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Impacts of implementation of electric scooters in daily transport: case study in Gavle

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Abstract

In the last years, some companies have implemented a new transport sharing system in cities based on a one-way trip with electric scooters with the advantage that they can be parked wherever in the streets. Such an implementation has not been realized in Gävle until now. The main objective of this thesis is to study the impact of electric scooters (ES) to the environment and compare their emissions with other modes of transport.

First, this thesis realize a study of the transport trends of people in the city of study, i.e. Gävle. Next, it is connected with a study of how a company like this will work in this city and which characteristics such as the operating area and the fleet number should it has. Finally, it is performed a full life cycle analysis of these scooters with the actual charging system and, also, how it would be if the actual collection and redistribution of the scooters at night is changed for a battery replacement. The main objective of that change is that the collectors will not need to collect the scooters at night in a big fueled vehicle and they will change it for a small EV or a simple bike in where carry the fully charged batteries. In addition, it has been calculated how the recycling of the batteries would affect to the total emissions compared with the disposal to the landfill.

The LCA of the ES has been compared with EV and ICE cars in order to know how effects to the transport emissions the implementation of a rental scooter company. The total emission for kilometer of electric scooters are higher than EV but lower than ICE vehicles.

The results show that electric scooters from a rental company are only reducing carbon emissions only if they replace car trips. At the moment that these scooters replace other modes of transport such as bus, bike or walking, it becomes a less clean option. Therefore, this company implementation does not reduce the CO_2 emissions.

Keywords: Electric scooters; Life Cycle Assessment; Electro-mobility; Rental Scooter Company

Preface

This work has only been possible thanks to my supervisor, Shveta Soam. She has helped me with the most important research of literature and with valuable comments and revisions of the thesis. Also, thank Pau and Ana for their patience and for provide me with coffee while I was writing my thesis.

Nomenclature

Abbreviations and Acronyms

CO_2 – Carbon Dioxide

CO_2eq – Carbon Dioxide Equivalent

E-fleet – Electric Fleet

ELV – Electric Light Vehicles

ES – Electric Scooter

EV – Electric Vehicle

GHG – GreenHouse Gases

ICE – Internal Combustion Engine

LCA – Life Cycle Analysis

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1. Introduction

1.1.Background

One of the main problems which the humanity is facing in the actuality is the climate change. It is well known that the pollution and carbon dioxide (CO_2) produced by humans is speeding up the climate change. The main cause of it is the carbon dioxide emitted by transports with a total of 31% [1] in the world and 33% in Sweden [2]. Nowadays, the entire world population has become used to travel longer distances than ever before. This trips are incorporated in our daily life and there is nothing to do in order to try to reduce their amount. Therefore, the only possible way to reduce the carbon emissions to the environment is introduce new clean modes of transport. For this reason, this thesis is based in the introduction of one of the most modern introductions to the electric transport: Electric Scooters (ES).

ES have started to appear in big cities all around the world, starting with San Francisco. These scooters are the logical evolution of the basic scooters which use the driver's foot as a propulsion. ES can be charged in a few hours and can last more than 20km, these characteristics made scooters a potential mode of transport to replace actual car transports in big cities, where people has to travel distances lower than 20km and they may found traffic jams or busses full of people. With ES it is possible to travel on the bike road (therefore avoid traffic jams) without any exercise (able for non-fit people). For these reasons some companies started to introduce ES with a rental system on big cities, where people is able to take an scooter and leave on the same street, without worrying about finding a place to park them.
In Sweden, companies like *Lime* or *Voi* have arrived to Stockholm, Gothenburg, Malmö, Lund and Uppsala.

1.2.Aims

Electric scooters have been appeared recently in cities because it makes people's life easier for short distance transports. Despite nowadays big cities have a public transport system, it results much faster and comfortable to take a scooter or a bike just in front of the destined place, when the trip distance is not so big. For this reason, some cities have used this idea to create a company who has a fleet of this ES on the streets and people can rent them paying for minutes of usage. Between these cities we have cities similar to Gävle, like Uppsala; and bigger cities like Stockholm.

This thesis is focused on the impacts of implementation of a rental electric scooter company in the city of Gävle. The research objectives of the thesis are:

(I) To study the travel patterns in Gävle to know the potential users and calculate the average trip length for users of the scooters.
(II) To study the best feasible way of implementing ES in Gävle.

(III) To study the environmental impacts of ES from life cycle perspectives and compare it with other modes of transport.

1.3.Literature review

The literature review is based on three search engines (Sciencedirect, Scopus and Google Schoolar) to find different peer-reviewed articles. In order to find the articles, the main keywords used are: *electric scooter*, *electric mobility, legislation electric scooters* and *LCA scooter batteries*. Statistical data about the travel patterns is based on a study conducted by Gävle Kommun [3].

It is seen that technological developments in light electric vehicles have made electric bicycles, skateboards and Segways viable alternatives with a great potential to substitute actual forms of transport in cities [4]. The main manufacturing of this new vehicles is in China, but nowadays many markets in Europe are also being developed [4]. For instance, Germany has a 10% share of electric bikes in the bicycle market [4].
However, Nordic countries face an extra challenge compared with other countries of central-south Europe, the climate. The incorporation of electric bikes to the finish market has been already studied in previous articles such as [4], which is very similar to the one in Gävle, Sweden. The result of this previous study explain the habits of people to use different transports like bikes, segway, skateboard... It also identifies the key barriers for which people don't use this ways of transport like prices, winter problems, number of charging points and the amount of dedicated paths or ways.

There are other real-life tests like the one made in Germany during the months of October-November in which 38 subjects are provided with electrical scooters. The authors of [5] tested electric scooters for a normal routine period of time and recorded different data. Also, a pre and post survey was released to the users of this test, providing important information about their perception and opinions about a normal day usage. The results gives some controversial opinions which were not expected before such as the advantages of electric scooters in rush hours traffic turned out to be not as good as was expected [5]. This affirmation contradicts most of people expectations to use this kind of transport in cities.
On the other hand, other study in the UK have shown that, after use an electric scooter, most users felt that their independence in mobility have increased and allows them to achieve more activities outdoors [6]. However, the impacts of the use of scooters on the functional health are not clear. There is a lack of study of how the reduction of physical activities, such as walking, can affect user's health, but it is clear that a lack of physical activities leads to a loss of functional capabilities including mobility in older adults.

To do an analysis of the market for the Electric Light category Vehicles (ELV) it has been used before a software called RESOLVE [7]. With the help of this software, it is possible to compare all together the cost, energy efficiency, attractiveness and the increase of willingness to use ELVs. The fundamental basics of RESOLVE's prototypes in the study realized by [7] are the tilt of four wheelers architecture combining the agility of two-wheelers with the stability of four-wheelers. It keeps the dynamic behavior of motorbikes, including at the same time an improvement of the stability and control during braking, even on slippery of bumping surfaces. This prototypes give an advanced idea of how a light vehicle can handle winters in cold places with lots of snow and ice.

Regarding the effect of the logistics operations to the level of congestion it has a huge impact of around 8-18% of the urban traffic flow and it has an effect to the road reduction capacity of 30% [8]. In fact, there is a high potential to reduce this impact using a bike logistic system [8]. In order to prove that it is possible to replace internal combustion engines, four different pilots have been tested in a two cities in Italy. For each different pilot, it has been studied different factors such as: price, consumption, battery range, time to charge and load. The results of this study are very promising because, in all test studies, the level of success is high with only a few weaknesses [6]. Furthermore, the study provides a calculation of costs and CO_2 reduction where it is compared the traditional fleet and the e-fleet. All of them show that e-fleet is worth to be applied. In addition, electric vehicles can mitigate most of the problems which presents the actual urban transport in cities such as noise and smog. The advantages are even bigger when they are used for the last-mile of delivery of goods in city centers [9].

On the other hand, there are some major drawbacks of the ES that have to be taken into an account, such as the short distance travel and the low load they can carry [10].
Comparing the energy consumption of ES with cars, the fuel consumption of an ICE is 5 L/100km that it is about 500Wh/km, whereas an EV consumes 250 Wh/km [7]. Furthermore, ICE engines consumes an extra fuel in the period of time while they are reaching the optimal operating temperature, while EV drivetrains do not have this effect. In contrast, the energy consumption for electric scooters is 0.45 MJ/km, but it is not possible to achieve a real 0% CO_2 emission because the electricity used is not completely renewable electricity [10].

