The electrically powered assisted bicycle's potential in improving the climate performance of the transport sector

A study of passenger transportation modes

Anders Arwefeldt

Examensarbete 2014

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Elcykels potential att förbättra klimatprestandan inom transportsektor. En studie av persontransportslag.

Sammandrag

Den här master-uppsatsen studerar elcykeln (EPAC) som ett framtida icke-kolintensivt pendlingsalternativ och dess framtida marknad. Syftet med rapporten är att utvärdera huruvida elcykeln kan användas för att minska utsläppen från transportsektorn och ge en utblick för hur marknaden kan komma att utvecklas. Elcykeln jämförs med vanlig cykeln, bil, buss och tåg och bedöms mot dessa.

Resultaten i den här rapporten visar att elcykeln är ett av de trafikslagsom släpper ut minst växthusgaser. Tåget och bussen som drivs av förnybara bränslen visar liknande utsläppsnivåer. Dessa är de främst alternativen när det gäller motordriva pendlingsalternativ. Elcykeln i kombination med kollektivtrafiken utgör ett mäktigt verktyg för att skapa högeffektiva transportkedjor, i termer av GHG-utsläpp. Internationella erfarenheter (Köpenhamn, DK, och Houten, NL) har visat att det behövs långsiktigt och strategiskt arbete för att marknadsandelen av cyklar och elcyklar ska stiga. Nyttan med dessa fordonsslag har visat sig vara betydligt fler än endast minskade GHG-utsläpp.

Den svenska elcykelmarknaden går en ljus framtid till mötes. Den nederlänska elcykelmarkaden har redan en 19 procentig andel nysålda elcyklar och den svenska marknaden följer i snabb takt. Tillverkarna siktar på nya kundsegment där man främst fokuserar på pendlarna. GHG-minskningspotentialen för Sverige är över 1 % om 10 % av bilpendlingstrafiken ersätts med EPAC-trafik. Ökat elcyklande leder troligen till ökad cykling överlag vilket ökar fördelarna ännu mer. Produkterna finns på marknaden för ett brett mottagande medan den svenska cykelinfrastrukturplaneringen halkar efter och prioriterar bilen som det främsta fordonet. Ökat fokus på cykeln och elcykeln behövs för att på bred front få folk att byta transportmedel.

Nyckelord

Elcykel, persontransport, koldioxidutsläpp, transportsektorn, utsläpp, personkilometer

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The electrically powered assisted bicycle's potential in improving the climate performance of the transport sector - A study of passenger transportation modes.

Abstract

This master thesis addresses the electrically powered assisted bicycle (EPAC) as a future low-carbon commuting option and its market. The purpose of the report is to evaluate whether the EPAC can be used to improve the climate performance of the transport sector and to assess the outlook for the Swedish EPAC market. The EPAC is compared to the bicycle, car, bus and train and assessed thereafter.

The result of the climate performance study shows that the EPAC performs among the best. The train along with buses powered by renewable fuel perform in the same order of magnitude in terms of emissions and should be considered a good alternative. These are the best options when it comes to motorized commuting alternatives. The EPAC together with the public transportation system offers highly efficient transportation chains, in terms of GHG emissions. As seen from international experience (Copenhagen, DK, and Houten, NL) the work to increase the bicycle and EPAC modal share has to be long-term and strategic. The reward of increasing the cycle modal share has proven to be significant with benefits far beyond reduced GHG emissions.

The Swedish EPAC market faces a bright future. The Dutch market has an EPAC market share of sold cycles of 19 % and the Swedish market is seeing rapid development. The manufacturers are exploring new customer segments with main focus on commuters. The potential for reducing the GHG emissions in Sweden is enormous and replacing 10 % of car commuting would decrease the total Swedish GHG emissions by more than 1 %. The means for wide market adaptation exists, i.e. products at affordable prices, but the one thing missing in Sweden is bicycle prioritization during infrastructure planning which at the moment is focused on car traffic. More focus on bicycle infrastructure is needed to improve the situation for bicycle and EPAC cyclists.

Keywords

E-bike, EPAC, pedelecs, climate performance, GHG emissions, transport sector, passenger transportation

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Preface

This is the concluding project within the Environmental Engineering-program at the Faculty of Engineering at Lund University. The project has been executed at the Division for Environment and Energy Systems Studies. I would like to greatly thank my supervisor, Max Åhman, for all his input and support throughout this project. Without his guidance the result would have been different.

I would also like to thank Klas Elm at Swedish Cycling, Berit Gibbs at CMS and everybody else for their help and participation during this project.

EPACs, or bicycles with electric assistance, are fairly new in the Swedish market. Even so, the market is growing and there is a general optimism regarding the continued growth. I myself never thought of the EPAC as an actual commuting option prior to this project but all the benefits I have found has convinced me that the EPAC is a truly great alternative.

Anders Arwefeldt

Stockholm, November 2014

Executive summary

This master thesis addresses the electrically powered assisted bicycle (EPAC) as a future low-carbon commuting option and its market. The purpose of the report is to evaluate whether the EPAC can be used to improve the climate performance of the transport sector and to assess the outlook for the Swedish EPAC market. The EPAC is compared to the bicycle, car, bus and train and assessed thereafter.

The human induced climate effect is a highly discussed topic in developed countries and much is being done to decrease the greenhouse gas (GHG) emissions where the transport sector globally accounts for approximately 27 % of all GHG emissions. To determine whether the EPAC can be part of the solution, this project has been done as a two part study;

1. Climate performance evaluation of the commuting options and
2. A market analysis of the emerging EPAC market.

The result of the climate performance study shows that the EPAC performs among the best. The train along with buses powered by renewable fuel perform in the same order of magnitude in terms of emissions and should be considered a good alternative. These are the best options when it comes to motorized commuting alternatives. The EPAC together with the public transportation system offers highly efficient transportation chains, in terms of GHG emissions. As seen from international experience (Copenhagen, DK, and Houten, NL) the work to increase the bicycle and EPAC modal share has to be long-term and strategic. The reward of increasing the cycle modal share has proven to be significant with benefits far beyond reduced GHG emissions.

The Swedish EPAC market faces a bright future. The Dutch market has an EPAC market share of sold cycles of 19 % and the Swedish market is seeing rapid development. The manufacturers are exploring new customer segments with main focus on commuters. The potential for reducing the GHG emissions in Sweden is enormous and replacing 10 % of car commuting would decrease the total Swedish GHG emissions by more than 1 %. The means for wide market adaptation exists, i.e. products at affordable prices, but the one thing missing in Sweden is bicycle prioritization during infrastructure planning which at the moment is focused on car traffic. More focus on bicycle infrastructure is needed to improve the situation for bicycle and EPAC cyclists.

Sammanfattning

Den här master-uppsatsen studerar elcykeln (EPAC) som ett framtida icke-kolintensivt pendlingsalternativ och dess framtida marknad. Syftet med rapporten är att utvärdera huruvida elcykeln kan användas för att minska utsläppen från transportsektorn och ge en utblick för hur marknaden kan komma att utvecklas. Elcykeln jämförs med vanlig cykeln, bil, buss och tåg och bedöms mot dessa.

Den mänskliga klimatpåverkan är ett hett debatterat ämne idag i de utvecklade länderna och mycket görs för att minska utsläppen av växthusgaser (GHG). Av världens alla utsläpp står transportsektorn globalt för 27 %. För att bedöma om elcykeln möjlighet att bidra till lösningen är rapporten uppdelad i två huvuddelar,

1. Utvärdering av klimatprestandan hos olika pendlingsalternativ och
2. En marknadsanalys av elcykelmarknaden.

Resultaten i den här rapporten visar att elcykeln är ett av de trafikslagsom släpper ut minst växthusgaser. Tåget och bussen som drivs av förnybara bränslen visar liknande utsläppsnivåer. Dessa är de främst alternativen när det gäller motordriva pendlingsalternativ. Elcykeln i kombination med kollektivtrafiken utgör ett mäktigt verktyg för att skapa högeffektiva transportkedjor, i termer av GHG-utsläpp. Internationella erfarenheter (Köpenhamn, DK, och Houten, NL) har visat att det behövs långsiktigt och strategiskt arbete för att marknadsandelen av cyklar och elcyklar ska stiga. Nyttan med dessa fordonsslag har visat sig vara betydligt fler än endast minskade GHG-utsläpp.

Den svenska elcykelmarknaden går en ljus framtid till mötes. Den nederlänska elcykelmarkaden har redan en 19 procentig andel nysålda elcyklar och den svenska marknaden följer i snabb takt. Tillverkarna siktar på nya kundsegment där man främst fokuserar på pendlarna. GHG-minskningspotentialen för Sverige är över 1 % om 10 % av bilpendlingstrafiken ersätts med EPAC-trafik. Ökat elcyklande leder troligen till ökad cykling överlag vilket ökar fördelarna ännu mer. Produkterna finns på marknaden för ett brett mottagande medan den svenska cykelinfrastrukturplaneringen halkar efter och prioriterar bilen som det främsta fordonet. Ökat fokus på cykeln och elcykeln behövs för att på bred front få folk att byta transportmedel.

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1 Introduction

This chapter gives a short introduction to the subject, i.e. transportation, and presents an overview of the project with its goal and boundaries.

1.1 Background

The transport sector is accountable for approximately a third of all greenhouse gas (GHG) emissions in Sweden (Energimyndigheten, 2012). Globally the corresponding number is approximately 27 % (International Energy Agency, 2012). Since the GHG emissions, as a result of human activity, causes climate change this poses a threat to the current human way of life. Governments in developed countries are trying to reduce the emissions and the current ambition is to phase out the fossil fuels after 2050. The Swedish governmental investigation regarding a fossil fuel independent vehicle fleet (in Sweden known as the FFF-investigation) had the goal of finding measures that will reduce the need for fossil fuels in the transport sector, making it fossil fuel independent by 2030 (Ministry of Industry, Employment and Communications, 2012). In December 2013 the investigators presented their final report on the matter. The report outlines several strategies including biofuels, electrification, public transportation etc. that combined can achieve the ambitions set for the transport sector. However, a search for the terms *elcykel*, *e-bike*, *pedelec* and *EPAC* does not return any hit(s) in the report which can only be described as the EPAC not being considered important enough to make a noticeable difference for the emissions of the transport sector. Of the total trips in Sweden, irrespective of purpose, just under 40 % is commuting, i.e. business, work and study-related trips, but only around 2.4 % of all commuting trips are currently done by foot or bicycle (Trafikanalys, 2013). The average traveled distance per person and day in Sweden is 10 km for commuting, i.e. 5 km one way, which would seem like a suitable distance for the EPAC. With this in mind, bicycle and EPAC commuting has large potential to grow giving a positive effect on the GHG emissions.

Bicycles with auxiliary electric engine, often called e-bikes, EPACs or pedelecs, have recently emerged in the market and are rapidly growing in a number of countries. Bicycles, and EPACs, can assist in solving many urban related issues such as congestion, traffic barriers, public health, noise, air pollution and the sense of safety. It is important not to forget these parameters when looking at the full effects of a wider spread of EPACs and bicycles.

1.2 Goal and purpose

This report fills the apparent knowledge gap regarding the relatively new vehicle EPAC and its emerging market. The aim of the report is to assess the EPAC as future low-carbon commuting alternative to cars, buses and trains. This is done through analyzing the climate performance of different commuting options and by describing the current situation of the EPAC market. The material presented gives the reader a better understanding of the EPAC market and the effect on the climate if the EPAC market share changes. This report can thus be used as support in strategic decision-making related to the transport sector. Ultimately this report will state if and how EPACs can be used to improve the climate performance of the transport sector.

The goal and purpose will be achieved through a two part study including:

- Comparison of the climate performance of on-road vehicles and trains used for passenger transport and a
- Market analysis of the EPAC market.

1.3 Method

The climate performance comparison is done through an energy systems analysis including the emissions levels for each energy carrier based upon available literature, databases and primary data. A *life cycle perspective* is used in order to get full understanding for the GHG emitted that is produced to sustain a certain commuting option. The functional unit for the comparison is chosen to be *carbon dioxide-equivalents (CO_2-eq) per passenger kilometer*.

The market analysis consists of a quantitative part and a qualitative part. The dataset used for the quantitative part was gathered through an online survey where the respondents were all commercially involved with EPACs and secondary sources. The dataset used for the qualitative study was gathered through interviews with EPAC manufacturers, wholesalers and retailers. The technical information gathered about the products in the market is collected though secondary sources, i.e. the internet and retailers'/manufacturers' webpages.

1.4 Scope

The EPACs discussed meet the requirements of type approval found in EU Directive 2002/24/EC, see definition in chapter 3.1. The commuting distance discussed here is shorter than the typical medium range of an EPAC, i.e. <50 km.

The comparison focuses on the life cycle GHG emissions of the different commuting options. The life cycle is mainly divided into three stages in this report; (1) manufacturing of vehicles and fuels, (2) the usage of vehicles and finally (3) disposal of vehicles. These three phases are all considered but with focus on the manufacturing phase and the usage phase based on reasonable assumptions to simplify the work (specified in Chapter 4). The vehicles discussed are the ones used for passenger transportation, namely cars, busses, trains and EPACs. Conventional bicycles are used as reference. The fuels discussed are gasoline, diesel, natural gas, biogas, ethanol, biodiesel (FAME) and electricity. Of course, vehicles have engines designed for different fuels and this thesis includes the most common in the Swedish market, i.e.

- Cars with internal combustion engines (ICE) designed for gasoline, diesel, ethanol, biodiesel, natural gas, hybrid vehicles (vehicles with more than one power source) and cars powered by electricity,
- Busses with ICE designed for diesel, ethanol, natural gas and biogas,
- Trains, all electric. The energy consumption used, also considered the market average, is the average energy consumption for “Öresundståg” (trains trafficking Scania and the west coast), “Pågatåg” (trains in the service of the Scanian public transportation system) and the Stockholm metro trains.

2 Climate, transport and bicycles

2.1 The climate issue

The earth is kept at a livable temperature (for humans) because different gaseous chemical compounds are able to absorb the energy from solar radiation. The amount of energy stored in the earth's atmosphere is dependent on the concentration of these compounds in the atmosphere. From burning fossil fuels, humans increases the concentration of these compounds and as a result the average temperature on the planet is rising. The Intergovernmental Panel on Climate Change (IPCC) states in its latest report that the increase is with 95 % probability caused by humans (IPCC, 2013). The United Nations Framework Convention on Climate Change (UNFCCC) decided in 1992 to avoid the dangerous greenhouse gases which lead to the signing of the Kyoto Protocol in 1997 (UNFCCC, 2014). The Kyoto protocol states binding GHG reduction targets for the period 2008 to 2012 and was recently prolonged to 2020 for a limited number of countries. The parties are currently discussing what kind of targets, binding or non-binding, that should apply after 2020 (UNFCCC, 2014). The EU implemented part of its commitment through the EU Emissions Trading Scheme (EU ETS). EU also has the 20/20/20-targets with the amendment of 10 % biofuels in the transportation sector by 2020. The EU 2050 roadmap, regarding the path towards a low carbon economy, indicates that the transport sector has to decrease its emissions by around 60 % (European Commission, 2014). Another global initiative, especially relevant to non-motorized transport, is the *Share the Road* initiative by the UN Environment Programme (UNEP) which addresses environment and safety agendas in urban transportation in developing countries where the majority of all people moving on the road are pedestrians or cyclists under the parole *"Invest in walking and cycling"* (UNEP, 2013).

2.2 The Swedish situation

The Swedish Environmental Protection Agency (SEPA) was commissioned by the Swedish government to draft a proposal for a roadmap for a GHG emissions neutral society in 2050. In the report, *Underlag till en färdplan för ett Sverige utan klimatutsläpp 2050 (2012)* (translation: *"Basis for a roadmap for a Sweden without greenhouse gas emissions in 2050"),* SEPA points out the industrial sector and transport sector as the two most urgent sectors to address. The transport sector alone accounts for almost 30 % of the energy use in Sweden which equals approximately 35 % of the total GHG emissions (The Swedish Environmental Protection Agency, 2012). The non-binding goal of 10 % renewable energy within the transport sector by 2020 was set by the EU and was in 2012 achieved in Sweden (The Swedish Energy Agency, 2013). The Swedish Parliament has approved a bill stating that the Swedish vehicle fleet should be fossil fuel independent by 2030 giving Sweden a broad range of political drivers for decreasing the emissions in the transport sector. The investigation suggested a target for reducing GHG emissions from the Swedish transport sector with 80 % by 2030 (Ministry of Industry, Employment and Communications, 2013).

In addition to this Sweden has a national transport policy objective;

> “
>
> *Ensure an economically efficient, and sustainable transportation supply for the citizens and businesses throughout the entire nation.*

(The Swedish Ministry of Industry, Employment and Communications, 2009)

The target has two equally important sub targets

- A functionality goal regarding accessibility and
- A consideration goal regarding health, safety and environment.

The goal related to the environment is primarily coupled to three of the sixteen Swedish national environmental objectives, i.e.:

- Reduced climate impact,
- Clean air and
- A good built environment.

(The Swedish Transport Administration, 2007)

At the moment 94 % of the energy use in the transport sector stems from on-road traffic and because of this a majority of the emissions from the transport sector originates from cars and trucks (The Swedish Energy Agency, 2013).

There are indications that the usage of cars around the world is decreasing, a phenomenon called peak-car. The concept describes a situation where the point of maximum car usage have been reached and people to a larger extent refrain from using the car. The ownership and usage of the car is decreasing due to a number of reasons. Newman and Kenworthy argues six possible causes for the reaching of peak car use in their report *Peak car: Understanding the demise of automobile dependence*;

- Reaching of the maximum acceptable commuting time,
- The growth of public transportation,
- The reversal of urban sprawl,
- The aging of the citizens in cities,
- The growth of a culture of urbanism and
- The rise of fuel prices.

(Newman & Kenworthy, 2011)

The change in attitude from older generations to the younger ones are resulting in peak-car and the result of less car usage leads to decreased GHG emissions. The benefits of decreased car usage have been observed by several public authorities and in 2002 the Swedish National Board of Housing, Building and Planning released a guide, *Town planning – instead of traffic planning and city planning*, with the core message that urban planning should simultaneously include both traffic planning and building planning in order to create more livable and attractive cities (The Swedish National Board of Housing, Building and Planning, 2002). In planning documents directed towards traffic planners, a similar development occurred during the first decennium of the 21st century. *Trafik för en attraktiv stad (TRAST)* (translation *Traffic for an attractive city*), one of the largest Swedish conceptual planning guides discusses how the different modes of transportation can coexist and together create an attractive transportation system in cities. It stresses the importance of walking, cycling and public transportation as a tool in achieving an attractive city (The Swedish Transport Administration, 2007). The same guide also points out other problems with the large amount of car traffic in today's cities.

