The E-bike: opportunities for Commuter Traffic

The potentials of using electric bicycles and -scooters in commuting traffic in relation to the accessibility and quality of the local environment of a compact Dutch city

Master Thesis Energy and Environmental Sciences

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Preface

To combine the master thesis of Energy and Environmental Sciences with an internship I started looking for a company in the summer of 2011. For me this was the opportunity to gather work experience. DHV in Groningen invited me to conduct a research in the field of sustainable mobility. As precondition the topic should be relevant for one of DHV’s initiators. Therefore region Groningen-Assen was approached and resulted in “the E-bike: opportunities for commuter traffic”. I am very grateful that Kees Anker was pleased to be my mentor within region Groningen-Assen. Moreover I would like to thank Ronald Eenkhoorn for his support in the field of sustainability and as my mentor within DHV. I would like to thank Gilbert Mulder for his support in the field of mobility and Henk Moll for his support within the university and as my mentor. Finally this report would not be here without the support of the colleagues and interviewees. I look back at an interesting and fun period at DHV and region Groningen-Assen. The combination of consultancy business and policy makers gave me the opportunity to discover two different work fields. The freedom and support were much appreciated and resulted in, what I believe a good product.

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Summary

The electric bicycle and -scooter are entering the personal mobility market quickly due to a number of advantages over conventional modes of personal mobility. However, the effects of this relative new mode of transport are quite unknown. Therefore this master thesis addresses the effects of E-bike use on accessibility and environment for commuter traffic in compact Dutch cities. Tangible scenarios for commuter traffic to the city of Groningen show effects of E-bike use on total energy usage and emissions. This research was initiated by region Groningen-Assen (cooperation of 2 provinces and 12 municipalities in the Netherlands) and DHV BV with the aim to investigate whether the E-bike might be suitable for mitigating accessibility problems and reducing the environmental impact of commuter traffic. Secondly, this thesis might provide valuable information for policy makers, when they want to continue their efforts to promote the use of E-bikes in daily commute traffic.

What is the effect of E-bike usage on the accessibility of commuting traffic and local environment in compact cities in the Netherlands?

Literature study and expert interviews show that the image that E-bikes are something for the elderly is changing. The E-bike appears to be a cheap, clean and flexible alternative for the car. However, the E-bike is theft sensitive, traffic safety is an issue and it has a higher environmental impact than the conventional bicycle. The effect of E-bike use on the accessibility of a city and the quality of its environment depend on the change of habits of commuters starting to use an E-bike. Therefore behavioral sciences are needed to understand a commuter’s choice.

Mode choice for commuters is determined by objective and subjective factors. It is hard, if not impossible to model mode choice sufficiently. The literature study shows that many factors determine the mode choice of commuter. Working together with experts resulted in a model with the relevant factors for E-bike usage. Costs, traffic safety, image, weather, habits (car use), quality of cycling infrastructure and the presence of facilities are most relevant. Measures focusing at a single factor are ineffective due to the many factors at stake. A balanced package of incentives contains cycling infrastructure and public cycling facilities. Finally different target groups and situations demand for tailor made incentives. Mobility management is an effective measure to persuade the car commuter to switch in particular to E-bike.

Improvement of cycling infrastructure results in more cycling movements and better accessibility of a compact city. Traffic counts at upgraded cycling routes show in all cases more cycling movements per day; in some cases up to 17%. The utilization of E-bikes enhances the above mentioned effects. A literature study (including model studies, traffic counts and market research) and expert interviews show an increase in the number of cycling movements, a decrease in the number of car movements, a better traffic flow, higher average speeds for commuter traffic and less parking problems in city center. E-bike use results in a larger share of the E-bike in the total number of movements for commuter traffic (modal split). Size and cause of the shift differs per situation and the applied research method. Market research concludes that the total number of commuting cycling trips potentially increases with 4-9% due to a large availability of E-bikes. The E-bike appears to substitute for other means of transport for commuting traffic. More than 50% was previous conventional bicycle user, around 25% car user and the rest public transport and scooter.
The E-bike offers advantages concerning energy use and emissions compared to car and bus use. Accurate emission data was available for car and bus in the Netherlands. Since accurate data for E-bike for the Dutch situation was not available, Chinese data sets were analyzed and modified to fit the Dutch situation. The data was used for the scenario analysis for commuter traffic (<15 km) to the city of Groningen in 2020 (Netherlands). The scenario with 10% more E-bike use (modal split: 67.5% car, 7.5% bus, 15% bicycle and 10% E-bike) results in lower total energy use and emissions compared to a business as usual scenario (modal split: 70% car, 10% bus, 19% bicycle and 11% E-bike). Alternative options to reduce environmental impact of commuter traffic were calculated as well. E-bike use was put into perspective with the improvements of energy efficiency of cars, car sharing and the E-bike in combination with renewable electricity. The use of E-bikes offers a substantial contribution to the reduction of the total environmental impact of commuter traffic. Moreover batteries have a large environmental impact due to scarce material use. Therefore further development of batteries and recycling of materials is important for sustainable personal transport.