The LCA for EV has the advantage that it produces very low emissions in use phase as compared to ICE. Although, there are emissions when the electricity is produced [11]. In addition, it has to be taken into an account the life cycle assessment from raw material extraction to production, use and disposal of components as the batteries [11]. When the LCA of an electric bus is compared with a diesel bus, the results shows clearly that electric bus has less emissions [11].
To achieve a reliable and safe functioning of an electric bus system in a city, it is required to develop both, a network of charging stations and an upgrade of the existing servicing system [12]. It has been studied by the authors of [12] the measures to provide a safe operation of a fleet of electric vehicles, its maintenance and problems that can occur.

When a battery is retired from an ES, it still has around 80% of the primary energy so it can still have another use [13]. Despite this second hand batteries have a lower cost and still have power, they have some important issues such as degraded performance and may suffer from failure [13]. But with the continuous increasing of retired batteries from EV, some possible applications are for instance energy storage systems, mobile charging stations and frequency response service [13].

One of the most critical issue of scooter is the lifespan. This life expectancy may vary from one scooter to another and, the fact that the scooters have to face every day outdoor weather and vandalism, their durability is decreased. As the Washington Post says [14]:
"Scooters that reach their expiration date after being worn down merely by inclement weather, overuse, and other hazardous potholes are the lucky ones. Many others can expect their final moments to be undeniably barbaric and marked by vandalism and destruction. Based on the rougher treatment dockless scooters receive, it seems reasonable to estimate the lifetime of these scooters is on the lower end of an average expected lifetime."
The typical electric scooters have been estimated to last for at least 500 lifetimes rides or between 500 and 1,000 charging cycles [15][16]. So, this thesis analysis will use an assumption of 500 total lifetime rides. This is the more pessimistic option, but as the Washington Post and the rental scooters companies say, the ones who reach the expected lifetime are lucky.

Regarding to companies who have tried to implement EV for residents and tourists, the best known is Autolib [17]. Autolib had a structure which includes Paris and other 85 municipalities in the Paris region [17]. With 1,042 stations and 3,698 vehicles for rent, their average car was hired 4.7 times per weekday with an average journey of 9.3km [17]. Other companies such as Renault have tried to implement a sharing company in a city with a bad end, in this case, with 50 Twizy. The mistake in both projects was the same, base their service to residents and not to include tourists [17].
Despite of all the previous studies that have been realized before, there is a research gap on the environmental effects by real implementation of ES. As can be read in this paragraph, some articles have studied the emission savings that it will produce, but no-one has realized a general study including the life cycle analysis of the batteries and the components of the scooters. Knowing that the batteries do not last forever and they contain some materials, like lithium, that can be prejudicial for the environment, it is relevant to study all these aspects together to evaluate the potential impacts of ES. Furthermore, there are only a few studies in cold climates as Sweden and even less in small cities such as Gävle.

1.4.Approach

This study is a system analysis of ES using qualitative and quantitative assessment methods. LCA is used to evaluate the environmental impacts of ES using different scenarios related to battery charging and disposal.

2. Method

This thesis is based on gathering the data from peer-reviewed articles, reports, book chapters, webpages of existing public companies and news articles. The characteristics of the scooters analyzed in this thesis is from webpages, dedicated exclusively to sell products to other business, not particulars.

The first part of the thesis is based on a research about the main components of the electric scooters and their relation with the performance of the vehicle. This information has been extracted from some webpages and manufacturing guides for scooters.
The electric scooter legislation and policy has been searched in journal databases, but nothing has been found. That is because the incorporation of this vehicles is new and there is no specific laws for electric scooters. In fact, scooters are treated as electric bikes (under some specifications) and the same rules have to be applied. In consequence, it has been used a document of the normative of electric bikes from the European Union.

The specific method used to answer the three research objectives of this report are described in following sections:

2.1.Travel patterns

Travel patterns of Gävle are obtained from a report, published by Gävle Kommun [3]. This report is based on a questionnaire sent to the population of Gävle municipality. This study has been carried out by Gävleborg Region for the people using a mobile app called TRavelVU.

Those who have participated in the survey have downloaded the app TRavelVU, which collects information on how the person is moving and try to determinate the mode of travel. The participant reviewed the result and adjusted with the correct information if it was necessary. The quality of data was based on a combination of technology and people. The participant's review and any correction is therefore important and only days that the participants reviewed and approved were used for analyzes. The app also asked some questions about the participant and its household.

2.2.Implementation

The implementation of the scooters has been divided in three parts, operating area, fleet number and scooter model. For the first part, an image which represents the most common trips in the city is used. The operating area has to be a zone which has to englobe the maximum trips as possible and, at the same time, minimize the area. The reason of this is that the more area used, more vehicles will be needed. So, the external part of Gävle's municipality has been excluded for this project.

Next, in order to have an approximation of the optimum fleet number, it has been taken as a reference the amount of scooters in a city next to Gävle, Uppsala. Since, there is no actual ES company in Gävle, it is assumed that the company in Gävle would have similar characteristics, number of ES is scaled down based on the area and population density (multiplying the amount of scooters by the ratio AreaGävle/AreaUppsala).
In this thesis two different options of scooter charging system are presented in order to evaluate the CO_2 emissions. These options are:

- **Charging Option 1**: Actual charging system. Charge the scooters at night. Scooters are collected by trucks, charged and, then, redistributed again around the city.
- **Charging Option 2:** New improved system. The aim of this option is to reduce the carbon emissions of the charging process. Have some extra batteries which will be exchanged with the discharged batteries of the scooters in the same street. This avoids the need of taking a truck or a big vehicle which consumes fuel to collect them. This includes a pack of batteries corresponding to the half of the fleet. These batteries will be also charged during the night. Due that the charging time of the batteries is short, it is possible to do two charging rounds and two distribution trips.

2.3. LCA of ES

LCA is a technique for assessing the potential environmental aspects and potential aspects associated with a product by (1) compiling an inventory of inputs and outputs, (2) evaluating the potential environmental impacts associated with those inputs and outputs, and (3) interpreting the results in relation to the objectives of the study [18].
The analysis of the energy consumption and the environmental impact is composed by the raw material acquisition, manufacturing, assembling, transport, operation and recycling.
First, the scooters are analyzed to obtain the CO_2eq emissions. Then, the two charging options mentioned above are compared and, finally, the total emissions are compared with the total emissions of cars.

For the calculation of the LCA of the scooters, data is gathered from a report realized by Argonne National Laboratory using the Greenhouse gases, Regulated Emissions and Energy use in Transportation (GREET).

To calculate the lifetime emissions of the electric scooter, the emissions have been divided in five parts: manufacturing, assembly, scooter transport, charging, collection and redistribution and recycling and disposal.

2.3.1. Manufacturing

First, the manufacturing analysis assumes that most of the scooter material is aluminum and is produced and extracted in the manufacturing country, China. The manufacturing of the battery and the structure body (tires included) are calculated separately. These two elements have to be treated separately because the battery manufacturing emissions are one of the most contaminant parts of the scooter due to the elements which it contains (such as lithium, nickel, copper and cobalt).

2.3.2. Assembly

Second, the carbon emissions produced in the assembly process of the ES is calculated. These emissions include the production of assembly equipment, energy and consumables (oil, water).

2.3.3. Transport

In order to calculate the transport emissions from the factory to the end-use-location, it has been considered that each ES has traveled by airplane from China to Sweden and by truck from the airport to Gävle.

2.3.4. Charging

The charging emissions have been calculated considering that the batteries are fully charged every night. Even if the daily distance is less than the 20km that is supposed to last according to the seller, there are other factors which consumes battery power. These factors are the driving mode (accelerate and brake continuously), the inclination of the road (in Gävle there is a difference of altitude between some parts, for instance Satra) and other electronic devices (GPS, controller, lights).

2.3.5. Collection and redistribution

The actual charging system of all renting companies around the world is planned in a way that the renting companies are not the ones who charge the scooters. This responsibility is for particulars who wants to earn some extra money. They are called in a different way depending of the company, for example, “Bird hunters” for the company Bird or “Lime juicers” for the company Lime. These people travels at night through the streets looking for scooters to take them and charge.

Bird company caps the number of scooters a single contractor can charge per night at 20 [19]. However, the strong competition between this contractors could limit them to 5 or 10 scooters per night. There is no data available about how many scooters each contractor takes per night or how much kilometers they travel in order to collect them. For this reason, in this thesis is assumed that each collector takes a total of 10 scooters and travels a round-trip of 8 km with a fuel-powered van.

With the charging option 2, this emissions are supposed to be reduced because there is no need of a van to collect the scooters. This process could be realized with a small EV or even a bike. In order to study how this implementation can reduce carbon emissions, these emissions are considered to be zero.

