooters/month (own work).

In case of privately owned, the respondents use electric scooters 23.3 times per month on average, while rented ones are only used 6.1 times on average per month. The 95% confidence interval for private scooters is 16.54 to 29.99 and for rented it is 0 to 12.29. The p-value reveals that only results for private scooters are significant.

10.2. Use patterns - privately owned electric scooters

This section describes how respondents use their privately owned electric scooters and will first address what other transport modes are being substituted, and then assess how the respondents use their electric scooters in combination with other transport options. Furthermore, the section looks at when the respondents used their electric scooters, the duration of the ride and finally the reasoning for choosing privately owned electric scooters.



Error bars display the 95% confidence interval, while "*" show that results are significant with a p-value less than 0.05.
Figure 34. Average modes of transport substituted by privately owned electric scooters (own work).

Figure 34 shows that the largest part of the respondents (28.5% average) use private electric scooters instead of a car or taxi with internal combustion engine, 20.1% of the rides substitute biking, 14.9% walking or running, and 20.4% public transports. Privately owned electric scooters substitute other transport modes in smaller proportions, around 10% overall. An average of 6.1% of respondents state that they would not have taken the trip, and these represent the joyrides which are taken for the sake of just riding electric scooters. One sample t-test reveals that results for electric car, motorcycle or moped, other electric transport, nonelectric transport are not significant and that confidence intervals for the significant categories are relatively wide (see appendix 3).

On average the respondents use their privately owned electric scooters in connection with other transport modes 25.44% of the time and most frequently with public transportation. Figure 35 below shows the distribution graphically, where cars are the other significant element. The confidence interval for the average is 12.83–38.05 with a p-value less than 0.05 (see appendix 3, table 7).

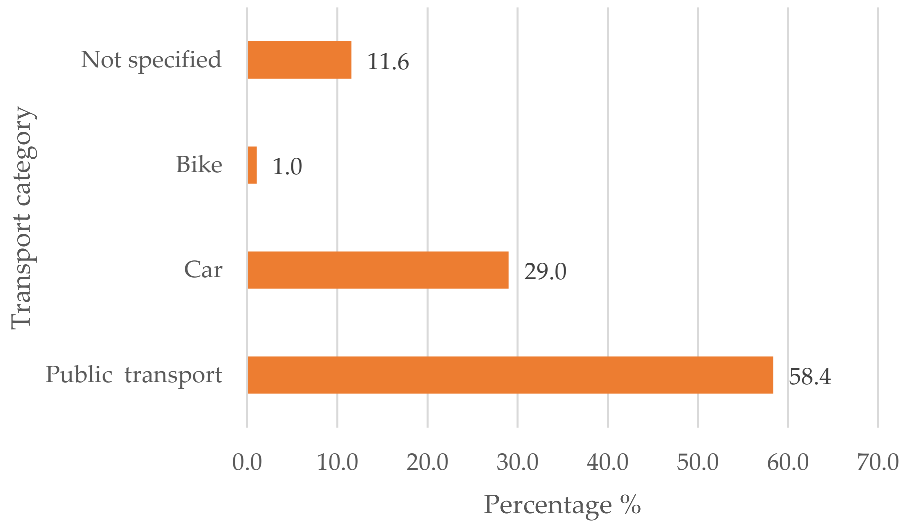
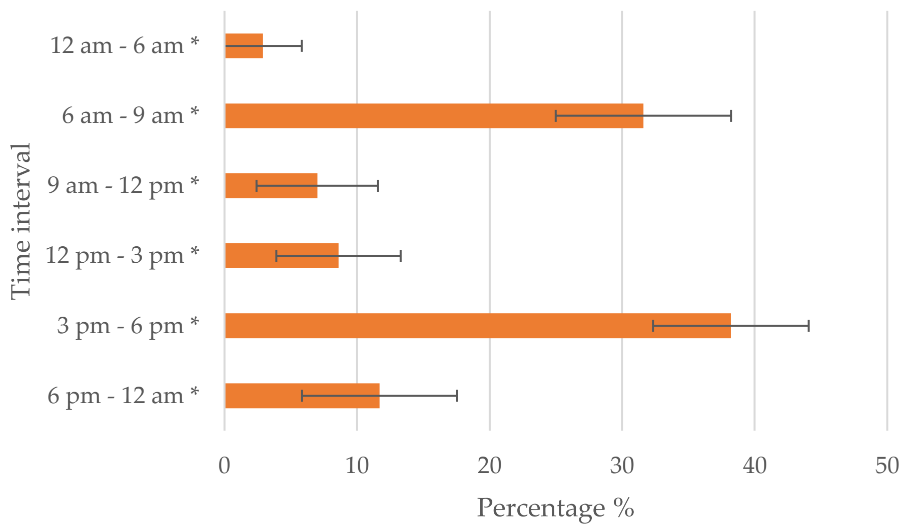


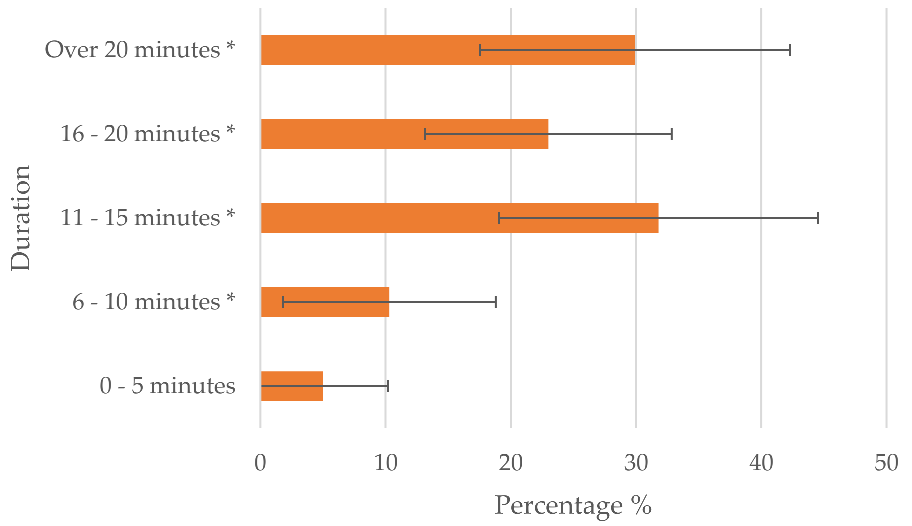
Figure 35. Privately owned electric scooters used in connection with other transport modes (own work)

Figure 36 reveals that on average 69.8% of the rides on private electric scooters are taken between 6 am and 9 am (31.6%) and 3 pm to 6 pm (38.2%). This coincides with normal school and work hours in Denmark between 8 am and 4 pm.



Error bars display the 95% confidence interval, while "*" show that results are significant with a p-value less than 0.05.
Figure 36. Privately owned electric scooter use in periods of the day (own work).

The period with the least number of rides is 12 am to 6 am when only 2.9% of the respondents use private electric scooters. Somewhat equal distribution can be observed between the time frames: 9 am to 12 pm, 12 pm to 3 pm, and 6 pm to 12 am while noting that 12 am to 6 am and 6 pm to 12 am are 6-hour periods while all the other periods only contain three hours. Confidence intervals for all the response categories are significant (see appendix 3, table 2).



Error bars display the 95% confidence interval, while "*" show that results are significant with a p-value less than 0.05.
Figure 37. Duration of rides with privately owned electric scooters (own work).

The data displayed in Figure 37 reveals that on average 31.8% of rides with privately owned electric scooters have a duration between 11 and 15 minutes, while 29.9% are long rides with duration more than 20 minutes. Rides with a duration less than 10 minutes total only 15.3% on average. Results are significant for all categories except rides of 0 – 5 minutes, but the confidence interval is relatively wide (see appendix 3, table 3).
The stated reasons behind using privately owned electric scooters are shown in figure 38.

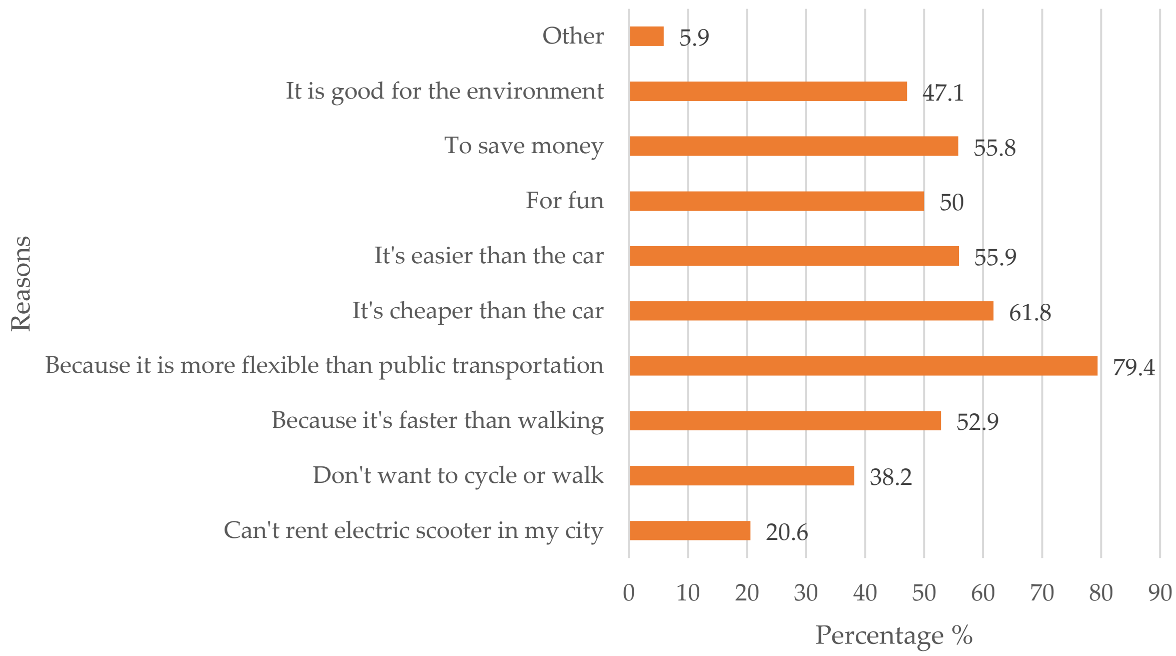


Figure 38. Reasons to use privately owned electric scooters (own work)

It can be observed that respondents use privately owned electric scooters primarily because they consider it more flexible than public transportation (79.4%) and because they believe it is faster than walking (52.9%). Further, 61.8% of the respondents consider that using a privately owned electric scooter is cheaper than using a car, while 55.9% think it is easier. Half of the respondents stated "fun" as a reason for using privately owned electric scooters, while more than 40% use it because they consider it environmentally friendly. 5.9% of the respondents chose "other" and completed the enlisted responses with "It is by far the most fun and easiest way to get around big cities", "Just quick and easy from 0-10 km" and "You can take on a train without a cost". It is also interesting that 21.1% of respondents use private electric scooters because it is not possible to rent electric scooters in their city.

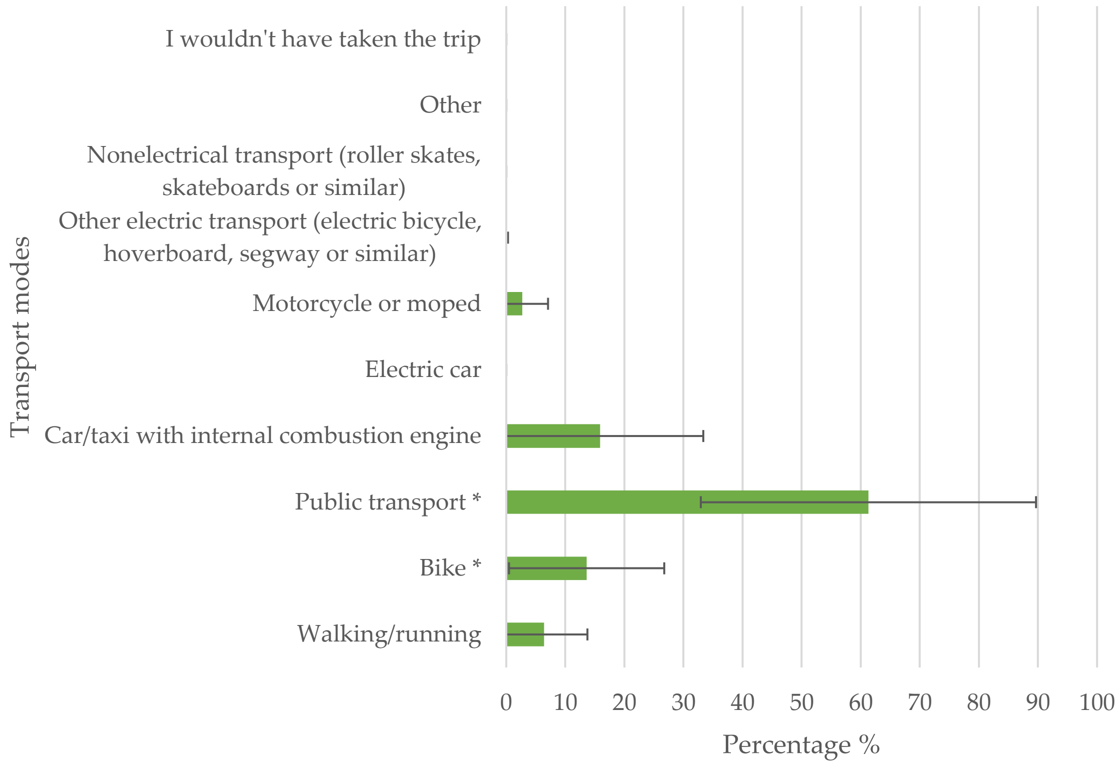
A test for correlation between "reasons for use" and the actual substituted transport alternative found a correlation only when "car/taxi with internal combustion engine" is substituted with electric scooter because "it's easier than the car". The regression analysis indicated a strong significance for the mentioned statement (p-value 0.03) but a coefficient of determination of just 13.76% (R^2=.1376).