Cycling has become increasingly popular, and as Newman and Kenworthy points out, urbanism rhymes well with the work for more attractive and livable cities. The last national plan for the transport sector (concerning the period 2014 – 2025) puts emphasis on cycling, walking and public transportations (The Swedish Transport Administration, 2013) and in October 2012 a major governmental investigation called *"Ökad och säker cykling – en översyn av regler ur ett cyklingsperspektiv"* (translation: *Increased and safe cycling – a review of rules and regulations from a cycling perspective)* was completed. It states that the potential of cycling is big since most cycling trips are as short as three kilometer and only one out of ten trips is done by bicycle (Ministry of Industry, Employment and Communications, 2012). The same investigation states that the average distance of cycling trips increases in larger cities where the same figure is eight to nine kilometers.

There are examples around Sweden where much is being done to heighten the awareness concerning the advantages of cycling and the EPAC is being brought into the spotlight more and more. The municipality of Halmstad has a project called *Elcyklist* (translation app. EPAC cyclist) where 100 car commuters are being offered to try an EPAC during six months and their progress can be followed on the internet[1].

2.3 International cases

There are many cities around the world where cycling has been given a more central role compared to Sweden. Houten and Copenhagen are two examples where the work to improve cycling conditions has come further relative Sweden.

2.3.1 Copenhagen

The city of Copenhagen has a population of approximately 550 000 people and the capital area as much as 2.1 million people (National Encyklopedin, 2014). The city has systematically worked to improve and promote cycling since the 1960's and is a great example of a cycling friendly city. In 2013 the city was awarded the world's most livable city (Copenhagen Capacity, 2013). 36 percent of all commuting to work and educational institutions is made with bicycles, conventional or electric in the capital region, showing that the bicycle is an important vehicle in the city (City of Copenhagen, 2013). Even though Denmark is a small county, it had the sixth highest sales of EPAC in Europe in 2011 and an EPAC market share (in sales) of four percent (COLIBI, 2012).

The bicycle strategy of Copenhagen; *Good, Better, Best*, sets ambitious goals for the future of cycling in Copenhagen but cycling in itself is not the primary focal point, but the effects such as less congestion, improved public health and less urban air pollution (The City of Copenhagen Traffic Department, 2011). EPACs, with their superior range and travel time (compared with conventional bicycles) are specifically mentioned in the strategy regarding longer commuting distances and decreased travel time as a tool to increase the number of commuters.

The recipe for success in Copenhagen has been to focus on five areas; *Travel Time*, *Sense of Security*, *Comfort*, *Lifestyle and Image* and finally *Experiences*. One of the key principles in the bicycle strategy is *Prioritizing*, meaning that the bicycle is the prioritized vehicle in infrastructure planning. Not only is Copenhagen focusing on tangible aspects but intangible ones such as affecting the lifestyle view of using the cycle as the primary mode of transportation. Copenhagen is a good example of holistic cycle planning where long term commitment, infrastructure planning and marketing is needed to create a high modal share for the cycle.

[1] http://www.halmstad.se/resortrafik/hallbartresande/elcyklist/elcyklist2014.11062.html

2.3.2 Houten

The Netherlands, with a very strong tradition of cycling, is the only country in Europe with more bicycles than people (Netherland Ministry of Transport, Public Works and Water Management, 2009). Houten, the 2008 Cyling City in the Netherlands, is a great example of a city where urban planning has benefited both cycling and walking. Houten have been planned according to an urban design concept known as *Filtered Permeability*, a concept meaning that walking and cycling is given priority over motorized transportation modes through an area. In the mid 60's Houten was identified as a high growth area by the Dutch government and Houten, at the time with a population of 3 000, was asked to prepare for a situation where the city could have 100 000 inhabitants. In the late 60's the city council approved the plan which focused on cyclists and pedestrians. The permeability is the heart of Houten's urban design, with the thoroughfare which takes cyclists and pedestrians through the city center. The bicycle network is 129 km (approximately 3 meter per person compared to Malmö with a corresponding figure of 1.5 meters) and while motorists have to use the ring road to gain access to the different parts of the city, cyclists can use the more direct bicycle network (see Figure 1 for street layout). The modal share of bicycles in Houten is 28 percent of all trips and because the city was planned for both cyclists and pedestrians the modal split of walking is as high as 27 percent for all trips. (Foletta & Field, 2011)

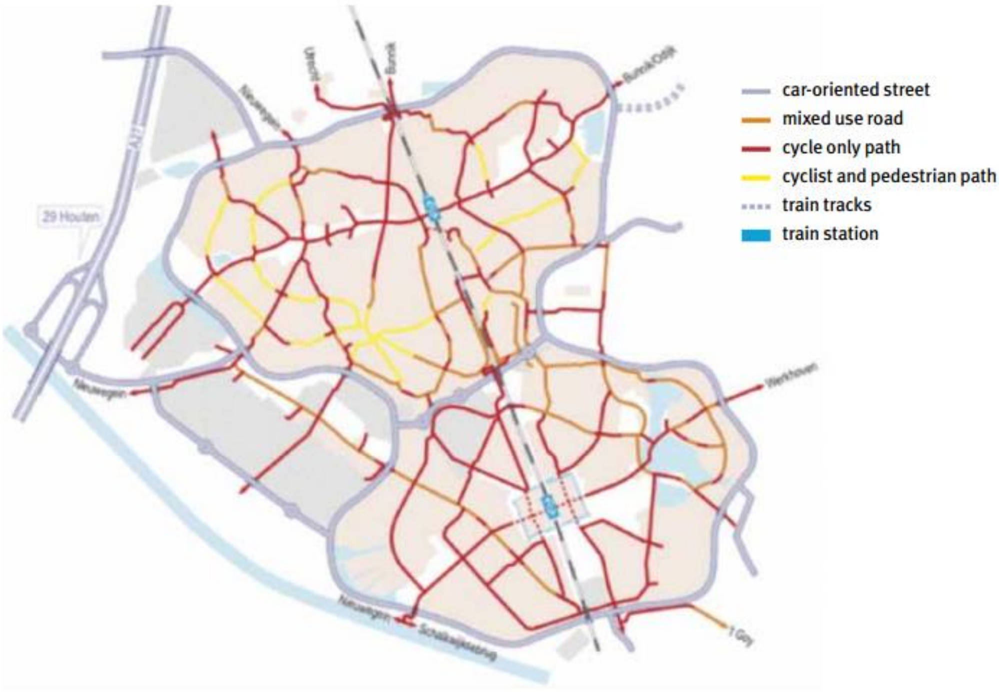

Figure 1. The road network layout of Houten. (Netherland Ministry of Transport, Public Works and Water Management, 2009)

2.3.3 Lessons learned

Copenhagen and Houten are only two of several examples where bicycle planning has been successful with a high modal split as the result. Another important effect from increased cycling, and in the case of Copenhagen, the ultimate goal, is the increased attractiveness and livability of cities. As Copenhagen, Houten has had a long term commitment to bicycle planning and prioritized the bicycle equally or higher compared to motorized alternatives.

The two examples show us that turning a city into a cycle friendly and highly livable city isn't something that is done over night. It takes long term commitment and planning, prioritizing along with a broad range of measures to make the cyclists situation as convenient as possible.

3 What is an EPAC?

This chapter introduces the concept of electrically power assisted bicycle (EPAC). It begins with a definition of the EPAC, according to EU directive and continues with the technical specifications, systems of the bicycle and finishes with a comparison between the EPAC and the conventional bicycle.

3.1 Definition

There are several documents governing the many aspects of an EPAC. In 2002 the EU Commission approved Directive 2002/24/EC regulating which two and three wheel vehicles that require type approval. The directive states by the first article in the first chapter that EPACs are

> *Cycles with pedal assistance which are equipped with an auxiliary electric motor having a maximum continuous rated power of 0.25 kW, of which the output is progressively reduced and finally cut off as the vehicle reaches a speed of 25 km/h, or sooner, if the cyclist stops pedaling.*

By declaring that the EPAC does not need type approval, the vehicle can in legal terms be classified as a conventional bicycle if the member state (of the European Union) wishes so. In Sweden, the same laws and regulations apply to both the bicycle and the EPAC (SFS 2001:559). Today's regulations state that an EPAC does not need traffic insurance, the rider is not required to wear a helmet and special traffic regulations apply, compared to other motorized vehicles (The Swedish Transport Agency, 2012).

Table 1. The different requirements for two-wheel vehicles (excluding motor cycle).). (The Swedish Transport Agency, 2013)

Vehicle	Requirement(s)
Bicycle	None
EPAC	EU standard EN 15194
Moped class II	Driver's license (moped class II) Traffic insurance Top speed: 25 k/h Helmet (unless the vehicle has a vehicle body) Passenger allowed if seat(s) exist
Moped class I	Driver's license (moped class I) License plate Traffic insurance Top speed: 45 k/h Helmet One passenger max Unregistered vehicles can only be driven in an enclosed area.

The different components of the EPAC, such as the battery, controller and wiring, are regulated in the EU standard EN 15194. This standard primarily regulates safety aspect of these components such as radiation and possible cause of fire.

The EPAC goes under several different names. The most common ones are (apart from EPAC) pedelec and e-bike. E-bike is also used as family name for all electric cycles hence used to denominate electric bicycles with other specifications than the EPAC but since most e-bikes today are EPACs it is common to refer to EPACs as e-bikes (this applies to the European market). Pedelec normally refers to the same technical solution as the EPAC. Apart from the name e-bike, electric bicycles with motors stronger than 250 W can be referred to speed-pedelecs, and as the market for these types of vehicles increases it can be expected that new names arise.

3.2 Technical specifications

Due to the restrictions in the EU definition, in practice only smaller technical variations occur between EPACs from different manufacturers. The motor power is almost always 250 W and the battery, normally a lithium ion battery, has a capacity of around 10 Ah. The one thing that differ the most between manufacturers is the system design. As described later, there are different ways of arranging the components in the electrical drivetrain and manufacturers do not offer a complete range of solutions in their assortment.

3.2.1 Battery

For practical reasons, all EPACs today use lithium ion battery because of its superior capacity and weight characteristics compared to the previously used lead batteries. The capacity varies between models and rarely exceeds 15 Ah with most models in the range 7 – 11 Ah. The systems are exclusively 36 volt systems which is sufficient for the motor power and this gives a capacity just over 300 Wh.

Figure 2. EPAC with motor in back hub and battery under carrier. Copyright Merida Sweden AB.

The battery is charged by connecting it to a converter and then to a power socket. For practical reasons, the battery is normally removable in order for the user to bring the battery to his or her home. There are EPAC models where the battery is integrated in the frame, meaning that the EPAC itself must be close to the power socket (depending on the length of the cord) in order to charge the battery.

The range of EPAC stands in direct relation to how much the motor is used and this in turn depends on the rider and how much she chooses to use it. Because of this there is no absolute distance the electric engine is operational. The range is normally between 35 and 70 km.

3.2.2 Motor

The motor output power of different EPACs differs very little. The market almost exclusively offers EPACs with the maximum power output, i.e. 250 W. The engines are brushless resulting in minimum maintenance. A popular manufacturer of EPAC drivetrains is Bosch.

Figure 3. EPAC with engine in front wheel hub and battery under carrier. Copyright Merida Sweden AB.

Box 1: How long does the battery last?

Let's assume an EPAC system where the engine is 250 W of power output, the battery 10 Ah and the voltage 36. How long does the battery last then?

The battery capacity is 360 Wh, and by simply dividing the battery capacity with the motor power the maximum operating time is given, in this case 1.44 hours or 1 hours 26 minutes. It has to be remembered that this is continuous maximum power which is rarely how an EPAC cyclist uses her EPAC.

If using the EPAC under these conditions, how long is the range? Simply multiply 25 km/h with the time and the range equals 36 km. This ranges is the minimum range of the EPAC and as the cyclist uses his or hers own power, the range in which the electric engine can operate increases.

As can be seen in the pictures in this chapter, there are different ways of arranging the system components. In practice, there are three places to put the motor; the front wheel hub, back wheel hub and close to the crankset. The engine placement affects other parts of the bicycle such as brakes, gears and the frame. If the motor is found in the back hub then either brakes or gears cannot house in that hub. A front hub engine does not intervene with brakes or gears but since not as much weight is put on the front wheel, this setup results in less traction. A crankset motor on the other hand requires an enforced frame but it does not intervene with any of the other components.

3.2.3 Different technical designs of the EPAC

The electrical system of the EPAC mainly consists of three parts; the engine, the battery and the controller. Wiring is used to connect these parts and there is normally a regulator and display on the steering wheel for the cyclist to set the speed she wishes to travel by. This chapter will however only discuss the three main parts since it is these that are interesting in terms of design.

The battery is normally mounted in either of three different locations; under the carrier as seen in Figure 3, on the diagonal frame as in Figure 4, or vertically along the frame leading to the saddle (not in any picture). In the latter case, the battery is mounted towards the back wheel. There are technical differences with the different placements. The lower the battery is placed, the lower the center of gravity. This affect the EPAC as a bicycle with higher center of gravity can feel wobblier compared to a bicycle where the battery is

Figure 4. EPAC with engine in crankset and battery on frame. Copyright Merida Sweden AB.

placed lower. The battery itself adds around 15 percent of the weight of a conventional bicycle meaning the placement of this could make noticeable difference, depending on the weight of the cyclist.

The motor can, as mentioned earlier, be put in three different places; either in one of the wheel hubs or in the crankset. The placement of the motor has impact on the performance, maybe not on speed, but several interviewees from the market analysis state that when the motor is placed in the front wheel it feels like the bicycle is being pulled forward. A similar feeling arises with a back wheel hub motor, it then feels like the bicycle is being pushed. From the interviews held with manufacturers and wholesalers (fully examined in Chapter 5), the interviewees claim that when the motor is placed in the crankset, it feels like being stronger since the motor in that case assists in the actual pedaling of the bicycle. The motor placement also affects the handling of the EPAC in tougher conditions. At slippery conditions, a front motor can cause the bicycle to understeer whereas the rear engine can cause the back part of the EPAC to drift, i.e. oversteer. As more weight is placed in the back of a bicycle, a front wheel hub motor should be avoided because of superior traction in the other two configurations.

The superior technical design of an EPAC is therefore shown in Figure 4, with crankset engine and a low placement of the battery. As the market grows, evolves and new technologies arise we can expect new designs of the systems. The bicycle has looked virtually the same for many decades and a revolutionizing frame design might seem unlikely.

3.3 A comparison between bicycle and EPAC

The EPAC is by definition a bicycle with an auxiliary motor. This subchapter maps the major implications the motor adds to the EPAC, compared with the conventional bicycle. Koucky and Ljungblad (2012) speak of four major differences;

- power addition,
- weight,
- the need of charging and
- price.

The additional power of the EPAC is maximum 250 W which is approximately a 100 percent addition (Koucky & Ljungblad, 2012) relative the power a normal trained person generates cycling. Since the engine cuts off at 25 km/h it does not add to the top speed, but merely makes it easier for the cyclist when she desires.

The electrical equipment needed to make a bicycle into an EPAC adds some weight. As seen in Table 2, the entire system builds another five to six kg. As a conventional bicycle weighs around 17 kg (Del duce, 2011) the addition of six kg corresponds to 35 percent of the total weight.

Table 2. Added weight from the different parts needed to have a functional electric motor on a bicycle. (Del duce, 2011)

System component	Added weight [kg]
Engine	2.7
Battery	2.6
Controller	0.4

The EPAC has two power sources, human muscle force and the electric motor. The motor runs on electricity supplied from the battery and it needs charging. Because of this, the battery needs to be plugged into a power socket, an effort not required for a conventional bicycle. In practice this means that the owner, or user, has to bring the battery with him or her every time it needs charging because of the few battery integrated models.

It is difficult to give an exact estimation of how much the electric engine system adds to the price of a bicycle. At the moment, it is hard to find an EPAC under 8 000 SEK in the Swedish market and most models cost around 10 000 – 13 000 SEK. The most expensive models costs around 30 000 – 40 000 SEK and are to be regarded as the high-end segment. There are high quality products that cost around 25 000 SEK, such as the model in Figure 4, but since the great price differences of conventional bicycles the EPACs can also be found in extra premium models. As an example, a 5 000 SEK conventional bicycle corresponds to a 13 000 SEK EPAC (rough estimate).There are three rather clear price segments in the Swedish market, presented in the table below. The segments do not apply to cargo or family EPACs and these are more expensive.

Table 3. Price segments of different EPAC qualities.

Build quality	Price range (approximately) [SEK]
Entry-level models	8 000 – 14 000
Mid-end models	15 000 – 29 000
High-end models	30 000 – 40 000

4 EPAC climate performance

This chapter presents the approach used for evaluating and comparing the climate performance of the different vehicles and fuels benchmarked in this thesis. Chapter 4.3 presents the GHG emissions related to manufacturing and usage while the total, life cycle climate performance can be found in chapter 4.4. Appendix 9.1 complements the chapter with detailed methodology, data and calculations.

4.1 The product life cycle

In order to present the best decisional material, a *life cycle perspective* is used throughout this report. This includes all emissions connected to a certain product during its entire lifetime. However, individual products are not investigated here but rather the market average. This means that the numbers in the report are not applicable on specific and individual vehicle models but on the larger system and should be considered an average of the current situation.

A product's life cycle can be divided into many different phases or stages and this comparison uses three phases in order to categorize the different processes during the life cycle, namely *Manufacturing*, *Usage* and *Disposal*. In Box 2, the car is used to describe what different processes and activities might occur in each phase.

The product's life cycle is also visually described in Figure 5 where the two additional arrows, in and out of the cycle, describes where material is either being added or retracted. The figure is a principal description of the life cycle and more accurate for the vehicle life cycle since there is no reuse or recycling in the life cycle of fuels. All the labels in the figure describe a group of processes that emits GHG and adds to the total GHG emissions of the system described. All emissions are allocated into one of these three phases.

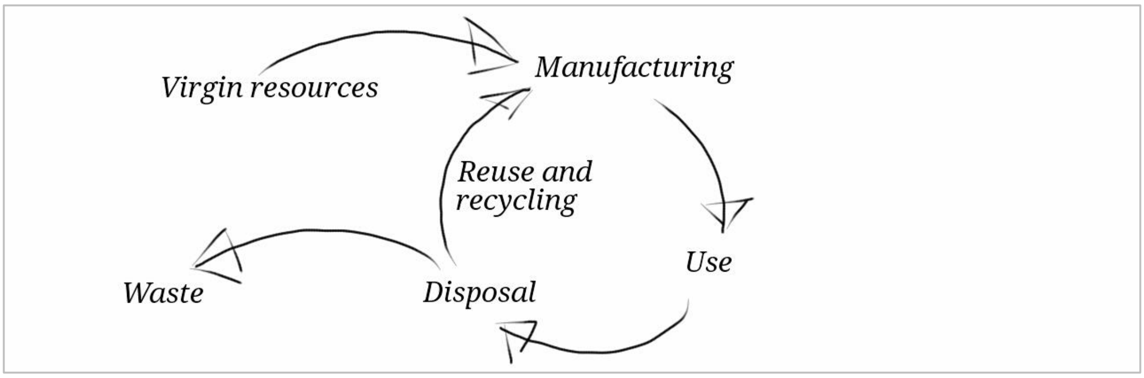

Figure 5. The product life cycle. A simplified picture of the product life cycle. The three major phases in the product life cycle is the production, use and disposal.