Finally this study shows the E-bike potential for different cycling corridors in region Groningen-Assen. An integrated public transport network in combination with the development of car infrastructure, cycling infrastructure and park and ride will guarantee good accessibility for region Groningen-Assen in the future. Different modalities will strengthen each other. In such infrastructural networks the E-bike will have its own role for commuter traffic.
Samenvatting (Dutch)

De elektrische fiets en –scooter winnen snel terrein op het gebied van personenmobiliteit, ze bieden een aantal voordelen boven de gangbare vervoersmiddelen. De effecten van deze relatief nieuwe modaliteit zijn nog onbekend. Deze master scriptie geeft een gedetailleerd beeld van de effecten van E-bike gebruik op bereikbaarheid en milieu voor woon-werk verkeer in compacte Nederlandse steden. Het effect van de E-bike op totaal energie gebruik en emissies wordt inzichtelijk gemaakt aan de hand van verschillende scenario’s voor woon-werk verkeer naar de stad Groningen. Het onderzoek is uitgevoerd in opdracht van regio Groningen-Assen (samenwerking van provincie Groningen en Drenthe en 12 noord Nederlandse gemeentes) en DHV BV. Het doel is om te onderzoeken of de E-bike een geschikte optie is voor het verminderen van bereikbaarheidsproblemen en de milieu impact van woon-werk verkeer. Daarnaast kan dit rapport waardevolle informatie bieden voor beleidsmakers wanneer zij door willen gaan met het actief stimuleren van E-bike gebruik voor dagelijks woon-werk verkeer.

Wat is het effect van E-bike gebruik op de bereikbaarheid van woon-werk verkeer en milieu in compacte Nederlandse steden?

Een uitgebreide literatuurstudie en expert interviews tonen aan dat het imago van de E-bike, *het is iets voor ouderen*, veranderd. De E-bike blijkt een goedkoop, schoon en flexibel alternatief voor de auto. Echter, de E-bike is diefstalgevoelig, verkeersveiligheid is een punt van aandacht en de E-bike heeft een grotere milieu impact dan de gangbare fiets. Het effect van E-bike gebruik op bereikbaarheid en milieu hangt sterk af van de verandering van gewoontes van de forens die E-bikes gaan gebruiken. Om de keuze van de forens volledig te begrijpen is goed gekeken naar literatuur uit de gedragswetenschappen.

De keuze van de forens voor een bepaalde modaliteit is gebaseerd op objectieve en subjectieve factoren. Het blijkt moeilijk, al dan niet onmogelijk om modaliteitskeuze voldoende te modelleren. De literatuurstudie toont vele factoren die invloed hebben op de modaliteitskeuze van de forens. In samenwerking met experts is een overzicht gemaakt van relevante factoren voor E-bike gebruik. Kosten, verkeersveiligheid, imago, weersomstandigheden, gewoontes (auto gebruik), kwaliteit van fietsinfrastructuur, buiten zijn (beleving) en aanwezige fietsfaciliteiten blijken meest relevant. Maatregelen die in relatie staan tot een enkele relevante factor voor E-bike gebruik, blijken inefficief. Daarom is een gebalanceerd pakket noodzakelijk om E-bike gebruik te stimuleren; het pakket van maatregelen is gebaseerd op verbeterde fietsinfrastructuur en fietsfaciliteiten. Tot slot vragen verschillende doelgroepen en situaties om maatregelen op maat. Mobiliteitsmanagement is een effectieve maatregel om de autogebraikker te stimuleren de overstap naar de E-bike te maken.