10.3. Use patterns - rented electric scooters

This part will be structured similarly to the previous section and will address how rented electric scooters substitute other modes of transport, how they are used in connection with other transport as well as the time, duration, and reason for riding.

It is important to mention the Central Limit Theorem, which says that a large sample size can predict a population's characteristics. Only a sample size with a minimum of 30 will have a distribution close to a normal distribution (Ganti 2019). Since we only have 11 respondents who use rented electric scooters, the mean of observations as well as the standard deviation will not necessarily describe the mean and standard deviation of the examined population. Results should be viewed only as an example of a subgroup.

Figure 39 shows what type of transport modes are substituted by respondents using rented electric scooters.



Error bars display the 95% confidence interval, while "*" show that results are significant with a p-value less than 0.05.
Figure 39. Modes of transport substituted by rented electric scooters (own work).

On average 15.9% of respondents use rented electric scooters instead of car or taxi with internal combustion engine, while 61.3% of them use it instead of public transportation. However, confidence intervals are extremely wide and results for rented scooters are not very meaningful (see appendix 3, table 4). Other transport modes substituted by rented electric scooters include biking, walking/running, motorcycle or moped, and other electric transport.

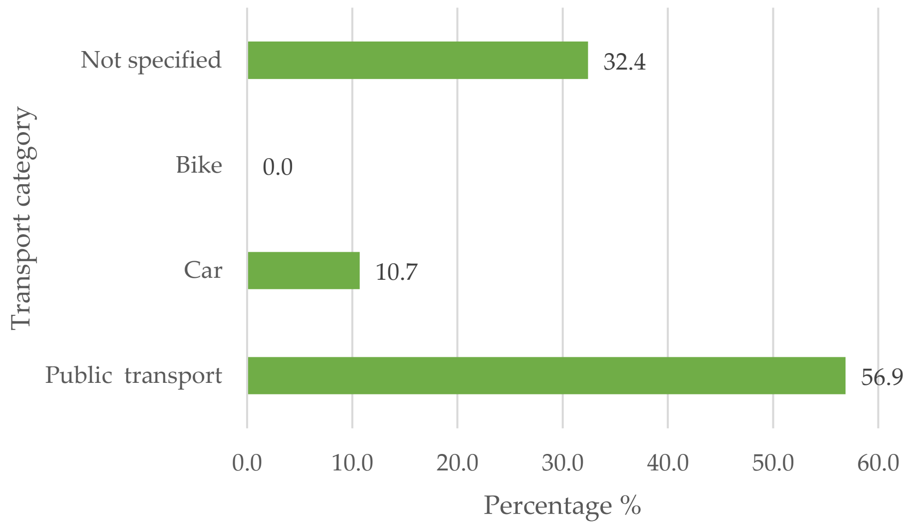
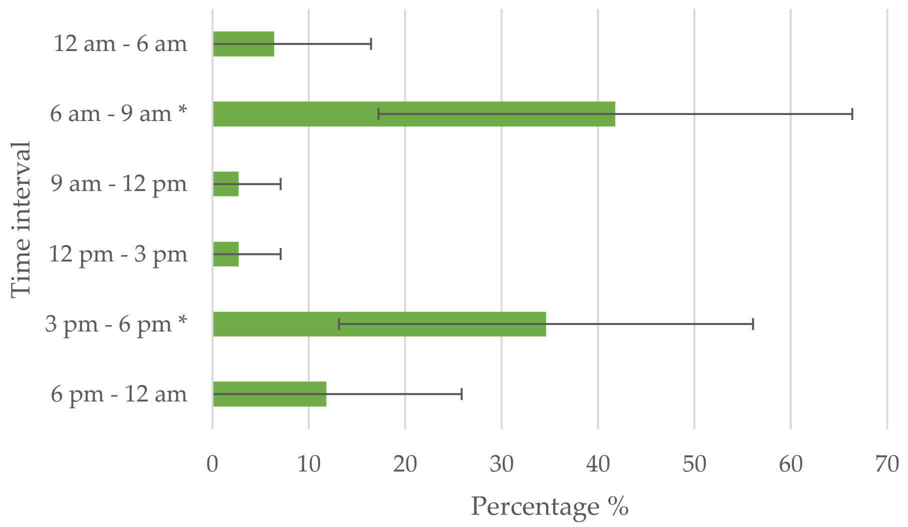


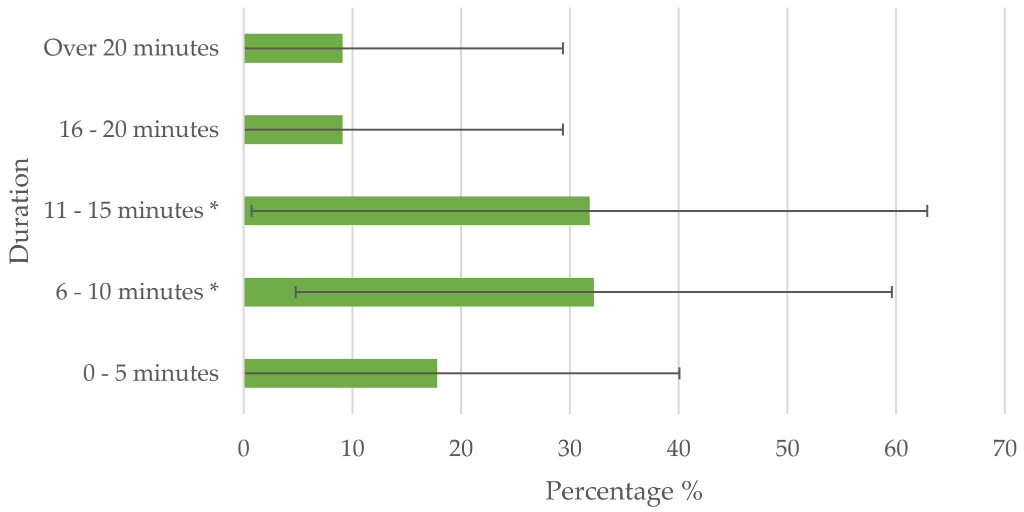
Figure 40. Rented electric scooters used in connection with other transport modes (own work)

On average the respondents use rented electric scooters in connection with other transport modes 7.45% of the time and most frequently with public transportation. Figure 40 above shows the distribution graphically, where Car is the other transport category specified with 10.7%. The confidence interval for the average is 0-16, but not significant as p-value is higher than 0.05 (see appendix 3, table 7).



Error bars display the 95% confidence interval, while "*" show that results are significant with a p-value less than 0.05.
Figure 41. Rented electric scooter use in periods of the day (own work).

Respondents use rented electric scooters most frequently between 6 am and 9 am on average. This period of the day includes 41.8% of all rides, while 34.6% of the rides are within 3 pm to 6 pm. Yet, the significance is still lacking with confidence intervals spanning extremely wide (see appendix 3 table 5).



Error bars display the 95% confidence interval, while "*" show that results are significant with a p-value less than 0.05.
Figure 42. Duration of riding with rented electric scooters (own work).

Regarding the ride duration of rented electric scooters, 32.2% on average are between 6 to 10 minutes, while 31.8% last 11 to 15 minutes. The longer duration intervals from 16 to 20 minutes and over 20 minutes each include 9.1%, while the short rides up to 5 minutes represent 17.8% of responses. The data is statistically significant only in case of rides with duration between 6 to 10 minutes and 11 to 15 minutes, but the confidence intervals are extremely wide-spanning op to 60 percentage points making the results meaningless (see appendix 3 table 6).

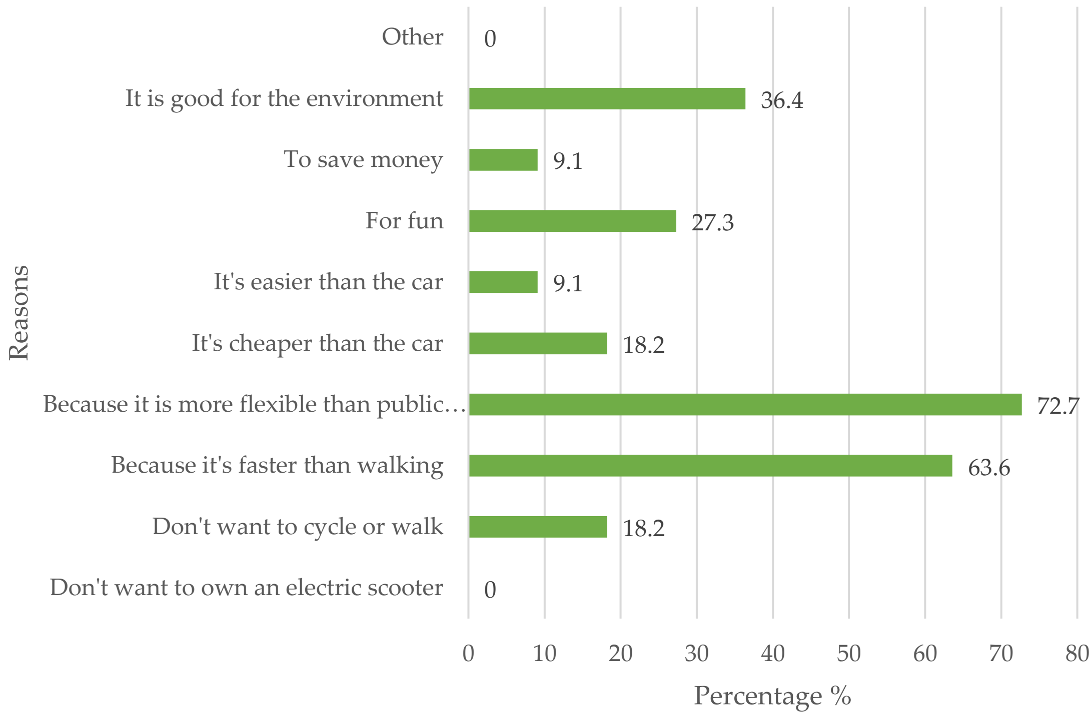


Figure 43. Reasons to use rented electric scooters (own work)

Answers show that rented electric scooters are used primarily because they are more flexible than public transportation (72.7% on average) and because they are faster than walking (63.6%). More than one third see them as environmentally friendly (36.4%) and 27.3% state fun as a reason for use. 36.4% of respondents riding rented electric scooters believe that they transport themselves more after the electric scooter has arrived, while this proportion of private users is 38.2%.

10.4. Regression analysis

It was hypothesized that the level of income and/or age could affect why respondents chose to use electric scooters, so regression analysis was used to test for correlation.

The results indicate that the independent variable - income level explains the dependent variable "it's more flexible than public transport" with a p-value of 0.025 (95% confidence level) in results from private electric scooters. However, the independent variable only explains 15.55% (R^2=0.1555) of the variation in the dependent variable, which is a very low coefficient of determination. No other correlation was found between the level of income or age and "reasons for use" in results from private electric scooters.

In the case of rented electric scooters, income as an independent variable explained 57.62% of the variance in the dependent variable "Don't want to walk or cycle" with a high significance of correlation (p=.0067).

11. Questionnaire comparison

This section compares some of the results from the questionnaire analysis with results from the three similar studies in Denmark and the US: the survey by GreenMobility, the LCA from North Carolina State University and the survey by Portland Bureau of Transportation (see section 9.1 Choice of variables). Surveys from the evaluation report by the Danish Road Traffic Authority (2020) was also included. This was done to assess any anomalies and see how the findings compare between the US and Denmark.

In the evaluation report by the Danish Road Traffic Authority (2020), there are two surveys on substituted modes of transport. The first was conducted as interviews with 208 riders in Aarhus and Copenhagen, the second was an online questionnaire with 427 riders in Denmark. Both are used in the following comparison.

11.1. Substituted modes of transport

Table 3 shows the results on substituted modes of transport from this paper and the range of results from other Danish and US surveys. The transport categories are not identical across the surveys, so grouping has been done to make comparison possible. If total comparability was to be achieved, it would also be necessary to split up some groups from other surveys. As this is not possible, the numeric values should be viewed with some scepticism, but the results are still believed to give a good overall impression of the differences in use pattern between Denmark and the US. Another thing to note is that only the survey by Portland Bureau of Transportation investigates substitution by rental scooters specifically, whereas the other surveys do not differentiate between rented or privately owned electric scooters in their questions.

Table 3. Range of substituted modes of transport from own survey, Denmark, and the US (own work based on Berlingske 2019; Danish Road Traffic Authority 2020; Hollingsworth, Copeland and Johnson 2019b; Portland Bureau of Transportation 2018)

	Privately owned -own survey	Rented - own survey	DK range	US range
Walking/running	7-22%	0-14%	19-50%	35-41%
Bike	10-30%	1-27%	29-46%	4-7%
Public transport	9-32%	33-90%	13-25%	4-11%
Car/taxi with ICE	16-41%	0-33%	12-12,1%*	34 -50%
Electric car	0-9%	0%	-	-
Motorcycle or moped	0-10%	0-7%	0%	-
Other electric transport	0-4%	0%	3%	0%
Nonelectric transport	0-2%	0%	-	-

Other	0%	0%	2 %	1%
Wouldn't have taken the trip	1-12%	0%	3-12 %	5-7%

*Numbers from GreenMobility refer to shared car usage. The last 6,4 percentage point of their survey is distributed between train, car and "don't know" in an unknown allocation, making the theoretical maximum 18,5%.