The entire life cycle is commonly known as Cradle-to-Grave and this report used the term Cradle-to-Showroom for the manufacturing of the vehicles while the usage phase is called Tank-to-wheel. The fuel life cycle is commonly known, in its entirety, as Well-to-Wheel, and can be divided into two sub-phases; Well-to-Tank representing the production of the fuel and Tank-to-Wheel representing the phase when the fuel is being combusted in the vehicle.

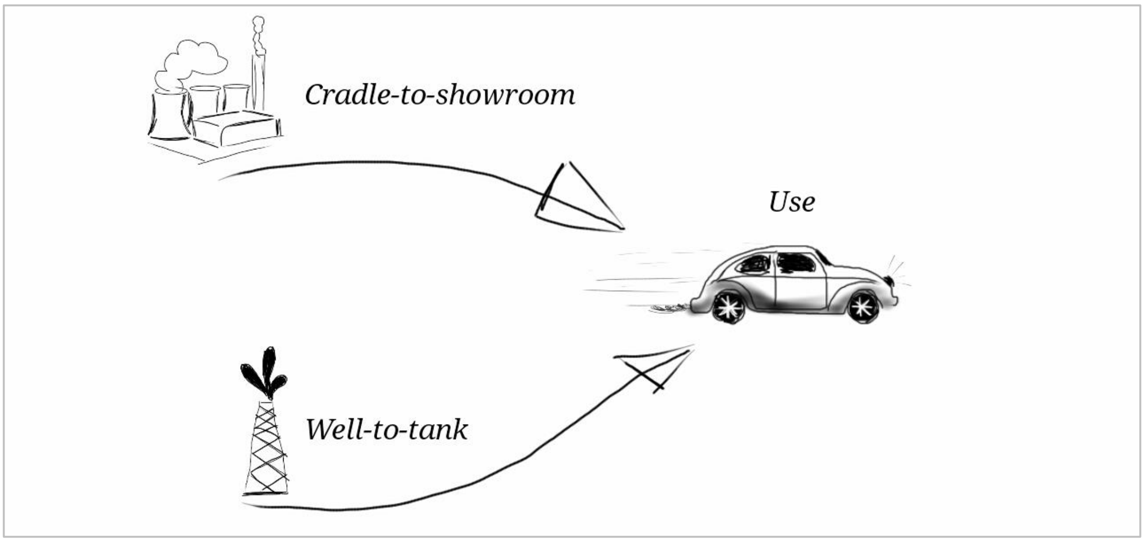

Figure 6. The three phases where the investigated emissions occur. The emissions investigated in this report originates from three phases of the fuel and vehicle life cycle; Well-to-tank for the fuels, Cradle-to-showroom for the vehicles and the Use phase where the two products (fuel and vehicle) interact and causes the emissions from driving a specific vehicle.

Box 2: Example of activities from the life cycle of the car

The *Manufacturing* phase refers to all the processes and activities happening before the car is sold to the end-consumer. This could for instance be the extraction of natural resources, refinery, production of components, assembly and transports between these activities. Once the car is sold to the customer, the *Use* phase commences which includes the driving of the car and maintenance. When the car leaves the open market it heads for the last phase, *Disposal*, where the remainder is either reused or recycled.

The total emissions include emissions originating from manufacturing of the vehicle, the production of fuel used for respective vehicle and the emissions when operating the vehicle, i.e. driving the vehicle. As explained later, the *Disposal* phase is not included in the calculations. The total emissions are calculated through the principle of adding the emissions from each phase to the total. In order to make the emissions comparable between each vehicle, the respective engine efficiency and number of riders are also considered. Equation 1 presented below describes the mathematically approach.

$$\sum Emissions\ [gCO_2eq/p\ km] = \frac{(gCO_2eq/vkm_{CtS} + gCO_2eq/kWh_{WtT} \cdot kWh/vkm + gCO_2/vkm_{TtW})}{\alpha} \qquad \text{Eq 1}$$

Equation 1 can also be described in words:

Total emissions = Well-to-tank emissions + Cradle-to-showroom emissions + Tank-to-wheel emissions

The first part in Equation 1, gCO_2eq/vkm_{CtS}, is a measurement of the emissions for each vehicle kilometer. *CtS* refer to the phase *Cradle-to-Showroom.*

The second part of the equation, $gCO_2eq/kWh_{WtT} \cdot kWh/vkm$, consists of two factors; gCO_2eq/kWh_{WtT} which is a measurement of how much GHG emissions originating from the manufacturing of fuels and kWh/vkm which is the energy efficiency of respective engine. *WtT* refers to the phase *Well-to-Tank.*

The third and last part of the equation, gCO_2/vkm_{TtW}, simply denominates the tailpipe emissions of the vehicles, or put in other words; the emissions from driving respective vehicle. As later explained this factor is zero for electric vehicles. *TtW* abbreviates *Tank-to-Wheel.*

α, alpha, denominates how many passenger kilometers being travelled for each vehicle kilometer. This ratio is also called *load factor* For example, if there are two persons travelling in a car, the ratio (p km/v km) is 2/1 for each kilometer travelled. In practice this means that the total emissions are divided by the number of riders for each vehicle in order to obtain the functional unit.

The results from investigating the three phases are presented in chapter 4.3, the *Well-to-Tank* and *Cradle-to-Showroom* phase in chapter 4.3.1 and *Tank-to-Wheel* in chapter 4.3.2. The three phases corresponds to the three factors in Equation 1, in the order presented in this paragraph.

4.2 Approach

4.2.1 Data

The systems analysis is based on both primary and secondary data gathered from multiple sources. Data not found through secondary sources have been complemented with information from primary sources. The exact origin of data can be found in Appendix 9.1.

4.2.2 Functional unit

The different vehicle and fuel data is comparable due to a common comparison unit, called functional unit in this report (also used in the LCA methodology). The functional unit of this report is *g* CO_2*-equivalent emissions per passenger kilometer* and is calculated through Equation 1.

4.2.3 System boundaries

This report focuses on the emissions from manufacturing and usage since the emissions from disposal is assumed to be negligible in relation to other emissions. This limitation is based upon the emissions from the Regina Intercity X55 where the disposal phase accounts for 1.6 percent of the total emissions (Bombardier Transportation Sweden AB, 2012) and the bus VOLVO 8500 where the disposal phase has a positive environmental effect (Volvo Bus Corporation). Furthermore, the EU Directive 2000/53/EC states that 85 percent of the average weight per vehicle and year, has to be reused or recycled, a threshold which will rise to 95 percent in 2015. As the reuse and recycling ration increases it would be more appropriate to regard these resources as raw materials and allocate these emissions to the manufacturing phase.

The emissions caused by maintenance are also disregarded based on the assumption that these emissions are substantially less compared to the emissions from manufacturing and usage. This assumption is based on numbers in the LCA of the Bothnia Line (Stripple & Uppenberg, 2010) and EPD of Volvo bus 8500 where the GHG emissions from vehicle maintenance is a thousandth and hundredth respectively compared to the usage of the vehicles (see reference above).

4.3 Climate performance of vehicles and fuels

This subchapter presents the result of the climate comparison, where Chapter 4.3.1 and 4.3.2 presents the emissions from manufacturing and usage respectively and the emissions are allocated to the phase where the emissions actually happens. For instance, the emissions of the electric vehicles (EVs) are allocated to the manufacturing and not to the usage because the EVs don't have any tailpipe emissions.

4.3.1 Emissions during manufacturing of vehicles and fuels

There are several figures in this chapter and there are a few things to keep in mind; Cradle-to-showroom emissions refer to the emissions cause from manufacturing of vehicles, Well-to-tank emissions to the fuel production emissions. Note the units of the respective graphs, these vary depending on the information presented and these are later translated according to Equation 1 to obtain the functional unit, *g* CO_2*-eq / p km.*

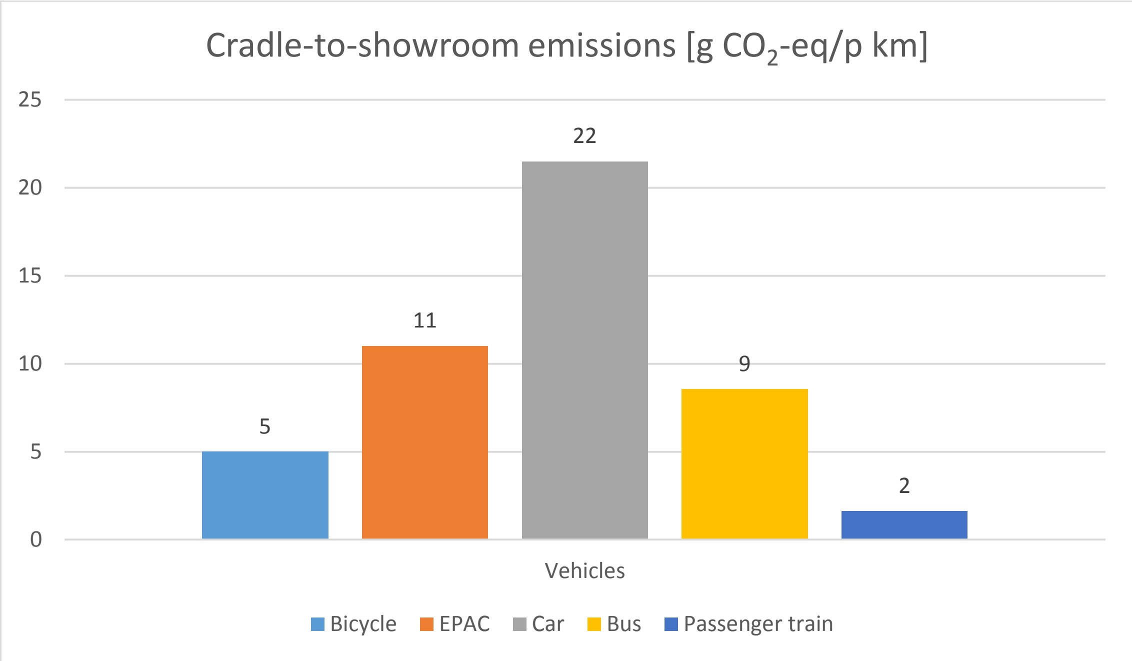

Figure 7. Emissions from vehicle manufacturing. The emissions from manufacturing is spread over the projected life time passenger kilometer of each vehicle. The emissions of the bicycle, EPAC and car are produced by Del Duce (2011). The car have a life expectancy of 150 000 km. Both the bicycle and the EPAC have a life expectancy of 150 000 km and a change of tiers every 4 000 km. The result for the bus is calculated from data found in Life Cycle Assessment of Transportation Option for Commuters (Dave, 2010). The train data is found in the EPD of the Regina Intercity X55 produced by Bombardier and commonly known in Sweden as X3000 (Bombardier Transportation Sweden AB, 2012).

Figure 7 shows the vehicle production emissions, based on respective vehicle lifetime and projected passenger kilometer. Manufacturing of trains emit the least GHG due to the many kilometers it runs during a life time. Buses, which in average run only a sixth of the vehicle kilometers compared to trains, naturally cause more emissions than the train. The bicycle and EPAC, in absolute numbers, cause little emissions from manufacturing but due to the short distance travelled over life time the emissions per passenger kilometer is relatively high. Noticeable is that the addition on the electrical drivetrain increases the GHG emissions by more than 100 percent.

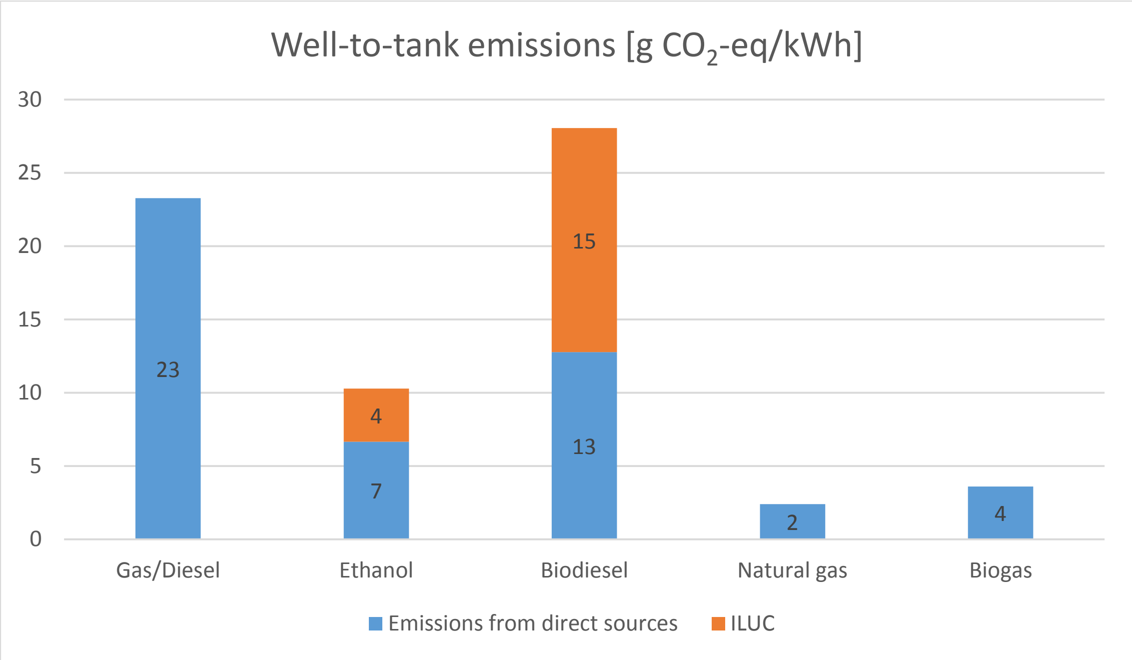

Figure 8. Well-to-tank emissions per delivered kWh of fuel for different fuels. The emissions for gasoline/diesel, ethanol, biodiesel and biogas have been found in the European Commission Directive 2009/28/EC on the promotion of the use of energy from renewable sources. The ethanol figure refers to ethanol produced from sugar cane, biodiesel is produced from rape seed and biogas from liquid manure. The natural gas figure is taken from NTM's database. The ILUC, or Indirect Land Use Change, numbers is found through the proposed amendment to EU Directive 2009/28/EC, procedure number 2012/0288.

The information collected from the EU directive 2009/28/EC are average numbers and it should be noted that there are, for instance, versions of ethanol with better climate performance compared to what is presented here (Börjesson, et al., 2008). One should also remember that the biofuels still cause tailpipe emissions but no net addition of GHG. Direct sources, as referred in Figure 8, are for instance farming of crops, processing and transportation of the fuel.

When modeling the GHG emissions of crop grown biofuels, the direct land use change is considered because introducing biofuel farming causes a change in the current land use, either from

Box 3: Indirect land use change

Potato farming is replaced by a biofuel crop, in this example rape seed. The net emissions change is referred to as *direct land use change emissions*. Let's say the rape seed is becoming increasingly popular leading to this crop claiming new agricultural land and the close by tomato farming is changed to rape seed. The tomato farming is still more profitable compared to the close by lettuce farming and as a result the lettuce crop is replaced by the tomato. The emissions caused by the switch from lettuce to tomato is known as *indirect land use change emissions*. ILUC emissions can also come from if the tomato is farmed at previously unused land.

switching from one crop to the biofuel crop or from starting farming in a previously unused location. When changing the use of a given land area, the biomass composition above and under ground changes causing either a net release or net uptake of GHGs. This is because the amount of biomass in that land binds carbon and the change in biomass either releases or absorbs carbon. The emissions caused by this are called *direct land use change* (DLUC) emissions. *Indirect land use change* (ILUC) is not as common to include in LCAs and the ILUC emissions refers to emissions caused when changes in land use occurs as a result of the farming of biofuel crops. If the introduction of a biofuel crop in one location causes a switch in crop at another location, the emissions caused by the latter switch is denominated ILUC emissions. The calculations is based on aspect that are not directly related to the production of biofuels, future food consumption, land use regulations and productivity hence leading to great uncertainties in the estimations. (Ahlgren & Börjesson, 2011) See Box 3 for further explanation.

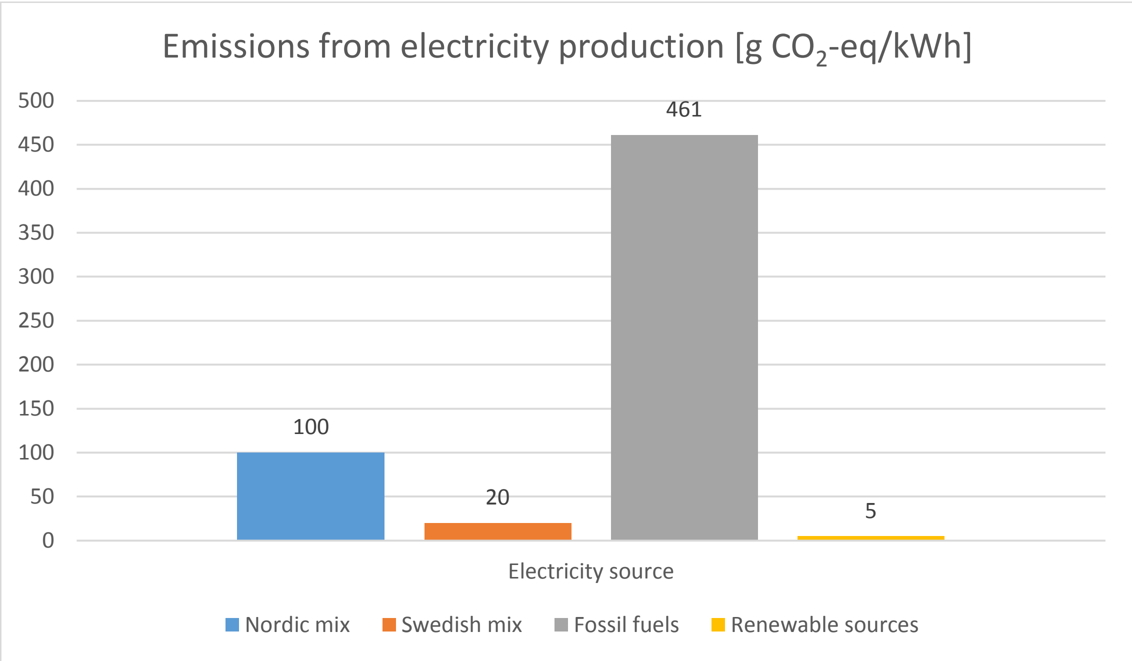

Figure 9. GHG emissions from electricity production (Svensk Energi, 2012). The emissions caused by electricity production can be viewed as Well-to-Tank emissions for the EVs.