Het verbeteren van fietsinfrastructuur resulteerd in meer fietsverplaatsingen en betere bereikbaarheid in een compacte stad. Verkeerstellingen op verbeterde fietsroutes tonen in alle gevallen meer verplaatsingen per dag in vergelijking met de situatie twee jaar geleden, met een maximale toename van 17% per jaar. Het gebruik van E-bike versterkt deze effecten; de literatuur studie (verkeersmodel studies, verkeerstellingen en marktonderzoek) en expert interviews tonen een toename van het aantal fietsverplaatsingen, minder autoverplaatsingen, betere verkeersdoorstroming, hogere gemiddelde snelheid in de spits en minder parkeerproblemen. Door het gebruik van de E-bike verschuift het aandeel van de fiets in het
totaal aantal woon-werk verplaatsingen (modal split). Reden en omvang van deze verschuiving verschilt per situatie en de gebruikte onderzoeksmethode. Marktonderzoek toont dat het grootschalig beschikbaar zijn van de E-bike leidt tot een potentiële toenane van 4-9% van het totale aantal fietsverplaatsingen in Nederland voor woon-werk verkeer. Hierbij vervangt de E-bike andere modaliteiten; meer dan de helft was voormalig fiets gebruiker, een kwart auto gebruiker en het overige deel openbaar vervoer en scooter gebruiker.

E-bike gebruik biedt voordelen betreffende energie verbruik en emissies in vergelijking met auto en bus gebruik. Er is betrouwbare data beschikbaar voor de Nederlandse situatie voor auto en bus. Aangezien betrouwbare data voor de E-bike en fiets niet beschikbaar was zijn Chinese data sets gebruikt, deze zijn grondig geanalyseerd en aangepast aan de Nederlandse situatie. De data is gebruikt voor de scenario analyse voor woon-werk verkeer naar de stad Groningen (< 15 km) in 2020. Het scenario met 10% meer E-bike gebruik (modal split: 67,5% auto, 7,5% bus, 15% fiets en 10% E-bike) leidt tot een lager totaal energie verbruik en emissies dan een business as usual scenario (modal split: 70% auto, 10% bus, 19% fiets en 1% E-bike). Tevens zijn scenario’s met alternatieve opties om de milieu impact van woon-werk verkeer te verminderen doorgerevkend. E-bike gebruik wordt in perspectief geplaatst met hogere energy efficiency van auto’s, hoger gemiddeld aantal izittende in auto’s (carpooling) en de E-bike in combinatie met hernieuwbare energie. Het blijkt dat het 10% meer E-bikes scenario een substatiële bijdrage levert aan het reduceren van de milieu impact van woon-werk verkeer. Tevens blijkt dat materialen die verwerkt zijn in accu’s een groot aandeel hebben in de totale milieu impact van elektrisch vervoer. Dit bednadrukt de urgentie van verdere ontwikkeling van accu’s en recycling van materialen voor duurzame mobiliteit.

Tot slot is de de potentie berekend van de E-bike voor woon-werk verkeer op verschillende corridors in de regio Groningen-Assen. Goede bereikbaarheid zal gerealiseerd worden door een intergaal openbaarvervoersnetwerk met daarnaast de ontwikkeling van auto –en fiets infrastructuur, park and ride (P+R) en beleid om trent E-bikes. Hierbij zullen de verschillende modaliteiten elkaar versterken en zal de E-bike een belangrijke rol spelen.
1 INTRODUCTION

Despite strong head winds and steep hills you are overtaken on your bicycle by someone who has seemingly no effort of pedaling his/her bicycle whatsoever. This person’s bicycle looks conventional at first sight. But take a closer look and discover it is an electric bike (E-bike). The E-bike gains popularity in Dutch cities quickly. The pedal assisted bicycle and the fully electric versions are sold more and more, its market share is increasing substantially. The E-bike is promoted as a sustainable and zero emission mode of transport since it does not produce direct emissions. The E-bike should also mitigate accessibility problems in urban areas. However, the effects of this relative new mode of transport are quite unknown. Therefore this master thesis addresses the effects of E-bike use on accessibility and environment for compact Dutch cities.