As displayed in table 3, the category Walking/running seems to represent a smaller fraction of substitution in our own survey than in the other Danish and US surveys. However, the Danish range is quite wide from 19-50% and does overlap a slightly with the maximum from our survey for privately owned scooters, so we can't say for sure.

Our results for the Bike category lie somewhere between the Danish and US range which are significantly different. The US maximum is only 7% compared to the Danish minimum of 29%.

For public transport, we see a huge difference in our own survey between privately owned and rented electric scooters, but because results for rented scooters are so insignificant, we cannot say much about it. The range for privately owned is similar to the range from other Danish surveys but somewhat wider. It overlaps slightly with the US range but could be larger.

The category for car/taxi with internal combustion engines (ICE) shows a high fraction of substitution for privately owned scooters in our own survey compared to the results from other Danish surveys. The numbers for privately owned scooters are closer to the US range, although the US range have higher min and max with and ICE cars representing up to 50% of the substituted modes of transport.

It has not been possible to compare results for electric cars and nonelectric transport as the categories are not included in any of the other surveys. For the rest of the categories, there are no substantial differences between the results from our survey and the results from other Danish and US surveys.

The comparison between Danish and US surveys show interesting differences in substituted modes of transport and this makes it relevant to do calculations for the Danish baseline displacement (see chapter 16. Benchmark displacement).

11.2. Private or rented

The evaluation report by the Danish Road Traffic Authority (2020) examined the relationship between privately owned and rented electric scooters in Aarhus and Copenhagen with observations and interviews. They found a ratio of 81% rented electric scooters and 19% owned in Copenhagen, and a ratio of 56% rented and 44% owned in Aarhus. This is used to calculate a national average of 69% rented and 31% owned electric scooters in Denmark.

Our survey showed 89% of respondents using privately owned scooters and only 29% using rented ones. This can't be directly translated into a ratio between scooters, but it clearly indicates that our sample contains more users of privately owned scooters than the average. This is a potential bias that might have influenced other variables although results are presented separately for privately owned and rented scooters in this paper.

11.3. Rides per month

Danish Road Traffic Authority (2020) also examined how often people rode electric scooters and their results are presented in the second column of table 4. Our own survey results have been formatted in columns three and four to match the categories of the evaluation report.

Table 4. Ride frequency from own survey and Danish evaluation report (own work based on Danish Road Traffic Authority 2020)

Frequency of use	DK evaluation report	Privately owned - own survey	Rented - own survey
Has only used once	48%	4%	25%
Fewer than once per week	32%	8%	42%
1 time per week	7%	8%	8%
2 to 4 times per week	6%	27%	17%
5 to 7 times per week	6%	23%	0%
Several times per day	3%	29%	8%

The comparison showed that many more people in our survey had tried electric scooters more than once. This could be because the survey from the evaluation report was done sometime in 2019 and our survey was done in spring 2020. This gave people more time to ride scooters before answering our questionnaire. Our sample is also taken from a community of people interested in electric scooters, so they have likely ridden more than the average population.

Comparing the privately owned and rented scooter results from our own survey it is evident that the privately owned are used much more frequently. Almost 80% ride privately owned scooters more than 2 times a week compared to 25% for rented and 15% from the evaluation report. Despite the insignificance, the results for rented scooters are more similar to the evaluation report than the result for privately owned scooters.

12. LCA Theory

The following chapter is adopted from (Christensen and Händeler 2018).
Life cycle analysis (LCA) is a tool used to examine all stages of a product's life and evaluate its effects on the environment. This section examines the theories and methods used in LCA.
A life cycle can be divided into five stages:

- Raw material extraction
- Processing
- Production
- Use
- End of life

The impact of each stage is highlighted in the life cycle analysis, which quantifies all inputs and outputs in four phases:

- Goal and scope
- Life cycle inventory
- Impact assessment
- Interpretation

12.1. Goal and Scope

The goal describes the purpose and contexts of the study. Possibly also an environmental focus. According to the ISO 14040 standard, this definition must be unique and describe how the analysis will be conducted and used (Pizzol 2016a).
When the scope is described, the functional unit must be defined as the first thing. It can be described as a quantification of the function that the product has. As an example, one could imagine *paint* as a product whose function is coating walls. The functional unit could then be 1 m^2 of coated wall.
The next step is to determine the quantity of the product that is needed to meet the functional unit. This is called "reference flow". In our example, this would correspond to the amount of paint used to coat 1 m^2 of wall. The definition of the functional unit is important because it allows comparison of multiple products based on the same function and shows the differences between them.

12.2. Life Cycle Inventory

In this stage of the analysis, the model is described, which quantifies flows to and from the environment and the connections between the processes. In the previous section, the word "product" was used as a physical thing, but in practice, a product in LCA can be any product or service. These are part of a product system showing the connections between the processes, which produce the functional unit.
The product system can be displayed graphically, where processes are shown as boxes and products as arrows. The product flow, consisting of all the products between the processes, travels

horizontally, whereas the environmental flow, consisting of the exchanges with the environment, travels vertically. This is illustrated below in Figure 4444.

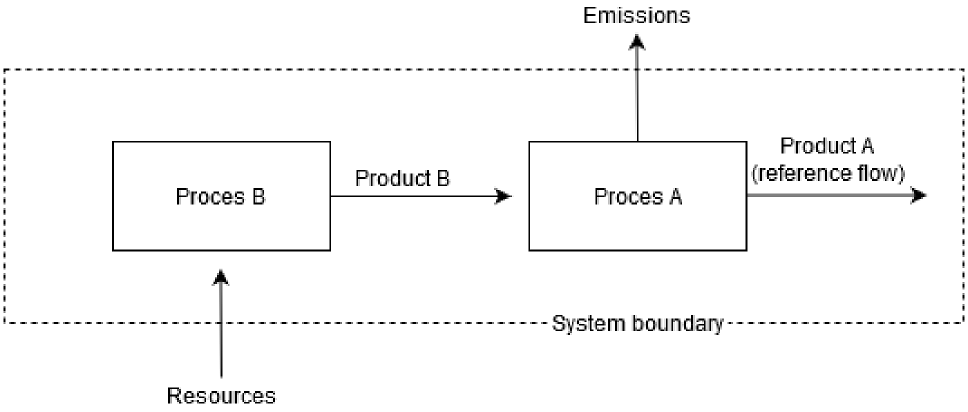


Figure 44. Description of a product system (own work)

Product systems may contain processes that have more than one product, which are called "multifunctional processes". One of the products will be the point of interest, and so-called determining product and the other will be the dependent by-product. In order to divide the emissions and resource consumption between the products, there are two different methods:

- Allocation, which bases the division on physical attributes or monetary value
- Substitution, which assumes that there is a market for the by-product and that it will be affected by the production.

12.3. Impact Assessment

It can be difficult to get a good overview of the results from the Inventory phase due to the large amount of data that is often produced. Impact Assessment is used to classify and characterise the results to create comparability and overview.

Classification

First, each emission must be assigned a category according to the impact of the substance. These categories, called "midpoint categories", tell something about where the impact is created in the environment. An example could be nitrate that runs off into streams and is assigned the category eutrophication. Midpoint categories are further categorized into "endpoint categories", which looks more broadly at the damages the categories inflict on the planet. It can be Ecosystem quality, Resource extraction, Climate change or Human health. For example, eutrophication is not a problem in itself, but because it leads to biodiversity loss and lower ecosystem quality, it causes problems and becomes interesting to look at.

Characterization

The next step is to quantify these damages in each category and doing so requires deciding on an indicator. An indicator is a substance that all other substances in the category can be converted to, so that the entire category can be measured in one unit. Eutrophication, for example, can be measured in phosphate equivalents. To convert everything, a characterisation factor is needed for

all the substances in the category. It must be determined how much of an impact each substance has compared to the indicator. According to Matthews, Hendrickson and Matthews (2015: 298), a substance such as nitrous oxide has a characterisation factor of 265 kg CO2 equivalents per kg N_2O. Therefore, emitting 1 kilo of nitrous oxide is equivalent to emitting 265 kilos of CO2.
Endpoint categories have different indicators, such as the Disability-Adjusted Life Years (DALY) for Human health, and characterisation factors are used to convert each midpoint indicator.
Two voluntary steps, which can also be taken in Impact Assessment, are "Normalization" and "Weighting", which are not further addressed in this report.

12.4. Interpretation

The final step of the LCA focuses on analysing and interpreting the results. This is done to put the results into perspective and make recommendations for improvements (Matthews, Hendrickson and Matthews 2015).
The following four techniques are useful in this context (Pizzol 2016b):
Contribution analysis – Creating figures that show what significance each stage, or process, has on the overall result in a category. This provides a good overview and helps determine how possible improvements can be achieved.
Sensitivity analysis – Analysis of the methods and data used to produce the results. Testing how much the results shift if the methods and data changes, demonstrates the credibility of the results.
Influence analysis – Identification of processes and substances that are significant to the environmental impact.
Anomaly assessment – Analysis of how the results deviate from previous studies in the field. If something sticks out, it may be interesting to investigate in relation to sources of error.

13. North Carolina LCA

The life cycle analysis done in this paper is based on a study by Hollingsworth, Copeland, & Johnson (2019a) from North Carolina State University. The study is focused on Raleigh, North Carolina and is believed to be the first peer reviewed life cycle analysis of rented electric scooters. This chapter describes the methodology used by Hollingsworth, Copeland, & Johnson (2019a) and presents the results of their analysis.

The study uses primary data from production companies and quantifies the results for the functional unit of one passenger mile, in the following four impact categories: total global warming, acidification, eutrophication and respiratory impacts. It explores the drives behind the environmental impact using Monte Carlo analysis and creates scenarios that change the underlying assumptions in the Use Phase. Figure 4545 shows the system boundary for the life cycle of rented electric scooters in five different phases from Materials and Components to End-of-Life.

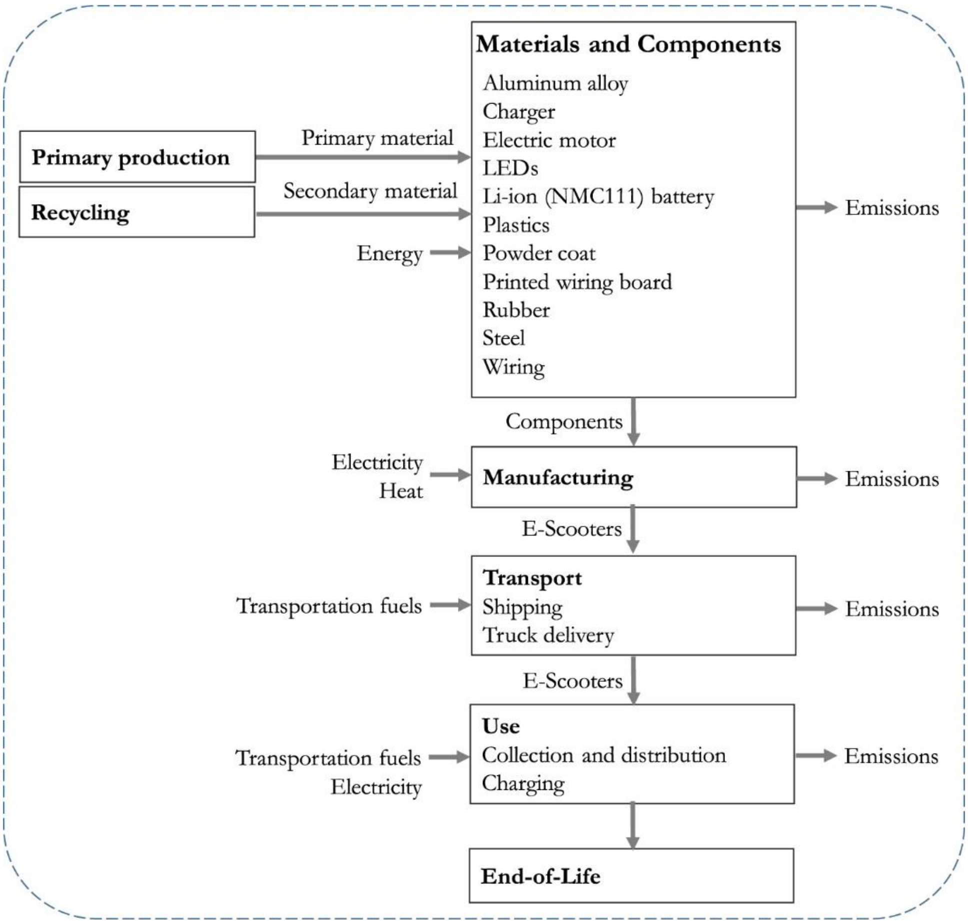


Figure 45. System boundary for the life cycle of a rented electric scooter (Hollingsworth, Copeland and Johnson 2019a)

The materials needed to construct an electric scooter is based on the requirements for the Xiaomi M365 model that the rental companies Bird and Lyft utilize. The list of parts is long and includes an

aluminium frame, steel parts, lithium ion battery, electric motor and tires as the most important ones. However, the list does not include materials for routine maintenance such as spare tires.
The manufacturing process itself is modelled using an electric bicycle production process from the ecoinvent database. This gives an approximation of the energy requirements for the assembly.
Manufacturing is assumed to take place in China, so transportation is calculated on a 17.5 kg package from Shenzhen, China to Raleigh, North Carolina. This journey includes 11,800 kilometres of freight shipping and 4,000 kilometres of truck transport and is equivalent to 207 ton-km of shipping and 70 ton-km of truck transport.
The Use Phase of the electric scooter contains collection and charging at the end of each day, followed by redistribution to the sidewalks in the morning. The transport is done using gasoline and diesel-powered trucks that travel 1-4 km per scooter for collection and redistribution. The batteries need a 0.335 kWh charge with an assumed charging rate of 84 W and the emissions from electricity generation is modelled using seasonal marginal emissions for the region.
Based on manufacturer specifications, a high usage approach would give the scooter and battery a lifespan of 18 months with the manufacturer providing a 12-months guarantee for the main body of the scooter. However, rented electric scooters may have shorter lifespans due to mistreatment, so the lifespan is analysed in a range of 0.5-2 years.
Hollingsworth, Copeland, & Johnson (2019a) uses Monte Carlo analysis to determine the distribution of the life cycle impacts and develop 4 additional scenarios, on top of the Base Case, to investigate the key parameters. The scenarios are:

- Low Collection Distance: The distance travelled for collection and redistribution is only 1 km per scooter.
- Battery Depletion Limit: Batteries are only charged if they are below 50%.
- High Vehicle Efficiency: The trucks used for collection and redistribution have an efficiency of 14.9 kilometres per litre.
- High Scooter Life: Scooter lifespan is set to two years.