As seen in the Figure 9, the GHG emissions caused by electricity production vary greatly depending on production facility. According to Börjesson et al. (2008) there are three different allocation methods to use when assessing which source the electricity comes from; marginal production, dynamic marginal production and the electricity mix. *Marginal production* refers to the production meant to meet passing short term increase in demand and is normally generated from the facilities with the highest variable cost. In the EU, the marginal production normally comes from coal-fired condensation power plants. *Dynamic marginal production* refers to the electricity production capacity installed to meet the long term demand which can be assumed to be generated from renewable sources and *the electricity mix* is an average of a given market. Since all the Nordic countries have a common electricity market, the electricity bought can originate from any of the facilities in the Nordic countries (including Estonia) depending on the price offered to the customer. The three concepts presented by Börjesson et. al. relates to the denominations in Figure 9 the following way:

- Fossil based electricity production is equivalent to marginal production,
- Dynamic marginal production is equivalent to electricity from renewable source and
- Electricity mix corresponds to the Nordic electricity mix.

This report discusses long term changes in the electricity demand due to an increase of EVs in the Swedish transport sector, why the emissions of short term marginal production is not the most suitable source to use as base for calculations. Figure 9 shows that the Swedish electricity mix cause less emissions as opposed to the Nordic or EU mix but since Swedes buy their electricity on the common Nordic market this is neither a suitable option to use. This report uses the Nordic mix for emission calculations because the long term perspective is more accurate for the transport sector because the EVs in the Swedish market could use electricity from either country connected to Nord Pool (the Nordic electricity trade house).

The EPAC is a hybrid vehicle, with both an auxiliary electrical motor and shear human muscle force as power input and the cyclist decides for herself when to use the auxiliary motor which means that the EPAC doesn't need to have any environmental impact at all, depending on the cyclist.

However, if we assume that the EPAC is bought with the intentions of using the engine and assume a range of 50 km (normal range of different EPACs) the energy consumption is 0.0072 kWh per passenger km (36 volt system). This results in GHG emission of 0.72 g CO_2-equivalents per passenger km if the battery is charged with the Nordic electricity mix. The GHG emissions occurring during the usage of the EPAC is allocated to the production of fuels because the emissions are caused in those processes and not when the energy later is used to power respective vehicle.

By the same reasoning as with the EPAC, the electric car has its environmental impact occurring during the manufacturing and well-to-tank phases. Since the number of different electric cars in the Swedish market are limited and the only models available are smaller models it's been chosen to let the Nissan Leaf be representative for the market. In a longer perspective it is likely that the corresponding figure for the Swedish market will rise due to the introduction of larger vehicles. The emissions of the electric car are 17 g CO_2-equivalents per passenger km with the assumptions of Nordic electricity mix and no passengers along the driver.

There are very few diesel trains in Sweden today and this report only deals with electric trains since the commuter trains are all EVs. There are quite a few train models trafficking the Swedish railway system, both regionally and locally, and to assess the average energy consumption for the commuting trains three different systems have been used:

- The energy consumption from the Öresund regional train, Bombardier X31K, trafficking the Öresund region,
- The energy consumption of the Corradia Nordic X61 used for local commuting in Scania and
- The average energy consumption of the Stockholm metro system including train models Bombardier C20, C14/15 and C6.

The emissions of the three systems and the average can be seen in the figure below at different load factors.

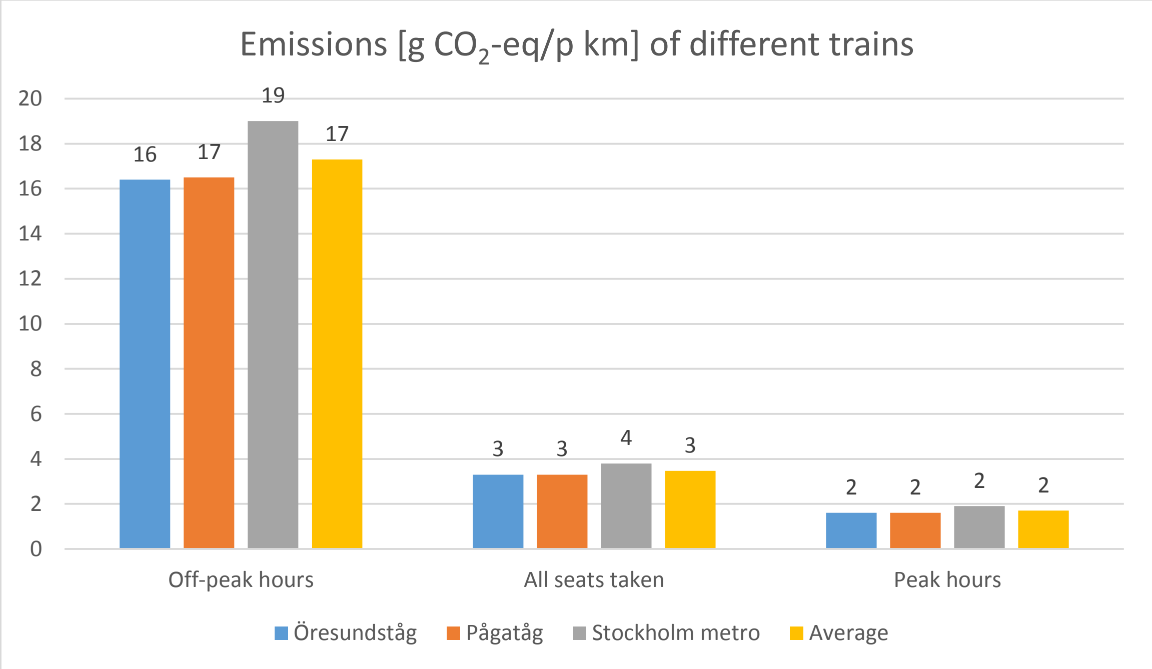

Figure 10. Emissions for three different types of train and the average value. There are three different scenarios in this figure; "Off-peak hours", "All seats taken" and "Peak hours". They refer to different amounts of travelers where Off-peak hours describes the situation between the morning rush and afternoon rush with a load factor of 20 %, All seats taken when all the seats are taken, typically in the beginning and end of the two rush hour periods which is here considered 100 % load factor and Peak hours refers to the hours during rush hour with a load factor of 200 %. The electricity mix is the Nordic average. "Pågatåg" is the Scania Local commuting trains (only operates in Scania), "Öresundståg" operates regionally, from Helsingör in Denmark to Gothenburg, Kalmar and Karlskrona in Sweden.

4.3.2 Emissions during usage of vehicles

The GHG emissions from the usage phase vary substantially between different vehicles. The electric vehicles (EVs) do not cause any emissions during usage. Their entire climate impact is located to manufacturing and disposal, the same applies to the conventional bicycle (if the emissions from food production are neglected).

In the findings presented here, the biofuel powered vehicles have, relative its fossil fuel siblings, low emissions. However, as noted earlier, biofuel vehicles still emits carbon dioxide out of their tailpipes. These emissions are regarded as impact-free since the carbon dioxide emitted does not add "new" CO_2 to the short term carbon cycle. This is because the fuel is produced from raw material harvested in the biosphere and not the fossil coal storages in the Earth's crust. Since the biofuel vehicles emits exhaust gases they still emits particles and others emissions that affect Earth in other ways than climate change which is important to understand when dealing with other aspects in cities and metropolitan areas. As hinted above, this report does not consider the emissions related to food, which could be considered the fuel of conventional bicycles and EPACs by providing humans with the energy needed to power these vehicles.

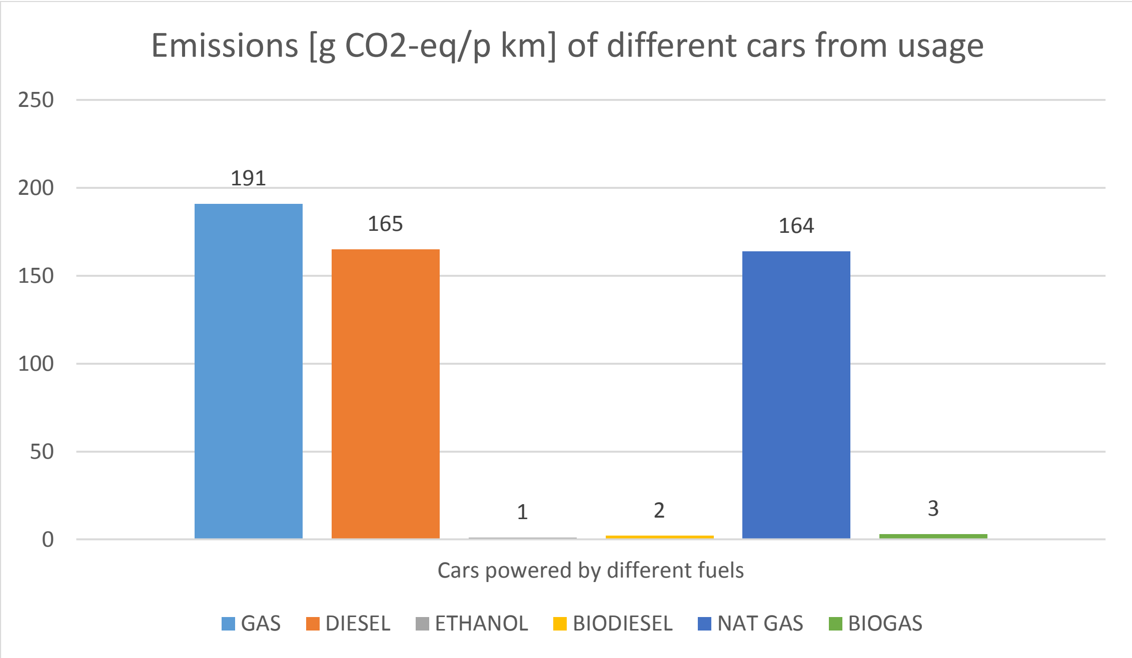

Figure 11. Emissions of cars using different fuel (and therefore different engines). The numbers presented in the figure have been calculated with base from different sources. These can be found in Appendix 9.1.2. The emissions (per passenger km) includes driver but excludes passenger(s). Technically, cars powered by ethanol, biodiesel and biogas still emits GHG but these emissions are assumed to be renewable hence the (almost) lack of GHG emissions in this figure.

As Figure 11 shows, biofuel are principally emissions neutral while fossil fuels have large emissions from the usage phase. The gasoline car has the highest emissions and this because its engine is less efficient compared to the diesel and natural gas engine. Again, note that there are tailpipe emissions when using biofuels, but these fuel does not cause a net addition on CO_2, hence the number is equal or close to zero.

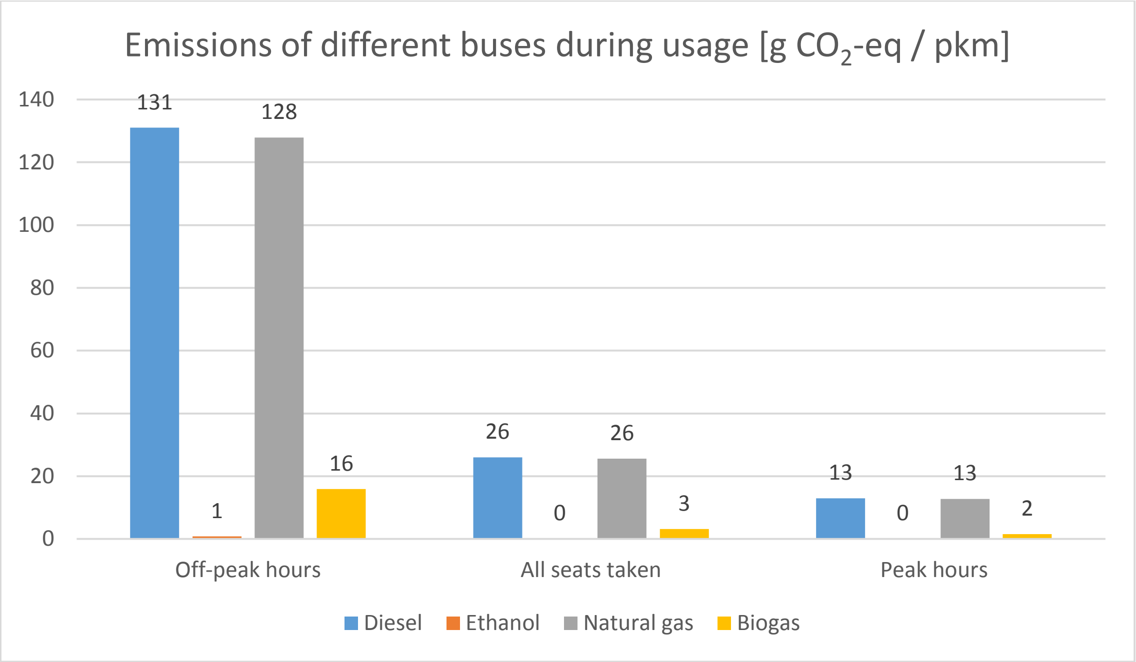

Figure 12. Emissions from buses powered by different fuels. As in the previous figures, 'Off-peak hours' refers to a 20 % load factor, 'All seats taken' to 100 % load factor and 'Peak hours' to 200 % load factor.

The emissions *per passenger kilometer* vary with the number of travelers in a bus why it's interesting to examine what happens with the results when changing the number of travelers. This is described in Figure 12 where three different scenarios are presented. Since the total emissions of the bus is split between the total number of travelers the emissions are very high in the case with few travelers (off-peak hours) but decreases rapidly with increased passengers.

Again it is clear that the fossil fuels emit and add much more carbon dioxide to the atmosphere. The diesel-bus' engine is more efficient compared to the natural gas-bus why they have approximately the same emissions.

4.4 Total climate effect of vehicles and fuels

There are a number of vehicles, power trains and fuels compared in this report. The total number of vehicle variations is large, therefore all results cannot be displayed here. The result of the comparison can be found in full in Appendix 9.1. The results presented here are chosen because they are representative for the Swedish transport sector or pose a viable future alternative to today's technology.

The result is presented in two figures; the first (Figure 13) displaying the distribution of the emissions between cradle-to-showroom, well-to-tank and usage phase and the second figure (Figure 14) how the emissions change with number of travelers. Calculations are all done according to Equation 1.

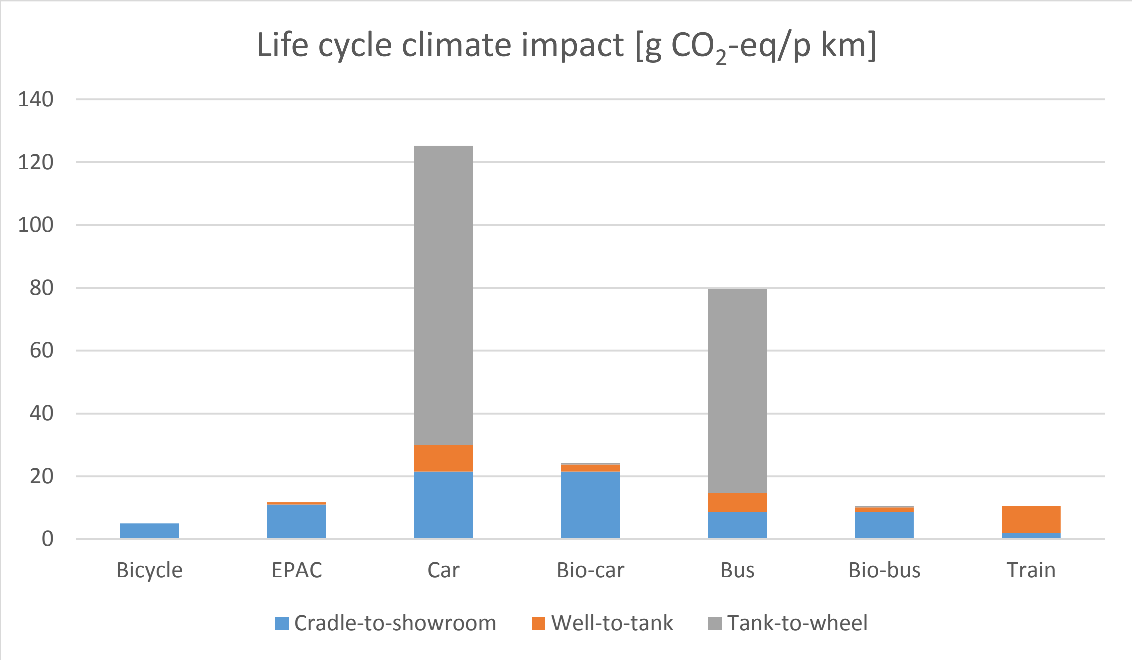

Figure 13. The total climate effect of different vehicles divided into cradle-to-showroom, well-to-tank and usage phase emissions. The emissions of the car, bus and train relates to a load factor of 40 %. The car is gasoline powered, the bio-car ethanol powered, the bus is a diiesel bus and the bio-bus is an ethanol bus. The train is the average emissions at 40 % load factor with Nordic electricity mix.

Figure 13 brings clarity to the interrelationship of the magnitude between the life cycle phases. Even though all configurations of the vehicles are not represented in the figure, the fossil fuel powered cars are all in the same order of magnitude as the example in Figure 13. The same applies to the other categories.

In order for Figure 13 to be representative, the load factor is set to 40 percent. All modes have been given the same load factor for them to be comparable. Naturally there are variations between specific vehicles but the chosen load factor is to be considered market average.

As seen in Figure 13, the bicycle is the most emissions efficient vehicle with respect to the entire life cycle. Among other reasons, this is because the bicycle is not a motorized vehicle like the others. The train, biofuled bus and EPAC emits approximately the amount GHGs per kilometer. In this particular scenario, the mass-transit vehicles emit slightly less compared to the EPAC. The fossil fueled vehicles, independent of mass-transit or not, are not able to compete in terms of emissions.

The emissions is presented by passenger kilometer which makes the mass-transit vehicles more sensitive to fluctuations in the number of passengers. The bicycle and EPAC emissions do not vary whereas a 10 % decrease in passenger number changes the emissions per passenger kilometer for the other vehicles.