2.3.6. Recycling and disposal

Regarding the end-of-life of the batteries, when a battery has only the 80% of its starting capacity is considered no longer good enough to be used. That still has some capacity that can be used in a second life. However, actually there is no reuse or second life market for this batteries [20].

In this respect, the next option is to recycle the batteries. There are some different methods to recycle batteries, but most of them are only prototypes [20]. However, there are some companies in Europe which recovers cooper and cobalt from car batteries. Steel, nickel and aluminum are also found to be commonly recovered, but other components like plastic and lithium are landfilled [21]. Car batteries are easier to recycle because they are big, but most of small batteries such as mobile and electric scooters are not recycled. For this reason, it has been considered two different options for the end-of-life of the batteries:

- **Disposal option 1**: It is considered that the batteries have the same destiny as the most of them, disposed to the landfill. This gives some CO_2eq emissions which are considered in the GREET Model.

  Focusing on the charging option 2, the extra batteries are included in the Manufacturing part of the LCA but not separately in the disposal part. This is because the battery disposal emissions are included in the value of the GREET Model together with the rest of the scooter. When a scooter breaks or is not able to work anymore, the batteries are still able to work longer because they have not worked every day. Then, when a scooter is disposed to the landfill, the battery is removed. Finally, when the lifetime of the battery is over, it is disposed separately, resulting on the same emissions that the GREET Model gives.

- **Disposal option 2:** It is used the hydrometallurgy method presented by the LithoRec project [20]. This method produce benefits regarding the energy and CO_2eq emissions, this values are shown in the Table 1.

Table 1. LithoRec method to recycle batteries for each kilogram of battery

	Dismantling	Cell separation	Cathode separation	Hydro-processing	Total
grams CO_2eq	234	586	213	1461	2494
Main impact from	Transport, Steel and Al recycling	Cu recycling, washing, burning of separator	Electricity	Supporting materials and electricity	
gram CO_2eq credit	-1966	-325	-269	-970	-3530
Materials recovered	Stainless steel and plastics	Copper and Aluminum	Aluminum	Cobalt and Nickel	
Net gram CO_2eq	-1732	261	-55	491	**-1035**
Energy					**-(16-28) MJ**

Finally, the LCA of electric scooters has been compared with electric cars and ICE cars. Taking a look at the total emissions is not possible to extract a conclusion of which option is better because cars and scooters have a very different lifespan. So, cars emits more CO_2eq when are manufactured but they also last more kilometers. For this reason, it has been realized a comparison of grams CO_2eq per kilometer.

2.4. Ethical considerations

The application of a rental scooter company in a city have an important effect to the inhabitants. Once the scooters are introduced into the streets, all other modes of transport will be affected and this may affect some transport companies.

Since the scooters are parked on the same streets, it is a responsibility of the scooter user to leave them on the side where do not disturb to anyone. Also, once a user is registered to be able to use the scooters, the user accepts the actual traffic laws and takes all the responsibility of any accident or injury to others.

3. Electric scooters

This chapter introduces and describe the electric scooter features and components. Then, the advantages of this vehicles are stated and analyzed. Finally, it is studied the actual regulation and its controversy.

3.1.Components

An electric scooter is a powered stand-up vehicle which uses a small utility electric motor. These scooters are designed with a large deck in the center on which the rider stands. They usually have two small wheels made of plastic with an aluminum chassis and a handlebar. Figure 1 shows the basic structure of this vehicles.

Figure 1. Two examples of electric scooters: Xiaomi Mijia [22]

The main components of a manual scooter are very simple. They are based in the chassis structure, wheels, bars and breaks [23]. On the other hand, electric scooters are more complex. Apart for the previous components, there are: batteries, motor, lights, suspension and a controller.

The electric motor is the only mechanical power generator of the electric scooter. It determines top speed, acceleration, ability to climb hills and power consumption. The power of the motor also determines how the scooter will perform depending on the rider weight [24].

There are two different types of scooter motors: Brushless DC and Brushed DC. Brushless DC motors is the newest technology which is more efficient, have better power-to-weight and are more durable. Brushed DC motors are the older version which is based on mechanical brushes that drag along the inside of the motor, while in the newer version this component is replaced by digital switching circuit [24].

The second main component is the battery pack. This component is the energy storage which provides the energy consumed by the motor and other components. Most of this vehicles have lithium batteries because have excellent energy density (high amount of energy per physical weight). They also have long life expectancy, being able to be discharged and recharged many times and still maintain their storage capacity [24][25].

The controller can be considered the scooter's brain. It receives inputs from the user and translates it into a current that is sent to the motor. This component is directly connected with the throttle and brake switch [24].

In this thesis, it has been taken into consideration two different scooter models in order to get a more accurate result to the reality:

- Jadi-Tech Scooter: Removable battery scooter.
- TopJHW Scooter: Non-removable battery scooter.

Both scooters can be bought in a Chinese company that sells products only to companies, so that is why the prices are lower than the most commercial brans for particulars. The characteristics of each scooter is shown in the following Table 2:

Table 2. Characteristics of the two scooter models [26][27]

	Jadi Tech scooter	**TopJHW scooter**
Price/unit	178 €	129 €
Power	250 W	250 W
Battery capacity	4.4 Ah	4.4 Ah
Battery voltage	36 V	36 V
Distance	18 km	20 km
Charging time	3 h	2 h
Speed limit	25 km/h	25 km/h
Product weight	13.9 kg	10.5 kg
Tire size	21.59 cm	21.59 cm
Product size	1080x430x1140 mm	1000x405x920 mm

3.2.Advantages

There are many advantages of electric scooters related to the economy. For instance, the first investment is much lower than with a fuel vehicle (in order of 50-100 times cheaper). In addition, its simplicity makes it easy to repair if some component breaks and also the replacement parts are cheap [4][28]. Since these vehicles do not require a driving license, it is available to use also for young people and people who do not have the license.

In the company point of view, there is a study [29] which states that 70% of people across U.S. view electric scooters positively so companies uses this view to provide renting scooters which are paid for minute of use.

E-scooters are compact and light, so it results to be easy to move around. Some of them weight 10.5 kg, which is not heavy to carry it with one hand. Also, some have a folding design that allows to take it inside buildings or public transports.

The advantages of rental electric scooters are the possibility to use a fast and agile mode of transport and forget about to park it and forget about security issues. Also, before the user unlock the scooter with his phone, the battery remaining is shown in the mobile app. So the user can know if he has enough battery for his trip.

Older adults start using scooters in order to maintain their travel patterns as a consequence of losing physical capabilities or when they have to stop driving [6]. It allows the users to travel distances they previously would have made with any problem by foot or vehicles without physical effort. Therefore, it provides a sense of more independence.

Finally, ES are powered by electricity, not fuel, so they do not produce toxic gases or GHG. But this is only true if the energy used is produced with renewable sources [11]. Despite they use non-renewable electricity, the GHG emissions with an electric scooter is considerably lower than with a fuel scooter.

3.3.Challenges

The implementation of vehicles such as electric scooters as a share mode of transport has appeared only a few years ago, so there is still no a specific legislation for this scooters [30][31]. For this reason, after the first introduction to a city (San Francisco), the result was problematic [32][33]. Despite the company had a strong beginning, the city announced a ban for the sharing scooters after the inhabitants of the city have complained several times about the bad usage of the scooters.
The main problems of the introduction of a sharing scooter company are vandalism, inappropriate use and parking in forbidden places [33]. In cities like Stockholm, there is no control or requirements for a company to put scooters out the streets, so it all ends with a dissatisfaction of the local inhabitants.

Regulations for the usage and rental of electric scooters has yet to be stablished. However, the legal requirements to use this vehicles may vary between different countries, but in general they are treated as electric bikes (or bikes) [30][31]. This requirements include, among others, have a suspension system, the right tires, a rearview mirror, a horn, headlights, signal lights, brake lights, use helmet and power steering.

In Sweden, the Swedish Transport Agency has classified electric scooters as a bicycle and, therefore, must comply the rules and regulations on electric cycles in the EU. This European regulation [34] states that the maximum speed is 25 km/h and the maximum power of the engine is 250 W. Vehicles with higher values are not considered electric cycles and can be considered as a moped.

3.3.1. Battery transportation

The transport of batteries and battery-powered equipment has a big risk of short-circuit as a result of the battery terminals coming into contact with other batteries, conductive surfaces or metal objects. Therefore, the transport of this products is subject to very strict rules.

Any Lithium-Ion battery over 100 Wh is classified as CLASS 9 (miscellaneous dangerous goods) and is under different regulations depending on the transport. For instance, road transport is under ADR regulation. The batteries proposed in this thesis are 158 Wh, so they have to be managed by member staff with a specific training or it has to be hired a specialist company to handle, pack and label them.