The Dutch city of Groningen is dealing with an increase in daily commuter traffic. Possibilities for additional car infrastructure are limited in the compact city. Moreover the local government aims at promoting sustainable transportation. Not only public transport is considered as a sustainable alternative for the car, but cycling as well. An important measure is to improve cycling infrastructure and to stimulate the use of E-bikes. This research was initiated by region Groningen-Assen with the aim to investigate whether the E-bike might be suitable for mitigating accessibility problems and reducing the environmental impact of commuter traffic. Secondly, this thesis might provide valuable information for policy makers, when they want to continue their efforts to promote the use of E-bikes in daily commute traffic.

The chapters 3 and 4 address strengths, weaknesses, opportunities and threats of E-bike use in comparison with using cars. An analysis of commuter traffic in the Netherlands is included. The environmental impact of the use of E-bike, car, bus and bicycle is compared with respect to energy use, local air emissions and battery use. The Dutch fossil energy demand is increasing every year, which makes the improvement of the energy efficiency of the mobility sector essential. Moreover local air emissions cause problems for human health and nature. Finally E-bike batteries contain hazardous and scarce materials; therefore battery use is part of the analysis as well.

Chapter 5 addresses the modality choice of the commuter. It is known from the behavioral sciences, that many factors are influencing the modality choice of the commuter. It results in a model with the relevant factors for E-bike usage.

The effect of E-bike use on accessibility is treated in chapter 6. The chapter is focused on the effects of both improved cycling infrastructure and a better availability of E-bikes for commuter traffic. Daily commuter traffic is increasing every year in the Netherlands. Additional car use is one of the main reasons for stagnating commuter traffic. Therefore Dutch policy makers aim at stimulating public transport, park and ride and cycling. Additional E-bike use will replace other modes of transport. Therefore the total environmental impact is determined by the share of bicycle movements in comparison to car and bus movements which are replaced by E-bike.

Chapters 7 and 8 concern the accessibility program of the region Groningen-Assen which includes measures for public transport, park and ride and cycling. The potential E-bike use was calculated. Different scenarios between now and 2020 were constructed, which show the environmental impact of additional E-bike use. The model includes commuter traffic for the city
of Groningen within a range of 15 km. A scenario with 10% E-bike usage in 2020 is compared to a business as usual scenario and various other options to reduce the environmental impact of commuter traffic.
2 RESEARCH METHODS

This chapter comprises applied research methods and the structure of this master thesis. The chapter includes the company description, problem analysis, boundaries, research questions and research methodology and process.

2.1.1 Company description

_DHV BV_ is an international consultancy and engineering firm. The main work fields are environment and sustainability, general buildings, manufacturing and industrial process, urban and regional development and water. The range of services covers the entire project cycle, including management consultancy, advice, design and engineering, project management, contract management and asset management. The DHV headquarters is positioned in Amersfoort. DHV has a number of regional offices throughout the Netherlands; including one in Groningen.

.Region Groningen-Assen_ (RGA) is a cooperation on policy level between the province of Drenthe, the province of Groningen and 12 municipalities in the northern part of the Netherlands. The partners work together on four different fields which are residential, business and economy, accessibility and environment.

2.1.2 Problem analysis

Accessibility is one of the work fields of region Groningen-Assen. The different partners of RGA work together on an integral accessibility program. The aim of this program is to guarantee good and safe accessibility of the region on behalf of economic development. Fact is that the accessibility of the city of Groningen is under pressure. The number of car movements for commuter traffic is expected to increase substantially in the coming years. Since Groningen is a compact city there is not enough space for additional car infrastructure and car parking. Moreover construction of the most important feeder road (southern belt road) will cause additional disutility for commuter traffic. Therefore the accessibility program includes smart transport solutions and alternative modes of transport; including park and ride (P+R), public transport and the bicycle.

Another problem is the environmental impact of commuter traffic. The Dutch mobility sector uses large quantities of fossil fuels and it is a large contributor of local air emissions. Moreover governments are forced to mitigate air pollution since European environmental regulations become stricter. Local air emissions have serious consequences for human health and nature. Global warming raises the necessity of mitigating CO₂ emissions. Finally energy use by the mobility sector is a problem since fossil fuels are scarce.