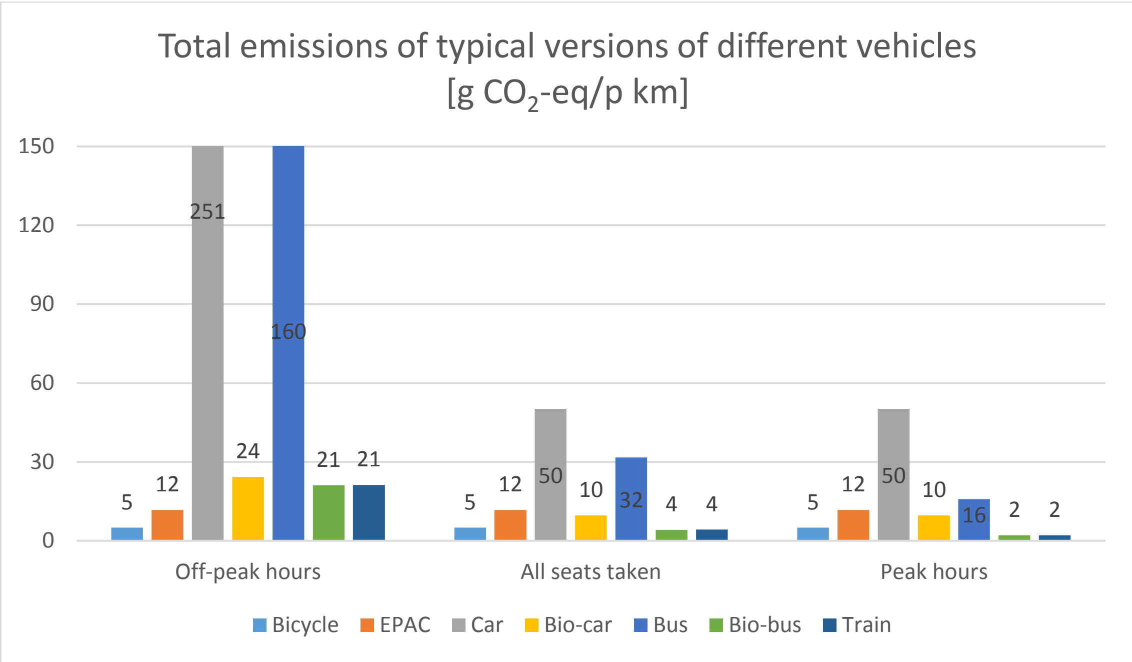

Figure 14. A comparison between the total emissions of different typical versions of different vehicles. The comparison includes Cradle-to-showroom, Well-to-tank and Tank-to-wheel emissions and shows how the different emissions varies with number of travelers. "Off-peak hours" represents a 20 % load factor, "All seats taken" 100 % and "Peak hours" 200 % load factor. The car has a maximum load capacity of 5 persons, even so in the two latter scenarios. The car used in this example is the gasoline powered car and the bio-car is a ethanol powered car. The bus is diesel powered and the bio-bus is powered by ethanol. The emissions from the train is the average of the three systems used, with Nordic electricity mix.

The load factor sensitivity can be seen in Figure 14 where three different scenarios is simulated. Figure 13 presents yet another scenario in addition to Figure 14 (40 percent load factor which is not presented in Figure 14).

Please note that the column for the conventional car during off-peak hours stretches further than the scale shows with a peak value of 251 g CO_2-eq per passenger km. It is not to be thought to emit the same GHGs as the bus even though the columns have similar visual height.

It's interesting that the biofueled bus, in this case ethanol, presents such a low number even at only 20 percent load factor and as mentioned earlier, there are versions of ethanol that, throughout its life cycle, emits even less CO_2-eq than the ethanol used in this example. This is mainly because the vehicle transport a large amount of people throughout its lifetime, hence the emissions can be distributed over many vehicle kilometers.

Note that the calculations for the condition *"Peak hours"* only affect the public transportation alternatives, i.e. buses and trains since a bicycle or EPAC cannot fit more than one person (not considering having a person on the carrier as an option) and the car cannot hold more than five persons (not considering minivans and such) their numbers are not affected by a rush hour situation.

4.4.1 Future performance

The vehicle performance is progressively improving as older vehicles are replaced by new vehicles with improved technologies. This chapter discusses possible future scenario for the vehicles addressed in this report. The principle for the scenario is that the top vehicles of today's vehicle fleet act as the basis for tomorrow's vehicle fleet average. The emissions from manufacturing and fuel production have been assumed to have decreased by 20 percent.

The car used in this scenario is the Toyota Prius, tested by the newspaper Dagens Nyheter, with an overall fuel consumption of 0.33 liter gasoline and 1.4 kWh per 10 kilometers (Dagens Nyheter, 2013). The Prius is a so called plug-in hybrid, which means it has a larger battery compared to hybrid cars. It can run on only electricity longer distances, approximately 20 km. The bus used, the Volvo 7700 Hybrid, has been assumed to have 30 percent less fuel consumption compared to the numbers for the bus used to represent today's market average. This figure is based on the EPD of the 7700 Hybrid (Volvo Bus Corporation, 2010). The emissions cause by producing the electricity powering trains is also assumed to have decreased 30 percent.

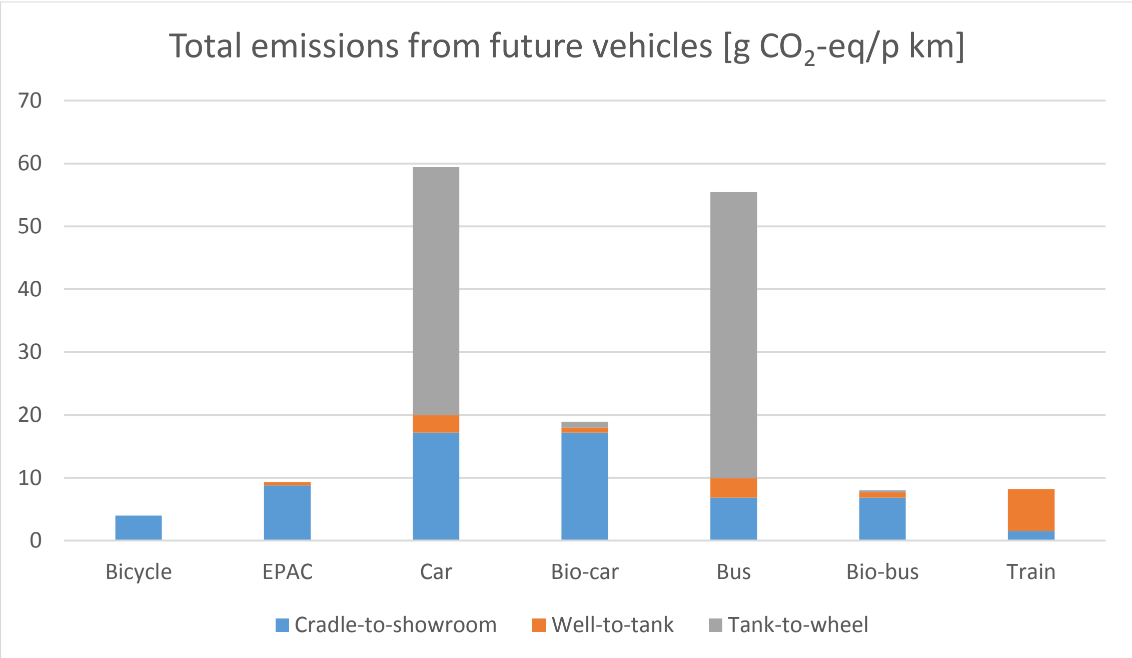

Figure 15. The total emissions of vehicles powered by future technology. The bicycle and EPAC numbers have not been corrected for future development. The load factor for the other three vehicles is 40 %. The car used is the Toyota Prius as described in Chapter 4.4.1 and the bio-car is the same setup but with ethanol as alternate fuel. The bus, based on the Volvo 7700 Hybrid, is assumed to consume 30 % less fuel compared to today's buses and the bio-bus assumed to have same characteristics as the conventional bus but powered by ethanol. The train is also assumed to be 30 % more efficient. The Cradle-to-Showroom and Well-to-tank phases have been assumed to be 20 % more efficient compared to today.

As can be seen when comparing Figure 15 and Figure 13, the overall trend is the same. The major difference is the scale which has decreased in the latter meaning the total emissions is lower in the future scenario compared to today's levels. However, the ranking of the vehicles remain. As mentioned earlier, the emissions from manufacturing have been corrected down 20 percent, for all vehicles. The vehicles constituting a viable option in the future are the ones with small tailpipe emissions. By assuring high reuse and recycling along with low emissions from manufacturing, the biofueled car could be a part of the future sustainable transportation system, where both the bicycle and EPAC could be near-zero emission vehicles.

The European Union has a target set for 2020 where new cars and other light weight vehicles are allowed to only emit 95 g CO_2-eq/v km, a number that in 2011 was 136 (European Commission, 2012). The car used in this future scenario emits 92 g CO_2-eq/v km. It has to be remembered that the figure above describes the average emissions of the entire vehicle fleet which means that it is not directly applicable to the year 2020 since the EU regulations only applies to new cars. With a lifetime of 150 000 km, it takes a normal Swedish car somewhere between 10 and 15 years to reach end of life meaning it could take as long as until 2035 before the average emission level reaches 95 g CO_2-eq per vehicle km. The goal that the entire Swedish vehicle fleet should be fossil fuel independent by 2030 should therefore be considered at great risk.

4.4.2 Summary

As can be seen in both Figure 13 and Figure 15, mass-transit vehicles such as the bus and train cause significantly less GHG emissions compared to the car. The non-motorized options cause small amounts of emissions due to their drivetrain setup.

One of the most important conclusions that can be drawn from Figure 15 is that even though the conventional technology is developed substantially, fossil fueled vehicles cannot be a part of the transport sector if the policy related ambitions are going to be reached.

From addressing the emissions stemming from manufacturing, bicycles and EPACs can become near-zero emissions alternatives and assist the transition to a sustainable transport system.

5 The EPAC market

This chapter presents the situation on the EPAC market at publication of this report. The approach and result of the market analysis are also presented and the chapter is concluded with a discussion regarding the present and the future of the EPAC market.

5.1 Why a market analysis?

The purpose of this thesis is to evaluate whether the EPAC can be a viable part of a sustainable transportation system or not. In Chapter 4 we saw the climate performance of the EPAC relative other commuting options, and from a glance its climate performance makes it a true option when designing future systems. Apart from many other aspects related to the use of the EPAC, one must also evaluate the EPAC market potential to see if it is possible for the EPAC to penetrate it and make a real impression on the customers. The full picture cannot be painted from simply looking at the technical features, but the market, i.e. customers, must be considered in order to assess which degree of impact the EPAC can have. This evaluation can be done in several ways, but the fundamental approach is to gather information about the market and map the characteristics, drivers and other relevant aspects. A problem is the fact that because of the youth of the EPAC market, there has not yet been any major third party collection of data, hence robust statistics do not exist. This report presents rough data collected to get a first overview of the EPAC market.

The market analysis herein consists of three parts; (1) the market size and growth, (2) technology trends and (3) customer needs. The first part of the analysis is based on both primary and secondary information. Manufacturers, wholesalers, retailers and trade organizations have been contacted, interviewed and this have been complemented by information from reports. The second part is based on information collected from both primary and secondary information. The main source of information is the interviews held with manufacturers and wholesalers. The third and last part of the analysis is optimally based on interviews with EPAC customers and focus group discussions. However, it is hard, if not impossible, to get in touch with enough customers to gather enough information under current conditions. Therefore, it has been estimated that the EPAC retailers are the second best source of information regarding the customers' needs and characteristics. These steps are taken in order to triangulate as reliable information as possible in order for the analysis to be as thorough as possible.

5.2 What is a market analysis?

There are many different ways to go about executing a study of a specific market. This task is commonly known as a market analysis, an arbitrary concept that consists of many different parts and tasks. David A. Aaker said that the goal of a market analysis is

> *To determine the attractiveness of a market and to understand its evolving opportunities and threats as they relate to the strengths and weaknesses of the firm.*

(Internet Center for Management and Business Administration, 2013)

Since *market* in market analysis is such a wide concept it is hard to assess which parts a proper market analysis should be constructed by. A market analysis is almost always unique in which market that is studied and the purpose of the analysis. This means the buyer of the analysis states the purpose which acts as basis when deciding the parts. Examples of different parts in a market analysis could be a situational analysis, competitor analysis, customer analysis, trend analysis, technology analysis, cost analysis and risk analysis. To companies the market analysis is meant to address the uncertainties in the market in order to minimize the risk of entering new markets or the existence in a certain market.

There are a number of frameworks that can be used to assist in the work. For instance, in order to assess the competitive landscape Porter's Five Forces can be used. Other frameworks that exists is the 5C model, PESTEL-analysis, SWOT-analysis and the 4P-model.

This market analysis studies primarily three aspects of the Swedish EPAC market, namely

- Market size and growth,
- Technology trends and
- Customer needs.

The reason for choosing these parameters is the based on the product adoption curve. The model describes how different customers adopt a product in different stages of the product life cycle and the customers can be segmented into five different groups; Innovators, Early adopters, Early majority, Late majority and Laggards. The product life cycle mentioned in this chapter does not refer to the same life cycle as Chapter 4 deals with. The life cycle in the market analysis refers to time the product spends the market and how it's adopted by the customers, whereas the life cycle in chapter four deals with the product from cradle to grave.

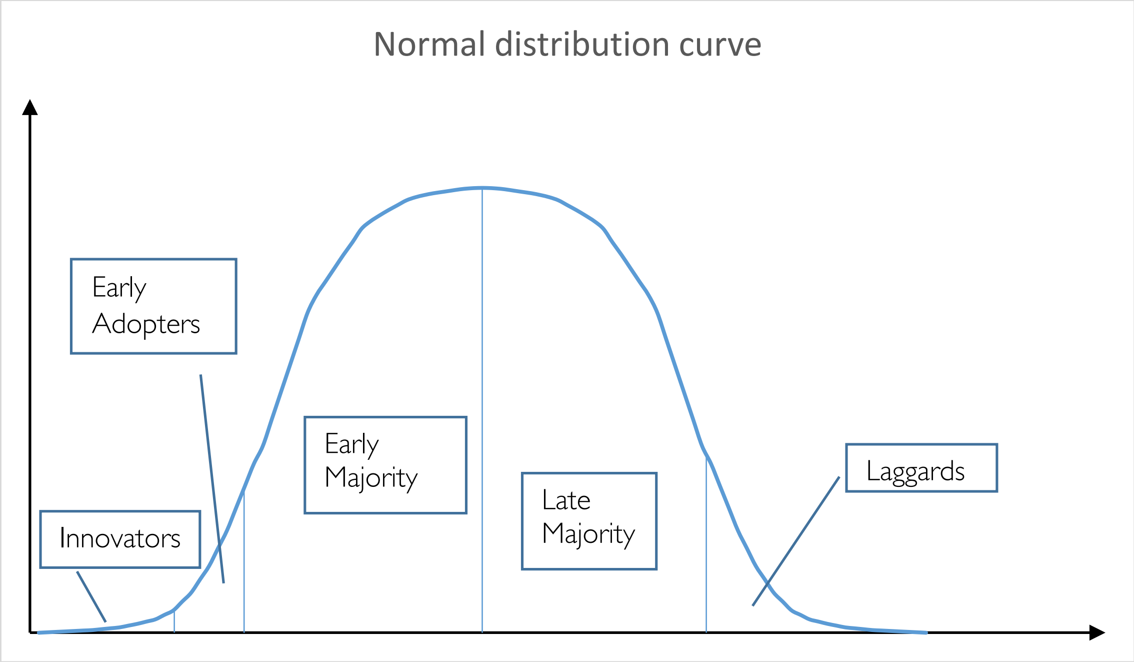

Figure 16. Product life cycle curve. The five different customer types are represented by the five different zones under the curve. From left: Innovator, Early Adopters, Early Majority, Late Majority and to the far right Laggards. The area under the graph represents the possible sales of each segment.

The different segments have different needs why entrepreneurs often say that there is "a chasm" between the *Early adopters* and *Early majority* and this chasm is very important to cross since the accumulative sales is normally not enough in the segments *Innovators* and *Early adopter* to run a profitable business. (Baron & Shane, 2008)

The EPAC market is young and presumably the maturity of the market corresponds to a situation where the *Early adopters* are adopting the new product. Because of this, the most important drivers of the market at this point is estimated to be the products and technology trends along with the needs of the customers. The market size and growth are important because these aspects can tell us plenty about a market, and in combination with qualitative aspects can construct a powerful tool during analysis.

The technology trends of a market is important to its future growth since a wide expansion of application areas can allow for a much larger market and completely new customers. From a possible expansion it is also possible to get a hunch whether a new customer segment is about to be penetrated or not and if the new segment is different from the old ones.

5.3 Approach

5.3.1 Method

The data gathered is meant to give a better understanding of the three aspects investigated in this thesis. The sources of the data are

- Interviews with manufacturers, wholesalers and retailers,
- Online survey for EPAC retailers and
- Reports and other secondary data.

The online survey has been distributed by *Svensk Cykling* (app. Swedish Cycling, the Swedish bicycle trade organization), to its over 1 000 members, and *Cykel, Motor och Sportfackhandlarn* (app. Professional cycling, motorbiking and sport traders, shortened CMS) to its 128 members.

Swedish Cycling has a big variety of members, from pure bicycle retailers to gas stations offering a small assortment of spare parts. The membership is limited to actors selling bicycle related products, this includes shops that only temporarily sells spare parts, for instance during summer. Approximately 1 000 retailers received notification about the survey due to bouncing e-mails but since the survey was explicitly directed to the EPAC retailers one cannot expect the potential respondents to be 1 000. A more likely estimate would be 20 % of that, i.e. approximately 200 retailers. With a total of 44 respondents this would give a response frequency of 22 percent.

Swedish Cycling sent a separate e-mail with the link to the survey accompanied by a letter written by me. In the case of CMS the survey was mentioned in the monthly newsletter, why it cannot be expected that all persons receiving the newsletter noticed the mentioning of the survey. I have communicated with the retailers through these two organizations and not personally been able to send reminders to the members.

Interviews have been held with representatives from Merida Sweden AB, Trek Sweden AB, Cresent AB, Vartex AB and Jaguarverken AB. Jaguarverken AB is representing several brands including Giant and Marvil. These organizations were chosen because they were estimated to be credible actors in the EPAC market with active development of the assortment. It is estimated that they individually hold a significant market share. Scott Sweden AB and EcoRide AB have been sought but chose not to participate.

Merida, Trek and Giant are closely related in terms of assortment and offers more sportive alternatives compared to Cresent and Vartex, which are more focused on city and comfortable bicycles. The persons participating in the interviews are referred to as *interviewees* in the chapters below.

5.3.2 Scope

This market analysis focuses on three aspects, *the EPAC market size and growth, technology trends* and *the customer needs*. Because of time constraints, actual EPAC customers have not been interviewed, but the answers provided by the retailers are estimated to be representative for the customers' needs. Company specific information has not been possible to collect mainly due to the fact that this type of information is considered business intelligence and therefore classified.

5.4 The EPAC market by numbers

Knowing the market size is an important tool for many businesses. By looking at a specific market size, it is possible to make assumptions whether the market is growing or not. By comparing annual sales, the market growth rate can be determined which is important when possibly entering a new market or not. The gathering of this information can for instance be done by a third party organization, such as a trade organization, which has contact with all the major players hence being able to collect the relevant data and at the same time keeping the information anonymous to the general public.

According to BIKE EU (Steen-Olsen, 2013) the Swedish EPAC market saw the light of day in 2010 and had in 2011 a market size of 15 000 units (COLIBI, 2012). In 2012 the imported number of EPACs were 6 500 (Oortwijn, 2013). In the long run, the interviewees hope for the Swedish market to follow the Dutch, which currently has an EPAC market share of 19 percent. Two thirds of the respondents from the online survey says sales are increasing where 2013 was a good year in terms of sales. Relating the Swedish market to the product life cycle adoption curve, the Swedish market is likely to have begun to penetrate the segment *Early adopters* and if the penetration continues, a significant increase can be expected in the coming five to ten years.