3.4. Terms of use for electric cycles

These are the rules governing:

- Basic rules: To be considered a bike needs brakes and alarm clock.
- Night driving: Bikes and electric cycles must have lighting and reflections to be allowed to circulate when is dark.
- Helmet obligations: Each state member of the EU has its own regulation in what helmets respect. In Sweden, the use of helmets is compulsory for mopeds while the requirements for electric bikes has not been researched nor what type of helmet. Even though it is not mandatory, people under fifteen years old have to wear it.
- Insurance: Insurance is one of the most complex issues of the light electric vehicles. There is a European harmonized Directive 2009/103, which imposes insurance against civil liability in respect of the use of motor vehicles. The problem is in the interpretation of "motor vehicles". In some countries electric scooters and electric bikes are considered still bikes, so they do not enter to the category of motor vehicles and do not need a specific insurance to drive the vehicle. It is only needed their general family insurance.
- Traffic code: Electric scooters can be used where bikes can be used. In states such as Sweden, it can drive in the same places as mopeds. This includes bike paths and the right side of the road. Additionally, scooters must be lead on pavement and pedestrian roads.
- Driving license and age limits: 250 W / 25 km/h scooters are not subject to a driving license. Member states of the European Union may however impose an age limit on the use of mopeds and other electric vehicles by the requirement of a driving license. In the case of Sweden, there is no requirement to use electric scooters.

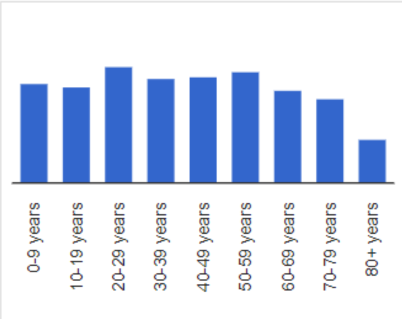
4. Results

This section shows the results of the analysis of the travel patterns of the city of Gävle. Also, it is defined the operating area, fleet number and costs of the rental scooter company. Finally, the results obtained from the LCA are shown and are compared with EV and ICE cars.

4.1. Travel patterns of Gävle

4.1.1. Age and gender distribution

The total population in Gävle municipality is 101,455 people in 2018 [35]. The population is equally distributed along the ages as can be seen in the Figure 2 [35].



Age Distribution (E 2018)	
0-9 years	11,825
10-19 years	11,485
20-29 years	13,765
30-39 years	12,430
40-49 years	12,653
50-59 years	13,154
60-69 years	10,951
70-79 years	10,002
80+ years	5,190

Figure 2. Age distribution in Gävle

In Gävle municipality, a total of just over 73,000 people live 16-74 years [3]. The age distribution of 2018 among the inhabitants and among those who participated in the survey made by the city hall is shown in Figure 3.

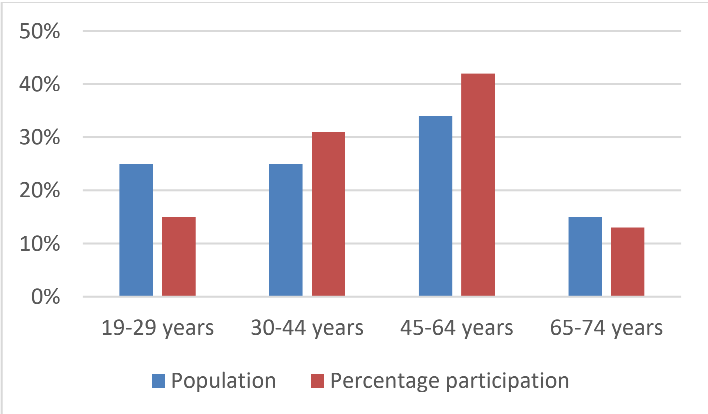


Figure 3. Percentage of population vs. participation

As the figure shows, people between the ages of 30 and 64 are over-represented in the answers in the survey with mobile app 2018 while people under 30 and over 64 years have less participation.

Regarding the gender distribution, Gävle is equally distributed with a 50% men and 50% women [3][35].

4.1.2. Employment

The employment of the population of the city have an important relevance to this thesis because determines the number of trips a person does every day and the amount of free time to do extra trips.

The distribution of the employment of the city of Gävle is shown in the next Figure 4. In this figure it can be seen that more than six out of ten people is working and 16 percent is studying and retired [3].

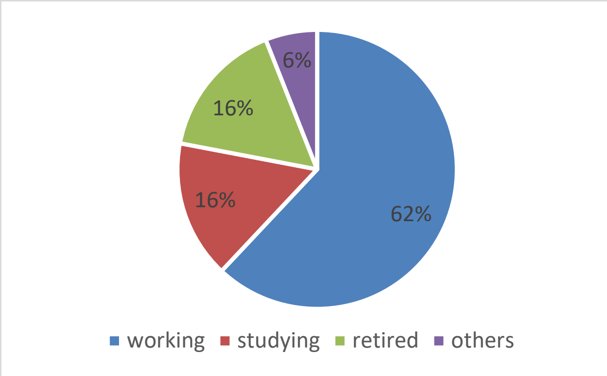


Figure 4. Percentages of employment of the population in Gävle

4.1.3. Access to modes of transport

The results of the survey [3] shows that a 92% of the population (older than 18 years old) have a driving license. Also, of those who are at least 18 years old and have a driving license, 70% always have access to a car when they need it and 93% always or almost always have access to a car[3]. Therefore, there is more than a 15% of the population that is not able to use a car (because is not 18, do not have driving license nor have a car).

Knowing that there are 73,000 people between 16-74 years old and that a 15% cannot use a car, it results in 10,950 citizens who have a high potential to change their habits to use an electrical scooter in their normal life.

Regarding the public transport card (bus card), each third inhabitant always has access to a bus card and approximately the same proportion sometimes has access to a bus card [3], see Figure 5.

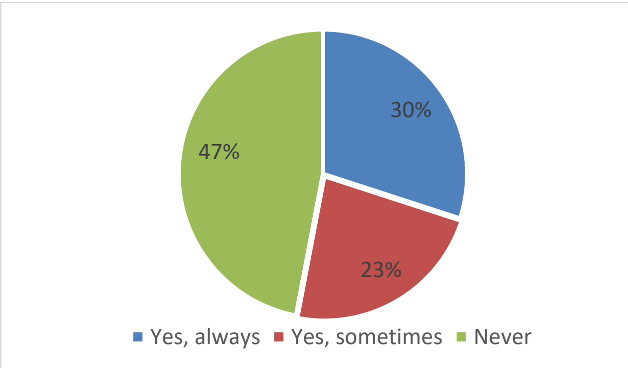


Figure 5. Access to a bus card

4.1.4. Travel attitudes

In order to find out the part of the population who is likeable to change their actual way of transport, some questions have been realized by Gävle's city hall [3] to analyze which mode of transport each person prioritizes the most. In the next Figure 6 is shown that most of the people prioritizes the most travels with bike and bus. In addition to the fact that 43% gives the lowest priority to cars, it reflects the aim of the population to use environmental-friendly ways of transport.

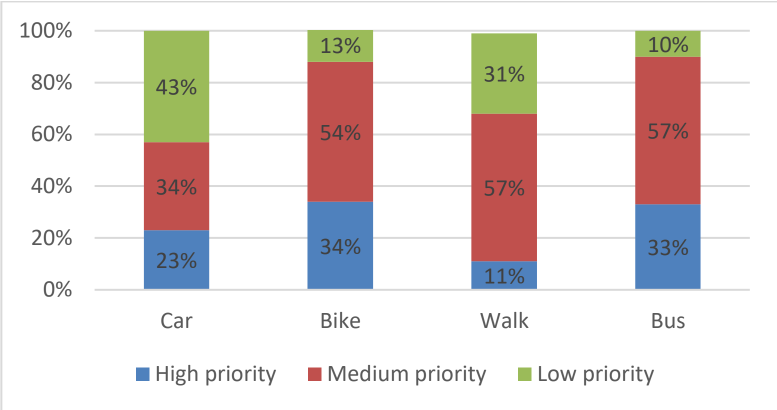


Figure 6. Priorities for different modes of transport

With a total population in Gävle of over 73,000 people in the age group 16-74 years, the average trips during the weekdays are 4.8 trips per day and during the weekend are 4.1 trips[3]. As a result, the average trips in a full week are 2,344,000.

4.1.5. Trips distribution

The trips have been divided into 5 categories: work/study, trips, services and groceries, entertainment and leisure and others. Figure 7 and Figure 8 shows that a quarter part of the trips are to go to work or to the school. However, the main part of the trips are the services and groceries. This category include trips such as visit hospital, post or the bank which are trips that can be done easily with a scooter.