The aim of this research is to determine if the E-bike is a suitable option to mitigate accessibility problems of cities and reduce the environmental impact of the mobility sector in the Netherlands. Second, when it does prove to be a suitable option, this thesis will provide valuable information for policy makers to promote the E-bike most effectively.
2.1.3 Boundaries
This study includes commuter traffic within a radius of 15km from the city center of Groningen as shown in Figure 1. The focus is on accessibility by different modalities and a number of environmental issues.

Accessibility
The time necessary and circumstances in which a commuter reaches its destination. Including:
- the flow of traffic
- average speed
- lost time in traffic
- car parking

Environmental impact
Including:
- Energy use
- CO₂ emissions
- NOx emissions
- SO₂ emissions
- Particulate matter
- Impact battery

Figure 1, Research boundaries: E-bike for commuter traffic within 15km from city Groningen

2.1.4 Research questions
What is the effect of E-bike usage on the accessibility of commuting traffic and local environment in compact cities in the Netherlands?

Sub questions:
1. What is an E-bike and what are the strengths, weaknesses, opportunities and threats?
2. Which factors determine the mode choice of Dutch commuters and for E-bike in particular?
3. What is the effect of improved cycling infrastructure and E-bike use on accessibility of a compact Dutch city for commuter traffic?
4. What is the role of the E-bike within the accessibility program for region Groningen-Assen?
5. What is the effect of E-bike usage on energy use and local air emissions on system level for commuting traffic in region Groningen-Assen?
2.1.5 Research methodology and process

The research methodology and process are shown in Figure 2. This study contains a literature review on the effect of cycling infrastructure and the use of E-bikes on accessibility and environment. Scientific journals, research reports, consultancy reports, traffic models and available data from municipalities where assessed. The literature review resulted in a SWOT analysis E-bike and a qualitative model containing all relevant factors for E-bike mode choice. Another part of the literature study comprises the accessibility program of region Groningen-Assen and the role of the E-bike. Finally the effect of different scenarios for commuter traffic in region Groningen-Assen shows the effect of E-bike usage on local environment.

Figure 2, Scheme research methodology and process

A number of interviews were conducted with experts, structured and un-structured. Experts were selected from different areas concerning E-bikes and cycling policy, e.g.: interest groups, research groups, consultancy firms and government. Table 1 shows the complete list of expert interviews, the companies, area and content of the interview. The main findings were discussed with Otto van Boggelen, (director of Fietsersbond) and Ben Boersma (smarter travel & working), before conclusions were defined.

Table 1, Expert interviews

<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
<th>Area</th>
<th>Content interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ben Boersma</td>
<td>Smarter travel &amp; working</td>
<td>Government</td>
<td>Mobility management and cycling policy</td>
</tr>
<tr>
<td>Bastiaan Possel</td>
<td>Goudappel Coffeng</td>
<td>Consultancy</td>
<td>National traffic model</td>
</tr>
<tr>
<td>Cecile Haffmans</td>
<td>Rijkswaterstaat</td>
<td>Control road infrastructure</td>
<td>Mobility management</td>
</tr>
<tr>
<td>Cor van der Klaauw</td>
<td>Province of Groningen</td>
<td>Government</td>
<td>Cycling policy</td>
</tr>
<tr>
<td>Eric Neef</td>
<td>ANWB</td>
<td>Traffic interest group</td>
<td>Mobility management</td>
</tr>
<tr>
<td>Jan Banninga</td>
<td>Goudappel Coffeng</td>
<td>Consultancy</td>
<td>National traffic model</td>
</tr>
</tbody>
</table>
The study was conducted in different steps:

1. SWOT analysis E-bike (interview & literature)
2. Comparison environmental impact E-bike with car, bus and bicycle (interview & literature)
3. Effect E-bike on accessibility compact Dutch city (interview & literature)
4. Accessibility program region Groningen-Assen (case study, interview & literature)
5. Scenario analysis region Groningen-Assen, environmental impact on system level (scenario analysis)
3 THE E-BIKE AND COMMUTER TRAFFIC IN THE NETHERLANDS

Commuter traffic in the Netherlands is a relevant topic when talking about personal mobility. The daily flow of traffic between residential and work areas is under pressure. Additional car movements result in congestion and local air emissions. Within this context the E-bike is promoted as a “sustainable” mode of transport for commuting traffic. This chapter will first address the current trends in personal mobility for the Netherlands and “sustainable mobility”. Then cycling in general is analyzed on different levels of scale. Finally a SWOT analysis is presented about the E-bike in particular.