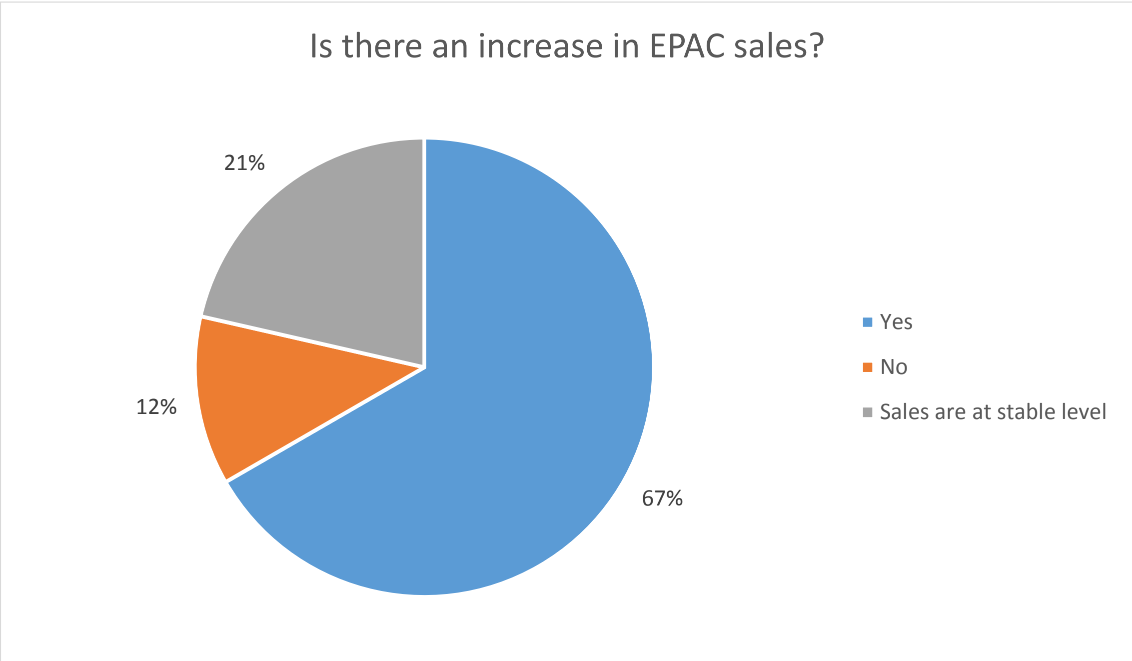

Figure 17. Question four in the online survey.

As indicated above, it is hard to estimate the exact number of units sold in the market 2013, partly as some of the interviews occurred before the end of 2013 and because there is no entity keeping track of the Swedish market size. Because of this, this report will not give a specific number to how large the market is but a better way to describe the size is through a span, estimated to 9 000 and 15 000 units for 2013.

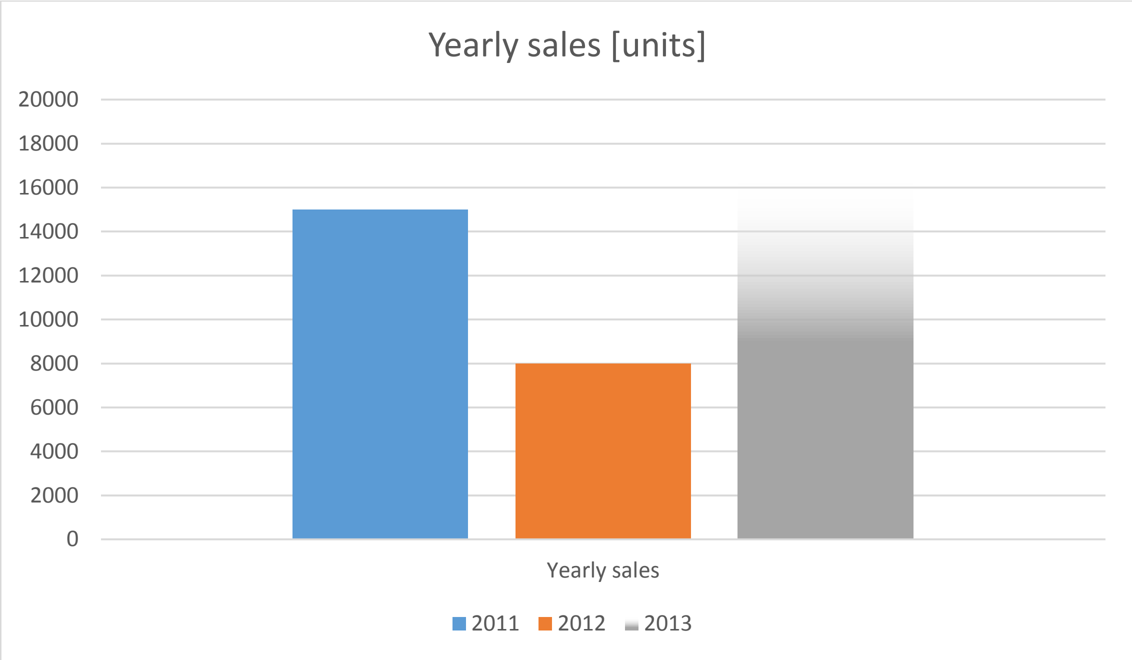

Figure 18. The yearly sales of EPAC in Sweden. 2011 – 2013 are the only full years EPAC have been sold in Sweden, hence the time interval. The sales for 2011 can be found in a market report done by COLIBI and COLIPED (2012) and the sales for 2012 is estimated based on information from Bike-EU (Steen-Olsen, 2013) and the sales for 2013 are estimations based on the interviews done.

The EPAC market share is naturally hard to determine since the specific market size is unknown. The report of 2011 is the last attempt to make a full market report of the Swedish EPAC market, and those numbers give us a market share just over 2 percent. Based on the information found throughout this project, today's market share is probably in the same region as it was in 2011. The retailers were asked about the market share, or more specifically *"How many percent of the total sales are EPACs?"*, and the overall average was 9.4 percent. Does this give us the EPAC market share? The only thing the numbers tells us is the average EPAC share of the retailers who answered the survey which is not synonymous with the entire market share. However, from the retailers selling EPACs, it is obvious that the EPAC plays a significant role in the total sales especially since an EPAC in general is more expensive compared to a normal bicycle.

5.5 Technology trends

The technology trends are important to keep track of. They might, for instance, lead to unexploited application areas or new customer segments that can prove lucrative. Responding to trends can also provide the opportunity to be the first into a new segment or application area. The time advantage, also known as *first-mover advantage*, is a very important competitive advantage for a number of reasons. One is that the first player has the possibility of setting a *"dominant design"* meaning that the following products in practice has to follow this design. Another advantage is the opportunity to make the brand synonymous with the product. This happens frequently and a recent example of this is the iPad which for a long time, and to some part still is, synonymous with tablets.

The EPAC industry is young and even though there are already many different variations of e-bikes in the market, customers are just adopting the EPAC. Since the technology itself is identical to conventional bicycles, with the exception of the addition of the electrical drivetrain, there is already a dominant design. Innovation at this point is rather incremental, i.e. by small steps, as opposed to radical innovations.

Because the EPAC market is young and the first versions is just being adopted by the customers, one might think that the focus at the moment wouldn't be product development, an assumption not true. At the moment manufacturers are exploring several ways of altering the EPAC, primarily the motor power output to make it even more suited for new users and segments. All the interviewees speaks in an almost visionary manner about how the power output could vary (between models) to increase the e-bike break-through. Almost all interviewed persons mention a more powerful engine (compared to the 250 W output of the EPAC) which could open up to several new segments where youngsters might choose an e-bike instead of a moped. Even though that version is not an EPAC per definition they think it would be beneficial in the long run also for the conventional EPAC. Another interesting modification would be to simply increase the power of the engine but to keep the throttle, especially for cargo and family EPACs. One example of this is the Urban Arrow, (see figure below) which could benefit from this since it is possible to transport two children in it and the extra weight sometimes require a more powerful motor. This is also applicable in the cases when the cyclist hangs a trailer on the back in order to transport children or goods.

Figure 19. The Urban Arrow, model Family. This e-bike still meets the demands of an EPAC but could gain from a more powerful engine since it is possible to transport two children in this bicycle.

The EPAC trends are of course heavily influenced by the trends of the conventional bicycles. The most prominent trend for conventional bicycles is the shift in focus from comfortable bicycles to more sportive ones (interviews) (Oortwijn, 2013). However, depending on the application(s) of the EPAC, its future trends might not follow the bicycle's.

Cycling is principally done for either of three different reasons; transportation (e.g. commuting), recreational cycling (e.g. cycling to the beach) or exercising. The characteristics of the EPAC fits two of these types; transportation and recreational cycling. This report specifically addresses commuting, a form of cycling that falls under transportation, which competes with a wide range of different modes of transportation. Commuting could basically be done with every imaginable transportation mode, such as by airplane, bus, train, car, bicycle, moped or on foot, meaning the EPAC has all these modes to compete with and their respective characteristics. When comparing functionality, the two most similar options are the bicycle and class two moped, indicating that the EPAC would replace these two modes primarily. This is to some extent confirmed by question eleven in the online survey (see Figure 26) where almost 60 percent of the retailers says their customers replaces the bicycle and in second place the car. Only two percent of the retailers think the EPAC replaces the moped. This is probably due to the fact that the moped is not a prominent mode of transportation in Sweden. If and when the EPAC strengthens its position as a commuting option the competing alternatives will probably to greater extent move towards the car and public transportation system.

Figure 20. The most popular bicycle in Sweden. © cykelmartin.se

The commuting distance plays a crucial role when choosing between EPAC and other modes. People accept a certain distance for traveling by bicycle. This is however dependent of where the person is located, geographically. In larger cities, people accept longer commuting distances compared to smaller cities. For instance, in smaller cities cycling trips decreases dramatically after five km whereas the average traveled distance in Stockholm, by bicycle, is eight to nine km (Sveriges Kommuner och Landsting, 2010).

5.6 The customers

The market analysis has the purpose (among others) of finding the customer's view of the product as it is today and what makes the customer chose an EPAC above the alternative, i.e. what needs does the customer have and how it is fulfilled by the EPAC. The climate comparison gave us the relative climate performance of the different vehicles. As can be seen in Chapter 4 the climate impact depends on several variables and overall the EPAC is a climate friendly alternative. Retailers might think to use this as a selling point to prove the EPAC superiority over other vehicles but from what can be deduced in the figure below, customer rarely buy an EPAC for environmental reasons.

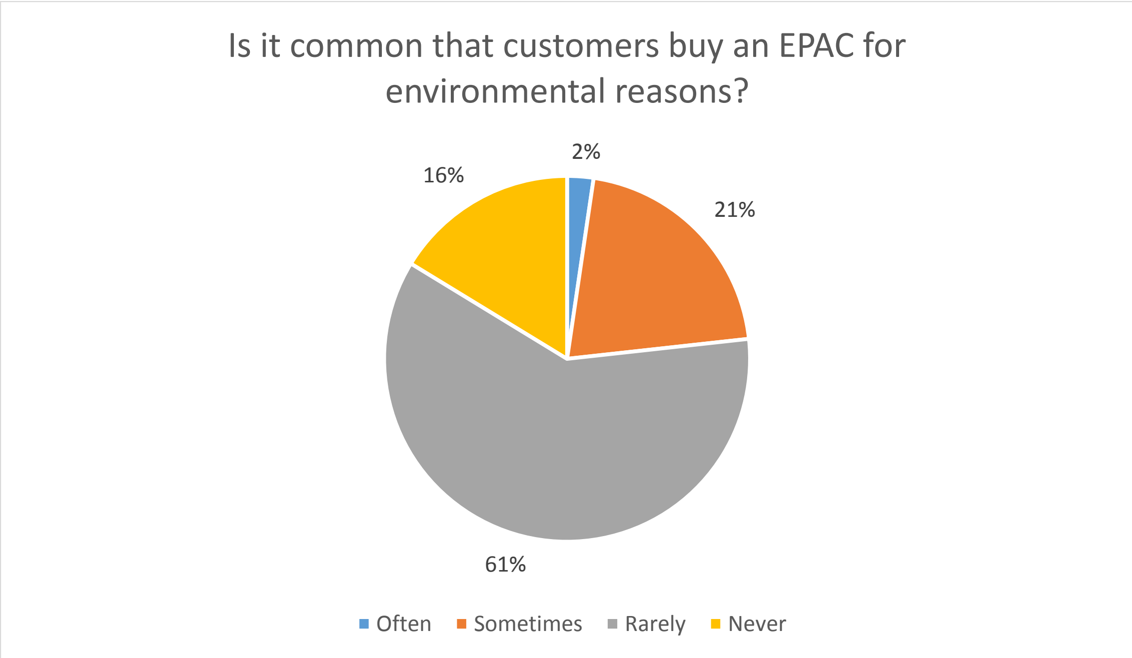

Figure 21. The 13th question in the online survey. This question was constructed as the respondents could only pick one alternative.

This picture of reality is not uncommon. In Stockholm, only 29 percent of the population usually buys organically grown foodstuff (Stockholms Stad, 2013). As can be seen, only 21 percent of the customers uses the environment as a distinct reason to buy an EPAC. A possible reason for this is the fact that the environmental issue is quite complex. The environmental gain or loss of switching to an EPAC depends on which mode of transportation that is replaced and to assess whether a person's situation leads to a gain or loss requires knowledge that the general public doesn't possess. Of course, it is possible to simplify and state that the EPAC is the most climate friendly mode there is, but this would simply not be true. As we will see later in this chapter, the reason why people choses the EPAC is of more direct character as opposed to the climate issue.

5.6.1 Who are the customers?

All the interviewees present the same typical EPAC customer; an older woman, around 65 years of age, with physical disability. The same verdict comes from the retailers, seen in Figure 24.

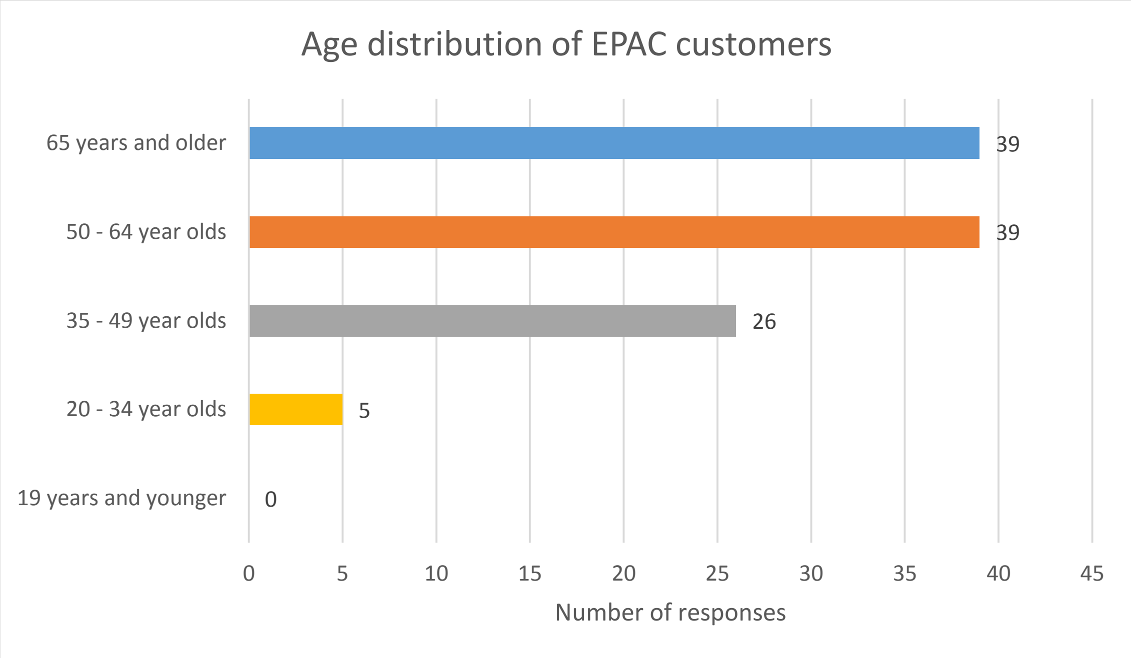

Figure 22. "How common is it that persons from each age category buys an EPAC?". The question was posed with five different options for each age category; Frequently, Somewhat frequently, Quite unusual, Unusual and Never. The figure displays the number of answers of Frequently or Somewhat frequently for each age group.

However, the typical customer is changing and the age at which a person gets an EPAC falls constantly. This can also be seen in the marketing material the wholesalers uses where younger persons (compared to the traditional customer) are highlighted. All respondents say that they are changing their focus from the elderly to a younger age group. The targeted customer at this stage is male, 45 years old, works in an office environment and therefore uses a suit as business dress code and he lives an active life and wants to cycle but cannot come sweaty to work.

Box 4: The EPAC market potential
The EPAC market share in the Netherlands is 19 percent. If we assume the Swedish market can have a similar market share, the Swedish EPAC market potential is 88 800 units, based on a total bicycle market size of 555 000 units.

If we also take the difference in bicycles per inhabitant into account, a difference of 39 %, the Swedish market potential is just over 54 000 units.

5.6.2 Why the EPAC?

As the picture of the new typical EPAC customer suggests, commuting is the primary field of application. This corresponds well with the answers from question five in the survey.

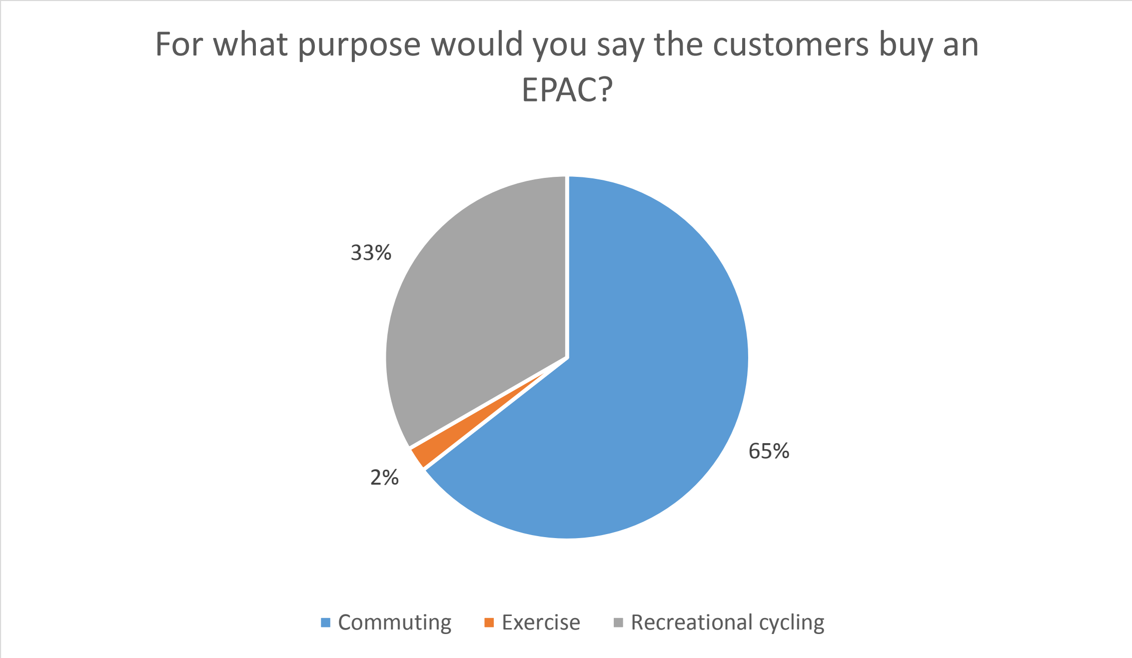

Figure 23. Question five in the online survey. The question had another answering option, "Other", where the respondents could write anything but all of these responses (four) could be categorized as one of the three options presented in the figure, hence I've choosen to only present these three options.