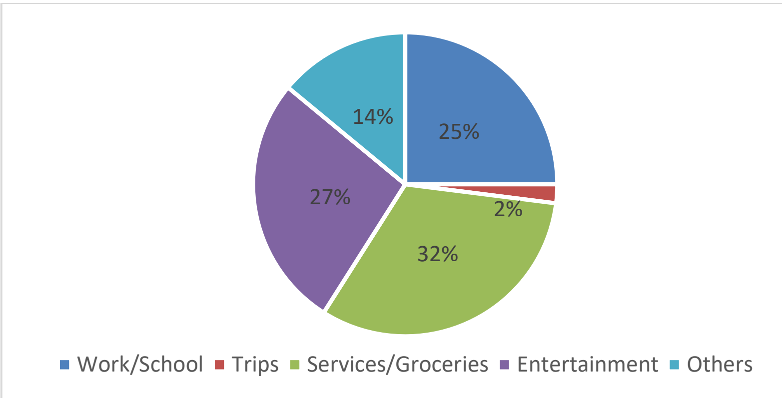


Figure 7. Trips distribution by categories

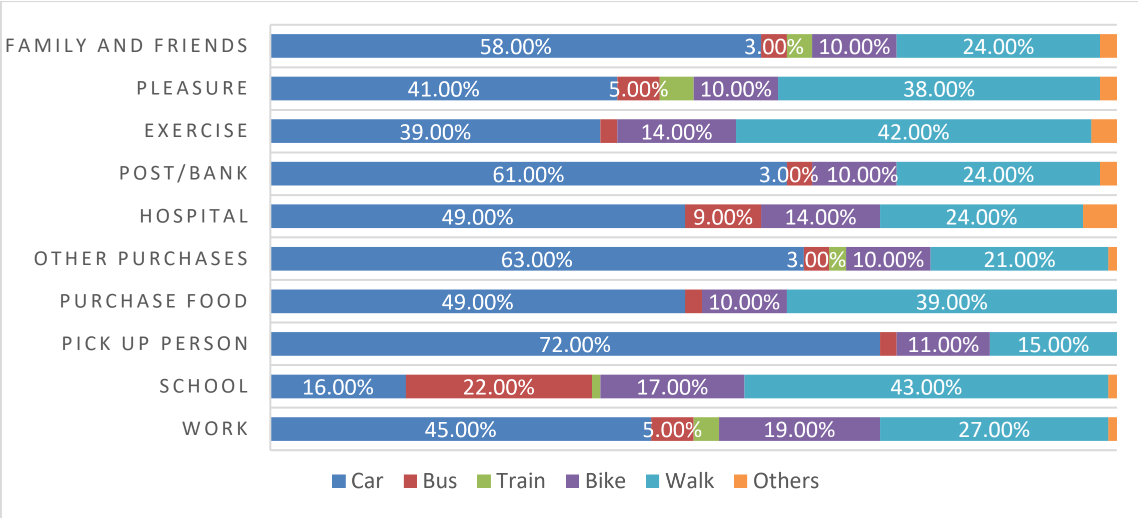


Figure 8. Percentages of mode of transport used for each category

Regarding the travel length, almost two thirds of the trips are shorter than four kilometers and half of them are shorter than two kilometers as it can be seen in the Figure 9 [3].

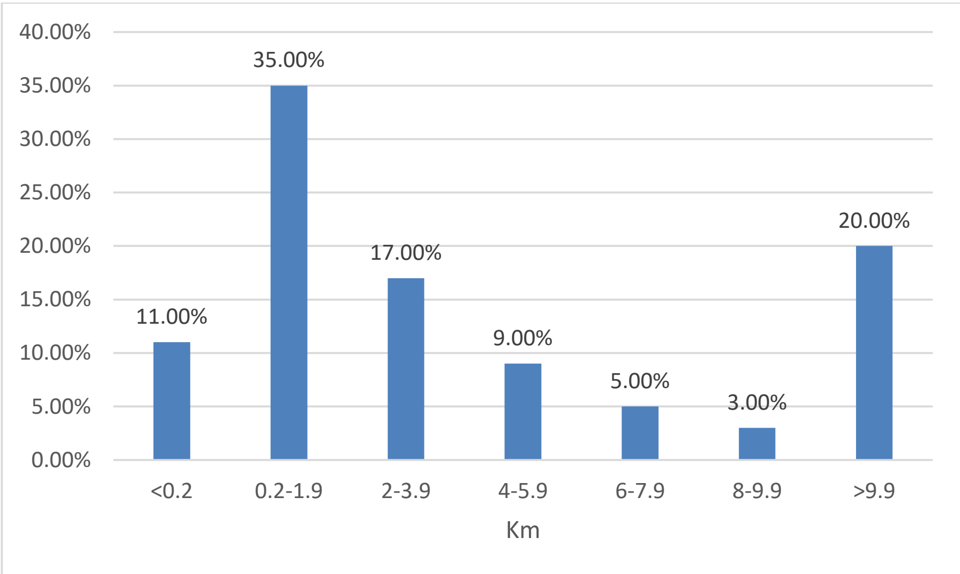


Figure 9. Percentage of trips depending on the distance

The application of a scooter rental company does not affect really short trips neither long distance trips. For this reason, the mean distance of scooter's trip is calculated with the weighted average of the trips from 0.2-5.9 km, giving as a result an average of 2.2 km/trip.

The choice of the transport mode is highly dependent on the length of the journey, as shown in the Figure 10. When traveling less than 2km the most common transport is by foot, while for trips longer than 2km the most common is by car.

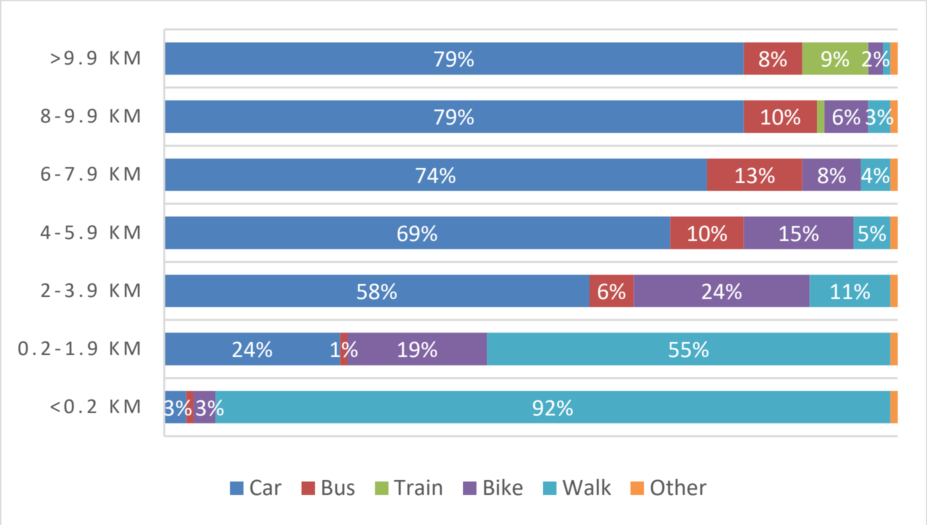


Figure 10. Transport mode depending on the length of the journey

4.2. Implementation of the electric scooters

4.2.1. Operating area

The operating area of the rental scooters has to be a balance between include the most part of the trips and occupying the less area possible. The amount of scooters needed will increase with the area, so it is an important factor to take into an account. For this reason, an image with the most common trips is represented in the Figure 11 [3].

Figure 11. Intensity of trips in Gävle's municipality

As it can be appreciated, the major part of the trips are done in the city center with some trips by car to the external part of Gävle municipality. Consequently, the proposed area to implement the company is the shown in the following Figure 12. The total area is about 22 km^2. The limits of this area are the limit place where it is possible to park the scooter after the usage.

Figure 12. Operating area of the electric scooter company

With this area the intention is to be a potential competitor with the short distance car trips. For example a trip to cross all the city from Satra (northern part) to the southern part.