3.1 Trends personal mobility and sustainability

A number of trends are noticeable within personal mobility in the Netherlands. These trends have effects on commuter traffic in the coming years [1].

1. Ageing of the population
2. Increasing number of nationalities
3. Individualization, households become smaller and more single person households
4. Intensification, people’s daily schedule becomes more intense and busy
5. Re-urbanisation, movement to central areas of the Netherlands, population of regional areas shrinkages

Above mentioned trends have effects on commuter traffic and the role of the E-bike. The number of car movements will increase. The use of public transport will increase in urban areas and shrink in rural areas. The share of bicycle movements will stabilize; the main reasons are increasing distances due to scale enlargements of facilities and increasing car possession. [1] This thesis will address the effect of current trends on the usage of E-bikes.

Besides above mentioned trends there is an increasing focus on “sustainable mobility”. Three elements, people, planet and profit, should be combined in harmony in order to develop a successful service. When the focus will be too much on a single element, the other two will suffer (Elkington J.). Figure 3 shows the three elements (P’s) applied on mobility.

<table>
<thead>
<tr>
<th>People</th>
<th>Planet</th>
<th>Profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>User</td>
<td>Modal shift</td>
<td>Flexibility</td>
</tr>
<tr>
<td>Vulnerable road users</td>
<td>Time shift</td>
<td>Long term profit</td>
</tr>
<tr>
<td>Behavior</td>
<td>Direct + indirect energy</td>
<td>Efficiency</td>
</tr>
<tr>
<td>Livability</td>
<td>Local air emissions</td>
<td></td>
</tr>
<tr>
<td>Future developments</td>
<td>CO₂ emissions</td>
<td></td>
</tr>
<tr>
<td>and uncertainties</td>
<td>Material use</td>
<td></td>
</tr>
<tr>
<td>Innovation and knowledge</td>
<td>Soil</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ecology</td>
<td></td>
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</tbody>
</table>

Figure 3, Sustainable mobility and triple P, [2]
Air emissions are increasingly relevant since legal emission standards become stricter within the European Union [3]. Moreover global warming and environmental degradation emphasize the necessity for reducing the environmental impact of personal mobility. Finally profit is an essential element in order to achieve a successful personal mobility service. The topics for each element (P’s) as presented above will be addressed throughout this research.

3.2 Cycling in Europe and the Netherlands

The bicycle is used throughout Europe for short distance trips already. Table 2 shows the share of bicycle trips in total number of trips for different European countries. The table shows that the Netherlands has the highest share followed by Denmark, Sweden and Germany.

Table 2, Share of bicycle trips in total number of trips Europe, [4]

<table>
<thead>
<tr>
<th>Country</th>
<th>Share of trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Netherlands</td>
<td>27.0%</td>
</tr>
<tr>
<td>Denmark *</td>
<td>17.2%</td>
</tr>
<tr>
<td>Sweden</td>
<td>12.6%</td>
</tr>
<tr>
<td>Germany 1989</td>
<td>12.1%</td>
</tr>
<tr>
<td>Switzerland</td>
<td>9.4%</td>
</tr>
<tr>
<td>Finland *</td>
<td>7.4%</td>
</tr>
<tr>
<td>Austria (Ober)</td>
<td>6.9%</td>
</tr>
<tr>
<td>Norway</td>
<td>6.2%</td>
</tr>
<tr>
<td>France – Grenoble</td>
<td>4.5%</td>
</tr>
<tr>
<td>France - Lyon</td>
<td>1.8%</td>
</tr>
<tr>
<td>Great Britain *</td>
<td>1.7%</td>
</tr>
</tbody>
</table>

With a total amount of 18 million bicycles in the Netherlands in 2010, there is one bicycle for every 0.9 citizen. Therefore the Netherlands has the most bicycles per citizen in the World. [5] The bicycle is the most popular mode of transport for distances up to 7.5 km in the Netherlands. [6]

Bicycle use differs per region in the Netherlands. Region Groningen-Assen (RGA) in the northern part of the country has a relative high share of bicycle use.