Almost two thirds of all customers buy their EPAC with the intention of using it for commuting. The manufacturers are pleased with this development since the large volumes are in the commuting segment.

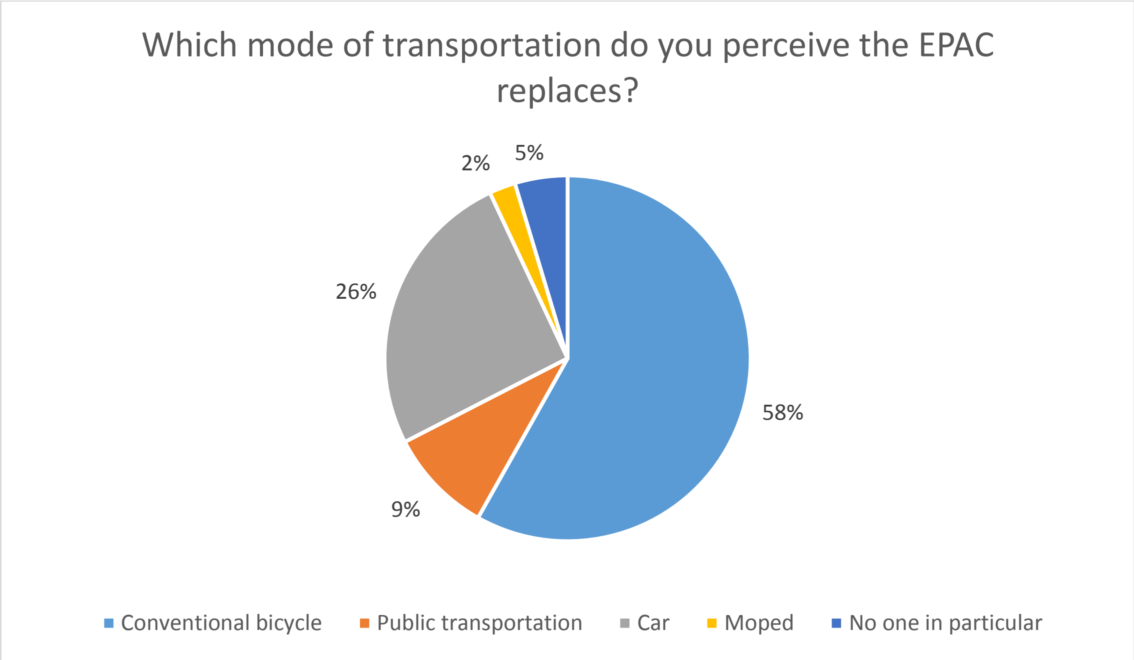

Figure 24. Question eleven in the survey. The question was asked with an extra option "Other" where the respondents could answer whatever they liked. These answers have been placed in one of the categories presented here since they were all a match. Not all survey respondents answered this question.

As we can see in the figure above, the EPAC replaces the conventional bicycle in a majority of all cases and in more than a quarter of the cases it replaces the car.

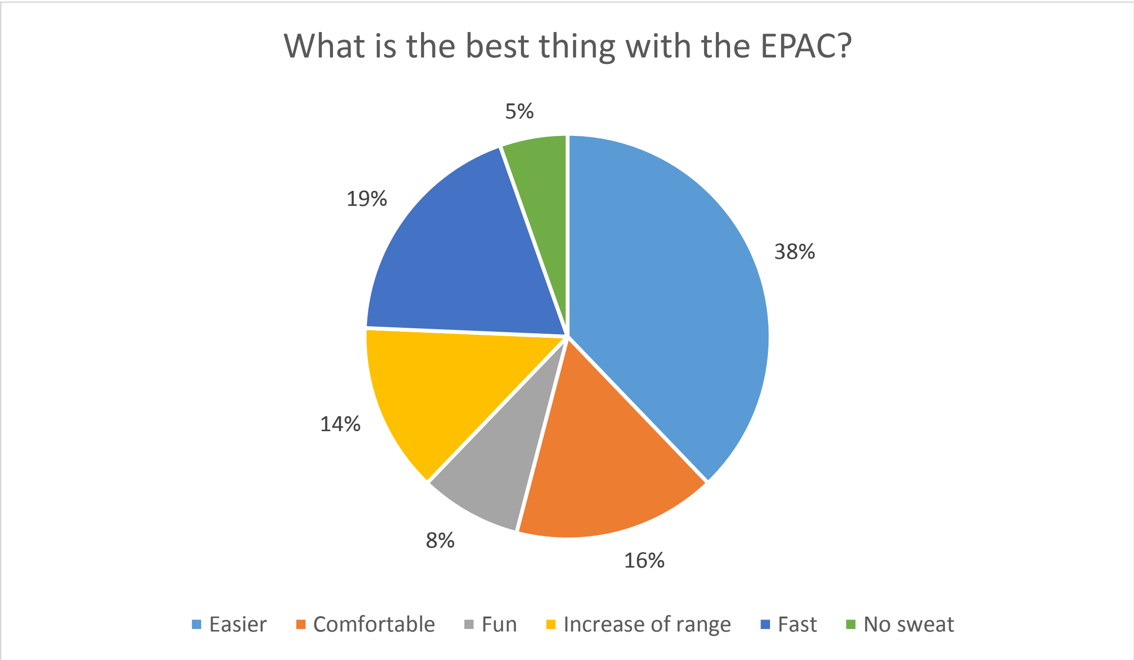

Figure 25. Question nine in the online survey. The answers was categorized into these five categories. The figure is an interpretation of the responses given. The figure covers approximately 97 % of all responses. Some respondents did not answer this question.

The purpose of this question is not to get a perfectly accurate picture of the best features of the EPAC, but to get a feeling for what reasons the customers choses the EPAC, ultimately: what needs does the EPAC fulfill. In order to be able to visually present these answers here, categories had to be created and the answers put in a specific category. Remember, the purpose of the question is not to be specific about a single feature but to address the more general picture, that's why several of the response categories are similar or overlapping. For instance, it is likely that the auxiliary motor is keeping the cyclist from sweating meaning *E-motor assistance* and *No sweat* is two responses quite similar. They could off course refer to entirely different underlying reasons and again, the purpose of the question is to focus on the major trends. The category *Easier* is named that way due to the fact that most retailer said that the best thing with the EPAC is that it is easier to ride than a regular bicycle, indicating that the cyclists don't have to use as much force as they do on a conventional bicycle.

Noticeable from the figure is that almost a tenth of all the customers thinks that the best thing with the EPAC is that it is fun to ride. This could be important to remember, especially for the retailers as this could turn out to be an important sales pitch. We can see that most customers think the best aspect of the EPAC is that it increases the comfort of the trip, i.e. you don't sweat, it's easier to get to certain places whereas a smaller portion appreciates features such as increasing the range and cycling faster.

We can see that the reasons for choosing an EPAC above the regular bicycle is somewhat corresponding to the best features of the same. The competitive advantages of the EPAC is even more accentuated in the figure below.

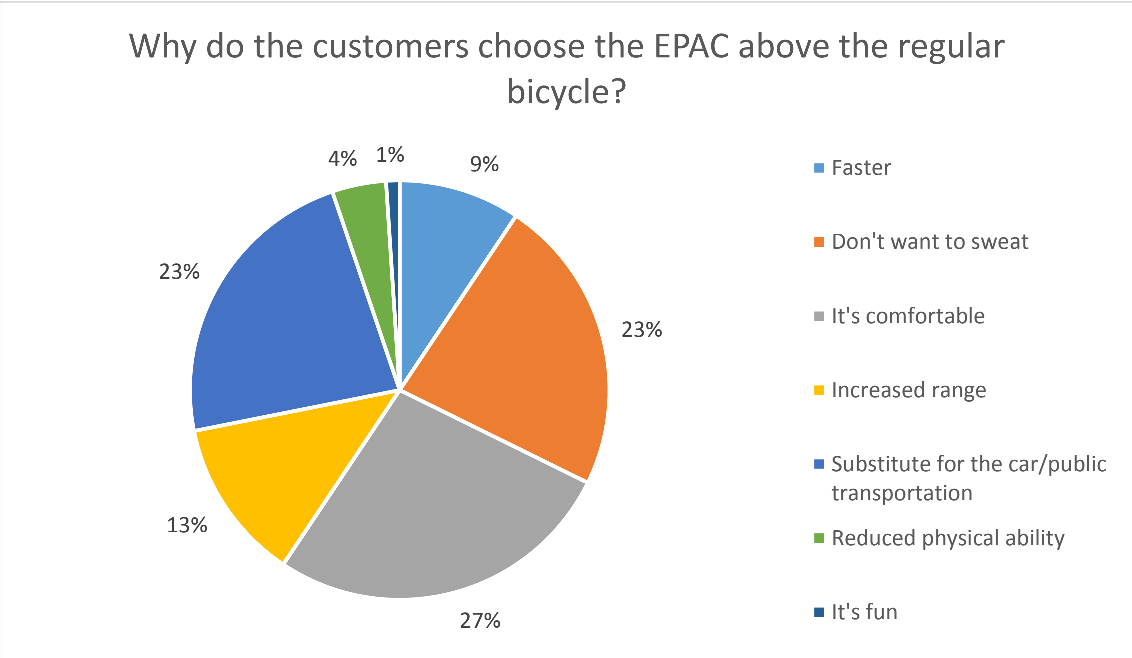

Figure 26. Question seven in the online survey. All responses but one, which is not relevant to the study, are shown in the figure. The question was posed as a multiple choice question along with an extra opportunity for the respondents to give

an answer outside of the proposed ones. There where six "Other" answers and these were categorized into "Reduced physical ability" and "It's fun" (see figure).

From question seven (Figure 26) we can see how the customers rank the main advantages compared to the regular bicycle. In this case, customers value no sweating higher compared to the question showed in Figure 28. We can also see that almost a quarter of the EPAC customers choses the EPAC because the EPAC (compared to the bicycle) constitutes a viable option when it comes to substituting the car or transportation with the public transport system.

As we saw in Chapter 3, the price of an EPAC is considerably higher compared to a bicycle of equal quality but the difference in price do not seem to bother the EPAC customers to any greater extent. The retailers estimate that only 16 percent of the customers are affected by the price, whereas 28 percent is not affected at all by the price.

Box 5: The implications of Figure 26

So what would it mean in terms of emissions if the EPAC customers switched to the EPAC from either the bicycle, public transport, car or moped according to Figure 26? This example assumes that 58 % of the EPAC customers switches from the bicycle, 9 % from public transportation, 26 % from the car, 2 % from the moped and 5 % from no particular mode of transportation. By using the numbers from Figure 13 the EPAC has

- 7 g CO_2-eq/p km loss compared to the bicycle
- 113 g CO_2-eq/p km gain versus the car
- 67 g CO_2-eq/p km gain compared to the public transportation system
- 12 g CO_2-eq/p km loss compared to the *No one in particular*-option
- The moped is assumed to have the same amount of emissions as the EPAC

The equation below describes the net result if 100 persons switches to the EPAC according above.

$$58 \cdot 7 + 9 \cdot (-67) + 26 \cdot (-113) + 5 \cdot 12 = -3075\ g\ CO_2 - eq/p\ km$$

Hence, every sold EPAC meant for commuting the climate gain is approximately 30 g CO_2-eq. A person commuting 10 km a day, five days a week, 40 weeks a year, the reduction equals 60 kg of CO_2-eq annually.

5.7 The present and the future of the market

Historically, the typical EPAC customer has been an older woman with physical disability. This is now turning as new segments are exploited and the manufacturers are unanimously targeting commuters, more specifically the male customer.

At the moment the customer buys her EPAC mainly for commuting and in a majority of the cases this is an upgrade from the conventional bicycle. The EPAC enables longer commuting distances, or in some cases fast commuting, with less physical effort. This opens up to individuals and groups that normally wouldn't consider commuting with a two-wheel vehicle.

As the commuting segment is just being penetrated the growth potential is enormous. Actors have realized this and the market communication is focused on the commuters, specifically male commuters. This leaves a gap in the market communication where market shares could be gained if the female customers are addressed. We saw earlier that the environmental argument is not an important trigger, which could either be interpreted as the customers not caring about this or that there is room for improvement and market communication within this area.

Reconnecting with the peak-car phenomenon, it is likely that younger people will respond positively to arguments about convenience and comfort of the EPAC. From presenting the functionality of the EPAC, and the fact that it in most cases can replace the car, retailers can get the appeal of the youngsters. By reaching people at young age (i.e. around 30), they might postpone their first purchase of a car resulting in a massive save in emissions.

6 Improving climate efficiency of the transport system

This chapter discusses the results presented in Chapter 4 and Chapter 5. Two examples are presented regarding the reduction of GHG emissions from the switch to the EPAC. The chapter is concluded with reflections about the EPAC market.

This project set out to evaluate whether the EPAC can or can't improve the climate performance of the transport sector and begin mapping the market preferences. Chapter 4 presented the GHG emissions related to the EPAC compared with the conventional bicycle, car, bus and train. Chapter 5 gave us a first look at three aspects of the EPAC market; the size, technology trends and customer needs.

This report focuses on commuting trips within the EPAC operating range, i.e. below 50 km. For commuting trips longer than this, the bicycle or the EPAC is not considered viable options, and not evaluated in this report. Hypothetically, within its operating range, the EPAC can replace any commuting option and the most common ones are investigated in this report. Walking is not considered in this report since the characteristics of walking differ a lot compared to the other options.

In terms of energy efficiency the EPAC performs far better compared to all the other commuting options. However, this report does not consider the energy in the form of food that is needed by the cyclist to drive the EPAC. As we can see in Figure 13 the EPAC has, relative the other vehicles, high levels of cradle-to-showroom emissions and is the largest point of improvement potential for the vehicle.

6.1 The EPAC versus the bicycle

When examining the results in Chapter 4, it is easy to say that the EPAC accounts for more GHG emissions compared to the conventional bicycle. Partly because the EPAC requires more parts in its construction but also because it consumes energy whilst used. However, this report does not consider the emissions arising from food production which is needed to give the rider enough energy and power to be able to use the two vehicles. It is unlikely that the food production emissions change the relative positioning between these two vehicles.

In terms of GHG emissions the bicycle is better, but the vehicle lacks many of the advantages of the EPAC which for commuting purposes make it inferior to the EPAC. This can be seen in Figure 26 which shows that more than 50 percent of all EPAC buyers switch from the conventional bicycle and because most EPAC buyers intend to use their EPAC as means of commuting (Figure 25) it can be concluded that the EPAC is more suitable for commuting.

6.2 The EPAC versus the car

From the results in Chapter 4, the EPAC is undoubtedly superior in its climate performance compared to the conventional car, independent whether it is diesel or gasoline powered, as seen in Figure 14. The same figure shows that the only car that can compare with the EPAC is the fully occupied biofueled car. But the climate efficiency is heavily dependent on how many people using the car.

Assuming that the car will not be, during its entire lifetime, fully occupied it is more reasonable that the purchase of a car will lead to more emissions per passenger kilometer compared to the EPAC. Over its entire lifetime, an average load factor of 40 percent is more reasonable why Figure 13 gives us a good picture of the average lifetime emissions per passenger kilometer.

In principle, the car is rarely better than the EPAC and it is possible that the purchase of a car generates more trips due to the fact that the newly bought car is available. The same goes for the EPAC, if one is bought it is likely that it is used for more travels than originally intended.

This report presents the biofuels, such as ethanol and biodiesel, as a fuel with great capabilities to reduce the climate impact if switch to. However, the biofuels are not problem free, especially the production phase where many problematic aspects are found. One dealt with here is the indirect land use change (iLUC) which alone can double the well-to-tank emissions. Another issue is whether biofuels are displacing food agriculture because of it high economic value. These issues need to be addressed before biofuled cars truly can become a part of the sustainable transportation system.

6.2.1 The climate gain of switching from car to EPAC

Example 1: Nationwide adoption of EPAC
This example presents a visionary scenario of the GHG decrease from increased EPAC usage. Today, almost 31 million passenger kilometer is travelled by car each year for commuting purposes. Only 1.3 million passenger km are done by foot or bicycle (Trafikanalys, 2013). This example assumes that 10 percent of all kilometers done by car is transferred to the EPAC. With Figure 13 as base, car commuting accounts for approximately 7.7 million tons of CO_2-eq annually which represents almost 13 percent of all GHG emissions in Sweden annually (The Swedish Environmental Protection Agency, 2014). If 10 percent of these trips were replaces by EPAC trips, the GHG decrease would amount to 0.7 million ton CO_2-eq, over 1 percent of Sweden's entire GHG emissions.

Example 2: Commuters from Lund to Malmö
56 000 business, work and study-related journeys are done to Malmö on a daily basis. Around 17 000 of those trips come from the municipalities of Lund, Staffanstorp and Burlöv which are the three closest municipalities north east of Malmö (Indebetou & Quester, 2008). The average length of those trips as 17 km (weighted by the number of travelers from respective municipality) and 57 percent of these as done by car, i.e. 9 700. Let's assume that we currently have zero EPAC commuting from either of the three municipalities. Again, let's imagine a scenario where 10 percent of the car trips are replaced by EPAC trips.

With the same conditions as in example one above, the decrease in GHG emissions is 75 tons of CO_2-eq per day, or over 15 000 tons annually.

6.3 The EPAC versus the public transportation system

The efficiency of the public transportation system is, just as the cars', heavily dependent on the load factor, i.e. the number of travelers. As can be seen in Figure 14, the efficiency of mass-transit vehicles, such as buses or trains, varies a lot with the number of travelers. Low utilization leads to a very ineffective system, while a public system with high level of utilization is probably the most emissions efficient transportation system existing today.

Another important deciding factor for the emissions of the public transportation system is the vehicle type, or rather the fuel used to power it. As we can see in Figure 13, there is a significant difference in emissions from a bus depending on if the fuel is fossil based or not. The gain from using a biofueled bus, compared to a fossil based bus, is approximately 70 g CO_2-equivalents per passenger kilometer. These two factors, utilization level and fuel origin, are the two most important factors to address if the GHG emissions are to be decreased significantly.