4.2.2. Fleet number

To determine the fleet number, this company has been compared with a very profitable company of rental electric scooters in another city near Gävle. This city is Uppsala, but Uppsala is considerably bigger than Gävle, so some adjustments have to be applied. In conclusion, the following formula has been used

$$N_1 = N_2 * \frac{A_1}{A_2} \qquad (1)$$

Where: N_1 = Fleet number in Gävle
N_2 = Fleet number in Uppsala
A_1 = Operating area in Gävle
A_2 = Operating area in Uppsala

The population of Uppsala is 160,952 in 2018 [36] but there are only 1335 users in Lime from this city [37]. Lime company has 100 electric scooters in operation on the streets of the city [38]. With this amount of scooters and registered users, each scooter is used in average 5 times per day. The operating area of Lime in Uppsala is about 33 Km^2, while the operating area in Gävle will be about 22 Km^2. Therefore, the equation is solved as it follows:

$$N_1 = 100 * \frac{22}{33} = 66.66 \rightarrow \boldsymbol{67\ scooters}$$

Regarding the removable batteries, it is going to be used some batteries bought in a Chinese company and they cost 31 €/unit [39]. As it has mentioned before, the amount of batteries bought will be half of the scooter fleet in order to be able to charge them all in two rounds, 34 units.

Next, the total costs of both charging options are calculated.
The electricity prices around Stockholm (27/04/2019) are shown in the Table 3 [40]. It can be seen that the lower prices take place during the night. Also, there is a period of four hours in the afternoon (from 13-15h) when the prices are also below the mean price.

Table 3. Electricity cost for each hour of the day [€/MWh] (based in prices of Stockholm in 27/04/2019)

TIME	€/MWH
00 - 01	31,25
01 - 02	29,38
02 - 03	28,35
03 - 04	27,37
04 - 05	26,78
05 - 06	26,12
06 - 07	27,02
07 - 08	31,99
08 - 09	37,22
09 - 10	38,04
10 - 11	38,02
11 - 12	37,57
12 - 13	33,92
13 - 14	31,55
14 - 15	30,89
15 - 16	30,98
16 - 17	32,04
17 - 18	33,92
18 - 19	38,02
19 - 20	38,96
20 - 21	38,60
21 - 22	36,72
22 - 23	32,83
23 - 00	30,82

To calculate the charging cost for a completely uncharged battery, it is necessary to calculate first the power of the batteries:

$$P\ [wh] = I\ [Ah] * V\ [v] \qquad (2)$$

$$P = 4.4 * 36 = \mathbf{158.4\ wh \rightarrow 0.0001584\ MWh}$$

Then, the energy cost is calculated using the mean cost between the 2 cheapest hours (between 4-6 AM):

$$Price\ [€] = P\ [Mwh] * Cost\ [\frac{€}{Mwh}] \qquad (3)$$

$$Price = 0.0001584 * 26.45 = \mathbf{0.004189\ €/charge}$$

To sum up, the options are shown in the Table 4:

Table 4. Summary of costs for the different charging options

	Fleet cost [€]	Battery cost [€]	Total capital cost [€]
Charging Option 1	67*129=8,643	0	8,643
Charging Option 2	67*178=11,926	34*31=1,054	12,980

The charging option 2 is 33.41% more expensive than the option 1.

4.3.Life Cycle Assessment

4.3.1. Assumptions

The battery power is the same as the calculated before, 158.4 Wh. To see the scooter's characteristics, see the section *3.Electric Scooters*.

The size of a battery of this characteristics weight 1.3kg and the tires 0.5 kg/each (1 kg in total). As a result, the rest of the scooter weights 8.2 kg (the non-removable battery scooter) and 11.6 kg (the battery removable scooter). The structure material is aluminum.

As it has been calculated on the previous part *4.1.Travel patterns of Gävle*, taking an average of 5 trips per day and an average ride distance of 2.2 km/trip we get:

$$Distance\ ridden\ per\ day\ and\ scooter = Daily\ trips * Ride\ distance = 11\frac{km}{day} \quad (4)$$

$$Total\ lifetime\ distance = \frac{Nº\ rides\ lifetime * Distance\ per\ day}{Average\ rides\ per\ day} = 1{,}100\ km$$

This results on 11 km/day per scooter and a total lifetime distance of 1,100 km per scooter. Also, dividing the number of rides in lifetime for the average rides per day we get the total lifetime charging cycles, that is 100 times.

4.3.2. Manufacturing

The first step of the analysis is estimate the emissions of the manufacturing of all the components. This thesis uses two different scooter models but, regarding the LCA of both models, there is no much difference between them as they have almost the same specifications. For this reason, it has been used the same LCA for both scooters in what manufacturing means. The components of the analyzed scooter provided by the GREET Model [41] are: 1.35 kg of lithium—ion battery, 1 kg of rubber tire and 9.85 kg of aluminum. The results are shown in the Table 5.

Table 5. Manufacturing emissions

	GHG Emissions
Lithium ion battery	19,824 grams CO_2eq
Scooter body and tires	184,247 grams CO_2eq
Total manufacture lifetime emissions	204,071 grams CO_2eq
Total manufacture per lifetime and km	185.52 grams CO_2eq/km

4.3.3. Assembly

Another notable aspect of the scooter used is the manufactured parts in the factory. Using the GREET Model [41] as before we get the values of the Table 6. The assumed lifetime rides and kilometers are 500 and 1,100 respectively.

Table 6. Assembly emissions

	GHG Emissions
Total assembly per scooter	5,431 grams CO_2eq
Total assembly per scooter and km	4.47 grams CO_2eq/km

4.3.4. Scooter transportation

The next step is calculate the transport of the scooter from the factory to the destination city where it will work. These scooters are made in China, so this means that the scooter will take some different modes of transport to be able to reach Sweden. Then, the transport has been split in two parts: truck and plane.
The transportation from China per ton of material via truck is 92,770 grams of CO_2eq/ton and via tanker is 115,148 grams CO_2eq/ton [41]. The results are shown in the Table 7.

Table 7.Transport emissions

	GHG Emissions
Transport via truck	1,248 grams CO_2eq
Transport via airplane	1,549 grams CO_2eq
Total transport emissions	2,796 grams CO_2eq
Total transport emissions per lifetime and km	2.3 grams CO_2eq /km

4.3.5. Charging

Despite the scooter's daily distance will be less than their capacity, it is considered that the batteries are fully charged every day at night. It has to be taken into account that the scooter has different electronic systems that also consumes energy even if is not working, such as the GPS track system and lights. For fully charge one scooter, it takes 0.1584 kWh of electricity. The recharging process in the European Union energy mix emits 337 grams CO_2eq per kWh, while Sweden emits 13 grams CO_2 per kWh [42].
Then, the CO_2 equivalent is calculated as follows:

$$Emissions\ fully\ charge = Battery\ capacity * Sweden\ energy\ mix\ emission \quad (5)$$

$$Emissions\ fully\ charge = 0.1584 * 13 = \mathbf{2.06\ grams\ CO2eq}$$

Therefore, the charging process of one scooter will account for 2.06 grams CO_2eq. This results in a lifetime emissions from charging a scooter of 206 grams CO_2eq (100 charging cycles assumed) and 0.187 grams CO_2eq/km.

4.3.6. Collection and Redistribution

Every night all the scooters are removed from the streets in order to charge them and relocate them for the next day. This job is done by private users who use their own vehicles. Consequently, this activity is not GHG free and has to be taken into an account.

There is a maximum of 20 scooters collected per day, but the competence between contractors highly reduce the amount of scooters collected. For this thesis, it has been assumed that an average contractor collects 10 scooters per night and travels around 8 kilometers to find them, charge them at home and, finally, redistribute them around the streets.

The average gasoline car consumption is 404 grams CO_2eq /mile [43][44], corresponding to 251 grams CO_2eq/km. Then, the collecting and redistribution emissions are calculated:

$$Van\ emissions = \left(\frac{Emissions}{km}\right) * km \qquad (6)$$

$$Van\ emisisons = 251 * 8 = \mathbf{2,008}\ \boldsymbol{grams}\ \mathbf{CO2eq}$$

$$Van\ emissions\ per\ scooter\ and\ day = \frac{van\ emissions}{collected\ scooters} \qquad (7)$$

$$Van\ emissions\ per\ scooter\ and\ day = \frac{2{,}008}{10} = \mathbf{200.8}\ \boldsymbol{grams}\ \mathbf{CO2eq}$$

$$Van\ emissions\ per\ scooter\ and\ km = \frac{Van\ emissions\ per\ scooter\ and\ day}{Distance\ ridden\ per\ day} \qquad (8)$$

$$Van\ emissions\ per\ scooter\ and\ km = \frac{200.8}{11} = \mathbf{18.254}\ \boldsymbol{grams} \frac{\boldsymbol{CO2eq}}{\boldsymbol{km}}$$

Comparing the daily consumption (assumed 5 trips of 2.2km, thus 11 km/day) of an electric scooter with the average car consumption per km, we get the results shown in the Figure 13.