13.1. Results

The Base Case analysis shows average life cycle emissions of 125.5 g CO2-eq per passenger kilometre (202 g per passenger mile) for a rented electric scooter. Materials and Manufacturing accounts for 50% of the impacts and collection and redistribution make up 43%. Charging the scooter and transportation to the US only account for 5% and 2% respectively.
Table 5 shows the average life cycle emissions for one passenger kilometre in all scenarios. All present possible reductions in emissions ranging from 12-30% in relation to the Base Case scenario. High Scooter Life has the highest reduction potential and the range of outcomes from the Monte Carlo analysis are primarily driven by the range in scooter lifespan. This indicates that the manufacturing process is the biggest contributor to the life cycle and that the lifespan of the scooter determines how big this burden will be per passenger kilometre. Similar results found in the other impact categories.

Table 5. Emission result under all scenarios (own work based on Hollingsworth, Copeland and Johnson 2019a)

Scenario	Reduction	Average life cycle emissions per passenger kilometre
Base Case	-	125.5 g CO2-eq
Low Collection Distance	27%	91.3 g CO2-eq
Battery Depletion Limit	19%	101.9 g CO2-eq
High Vehicle Efficiency	12%	110 g CO2-eq
High Scooter Life	30%	87.6 CO2-eq

Hollingsworth, Copeland, & Johnson (2019a) continue their investigations by examining what modes of transport are being replaced by rented electric scooters. They conducted a survey with 61 riders and asked them "If e-scooters were not available, what percentage of the time would you use these alternatives?" (see section 9.1. Choice of variables). The results show that 41% of respondents would have walked, 34% would have used car or ridesharing, 11% would have used public transport, 7% should have biked and the last 7% would not have taken the trip.

The answers are used to calculate a "benchmark displacement" where they assume that each passenger kilometre on an electric scooter displaces 0.34 passenger kilometres in a car, 0.11 passenger kilometre in a bus and 0.08 passenger kilometres on a bike (Hollingsworth, Copeland, & Johnson might have made a mistake when rounding off 7.39%). A car is assumed to emit 257 g CO2-eq per passenger kilometre based on Argonne National Laboratory's GREET 2 model with a 2012 vehicle model, average US petroleum mix, 11 litres per kilometre efficiency and one passenger. A bus is assumed to emit 51 g CO2-eq per passenger kilometre based on US calculations on diesel buses during peak hours and a bike is assumed to admit 5 g CO2-eq per passenger kilometre based on a review of the environmental performance of electric two-wheelers.

The benchmark displacement is calculated to 93,2 g CO2-eq per passenger kilometre which is roughly 26% lower than the Base Case for rented electric scooters. This suggests that rented electric scooters contribute more to global warming than the average transport it currently displaces.

14. LCA Design

This following chapters will present the life cycle analysis of both rented and private electric scooters and will compare the results with conclusions from other sources. This LCA is a modification of the LCA from Hollingsworth, Copeland and Johnson (2019a) described earlier in chapter 13. North Carolina LCA, adjusted to the Danish context.

Firstly, the product, the function of the product, and the functional unit are described. The subjects of analysis are both *"Rented electric scooters"* and *"Private electric scooters"* used in Denmark. As this analysis is modelled on Hollingsworth, Copeland and Johnson's LCA work, the same type of Xiaomi M365 electric scooter will be examined. The function of the product is to transport one person, while the functional unit examined was one passenger-kilometre. The analysis focuses on the global warming potential of the chosen electric scooter for one passenger-kilometre and will be defined in g CO_2-eq/passenger-kilometre.

14.1. System boundary

The next step is defining the system boundary.

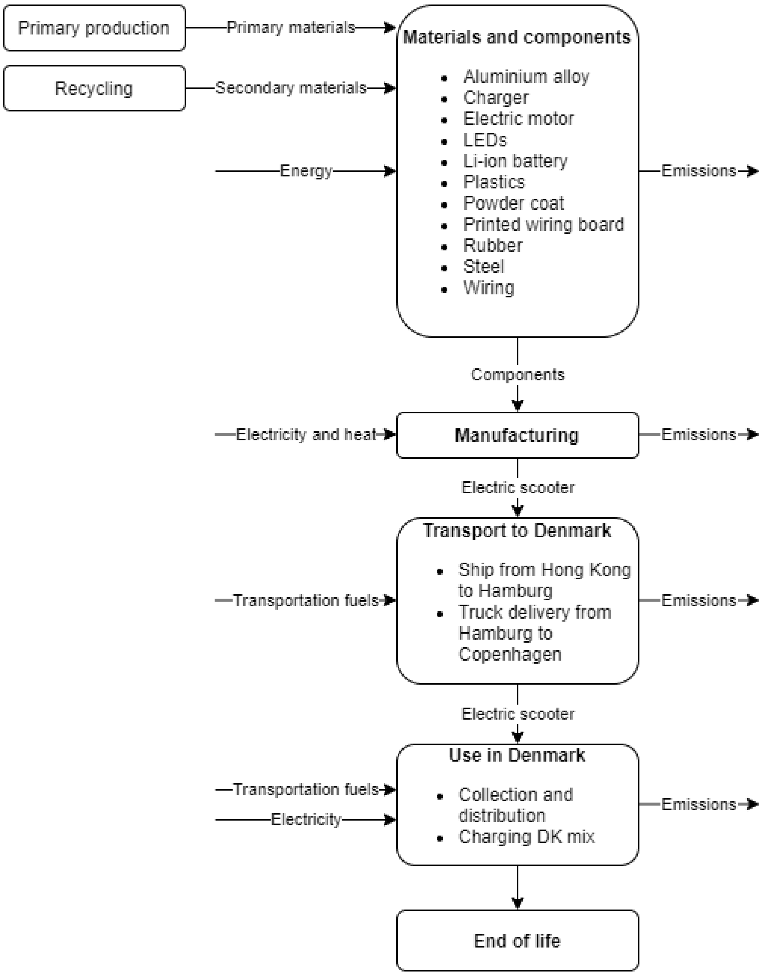


Figure 46. System boundary for the life cycle of a rented electric scooter in Denmark (own work based on Hollingsworth, Copeland and Johnson 2019a)

The system boundary for the electric scooter includes materials and components for the electric scooters, the manufacturing of the product, the transportation, the use phase, and the end-of-life of the product.
The rented electric scooter is modelled based on being manufactured in China, thus no modification to the material and components, and the manufacturing were made compared to Hollingworth, Copeland and Johnson's work. The transportation of goods is changed to include the shipping of an electric scooter from Shenzhen, China to Copenhagen, Denmark. For the use phase, the collection and distribution will be adjusted to the Danish market where the collection is done with different vehicles, while charging is done using the Danish electricity mix.
Private electric scooters are modelled similar to the rented scooters, but with the removal of the collection and distribution phase, as this is irrelevant.

15. Life Cycle Analysis

For the life cycle analysis mainly two types of software were used: SimaPro for finding global warming impact for different inputs, and Microsoft Excel for the Monte Carlo analysis. In SimaPro, the ecoinvent 3.4 database was used, and all analyses were run using the TRACI v2.1 characterization method to calculate environmental impacts focusing solely on global warming potential. This method is a midpoint-oriented life cycle impacts assessment methodology developed by the U.S. Environmental Protection Agency. The Monte Carlo analysis was used to generate random draws from a given distribution and it was simulated 10,000 times for every distribution. The calculation of the global warming potential was made using the same equation as Hollingsworth, Copeland and Johnson (2019a):

$$I = \frac{M + T + \sum_0^d (MPS_d * EF_{auto}) + \sum_0^d \sum_0^i (E_{grid,i,d} * EF_{grid,i,d})}{\sum_0^d D_d}$$

Where:
I – represent the life cycle impact (kg CO_2-eq/passenger-kilometre)
M – the manufacturing of the electric scooter (kg CO_2-eq/scooter)
T – the transportation of the electric scooter to Denmark (kg CO_2-eq/scooter)
MPS_d – the daily distance travelled for the collection and distribution of the electric scooter (auto-kilometre/scooter day)
EF_{auto} – the emission factor of the vehicle used for the collection and distribution (kg CO_2-eq/auto-kilometre)
$E_{grid,i,d}$ – electricity used for charging the electric scooter (MWh/scooter)
$EF_{grid,i,d}$ – the emission factor of the grid used for charging the electric scooter (kg CO_2-eq/MWh)
D_d – distance driven with electric scooter per day

15.1. Manufacturing

Even though the same Xiaomi M365 from Hollingsworth, Copeland and Johnson (2019a) is used for the LCA, it was decided to reproduce the analysis of manufacturing for two reasons. First, Hollingsworth, Copeland and Johnson were using the ecoinvent 3.3 database for their analysis, while our analysis was done in SimaPro using the ecoinvent 3.4 database. Secondly, it was a way to examine the reproducibility of their results. Table 6 presents the global warming potential for every material used in the manufacturing process of the Xiaomi M365 electric scooter.

Table 6. Electric scooter life cycle inventory for materials and manufacturing with global warming impact (own work based on Hollingsworth, Copeland and Johnson 2019b)

Flows into electric scooter production	Flow property	Unit	Amount	Impact (kg CO_2-eq)
Aluminum alloy, $AlMg_3$	Mass	kg	5.731	122
Aluminum cast alloy	Mass	kg	0.256	6.7
Li-ion battery cell produced	Mass	kg	1.159	8.54
Used Li-ion battery	Mass	kg	1.169	-3.23
Charger, for electric scooter	Mass	kg	0.385	12.2
Electric motor, for electric scooter	Mass	kg	1.187	17.7
Electricity, medium voltage, at grid	Energy	kWh	6.89	7.68
Heat, district or industrial, natural gas	Energy	MJ	13.6	1.04
Heat, district or industrial, other than natural gas	Energy	MJ	0.193	0.0032
Light emitting diode	Mass	kg	0.016	3.78
Polycarbonate	Mass	kg	0.266	2.07
Polycarbonate, misc. plastic	Mass	kg	0.008	0.0622
Powder coat, aluminum	Area	m^2	0.35	1.42
Printed wiring board	Mass	kg	0.059	4.21
Steel, low-alloyed	Mass	kg	1.349	2.93
Synthetic rubber	Mass	kg	1.185	3.15
Tap water	Mass	kg	0.744	0.000314

Transistor	Mass	kg	0.062	9.68
Welding, arc, aluminum	Length	m	0.75	0.304

The material and components, and the manufacturing (M) process total 200 kg CO_2-eq/scooter identical to the results of Hollingsworth, Copeland and Johnson (2019b). As can be seen from the table, the greatest impact is coming from the aluminium alloy (122 kg CO_2 eq) which is used for the body and frame of the electric scooter.

15.2. Transportation

For this purpose, an actual transport route between Denmark and China is modelled, consisting of 18,500 kilometres shipping from Hong Kong to Hamburg and 471 kilometres of truck transport from Hamburg to Copenhagen (Cargorouter 2020). The 17.5-kilogram package of the electric scooter results in 323.75 ton-km of shipping and 8.25 ton-km transportation by truck. The transportation of the 17.5 kg package results in 4.34 kg CO_2-eq emissions, where 3.6 kg CO_2-eq emissions comes from the shipping from Hong Kong to Hamburg, while the remaining 0.74 kg CO_2-eq emission comes from the road transport by truck from Hamburg to Copenhagen. For the calculation of the shipping the process "Transport, freight, sea, transoceanic ship (GLO)|market for|Conseq, U" is used and calculated for the 323.75 ton-kilometre transport because this process includes the life cycle of the production, maintenance and operation of the transoceanic ship and the construction of the port. The road transport is calculated using the process "Transport, freight, lorry >32 metric ton, EURO 6 (RER)|Conseq, U". This process was chosen because EURO6 engines were required in all heavy-duty trucks built from January 2013 or with EURO5 engines from October 2008 (Dieselnet 2020). Since the average age of a heavy-duty truck in Europe is 8.13 years (European Environment Agency 2016) most of the trucks likely have EURO6 engines, while the difference between EURO5 and EURO6 for the 8.25 ton-kilometre truck transport is only 0.043 kg CO_2-eq/scooter.