As we can see in Figure 13, the emissions level of the biofueled bus and train is in parity with the EPAC giving strong incentives to combine these different modes to form highly efficient transportation chains. It is more reasonable to consider the EPAC and public transportation system as complements to each other rather than competing modes. The EPAC and public transportation system offers different features and advantages where the EPAC is the more flexible mode while the public system offers means to travel longer distances and is normally not as weather dependent as the EPAC.

6.3.1 The climate gain of combining the public transportation system and the EPAC

From looking at Figure 13 it can be understood that a transportation chain constituting of taking the EPAC to the train station, getting on the train and finishing by EPAC to the final destination would in total have the same climate impact as going all the way by EPAC. From using similar assumptions as in Chapter 6.2.1 the net gain from making one person use such alternative instead of the car is approximately 230 g CO_2-equivalents per passenger kilometer. The gain from switching to the EPAC from the public system is around zero as presented in Figure 13. The above transport chain is a viable, realistic and good example of how the public transportation system and the EPAC complement each other. The system could either be designed in two different ways:

1. The commuter own the EPAC personally or
2. The EPAC is a part of the public transportation system.

The second variation requires the commuter to take a walk prior to getting on the EPAC, thus adds two elements to the entire chain.

6.4 The EPAC market

As we saw in Chapter 5, the traditional EPAC customer has not bought the EPAC for commuting reasons but because of physical disability. As younger age groups identify the EPAC as a highly potent commuting options it is nothing but reasonable that the market expands. The current low sales are not unexpected due to the fact that the main market segment has been the elderly, which is smaller compared to commuters. As more people get interested in the EPAC the product develops and more models/variations become available. Models solely designed for the EPAC market can now be found (such as the E-turn Neo) where the design has been given much more focus.

As Figure 27 and 28 shows, the EPAC customers appreciate the vehicle for several different reasons. This should be considered an opportunity for the dealers due to the fact that there are many unique selling points.

In Example 1 in Chapter 6.2.1 we have seen that there is a great potential in climate improvement for the transport sector if switching commuting trips from car to EPAC. However, the users' and customers' choices are not driven by the climate aspects as we saw in Chapter 5 (Figure 23) and the driver to buy an EPAC is mainly governed by other aspects. We can see that most people get their EPAC for commuting purposes which means that it is important that the trip is fast and convenient. From only looking at the characteristics of the EPAC it has the potential of traveling at 25 km/hour meaning in 30 minutes the cyclist could get as far as 12.5 km. This includes most commuting trips in Sweden.

For the EPAC to become a viable option and complement to the other modes of transportation the infrastructure needs to be planned in a manner that foster the use of EPAC. In terms of urban planning, constructing major routes adapted for bicycles and EPACs is one way of providing good alternatives to other forms of commuting. When looking through the literature and guidance provided by the government (such as TRAST), the rules and regulations today does not require any alteration between the bicycle and EPAC since major cycling routes are planned for 30 km/hours. However, since the range of the EPAC increases substantially compared the conventional bicycle the EPAC is to a greater extent more dependent on longer linked routes to take a person from A to B. From constructing bicycle freeways EPAC and bicycle commuting can be stimulated.

The probably two most influential documents dealing with commuting and EPAC is the document *"Ökad och säkrare cykling – en översyn av regler ur ett cykelperspektiv"* and *"Fossilfrihet på väg"* (referred to as *FFF-investigation*). The former addresses the safety aspects of cycling which is an important factor for choosing to travel by bicycle or EPAC and the latter is the investigation regarding how Sweden should have a fossil fuel independent vehicle fleet in 2030. The EPAC is not explicitly mentioned a single time in the latter document (search for *elcykel, pedelec, EPAC*) or mentioned in connection to the discussion of electrical drive. In the former investigation the definition of EPAC is presented but never after that mentioned (search for *elcykel, pedelec, EPAC*). An interesting observation from the FFF-investigation is that when searching for the term *cykel* (Swedish for "bicycle"), the bicycle is almost exclusively mentioned in connection to discussions regarding walking and the public transportation system even though these three ***different*** modes of transportation could constitute a large part of the emissions decrease in the transport sector. It is clear that the bicycle, and EPAC, is viewed as an insignificant alternative. As one of the interviewees point out, the bicycle is almost considered a toy in Sweden and not the transportation alternative it actually is. Locally and regionally the bicycle is being brought out in the spotlight. Such a region is the Malmö-Lund region where a bicycle freeway is planned between the two cities (Stark, 2011). The city of Uppsala and Örebro have similar initiatives.

7 Conclusions

The aim of this project was to evaluate the EPAC as a low-carbon commuting option, done through looking at the GHG emissions related to certain vehicles and to assess the market and the chance of the EPAC penetrating it.

The EPAC undoubtedly presents a good opportunity to substantially decrease the carbon dioxide emissions within the transport sector. Apart from the GHG emission reduction, improving the EPAC conditions also results in improved conditions for the conventional bicycle leading to synergy effects and additional benefits for the climate. Along with increasing the share of cyclists using either the EPAC or conventional bicycle are many other advantages. These two vehicles have no tailpipe emissions, resulting in no emissions of particles leading to improved air quality in cities, less congestion and daily exercise for the riders. In the long run, the ones benefiting from using an EPAC or a bicycle is the user herself. An increased use of two-wheel muscle powered vehicles results in more livable cities as seen internationally.

The EPAC is also progressively improving its sales figures and manufacturers all estimate the sales to keep increasing. From solely looking at the Dutch market, it is clear that the EPAC faces a bright future and during the time of this project an absolute increase in EPAC activities in media have been observed.

This report concludes the average climate improvement from introducing a new EPAC in the market to 30 g of CO_2-eq per passenger kilometer. Against individual vehicle types, the gain can

Box 6: Improving the EPAC

The major source of GHG emissions for the EPAC is the manufacturing and most likely the battery. The manufacturing accounts for 95 % of all emissions associated with the EPAC so the most efficient way of improving the EPAC climate performance is through addressing this part of the life cycle.

sometimes be as high as around 300 g CO_2-eq per passenger km depending on load factor and drivetrain. The fossil fuel based vehicles, including buses, cannot compete with the climate performance of the EPAC and the public transportation system needs renewable fuels to be able to compete. Public transportation should however be considered a complement and not a competing mode.

It is also clear that the EPAC touches upon many different stakeholders and that opinions sometimes can be strong on the matter. This most likely because the bicycle, or EPAC, challenges their current way of life. The car as main transportation form is rarely questioned and though it has many benefits and advantages compared to many other transportation forms, it is not superior when it comes to the environment and public health. If the vehicles investigated in this report is considered in the larger perspective, i.e. as one of many parts of society, all transportation modes but the car prove even stronger. This is because the car performs weaker in aspects such as congestion, air pollution, noise and safety.

So what is needed to increase the share of EPAC cyclists? The product (i.e. the EPAC) exists, hence providing the market with an important ingredient. The price of this product is considerably higher compared to the conventional bicycle which likely is the greatest barrier to a more rapid and wider adoption of the EPAC. Solely during the course of this project, the price of EPACs has dropped around 2000 SEK for the cheapest models lowering the threshold even more. A second important ingredient is the public space, ideally offering a safe and convenient place to use the bicycles/EPACs. As we could see in the Copenhagen and Houten example, the cycling planning needs to be long-term and with a strategic purpose in order to be successful. Here follows a list of important aspects to either investigate further or consider when increasing cycling.

- Developed infrastructure,
- Prioritizing the bicycle and EPAC equal to other vehicles especially in urban planning,
- Safer conditions for cyclists,
- Higher cost for the alternative modes, especially fossil fuel based ones,

The EPAC is a flexible vehicle that is fast, easy to use and at the same time not physically demanding unless you want it to, providing a great commuting opportunity along with several other benefits.

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9 Appendix

9.1 Environmental performance in the operations phase for different vehicles

This appendix presents the result of the calculations I have done for the emissions coupled to the operations phase. As stated many times earlier there are several different vehicles and fuels in this comparison. The different vehicles can be found in separate chapters. No separation have been done according to the different fuels in this study.

The tables have all the same title row independent of vehicle. The first three columns states the vehicle, engine type and which fuel that the data in that specific row discusses. The forth column states the emissions that originates from driving the vehicle. For the fluid petroleum and renewable fuels and gas fuels this means that the fuel is combusted in the vehicle engine and the emissions stated in that column is therefore only the emissions from that direct combustion. The emissions stated for the electric propulsion systems is calculated from a life cycle perspective by the trade organization Svensk Energi (Svensk Energi, 2011). The fifth column declares how much energy the specific vehicle uses per vehicle kilometer, i.e. the efficiency of the engine. I have not used specific engines as examples here but used numbers presented either by the manufacturer or NTM. The sixth column presents the maximum number of passengers for each vehicle. This number is only intents the number of seats in respective vehicle, not the total number of passengers during for instance rush hour. The last column, the seventh, presents the results of this comparison which is the emissions per passenger kilometer. The equation for calculating the results is shown below.

$$Emissions/p\ km\ [g\ CO_2 - eq/p\ km] = Emissions[g\ CO_2 - eq/kWh] \cdot Energy\ efficency[kWh/v\ km] \cdot Passengers^{-1}[nbr]^{-1}$$

The equation used to calculate the energy efficiency for the different vehicles is the one below.

$$Energy/km\ [kWh/km] = Energy\ density\ [kWh/L] \cdot Fuel\ consumption\ [L/km]$$

9.1.1 Bicycle and EPAC

9.1.1.1 Method

The calculations of conventional bicycles and EPACs is done according to the equations presented above. The fuel consumption is estimated with a battery capacity of 10 Ah, 36 volt system and a range of 50 km. The energy consumed by human muscles is not taken into account in these calculations.

9.1.1.2 Results

Vehicle	Engine	Fuel	Emissions / energy unit[g CO_2-equ / kWh]	Energy / journey [kWh / v km]	Passengers	Emissions / passenger km [g CO_2-equ / p km]
Bicycle	None	Muscle	0	0	1	0
EPAC	Electric	Swe mix	20	0,0072	1	0,144
		Nordic mix	100	0,0072	1	0,72
		Renewable mix	5	0,0072	1	0,036
		Fossil mix	461	0,0072	1	3,3192

9.1.2 Cars

9.1.2.1 Method

The majority of the calculations done for the emissions for the cars are based on figures from either the Network for Transport and Environment (NTM) or the Swedish Environmental Protection Agency. A complete list of the sources for each figure can be found in the table below.

Engine	Fuel	Database
ICE	Gasoline, diesel	(The Swedish Environmental Protection Agency, 2013) for emission factors. NTM for fuel consumption (avg). (The Swedish Energy Agency, 2013) for energy density of fuel.
	Biodiesel	(Triangle Life Cycle Assessment, LLC, 2012) for emissions. Fuel consumption and energy density same as for Gasoline, diesel.
	Ethanol	(The Swedish Environmental Protection Agency, 2013) for emissions. Fuel consumption from NTM. Energy density from (The Swedish Energy Agency, 2013)
Gas	Natural gas	Emissions from (The Swedish Environmental Protection Agency, 2013). Fuel consumption from NTM. Energy density from EM.
	Biogas	Emissions from (The Swedish Environmental Protection Agency, 2013). Fuel consumption assumed to be 14 % higher than for natural gas,

		due to the lower energy density (found at (The Swedish Energy Agency, 2013)).
Electric cars	Swe mix, Nordic mix, renewable and fossil.	Emissions based on numbers from Svensk Energi (2012). Fuel consumption taken from Nissan Leaf.

For biodiesel, LCA data have been found with results according to the table below. (Triangle Life Cycle Assessment, LLC, 2012)

Process	GREET Biodiesel [g CO_2-eq / MJ]
Feedstock	-67.13
Fuel production	11.05
Vehicle operation	76.37
Net	20.29
Percent reduction over diesel	79%

Since the data collected and used in the different tables (showing environmental performance) are gathered from NTM and the Swedish Environmental Protection Agency, I have chosen not to use the LCA data for biodiesel but only the data of the fuel production phase. This because I estimate these numbers to be the best comparison to the other number used. Since the data I collected is used to calculated the emissions originating from the vehicle operations phase I will perform these calculations myself, again because that the method of producing the numbers is going to be as similar between the different vehicles and fuels as possible which in turn means that the numbers can be compared.

9.1.2.2 Results

Engine	Fuel	Emissions / energy unit[g CO_2-equ / kWh]	Energy / journey [kWh / v km]	Travelers	Emissions / passenger km [g CO_2-equ / p km]
ICE	Gasoline	261	0,73	1	190,53
		261	0,73	2	95,27
		261	0,73	3	63,51
		261	0,73	4	63,51
		261	0,73	5	47,63
	Diesel	261	0,62[2]	1	161,82
		261	0,62	2	80,91
		261	0,62	3	53,94
		261	0,62	4	40,46
		261	0,62	5	32,36

[2] Figures from NTM. 0.062 liter per km.

	Biodiesel	3,07	0,62	1	1,9
		3,07	0,62	2	0,95
		3,07	0,62	3	0,63
		3,07	0,62	4	0,48
		3,07	0,62	5	0,38
	Ethanol	1,53	0,6726	1	1,0291
		1,53	0,6726	2	0,5145
		1,53	0,6726	3	0,343
		1,53	0,6726	4	0,2573
		1,53	0,6726	5	0,2058
Gas[3]	Natural gas	209	0,788	1	164,692
		209	0,788	2	82,346
		209	0,788	3	54,897
		209	0,788	4	41,173
		209	0,788	5	32,938
	Biogas	4	0,752	1	3,008
		4	0,752	2	1,504
		4	0,752	3	1,003
		4	0,752	4	0,752
		4	0,752	5	0,602
Electrical	Swe mix	20	0,173[4]	1	3,46
		20	0,173	2	1,73
		20	0,173	3	1,153
		20	0,173	4	0,865
		20	0,173	5	0,692
	Nordic mix	100	0,173	1	17,3
		100	0,173	2	8,65
		100	0,173	3	5,767
		100	0,173	4	4,325
		100	0,173	5	3,46
	Renewable	5	0,173	1	0,865
		5	0,173	2	0,433
		5	0,173	3	0,288
		5	0,173	4	0,216

[3] The energy density of natural gas is 11.1 kWh/m^3 and biogas 9.7 kWh/m^3. The fuel consumption for biogas is assumed to be 14 % higher than for natural gas due to the difference in energy density. Energy consumption for natural gas is assumed to be 0.68 m^3/10 km.

[4] The energy consumption is based upon the Nissan Leaf. Figures found at http://www.miljofordon.se/fordon?view=detalj&id=37478.

		5	0,173	5	0,173
	Fossil based	461	0,173	1	79,753
		461	0,173	2	39,877
		461	0,173	3	26,584
		461	0,173	4	19,938
		461	0,173	5	15,951

9.1.3 Buses

9.1.3.1 Method

The emissions for each bus' configuration have been found through the Swedish Environmental Protection Agency (2013).

The energy consumption of the buses have been taken from the NTM database.

9.1.3.2 Results

Engine	Fuel	Emissions / energy unit[g CO_2-equ / kWh]	Energy / journey [kWh / v km]	Passengers	Emissions / passenger km [g CO_2-equ / p km]
ICE	Diesel	261	4,8	9,6	130,5
		261	4,8	19,2	65,25
		261	4,8	28,8	43,5
		261	4,8	38,4	32,63
		261	4,8	48	26,1
	Ethanol	1,67	4,6	9,6	0,8
		1,67	4,6	19,2	0,4
		1,67	4,6	28,8	0,267
		1,67	4,6	38,4	0,2
		1,67	4,6	48	0,16
Gas	Natural gas	209	5,88	9,6	128,013
		209	5,88	19,2	64,006
		209	5,88	28,8	42,671
		209	5,88	38,4	32,003
		209	5,88	48	25,6
	Biogas	26,6	5,723	9,6	15,8575
		26,6	5,723	19,2	7,9287
		26,6	5,723	28,8	5,2858
		26,6	5,723	38,4	3,9644

		26,6	5,723	48	3,171

9.1.4 Trains

There are only electrical trains investigated in this thesis, hence all trains presented below have an electrical drive train.

9.1.4.1 Method

Energy consumption	Source
Öresundståg	NTM database
Pågatåg	Gunnar Åstrand at Skånetrafiken
Stockholm metro	Jan Ternanden at SL

The number of passengers has also been provided by the sources for respective train's energy consumption.

9.1.4.2 Results

Train	Fuel	Emissions / energy unit[g CO_2-equ / kWh]	Energy / journey [kWh / v km]	Passengers	Emissions / passenger km [g CO_2-equ / p km]
Öresundståg	Swe	20	7,78	47,4	3,283
		20	7,78	94,8	1,641
		20	7,78	142,2	1,094
		20	7,78	189,6	0,821
		20	7,78	237	0,66
	Nordic	100	7,78	47,4	16,414
		100	7,78	94,8	8,207
		100	7,78	142,2	5,471
		100	7,78	189,6	4,103
		100	7,78	237	3,28
	Renewable	5	7,78	47,4	0,821
		5	7,78	94,8	0,41
		5	7,78	142,2	0,274
		5	7,78	189,6	0,205
		5	7,78	237	0,16
	Fossil	461	7,78	47,41	75,6503
		461	7,78	94,8	37,833
		461	7,78	142,2	25,222
		461	7,78	189,6	18,917

		461	7,78	237	15,13
Pågatåg	Swe	20	8,0	48,4	3,31
		20	8	96,8	1,65
		20	8	145,2	1,1
		20	8	193,6	0,83
		20	8	242	0,66
	Nordic	100	8	48,4	16,53
		100	8	96,8	8,26
		100	8	145,2	5,51
		100	8	193,6	4,13
		100	8	242	3,31
	Renewable	5	8	48,4	0,83
		5	8	96,8	0,41
		5	8	145,2	0,28
		5	8	193,6	0,21
		5	8	242	0,17
	Fossil	461	8	48,4	76,2
		461	8	96,8	38,1
		461	8	145,2	25,4
		461	8	193,6	19,05
		461	8	242	15,24
Stockholm metro	Swe	20	4,8	25,2	3,81
		20	4,8	50,4	1,9
		20	4,8	75,6	1,27
		20	4,8	100,8	0,95
		20	4,8	126	0,76
	Nordic	100	4,8	25,2	19,05
		100	4,8	50,4	9,52
		100	4,8	75,6	6,35
		100	4,8	100,8	4,76
		100	4,8	126	3,81
	Renewable	5	4,8	25,2	0,95
		5	4,8	50,4	0,48
		5	4,8	75,6	0,32
		5	4,8	100,8	0,24
		5	4,8	126	0,19
	Fossil	461	4,8	25,2	87,81
		461	4,8	50,4	43,9
		461	4,8	75,6	29,27
		461	4,8	100,8	21,95

		461	4,8	126	17,56