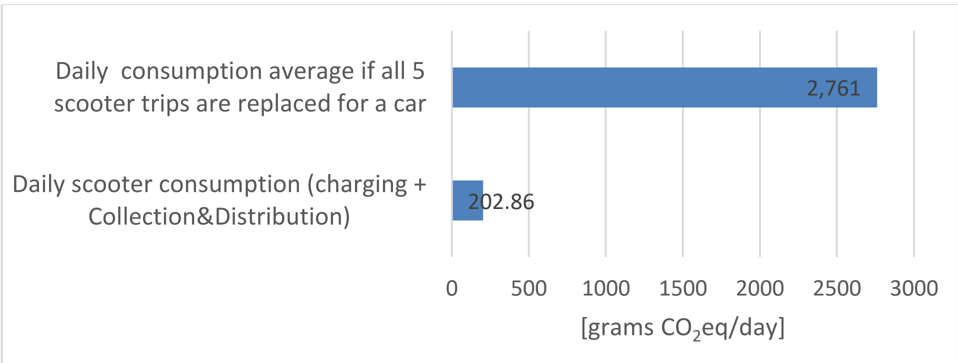


Figure 13. Daily consumptions for scooters compared with cars

Finally, the total lifetime emissions are calculated multiplying the daily emissions for the expected lifetime charges:

$$Total\ lifetime\ emissions\ per\ scooter = 200.8 * 100 = \mathbf{20,080}\ \boldsymbol{grams\ CO2}$$

4.3.7. Recycling and disposal

The chassis of the scooter is disposed to the landfill. Following the GREET Model data, the disposal GHG emissions per ton of vehicle is 221,442 grams of CO_2eq/ton. Then, the emissions for each rental electric scooter is 2,978 grams CO_2eq and the emissions per kilometer are 2.7 grams CO_2eq/km.

Regarding the end-of-life of the batteries, two options are presented:

- **Battery Disposal Option 1:** Once one battery reach its end-life, it is not recycled and is disposed to the landfill. Its emission cost is included in the vehicle emissions of the GREET Model.
- **Battery Disposal Option 2:** Batteries follow a series of processes in order to re-use as much material as possible and get a net benefit of CO_2eq. For a battery of 1.3 kg, the results of the process are shown in the following Table 8.

Table 8. Results of recycle one 1.3kg battery with the LithoRec Method

	Dismantling	Cell separation	Cathode separation	Hydro-processing	Total
gram CO_2eq	304.2	761.8	276.9	1899.3	3242.2
Main impact from	Transport, Steel and Al recycling	Cu recycling, washing, burning of separator	Electricity	Supporting materials and electricity	
gram CO_2eq credit	-2555.8	-422.5	-349.7	-1261	-4589
Materials recovered	Stainless steel and plastics	Copper and Aluminum	Aluminum	Cobalt and Nickel	
Net gram CO_2eq	-2251.6	339.3	-72.8	638.3	**-1346.8**
Energy					**-(21-23) MJ**

Therefore, with this method the CO_2eq savings are 1,346.8 grams per battery.

4.3.8. Life cycle emissions

Finally, all the aspects are assembled together to compare all the possible options.
In the charging option 2, there is no need to use a van to transport the scooters. Then, the batteries can be transported with a small electric vehicle or even a bike, so the collection and redistribution emissions are not considered.
On the other hand, it has to be considered the emissions of the extra batteries in the manufacturing and recycling part.

The total life cycle emissions per scooter on its 500 lifetime rides and 1,100 lifetime kilometers for all the options (including the extra batteries of the charging option 2) is calculated in the Table 9.

Table 9. Comparison of the total CO_2eq emissions for a scooter for different options

[gram CO_2eq per scooter]	Charging Option 1		Charging Option 2	
	Disposal Option 1	*Disposal Option 2*	*Disposal Option 1*	*Disposal Option 2*
Manufacturing	204,071	204,071	214,131	214,131
Assembly	5,431	5,431	5,431	5,431
Transportation	2,796	2,796	2,796	2,796
Charging	206	206	206	206
Collection and distribution	20,080	20,080	0	0
Disposal	2,978	1,631	2,978	1,631
TOTAL	**235,562**	**234,215**	**225,542**	**224,195**

The total life cycle emissions for the implementation of a rental scooter company in Gävle for the different options are the shown in the following Table 10:

Table 10. Total CO_2eq emissions for the implementation of the company in Gävle for different options

[total gram CO_2eq]	Charging Option 1		Charging Option 2	
	Disposal Option 1	*Disposal Option 2*	*Disposal Option 1*	*Disposal Option 2*
Manufacturing	13,672,757	13,672,757	14,346,773	14,346,773
Assembly	363,877	363,877	363,877	363,877
Transportation	187,332	187,332	187,332	187,332
Charging	13,802	13,802	13,802	13,802
Collection and distribution	1,345,360	1,345,360	0	0
Disposal	199,526	109,277	199,526	109,277
TOTAL	**15,782,654**	**15,692,405**	**15,111,310**	**15,021,061**

The total emissions for scooter and kilometer are calculated in the following Table 11:

Table 11. Total emissions for scooter and kilometer for the options

[gram CO_2eq/km]	Charging Option 1		Charging Option 2	
	Disposal Option 1	*Disposal Option 2*	*Disposal Option 1*	*Disposal Option 2*
Manufacturing	185.52	185.52	194.66	194.66
Assembly	4.47	4.47	4.47	4.47
Transportation	2.3	2.3	2.3	2.3
Charging	0.19	0.19	0.19	0.19
Collection and distribution	18.25	18.25	0	0
Disposal	2.7	1.48	2.7	1.48
TOTAL	**213.4**	**212.2**	**204.3**	**203.1**

If this emissions are compared with the emissions produced by a medium electric and petrol car [45] we get the results of the Figure 14.

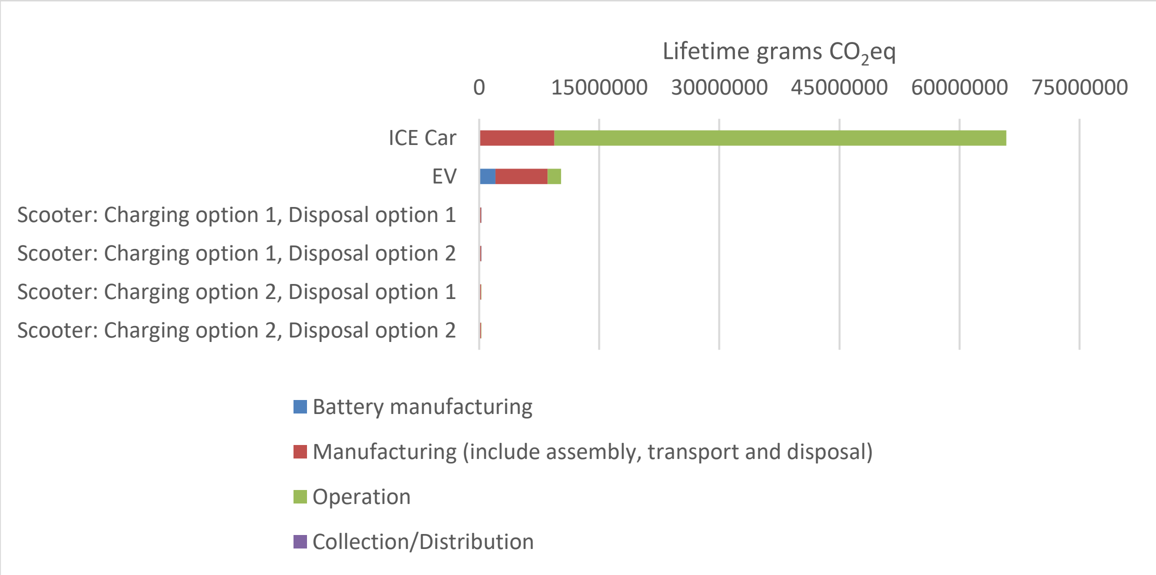


Figure 14. Comparison of total emissions between cars and scooters

Finally, the emissions are expressed in grams CO_2eq /km in the Figure 15.