15.3. Collection and distribution

For the collection and distribution, the following assumptions were made:

- Vehicles travel the same 0.96 to 4.02 kilometres (0.6 to 2.5 miles) distance for the collection and distribution as Hollingsworth, Copeland and Johnson (2019a)
- Vehicles used in Denmark are diesel vans, electric vans, and electric cargo bikes, resulting in an average emission of 0.268 kg CO_2-eq/auto-kilometre.
- It is also assumed that the rented electric scooters on the Danish market can be used (lifespan) between 1 to 1.5 years (Danish Road Traffic Authority 2020), resulting in 365 days to 547.5 days assuming that one year consists of 365 days.

In Aalborg, the scooters are collected using Nissan e-NV200 electric vans representing 2% of all pickups. In Herning, the collection is done with electric cargo bikes representing 3% of pickups. In the rest of the country, the electric scooters are collected using regular vans with ICE representing

95% of pickups (Sørensen 2020). No life cycle analysis was available for the Nissan e-NV200, so the emissions are modelled on a Nissan Leaf with a similar 40 kWh battery pack (CarbonBrief 2019). The electric cargo bike was modelled as an electric bike using numbers from Weiss, et al. (2015). Finally, emissions from the vans with ICE were modelled on the tailpipe emissions from a Volkswagen Crafter 2.0 TDI SCR (Volkswagen 2020) which is used in Copenhagen coupled with the manufacturing process "Light commercial vehicle (GLO)| market for| Conseq,U" from ecoinvent 3.4.

Monte Carlo simulations were used for the calculations and generated 10,000 random numbers for the distance travelled for collection and distribution, and the lifespan of the electric scooter. This resulted in a list of MPS_d between 0.96 to 4.02 kilometres and d between 365 and 547.5 days. These were then multiplied with the emission factor of the vehicles used for collection and distribution (EF_{auto}) to generate the total emissions associated with the collection and distribution of an electric scooter over its lifetime.

15.4. Charging

Assumptions for charging:

- It is assumed that scooters are collected for charging every night with the battery level between 18% and 66% and that the electric scooter has a maximum distance potential of 28.97 kilometres (18 miles) (Hollingsworth, Copeland and Johnson 2019a)
- The battery capacity of the electric scooter is 0.335 kWh on a full charge (Hollingsworth, Copeland and Johnson 2019a)

The charging of the battery it was modelled on the average electricity mix of Denmark using the process "Electricity, low voltage (DK)|market for|APOS, U" from the ecoinvent 3.4 database resulting in $EF_{grid,i,d}$ = 386 kg CO_2-eq/MWh. The electricity used for charging the electric scooter ($E_{grid,i,d}$) was calculated by generating 10,000 random numbers between 34% and 82% (the required charging for the battery to be at 100%, since the collection of the scooters is done when the battery is between 18% and 66%) and multiplying it with the amount of energy for the full charge (0.335 kWh). Then $EF_{grid,i,d}$ and $E_{grid,i,d}$ were multiplied with each other and the number of days d (as described earlier), to find the sum of emissions associated with charging an electric scooter over its lifespan. This produced average emissions of 34.15 kg CO_2-eq/scooter.

15.5. Distance

To calculate the emissions from riding one kilometre on a rented electric scooter it was necessary to find the distance ridden with an electric scooter per day (D_d). The list of battery states from calculations on $E_{grid,i,d}$ was multiplied with the distance potential of an electric scooter at full charge (28.97 kilometres) resulting in a list of 10,000 distances between 9.85 and 23.75 kilometres. These distances were then multiplied with the number of days d (as described earlier), resulting in total distance travelled with an electric scooter over its lifespan.

15.6. Impact

15.6.1. Rented electric scooter

All the variables of the equation were calculated and put into the formula, resulting in a 75.5 g CO_2-eq/passenger-kilometre emissions from rented electric scooters. The distribution of the emissions for the 10,000 Monte Carlo simulations can be observed in figure 47.

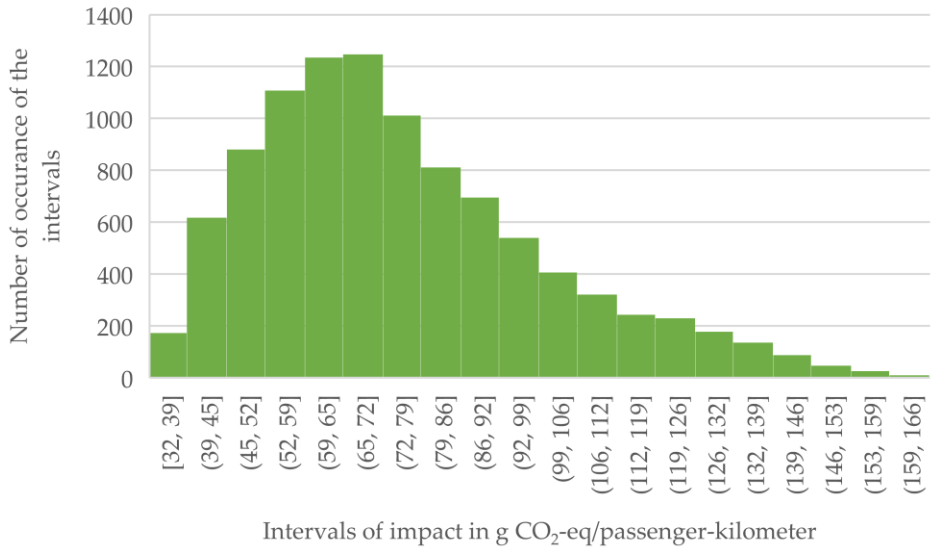


Figure 47. Distribution of emissions using Monte Carlo simulation for rented electric scooter (own work)

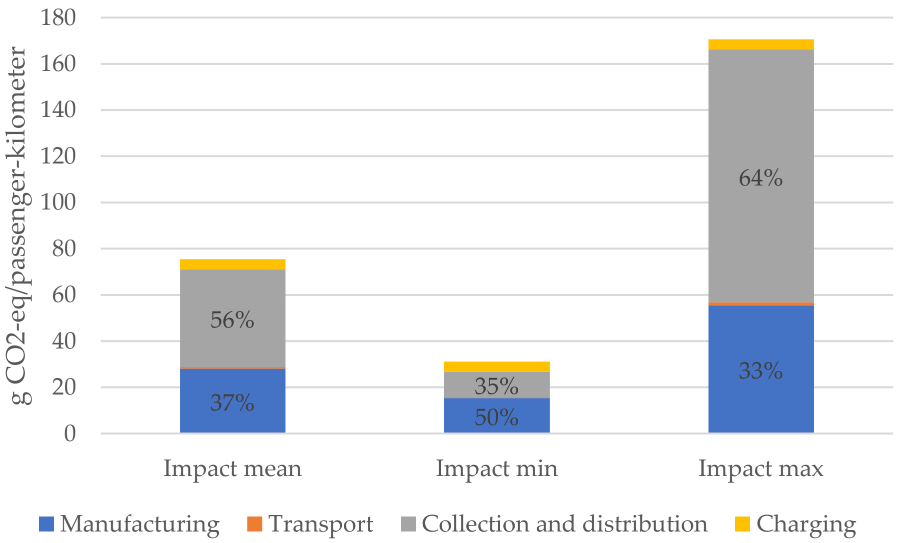


Figure 48. Emission levels from the base scenario for rented electric scooter (own work)

Figure 48 presents the emission levels from the base scenario and the distribution of the impact between the manufacturing, transport, collection and distribution, and charging. The chart shows the average impact calculated using 10,000 Monte Carlo simulations for the minimum impact (31.12 g CO_2-eq/passenger-kilometre) as well as the maximum impact (170.65 g CO_2-eq/passenger-kilometre). For the average impact, 55.9% of the emissions are generated by collection and distribution of the electric scooter, 37.25% by the manufacturing, while the charging and transportation only contribute 5.9% and 0.95% respectively. Under minimum impact the distribution is 49.3% manufacturing emission, 35.3% collection and distribution, 14.3% charging and 1.1% transport, while under maximum impact 64.1% of the emissions are from collection and distribution, 32.6% from manufacturing, 2.6% from charging and 0.7% of the emission represent the transportation. The results suggest that two elements are significantly affecting the results: collection and distribution, and manufacturing.

15.6.2. Privately owned electric scooter

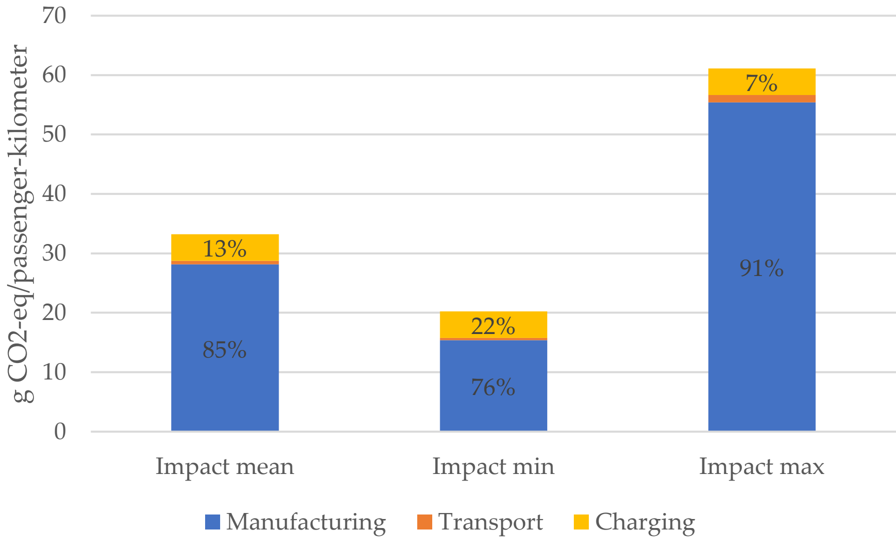


Figure 49. Emission levels at the base scenario for privately owned electric scooter (own work)

The figure above shows the emissions of privately-owned electric scooters from 10,000 Monte Carlo simulations. The chart illustrates three results where impact mean represents the simulation's average, the impact min is the lowest impact under the simulated scenario, while impact max represents the highest impact. The result indicates that the average life cycle emission of privately-owned electric scooter is 33.23 g CO_2-eq/passenger-kilometre, while the minimum and maximum under base scenario is 20.22 g CO_2-eq/passenger-kilometre and 61.1 g CO_2-eq/passenger-kilometre respectively. The chart also shows that the vast majority of emissions come from the manufacturing of the electric scooter (85% at the base scenario average) indicating that the lifespan can have a significant effect on the overall life cycle emissions.

15.7. Sensitivity analysis

15.7.1. Rented electric scooter

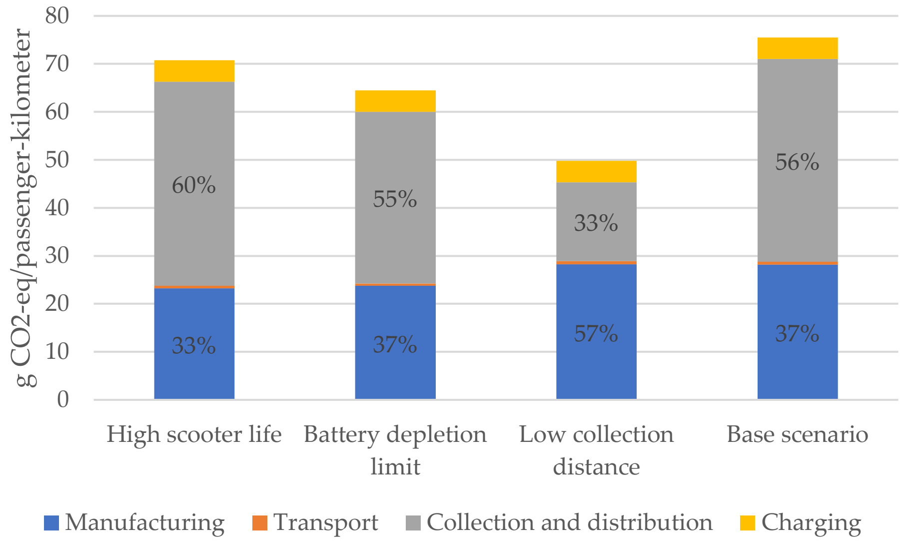


Figure 50. Sensitivity analysis according to Hollingsworth, Copeland and Johnson's (2019a) scenarios for rented electric scooter (own work)

Figure 50 shows sensitivity analysis with the scenarios from Hollingsworth, Copeland and Johnson (2019a) described in chapter 13. North Carolina LCA. In case of the high scooter life, the expected lifetime of the electric scooter was set to 1.5 years which is the highest one described by the Danish Road Traffic Authority in their evaluation report (Danish Road Traffic Authority 2020). In this scenario, the average life cycle emission of 1 passenger-kilometre is 70.77 g CO_2-eq, which is 6.9% lower than in the base scenario. When the collection is limited to electric scooters with a battery below 50% (Battery depletion limit scenario), the life cycle emission falls to 64.45 g CO_2-eq/passenger-kilometre. At the low collection distance scenario, the distance for the collection is set to 0.96 kilometres and result in 49.82 g CO_2-eq/passenger-kilometre life cycle emissions, a decrease of approximately 35% from the base scenario.

From the results and the comparison of different scenarios it was evident that collection and distribution, and the manufacturing have a significant effect on the life cycle emissions of electric scooters. Further analysis of the underlying lifespan of scooters will now be conducted. Figure 51 shows the results of testing emissions under the following scenarios for lifespan:

- Three months lifespan: the electric scooter lasts only 3 months, which was VOI's expected lifespan in March 2019 (Danmarks Radio 2019)
- Half year lifespan: this is the minimum expected lifespan from Hollingsworth, Copeland and Johnson (2019a)

- Half year to two years, where we test the lifespan period described by Hollingsworth, Copeland and Johnson (2019a)
- Two years, is the maximum lifespan described by Hollingsworth, Copeland and Johnson (2019a)
- Three years, where it is tested what would happen if a new generation with enhanced lifespan appeared on the market

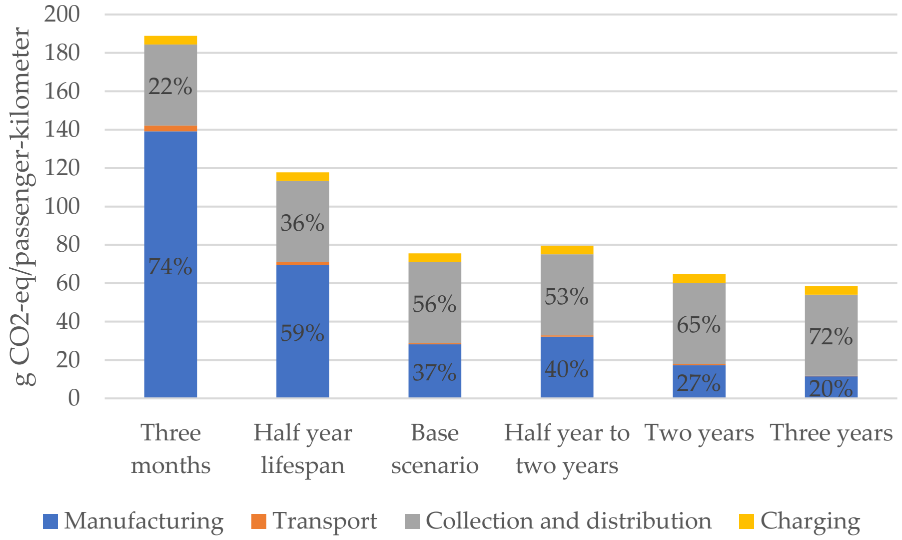


Figure 51. Sensitivity analysis at different lifespan for rented electric scooter (own work)

The result indicates that scooter lifespan is highly affecting the overall life cycle impact of rented electric scooter, as well as the relationship between the manufacturing, and collection and distribution. The Danish Road Traffic Authority (2020) suggested a 1-1.5 years lifetime for scooter represented by the base scenario in figure 51, while Hollingsworth, Copeland and Johnson (2019a) used a 0.5-2 year lifespan. From figure 51, we can see that the difference is minimal between the base scenario and the half year to two years scenario, the latter being only 5.3% higher. However, the other results show that the life cycle emissions of electric scooters are more critical to the lifespan. If the scooter is only used half a year, the life cycle emissions reach 117.81 g CO_2-eq/passenger-kilometre and if it lasts only 3 months, the life cycle emissions can hit 189 g CO_2-eq/passenger-kilometre, which is 2.5 times the emissions from the base scenario. In that scenario, 74% of the emission is connected to the manufacturing and only 22% to the collection and distribution. Of course, it is also possible that scooters last longer and can reach the maximum suggested lifespan. At two years lifespan, the scooter's life cycle emissions fall to 64.72 g CO_2-eq/passenger-kilometre, 14.26% lower than the base scenario. If the scooters evolve and reach three years lifespan at some point, this could lower emissions as far as 58.5 g CO_2-eq/passenger-kilometre.

Figure 52 shows that happens to life cycle emissions if the emission factor for the vehicles used for collection and distribution are changed under the following four scenarios:

- Half of collection with ICE, where we assume that 3% of the collection is done by electric cargo bikes, 47% with electric vans and 50% with ICE vans
- Collection with EV, where 100% of the collection is done with electric vans
- All with ICE, where the entire collection and distribution is done with ICE vans
- At "ICE high emission" it is assumed that the collection and distribution is done with ICE vans producing 50% higher emissions than the ones used in the base scenario

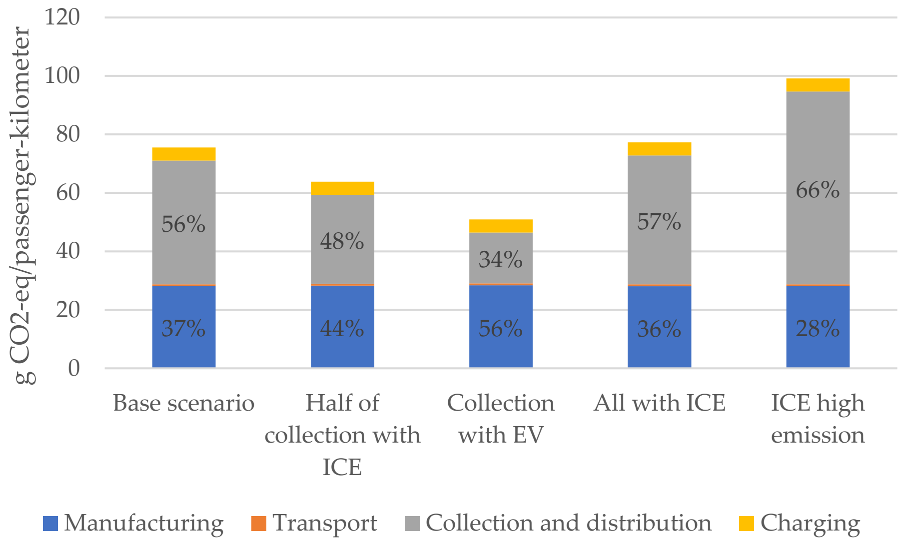


Figure 52. Sensitivity analysis with different collection and distribution options for rented electric scooter (own work)

Testing the collection and distribution with different vehicles and emission factors does change the life cycle emission of electric scooters considerably. For instance, if the collection and distribution is taken over by 50% electric vans, the emissions fall by 15.5% from 75.5 g CO_2-eq/passenger-kilometre to 63.8 g CO_2-eq/passenger-kilometre, while in the scenario where the full collection and distribution is done by electric vans, the decrease is 33% (50.88 g CO_2-eq/passenger-kilometre). When the full collection and distribution is done by ICE vans the life cycle emissions barely move. This is because the current Danish vehicle fleet already consists of 95% ICE vans, and the 5% difference only produces an extra 1.8 g CO_2-eq/passenger-kilometre.

A scenario was also examined, where the entire collection and distribution was done with ICE vans with a 50% higher emission factor. It was important to test because our ICE van's emission factor is based on a combination of data from ecoinvent 3.4 and data from Volkswagen. The result shows a 31.27% increase in life cycle emissions compared to the base scenario and the impact of collection and distribution rising to 66%.

15.7.2. Privately owned electric scooter

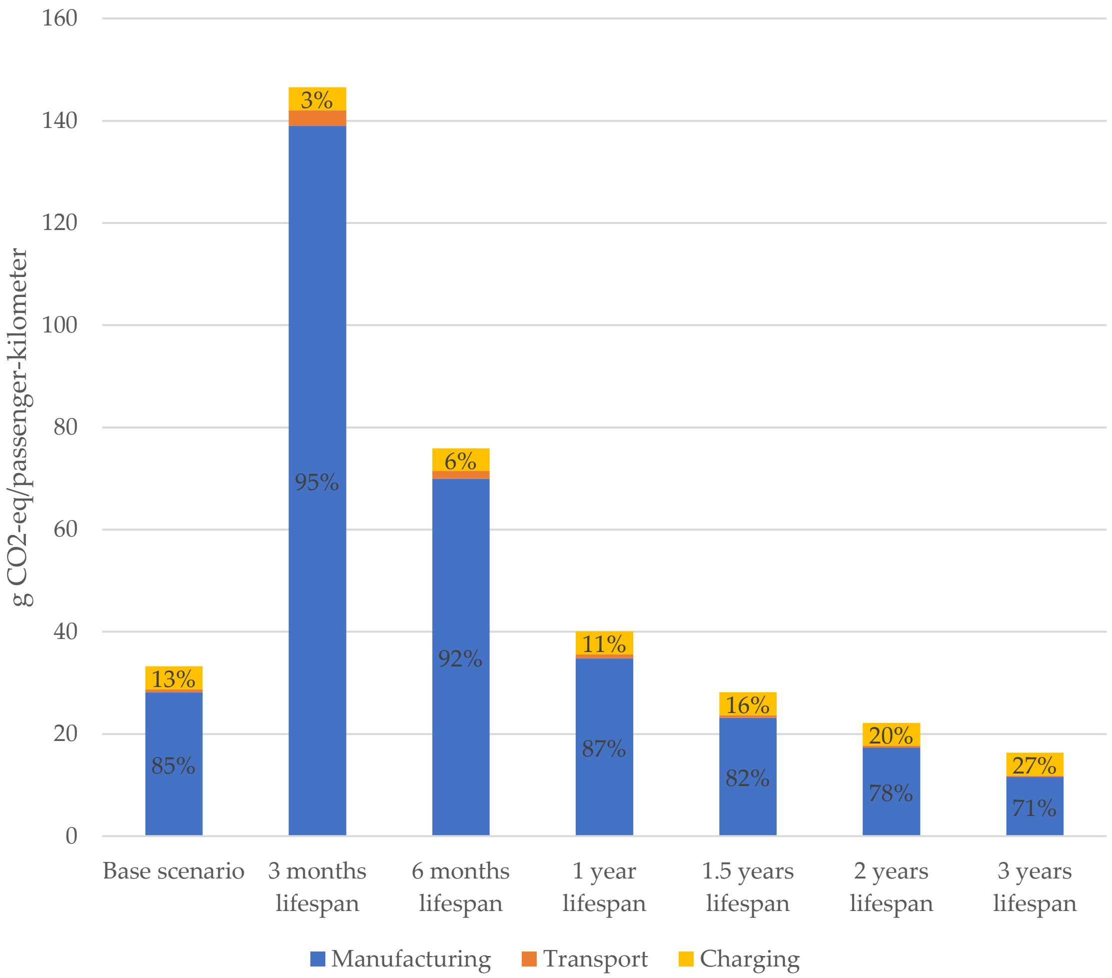


Figure 53. Sensitivity analysis with different lifespans for privately owned electric scooter (own work)

The sensitivity analysis in figure 53 shows that the lifespan also has a significant effect on the life cycle emissions of privately owned scooters. The chart demonstrates this, since a 3-month lifespan results in emissions that are 4.4 times higher than the base scenario (146.53 g compared to 33.24 g CO_2-eq/passenger-kilometre). A high 3-year lifespan results in emissions of 16.32 g CO_2-eq/passenger, falling 51% compared to the base scenario.

15.8. Result overview

This part compares our findings on rented electric scooters with the results from the North Carolina LCA and the evaluation report by the Danish Road Traffic Authority.

Table 7. Life cycle analysis results comparison (own work based on Danish Road Traffic Authority (2020) and Hollingsworth, Copeland and Johnson (2019a))

Scenario	North Carolina LCA (results in g CO_2-eq/passenger-kilometre)	Danish Evaluation Report (results in g CO_2-eq/passenger-kilometre)	Our results (results in g CO_2-eq/passenger-kilometre)
Base Case	125.5	91	75.5
Low Collection Distance	91.3	No data	49.82
Battery Depletion Limit	101.9	No data	64.45
High Vehicle Efficiency	110	No data	63.8
High Scooter Life	87.6	No data	70.77

From table 7 it is evident that our results are lower in every scenario compared to both the North Carolina LCA and the evaluation report by the Danish Road Traffic Authority (which is not a full LCA but only an estimate based on the scenarios from the North Carolina LCA). In the base case, our results are roughly 40% lower compared to the North Carolina LCA and roughly 17% lower than the Danish evaluation report's estimate. Interestingly our results show the lowest life cycle emissions under the "Low Collection Distance" scenario, while it was the "High Scooter Life" scenario in the North Carolina LCA. However, it is important to note that our "High Scooter Life" scenario is calculated with an 18 months lifespan, while Hollingsworth, Copeland and Johnson used 2 years.

16. Benchmark displacement

Benchmark displacement represents the average transport emissions that are being displaced by electric scooters. In real life, this number seems a bit obscure as a kilometre driven on an electric scooter cannot substitute an average of other transport modes. However, for the sake of comparison, we found it interesting to calculate the Danish Benchmark displacement using our questionnaire results and emission factors which reflects Danish conditions better.

Table 8 present Danish emission factors for each of the transport categories used in our survey. Some categories contain multiple modes of transport and so the overall emission factor has been calculated using a split between emissions of the individual modes of transport.