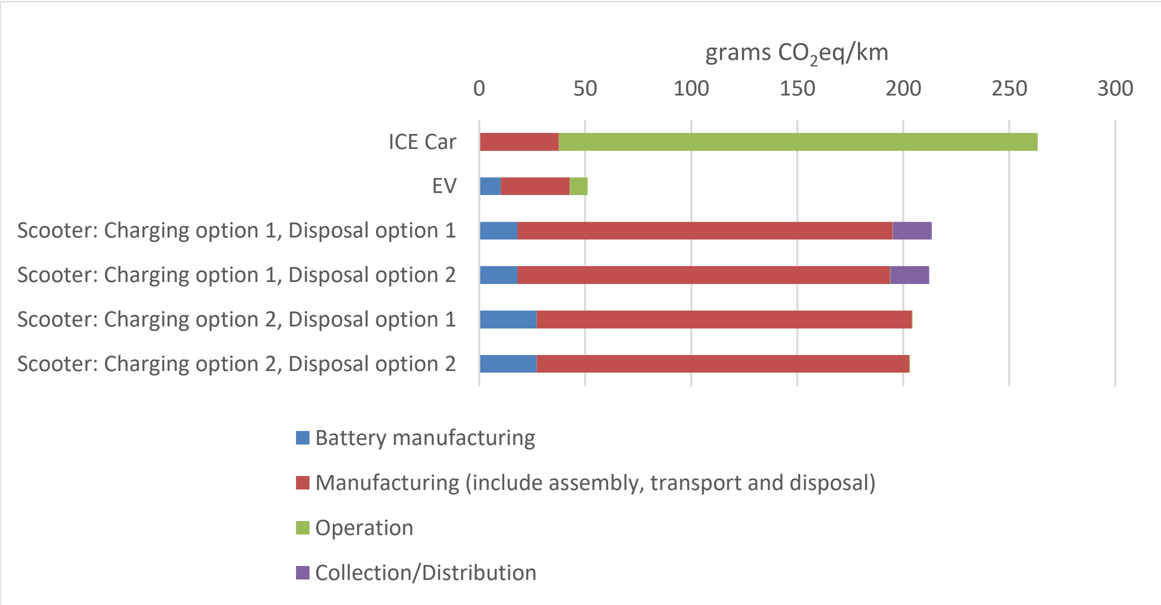


Figure 15. Comparison of total lifetime emissions per kilometer between cars and scooters

5. Discussion

It could perhaps be argued that the implementation of a rental scooter company can only be implemented in big cities because there is more opportunities with tourism and more density of people, but the city of Gävle may have some characteristics which can make it feasible. As the results show, there is 73,000 people between 16-74 years old that are able to use scooters, of which 15% do not have driving license (10,950 people with high potential to use scooters).

Also, Gävle is considered a student city due the University of Gävle. Most of these students live far from the city center, so they use public transport or bike to go there.

In addition, 72% of the total trips realized are less than 5.9 km. This is the maximum distance which has been considered to use a scooter. For longer distances, the most common and practical transports are cars and buses. Moreover, the most common distance trip is between 0.2 and 1.9 km, which fits perfectly for the use of an electric scooter.

Also, the most common mode of transport for longer distances than 2 km is the car, with more than half of the total trips. This trips are the main target to substitute for scooters, but there is no way to know how many of these people will really change his usual vehicle.

The operating area of the scooter company has included the main parts of the city and some transited parts in the periphery. It could be a largest area but, to make this company profitable, it has to cover the minimum area possible in order to not need to buy a large scooter fleet.

After the application of the formula to estimate the fleet number we get the result of 67 electric scooters. This number is just the initial amount of scooters that would be bought. Once the scooters become unavailable (independent of the reason), more scooters would be needed and, consequently, bought.

The analysis of the total cost of both options, it is clearly seen that the cost of the battery removable option requires a highest investment, exactly a 33.41% more.

As it can be seen in the Table 9, the Charging Option 2 reduces the total CO_2eq emissions compared with the Charging Option 1. Moreover, with the recycling method for the batteries, this emissions can be reduced even more.

The Life Cycle Analysis of the Charging Option 2 has been realized counting the initial investment of CO_2eq produced by the extra batteries on the total manufacturing emissions. In the hypothetic case that this company is created, these extra batteries should be bought only at the beginning. This is because it is considered that, when the scooter breaks or is not able to work anymore, the batteries are still able to work longer

because they have not worked every day. When a new scooter is replaced, there is a new battery which is available to use, so there will always be enough batteries.
As the extra batteries are only bought at the beginning, the manufacturing costs per new scooter will be the ones of the Charging Option 1. This will result in an even more reduced total emissions for the removable electric scooters.

The result of the LCA of both electric scooter charging options with electric cars and ICE cars is represented in the Figure 14. It can be seen that the total emissions of the electric scooters are almost not visible because are considerably smaller. This can give a false conclusion if is not analyzed in the correct way. It is true that the production and emissions of both types of cars are much higher, but they also have a much longer lifespan. So, at the end, to drive as much kilometers as it can be done with a car, it is going to be needed a large amount of scooters.
For this reason, the most relevant result is shown in Figure 15, where the total emissions are in grams CO_2eq /km. In this figure, it is taken into an account the lifetime kilometers of every vehicle and it can be seen how really the emissions are.

Unexpectedly, the results show that the most efficient mode of transport is the electric car. Next goes the scooter Charging Option 2, followed by the Charging Option 1 and the ICE at the end. Despite EV is the most environmental friendly, these vehicles are still expensive in the market and are not affordable for everyone. That gives a chance for the electric scooters to enter in the market and be cleaner than the actual fuel powered vehicle. The main problems of the electric scooters are the short lifespan and the high manufacturing emissions (for instance 87% of emissions per kilometer in Charging Option 1).

The operating costs of the electric scooters are almost not visible in the figure due to the clean energy produced in Sweden, which is only 13 grams CO_2 per kWh while the average in the European Union is 337 grams CO_2 per kWh. It is also affected by the light weight of a scooter and that it can only carry one passenger.

Even though the results show that the electric scooters, on a per-kilometer basis, are cleaner than fuel-powered cars, that may not be the case in practice. In general, it is incomplete to declare that they are eliminating CO_2 from the transportation sector. The reason is that this calculation assumes a one-for-one replacement of car trips with scooter trips. But this is not always like this, scooters are actually replacing options that are less carbon intensive (such as biking, public transport, walking) just as often as they are replacing more carbon intensive transports.

6. Conclusions

6.1.Study results

After this thesis, it can be concluded that:

(I) The study of the travel patterns shows that the implementation of an electric scooter company is viable in terms of potential users and the average distance trip for electric scooters in Gävle is 2.2km.

(II) Also, a rental electric scooter company in this city should has an operating area of 22 km2, including the areas of Gävle's center, Hagaström, Satra and Källbacken. Regarding the fleet number, it is needed 67 scooters and 34 extra batteries for a possible improvement of the actual charging system.

(III) As the results of the LCA show, the introduction of a rental scooter company may be not as suitable as it seems at the beginning. After an extended research, it can be found that the emissions per kilometer of the scooters are not better than the electric cars. The main problem for scooters is their short lifespan. This sort life make that the emissions per kilometer for the manufacturing process increases a lot and becomes even higher than bigger vehicles such as cars.

Despite having a high emission per kilometer, scooter emissions are less than ICE cars. So it can be said that electric scooters are cleaner than fuel powered vehicles. On the other hand, the introduction of this mode of transport not only competes with cars. Electric scooters will also substitute other modes of transports which are less pollutant (bike, walking or bus). When this happens, it can be stated that the electric scooters are not beneficial for the environment.

6.2.Outlook

Once the main problem of the electric scooters is identified (high manufacturing emissions per kilometer due the short lifespan), future research could be done in order to make them more effective. Basically, the problem would be almost solved if the scooter's lifetime will increase at least to the charging times specification (around 500-1000 charging times). To do so, more research on increase the scooter resistance to be everyday on the street should be done.

In addition, it could be also reduced the transport carbon emissions if the production is moved to Sweden. Moreover, due that the carbon emissions of the electricity in Sweden is much lower than China (13 grams CO_2/kWh against 711 grams CO_2/kWh), it would reduce the manufacturing emissions.

As the option 2 has revealed, the collection and redistribution emissions of the scooters are not negligible, so rental scooter companies should encourage low emission options to charge them. These options could start by paying more to the contributors who uses an EV to charge them. Also, it can be rewarded the ones who use solar energy to charge the vehicles. Finally, it can also be provided an efficient collection route to the collectors to reduce their traveling distance at night.

Finally, companies should incorporate a repairing system for the scooters instead of throwing them when stop working. And, when a scooter cannot be fixed, just reuse its components to fix another scooter.

6.3.Perspectives

This thesis is part of an evolution of our lifestyle in which governments, businesses, civil society and general public work together in order to build a better future for everyone. The main goal is achieve a sustainable development of our society, increasing our quality lifestyle but, at the same time, decreasing our GHG emissions. With the introduction of ES, the perspective is a future with good health and well-being in which we change our actual fuel-powered energy systems for sustainable cities and communities. As this thesis has shown, rental electric scooters are not completely developed to achieve this objectives.

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