Table 8. Emission factors for all modes of transport in Denmark (own work)

Mode of transport	**Emission factor - CO2-eq per passenger kilometre**	**Notes**	**Source**
Walking/running	**0 g**	No inputs	-
Bike	**5 g**	Also used by Hollingsworth, Copeland and Johnson (2019a)	(Weiss, et al. 2015)
Public transport (bus, train, metro)	**57 g**	Bus emissions are 89 g CO2-eq per person km based on calculations from Fynbus coupled with a European survey. The emission is a lot higher than the factor used by Hollingsworth, Copeland and Johnson (2019a) because it is not based on peak occupancy (25% instead) and thus believed to be more realistic. Train emissions of 12 g per person km are taken from S-trains, as they are assumed to be the only DSB train substitutable by electric scooters.	(Fynbus 2019) (European Cyclists' Federation 2011) (DSB 2019) (Metroselskabet 2018) (DTU Transport 2019)

		Metro emissions are 7 g per person km (only emissions from charging was available). Split between bus, train and metro is assumed to be 59/35/6 based on Danish transport numbers from 2019.	
Car/taxi with internal combustion engine	**161 g**	The average Danish ICE car emits 211 g CO2-eq per km coupled with the average Danish occupancy rate of 1.31 passengers per car.	(The Danish Council on Climate Change 2018) (DTU Transport 2014)
Electric car	**69 g**	The average Danish electric car emits 91 g CO2-eq per km coupled with the average Danish occupancy rate of 1.31 passengers per car.	(The Danish Council on Climate Change 2018) (DTU Transport 2014)
Motorcycle or moped	**123 g**	Emission factors are 150 g and 96 g CO2-eq per km for motorcycles and mopeds, respectively. Split is assumed to be 50/50.	(Weiss, et al. 2015)
Other electric transport (electric bicycle, hoverboard, Segway or similar)	**25 g**	An emission factor for electric bicycles was uses as a proxy for the whole category as the authors and the Danish Road Traffic Authority (2020) were unable to find data on hoverboards or electric skateboards.	(Weiss, et al. 2015)
Nonelectrical transport (roller skates, skateboards or similar)	**1 g**	As no data were available, emissions were assumed to be 1/5 of emissions from a bike, based on the weight difference between a skateboard and a bike.	(Weiss, et al. 2015)

Our survey results on substituted modes of transport from figure 34 and 39 are used to calculate the benchmark displacement for rented and privately owned electric scooters. Note, that results for rented scooters are not statistically significant and only provides an example of our subgroup.

Displacement - privately owned

$$0.149 * 0\ g + 0.201 * 5\ g + 0.204 * 57\ g + 0.285 * 161\ g + 0.029 * 69\ g + 0.043 * 123\ g + 0.02 * 25\ g + 0.008 * 1\ g + 0.061 * 0\ g = 66.3\ g$$

Displacement – rented

$$0.064 * 0\ g + 0.136 * 5\ g + 0.613 * 57\ g + 0.159 * 161\ g + 0.027 * 123\ g + 0.001 * 25\ g = 64.6\ g$$

A benchmark displacement of 66.3 g and 64.6 g CO2-eq per passenger kilometre shows that rented electric scooters have higher life cycle emissions than the average transport it displaces. However, the privately owned electric scooter has lower emissions than the average transport it displaces. This is an interesting result even though benchmarks displacement is a statistical and unrealistic concept. From the emissions factors in table 8 we can conclude that a passenger kilometre on a rented electric scooter has lower life cycle emissions than cars with ICE, motorcycles, and mopeds. On the other hand, walking, biking and other electric- and nonelectric transport, as well as public transportation and electric cars, all have lower emissions than the rented electric scooter.
The privately owned electric scooters have lower life cycle emissions than all types of cars, motorcycle, mopeds and public transportation. Only walking, biking and other electric and nonelectric transport have lower emissions.

The difference between the benchmark displacement from rented and privately own electric scooters is relatively small but seems to be incidental as they substitute other modes of transport in quite different numbers (see chapter 10. Questionnaire analysis).

These results are similar to the North Carolina LCA that found the benchmark displacement to be lower than emissions from rented electric scooters. The Danish benchmark displacement from both rented and privately own electric scooters is about 30% lower than the benchmark displacement of 93,2 g CO2-eq per passenger kilometre from Hollingsworth, Copeland and Johnson (2019a). This is due to less people substituting a trip in their car and a lower emission factor from Danish cars with ICE. It is also due to more people biking and using public transport in Denmark, but it is important to note that the Danish emission factor for public transportation is higher than the American one because we do not assume peak occupancy in the busses.

This also means that electric scooters do not necessarily have higher emissions than busses, contradictory to what headlines suggested after the publication of the North Carolina LCA (see for example Hvilkenbil.dk 2019). With a 25% occupancy rate in Danish busses, the privately owned electric scooter actually has lower life cycle emission per passenger kilometre. But if we assume peak bus occupancy like Hollingsworth, Copeland and Johnson (2019a) the emission factor would drop to 26 g CO2-eq per passenger kilometre (Fynbus 2019, European Cyclists' Federation 2011) making the bus more climate friendly again. Peak occupancy is however believed to be an unrealistic assumption for Denmark, especially outside Copenhagen, and so the electric scooter should not be considered less climate friendly than busses under all circumstances. It all depends on the occupancy rate of the busses, whilst keeping in mind that bus emissions do not change significantly if one person exits or enters the vehicle. It is also important to point out that many municipalities in

Denmark have begun rolling out greener busses running on electricity, biogas or hydrogen (see for example (TV2 Nord 2020, TV2 Lorry 2019, Energy Supply DK 2019)) that will decrease the life cycle emissions from public transportation in the coming years. It would have been interesting to investigate what occupancy rate is required to make the bus more climate friendly than the privately owned electric scooter per passenger kilometre, but that is outside the scope of this paper.

17. Discussion

What effect will electric scooters have on transportation patterns?

By looking at different types of data from the rental company VOI and our own questionnaire results we have gained an insight into the transportation pattern of electric scooter users. Unfortunately, the questionnaire had too few respondents in the rental category to be able to extract something significant from the results. The mobility data, on the other hand, was very comprehensive and provided a very sound insight into the rental users in Odense. So, what can we learn when comparing mobility data and questionnaire results?

Figure 15 and 36 showed the time of day when rides were started, for the mobility data from Odense and for the questionnaire results on privately owned electric scooters. Results indicate that the two forms of ownership result in two very different use patterns. The privately owned scooters are used mainly in the mornings between 6:00 and 9:00 and again in the afternoon between 15:00 and 18:00, suggesting that they are used to transport people to and from work or educational institutions. The rented scooters, on the other hand, are used later in the day and into the early hours of the morning, suggesting that they are used less in relation to people's workday and more for recreational purposes. This is also backed by figure 12 showing high rental usage on Saturdays compared to weekdays, although Sundays do not see an increase. Rental scooters additionally seem to fill in a gap at night when public transportation does not run, thus providing people who do not own a vehicle with a means of transport.

When comparing ride duration in figure 16 and 37 the different use patterns are still clearly visible. Rented electric scooters are used mainly for the shorter rides up to 10 minutes, whereas the privately owned scooters are used primarily for rides over 11 minutes. A full 30% is even over 20 minutes long.

This is interesting because micromobility is said to be the solver of the last mile problem. The data for rented scooters also backs this up, showing short ride durations that translate to just a few kilometres in length. The travel maps in figure 18 to 27 also reveal a lot of short trips on rented scooters are taken within the city centre helping people travel just a handful of streets. The general travel direction is also to and from the centre with very few rides going across town.

However, the high duration for privately owned scooters suggests that they do not perform this last mile function for most of the private owners. On top of that, just 25% of questionnaire respondents indicated that they used privately owned scooters in connection with other means of transport.

But if rented electric scooters help solve the last mile issue and the privately owned does not, how does that affect their carbon footprint and under what circumstances do they help reduce the Danish carbon emissions?

What effect will electric scooters have on climate change mitigation in Denmark?

If electric scooters are used in connection with public transportation, they make the overall trip faster for the passenger but not necessarily more climate friendly if the last mile would have been completed on foot. Essentially "solving" the last mile problem with any type of transport that has climate emissions is going to increase the overall emission level of a trip.

On the other hand, making the trip faster and easier for the passenger might make them more inclined to swap out their car for a combined trip with public transportation and electric scooter. This would decrease the overall level of emissions again, as cars produce much higher emissions than public transport and electric scooters. This is the crucial trade-off that needs to be considered by policymakers imagining electric scooters as part of future public transport systems. What is quantified in this paper is the direct substitution between electric scooters and other modes of transport.

First of all, we found that the electric scooter had lower life cycle emissions under Danish conditions compared to the US, making them more climate friendly. We also found that privately owned scooters have much lower emissions per passenger kilometre than the rented ones because they do not need collection and distribution by other vehicles.

A rented electric scooter only has lower emissions per passenger kilometre than cars with ICE, motorcycles, and mopeds. But since we know that they are used mainly for shorter trips, it seems more likely that they substitute other modes of transport. This is also backed by the, albeit insignificant, results from our questionnaire where rented scooters substitute public transport in 61% of the cases.

The privately owned scooter, on the other hand, shows potential emission reductions compared to all types of cars, motorcycles, mopeds, and public transportation. This is interesting because headlines in autumn 2019 proclaimed that electric scooters were worse for the climate than diesel buses. Our research revealed that this was based on an assumption of peak bus occupancy and the resulting low emissions per passenger kilometre. This is believed to paint an unrealistic picture of emissions from bus transport. Both rented and privately owned electric scooters have lower emissions than Danish buses with a 25% occupancy rate. But because public transportation also includes low-emission S-trains and Metro, we can only say that privately owned electric scooters produce fewer emissions than public transportation as a whole and if we increase the occupancy rate of the Danish buses to 100% the emissions fall below both rented and privately owned electric scooters. So, the claim that electric scooters are more harmful than diesel buses is very dependent on the occupancy rate of those buses, while keeping in mind that bus emissions do not scale linearly with the occupancy rate.

Our findings suggest that electric scooters in Denmark substitute cars and walking less than in the US but substitute biking and public transport more. Calculations on Danish benchmark displacement revealed lower emissions from the average mode of transport that electric scooters substitute. However, electric scooters also produce lower emissions under Danish conditions

resulting in a similar ratio between benchmark displacement and rented electric scooters compared to the US results.
Benchmark displacement is largely a statistical thought experiment, but the results are still interesting showing that rented electric scooters have higher emissions than their benchmark displacement whereas privately owned scooters only produce half of the emissions of the average transport being displaced.
Privately owned scooters represent possible emission reductions compared to many other modes of transport and they have already been widely adopted by young people, especially in Denmark. However, the questionnaire revealed that the main reasons for use are flexibility, speed, easiness, and cost of transportation. Many of which could be provided just as easily with an electric bike with lower life cycle emissions. Since many people use privately owned scooters for longer trips, the electric bicycle might even be better suited for the range, whilst still allowing people to get from A to B without breaking a sweat.
An electric scooter does have a lower purchase price and it is more compact than an electric bike, but responses also show that most people don't bring their electric scooter on to public transportation. This leaves the price difference as the likely reason, but we probably also have to consider the social aspect that electric scooters could be considered more "cool" than electric bikes.
Either way, it is interesting that half of respondents say they use electric scooters because they are good for the environment when that statement is highly dependent on the mode of transport being substituted. The most apparent reason is probably that people don't know how different types of motorised vehicles compared to each other and that rental companies have done a good job of marketing their product as climate friendly.

Suggestions for policy makers

We cannot unilaterally say that electric scooters are good or bad for the climate, but we can come up with suggestions on how to reduce climate emissions from electric scooter usage.
First, private ownership reduces emissions because no collection end distribution is required but it also changes the context in which the electric scooter is used. If people cannot rent scooters it takes away the convenience and makes it harder to see electric scooters as an extension to the public transport system. The use pattern of privately owned scooters also suggests that they could be substituted by electric bicycles producing lower emissions.
The performance of the rental scooter could be improved using low-emission transport for the collect and distribution by swapping out vans with ICE for electric vans or cargo bikes. A full conversion to electric vans would alone result in a 15,5% drop in overall emissions according to our sensitivity analysis. Companies could also restrict collection to scooters with a low charge and only pick up those with battery below 50%. This might lead to some frustration with more scooters remaining on the streets at night, but it wouldn't be against the law unlike the situation in the US.
Another crucial factor that could be improved is the lifespan of the electric scooter. This is vital to spread the burden of manufacturing across as many kilometres as possible. Companies and

policymakers must do this by ensuring good build quality from the factory and fighting scooter vandalism once the scooters are on the streets. The Danish Road Traffic Authority expects 12-18 month of scooter life based on information from rental companies, but VOI did not expect their scooters to last more than 2-3 months as of March 2019 (Danmarks Radio 2019). Our sensitivity analysis shows that a scenario like that would be catastrophic and increase the life cycle emissions of electric scooters 2,5 times. On the other hand, if the lifespan could be increased to three years we could expect a 22% decrease in emissions compared to the base scenario.

Limitations

Apart from manufacturing, the two most important factors for the life cycle emissions of an electric scooter are collection and distribution, and the scooter lifespan. As there was no data available on the lifespan of electric scooters in Denmark (rented or privately owned) we have had to rely on the information given by the rental companies themselves to the Danish Road Traffic Authority. These companies might have an interest in appearing environmentally friendly and thus report a higher lifespan than is actually the case.

For this reason, we have conducted a sensitivity analysis on the lifespan from 3-36 month, but for future analyses, we recommend obtaining primary data on this variable.

For collection and distribution, we would also have liked Danish data on collection distance to see if it varies from the US. We have had to assume similar distances in Denmark and conduct sensitivity analyses on the range. Finally, future analysis should strive to obtain data on the exact vehicle composition of the Danish fleet of collection vans with ICE. This would provide a more robust emission result reflecting the Danish conditions even closer.

Emission factors for the benchmark displacement could also be more precise, as metro emissions only represent charging and we were unable to determine if DSB emissions represent a full life cycle.

In relation to the questionnaire results, we would have liked more respondents for our survey. This is crucial to be able to say anything significant about users of rented electric scooters, but also for comparison with other studies. We found that substitution rates varied between Denmark and the US, but also within Denmark where our substitution rates for bike and car were outside the range of other studies. More respondents would help make these results more solid and significant. Ideally, researchers could survey users of rented electric scooters right after the end of a trip, on the app of the respective company. This would ensure that intentions behind the trip were fresh in memory and that the response reflected recent considerations for substituted modes of transport.

18. Conclusion

The first motorized kick scooter was already seen in the first decades of the 20th century but the electric scooter we know today came with the recent evolution of battery technology. Rental companies started operating in the US in 2017 and the service has since spread to many cities around the world. The business model relies on providing easy and flexible mobility in urban centres while relieving people of traditional responsibilities of vehicle ownership. This is done with relatively low investment and running costs creating a viable business case.

Electric scooters were allowed on the streets of Denmark from January 2019 when the Minister of Transport, Building and Housing introduced a pilot scheme for small motorised vehicles. The legalisation meant that retailers could start selling electric scooters to the private Danish consumers, and rental companies could start operating in Danish cities. However, companies also needed municipal permits to conduct commercial activities on municipal land, which some companies didn't obtain before putting electric scooters on the streets. As of February 2020, 7 different rental companies operate in Aalborg, Aarhus, Copenhagen, Herning, Odense and Vejle, with only 3 companies present outside of Copenhagen.

Mobility data from the rental company VOI was examined for the month of October 2019 to investigate the transportation patterns of electric scooter users. The data showed an average of 471-592 rides per day with a significant higher frequency on Saturdays. The rides were mainly taken in the afternoons, evenings and at night suggesting that people don't use rented electric scooters to get to and from work but rather to get around town after work hours. The rides were usually short, lasting between 7.40-7.67 minutes covering a maximum theoretical distance of 2.47-2.56 km, and producing an average revenue of 4.00- 4.11 euros. The trips were also mapped using Kepler and revealed that the main travel direction was to and from the city centre.

A questionnaire was created to study the differences between rented and privately owned electric scooters. Unfortunately, the sample of rental users was too small to say anything significant about the population. So, the comparison of use patterns is mainly based on the mobility data on rental users and questionnaire results for privately owned scooter users. The comparison revealed different use patterns with privately owned scooters being used predominantly in the mornings and afternoons. This suggests that they are used for people's daily commute to and from work or educational institutions. The ride duration is also significantly higher than for rented scooters with many rides lasting more than 20 minutes. While rented electric scooters can be seen as part of the solution to the last mile problem, this suggests that the privately owned scooters are not.

A regression analysis was also conducted to find out if background variables income and age could explain some of the variation in questionnaire answers but found little evidence of this.

The life cycle analysis from North Carolina State University was modified to reflect Danish conditions for rented and privately owned electric scooters. This included shipping from Hong Kong to Hamburg and truck delivery from Hamburg to Copenhagen. For rented scooters, the collection and distribution were modelled on the Danish fleet of diesel vans, electric vans and cargo bikes. For privately owned scooters this phase was removed completely from the life cycle. Finally, all charging was modelled on the average Danish energy mix resulting in a life cycle emission of 75.5 g and 33.2 g CO_2-eq per passenger kilometre for rented and privately owned electric scooters respectively. Results show that manufacturing and collection/distribution are the two main determinants of the greenhouse gas emissions, while transport and charging remain relatively insignificant. The sensitivity analysis revealed that the results are extremely sensitive to the lifespan of the electric scooter and that a lifespan of just 3 months could result in emissions up to 189 g CO_2-eq per passenger kilometre. The sensitivity analysis also shows that emissions could be reduced by only collecting scooters with low battery or reducing the distance travelled for collection and distribution. The LCA results were then coupled with the findings from the questionnaires on what modes of transport electric scooters substitute. A benchmark displacement was calculated for Denmark and showed that rented electric scooters have higher life cycle emissions than the average transport it displaces, whereas privately owned scooters have lower emissions. The results are interesting even though benchmark displacement is a thought experiment mainly.

We can conclude that rented electric scooters produce lower emissions than cars with ICE, motorcycles, and mopeds but higher emissions than walking, biking, other electric- and nonelectric transport, electric cars, and public transportation. Privately owned electric scooters have lower emissions than all other modes of transport except walking, biking and other electric- and nonelectric transport.

However, the investigations also found that the claim of diesel buses producing lower emissions than electric scooters are highly dependent on the occupancy rate of the buses and that buses with 25% occupancy rate have higher emissions per passenger kilometre than both rented and privately owned electric scooters.

To improve the environmental performance of electric scooters in the future it is recommended that low-emission vehicles are used for the collection and distribution and that the scooter lifespan is extended through better build quality and combating vandalism. For future studies on this topic, it is recommended that researchers obtain primary data on the lifespan of electric scooters in Denmark as well as distance covered for collection and distribution.

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Appendix 1

Fra: Info
Sendt: 11. februar 2020 10:42
Til: Bjarke Slater Christensen
Emne: RE: Contact form information

Dear Bjarke,

Thank you for your interests in Segway-Ninebot electric kickscooters.

Our products need to follow the following environmental requirements:

- RoHs
- REACH
- WEEE
- EU Battery directive

Best regards,

Segway-Ninebot EMEA

Appendix 2

Thank you for wanting to answer our questionnaire on electric scooters. All answers are treated anonymously and will be used in a master's thesis at the University of Southern Denmark, Esbjerg.

Before we get started, we have a few quick background questions.

Language

(1) ❑ Danish

(2) ❑ English

What is you gender?

(1) ❑ Man

(2) ❑ Woman

(3) ❑ Other

What is your age?

(1) ❑ 15-25 years

(2) ❑ 26-50 years

(3) ❑ Over 50 years

What is your age?

(1) ❑ Less than 100,000 DKK

(2) ❑ 100,000 - 199,999 DKK

(3) ❑ 200,000 to 299,999 DKK

(4) ❑ 300,000 to 399,999 DKK

(5) ❑ 400,000 to 499,999 DKK

(6) ❑ More than 500,000 DKK

(7) ❑ Prefer not to say

The following questionnaire examines the use of electric scooters in Denmark, and you should not include any trips on electric scooters abroad in your answers.

Do you sometimes ride privately owned electric scooters?

(1) ❑ Yes

(2) ❑ No

Do you sometimes ride rented electric scooters?

(1) ❑ Yes

(2) ❑ No

How many times do you ride privately owned electric scooters on average per month?

____

Out of the trips you ride on privately owned electric scooters, what modes of transport would you have chosen to use instead? (State as percentage of your total trips on privately owned electric scooters)

The sum of your answers must equal 100

Walking/running	_____
Bike	_____
Public transport (bus, train, metro)	_____
Car/taxi with internal combustion engine	_____
Electric car	_____
Motorcycle or moped	_____
Other electric transport (electric bicycle, hoverboard, segway or similar)	_____
Nonelectrical transport (roller skates, skateboards or similar)	_____
Other	_____
I wouldn't have taken the trip	_____

If other: Specify?

_____

How often do you use privately owned electric scooters in connection with other modes of transport, e.g. train travel? (Specify as percentage on the slider)

_____

If so: Which mode of transport?

_____

When do you ride privately owned electric scooters? (Specify percentage of your total trips)

The sum of your answers must equal 100

Between 00:00 and 06:00 _____

Between 06:00 and 09:00 _____

Between 09:00 and 12:00 _____

Between 12:00 and 15:00 _____

Between 15:00 and 18:00 _____

Between 18:00 and 24:00 _____

How long do your trips on privately owned electric scooters take? (Specify percentage of your total trips)

The sum of your answers must equal 100

0-5 minutes _____

The sum of your answers must equal 100

6-10 minutes _____

11-15 minutes _____

16-20 minutes _____

Over 20 minutes _____

Why are you riding privately owned electric scooters?

You can select more than one answer

(9) ❑ Can't rent electric scooters in my city

(1) ❑ Don’t want to cycle or walk

(2) ❑ Because it's faster than walking

(3) ❑ Because it is more flexible than public transport

(4) ❑ It's cheaper than the car

(10) ❑ It's easier than the car

(5) ❑ For fun

(6) ❑ To save money

(7) ❑ It is good for the environment

(8) ❑ Other

If other: Specify?

_____

How many times do you ride rented electric scooters on average per month?

____

Out of the trips you ride on rented electric scooters, what modes of transport would you have chosen to use instead? (State as percentage of your total trips on rented electric scooters)

The sum of your answers must equal 100

Walking/running	_____
Bike	_____
Public transport (bus, train, metro)	_____
Car/taxi with internal combustion engine	_____
Electric car	_____
Motorcycle or moped	_____
Other electric transport (electric bicycle, hoverboard, segway or similar)	_____
Nonelectrical transport (roller skates, skateboards or similar)	_____
Other	_____
I wouldn't have taken the trip	_____

If other: Specify?

_____

How often do you use rented electric scooters in connection with other modes of transport, e.g. train travel? (Specify as percentage on the slider)

_____

If so: Which mode of transport?

_____

When do you ride rented electric scooters? (Specify percentage of your total trips)

The sum of your answers must equal 100

Between 00:00 and 06:00 _____

Between 06:00 and 09:00 _____

Between 09:00 and 12:00 _____

Between 12:00 and 15:00 _____

Between 15:00 and 18:00 _____

Between 18:00 and 24:00 _____

How long do your trips on rented electric scooters take? (Specify percentage of your total trips)

The sum of your answers must equal 100

0-5 minutes ____

6-10 minutes ____

11-15 minutes ____

16-20 minutes ____

Over 20 minutes ____

Why are you riding rented electric scooters?

You can select more than one answer

(9) ❑ Don't want to own an electric scooter

(1) ❑ Don’t want to cycle or walk

(2) ❑ Because it's faster than walking

(3) ❑ Because it is more flexible than public transport

(4) ❑ It's cheaper than the car

(10) ❑ It's easier than the car

(5) ❑ For fun

(6) ❑ To save money

(7) ❑ It is good for the environment

(8) ❑ Other

If other: Specify?

____

Do you transport yourself more because the electric scooter has arrived?

(1) ☐ Yes, I transport myself more

(2) ☐ No, roughly the same

Thank you so much for your participation. We really appreciate your help.

Appendix 3

Table. 1. T-test for replaced transport modes by privately owned electric scooter

One-Sample Test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference Lower	Upper
Ride_private_Walk_run	3.980	33	.000	14.853	7.26	22.44
Ride_private_Bike	3.982	33	.000	20.088	9.82	30.35
Ride_private_PublicT	3.736	33	.001	20.412	9.30	31.53
Ride_private_Car	4.758	33	.000	28.500	16.31	40.69
Ride_private_E_Car	1.000	33	.325	2.941	-3.04	8.93
Ride_private_Moto	1.421	33	.165	4.265	-1.84	10.37
Ride_private_other_el	1.748	33	.090	2.059	-.34	4.45
Ride_private_Non_el	1.246	33	.221	.794	-.50	2.09
Ride_private_None	2.269	33	.030	6.088	.63	11.55

Table.2. T-test for period of the day use of privately owned electric scooter

One-Sample Test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference Lower	Upper
TimeP_0_6	2.074	33	.046	2.941	.06	5.83
TimeP_6_9	9.699	33	.000	31.588	24.96	38.21
TimeP_9_12	3.106	33	.004	7.000	2.42	11.58
TimeP_12_15	3.754	33	.001	8.618	3.95	13.29
TimeP_15_18	13.169	33	.000	38.176	32.28	44.07
TimeP_18_24	4.046	33	.000	11.676	5.81	17.55

Table 3. T-test for duration of ride with privately owned electric scooter

One-Sample Test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference Lower	Upper
LenghtP_0_5	1.960	33	.058	5.000	-.19	10.19
LenghtP_6_10	2.481	33	.018	10.324	1.86	18.79
LenghtP_11_15	5.062	33	.000	31.765	19.00	44.53
LenghtP_16_20	4.774	33	.000	23.029	13.22	32.84
LenghtP_over20	4.904	33	.000	29.882	17.49	42.28

Table 4. T-test for replaced transport modes by rented electric scooter

One-Sample Test

	Test Value = 0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Ride_rental_Walk_run	1.923	10	.083	6.364	-1.01	13.74
Ride_rental_Bike	2.319	10	.043	13.636	.53	26.74
Ride_rental_PublicT	4.808	10	.001	61.273	32.87	89.67
Ride_rental_Car	2.032	10	.070	15.909	-1.53	33.35
Ride_rental_Moto	1.399	10	.192	2.727	-1.62	7.07
Ride_rental_other_el	1.000	10	.341	.091	-.11	.29

Table 5. T-test for period of the day use of rented electric scooter

One-Sample Test

	Test Value = 0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
TimeR_0_6	1.406	10	.190	6.364	-3.72	16.45
TimeR_6_9	3.794	10	.004	41.818	17.26	66.38
TimeR_9_12	1.399	10	.192	2.727	-1.62	7.07
TimeR_12_15	1.399	10	.192	2.727	-1.62	7.07
TimeR_15_18	3.575	10	.005	34.545	13.01	56.08
TimeR_18_24	1.876	10	.090	11.818	-2.22	25.85

Table 6. T-test for duration of ride with rented electric scooter

One-Sample Test

	Test Value = 0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
LenghtR_0_5	1.767	10	.108	17.727	-4.62	40.08
LenghtR_6_10	2.630	10	.025	32.273	4.93	59.62
LenghtR_11_15	2.283	10	.046	31.818	.77	62.87
LenghtR_16_20	1.000	10	.341	9.091	-11.16	29.35
LenghtR_over20	1.000	10	.341	9.091	-11.16	29.35

Table. 7. T-test for use of electric scooter in connection with other transport mode

One-Sample Test

	Test Value = 0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Private_in_connection_with_other_transport_modes	4.105	33	.000	25.441	12.83	38.05
Rented_in_connection_with_other_transport_modes	1.943	10	.081	7.455	-1.09	16.00