Table 3 shows the share of bicycle movements within the total and for movements up to 7.5 km for different municipalities in the Netherlands. [7] It shows that bicycle use is relatively high in the municipalities which are part of RGA. The relative large share is the effect of years of cycling friendly policies and the "compact" spatial planning of the city Groningen. Car traffic e.g. is allowed to enter the city center coming from the belt road, but it is not possible to pass through the city center. Other measures are e.g. a network of separate cycling paths and parking facilities for bicycles.

Table 3, Bicycle use for different municipalities in the Netherlands, [7]

<table>
<thead>
<tr>
<th>Dutch Municipality</th>
<th>Share bicycle in total movements (%)</th>
<th>Share bicycle in movements &lt;7.5km (%)</th>
<th>Relative to Dutch average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haren (RGA)</td>
<td>32</td>
<td>43</td>
<td>Extremely high</td>
</tr>
</tbody>
</table>
Bicycle usage is relatively high in region Groningen-Assen. Nonetheless, BOVAG and RAI determine that policymakers tend to underestimate the positive contribution of cycling to accessibility and sustainable transport. Still there is a potential for growth. [8] The E-bike might be a strong incentive for cycling in general by commuters.

### 3.3 The E-bike

This report addresses the E-bike. The term “E-bike” comprises different models of electric two wheelers namely: electric bicycles and scooter style electric bikes. In the Netherlands a distinction is made between mofas type scooter (25 km/h) and moped type scooter (45 km/h). This study will focus on the mofas type scooter only because the maximum speed is comparable to the electric bicycle and no helmet is required. When E-bike is mentioned in this report it comprises the electric bicycle and the mofas type scooter. A few examples of E-bikes are shown below with general characteristics.

#### E-bike

- **A2B Metro**
  - Driving range: 30-80 km
  - Charge time: 4-8 hours
  - Price €1,000-€3,000
  - Helmet not obligated

- **Batavus BUB Easy**
  - Driving license and Insurance obligated for scooter type only (max speed 25 km/h)

- **Qwic Emoto lite**
  - Driving license and Insurance obligated for scooter type only (max speed 25 km/h)

- **Ebretti 318**

**Figure 4**, “E-bike” comprises different models of electric two wheelers

The total amount of new bicycles sold in the Netherlands has decreased between 2005 and 2010. The market share of E-bikes however increased. Figure 5 shows the development of the market share for E-bicycle and E-scooter. It shows the market share in comparison to the conventional non electric versions. There were 444,261 Scooters (mofas) in total in 2010. The share of E-scooters (mofas) was around 2,000 in 2010; the share increased to 11,000 in the course of 2011. [5] [9] The market share trend is expected to continue, but annual growth will slowly reduce according to assessed experts [3,10-14]. The current increase is to be found within
the target group “elderly”. It is likely that the relatively new target group “commuters” will result in a continuing growth in E-bike sales.

“Development of E-bike market share will depend greatly on the price, image and policy” [14]

The growth of E-scooter market share is less large because currently the scooter is popular among youngsters; the electric versions are less popular among this target group. It is likely that the E-scooter will be used increasingly among commuters; this development depends greatly on the image of the E-scooter.

Figure 5, Market share (%) E-bikes in comparison to non electric bicycle and E-scooter in comparison to combustion engine scooter (mofas), Netherlands 2006-2010

The less pressure the user puts on the pedals, the more power the electric motor provides. Therefore a constant maximum assisted speed of 25 km/h can be maintained easily by the user despite hills or head wind. The pedal assistance stops when a speed of 25 km/h is reached.

The E-bike is accessible for a large range of users and is in many ways similar to the conventional bicycle. The use of an electric bicycle does not require the driver to wear a helmet. Neither insurance nor a driving license is required. Therefore without any extra measures people are able to travel faster and with less effort compared to a conventional bicycle. The E-scooter is less accessible because it has fewer similarities with a conventional bicycle. The E-scooter is fully powered and there is a throttle on the steer. Therefore it does require insurance and a (scooter) license.
3.4 SWOT analysis E-bike

A SWOT analysis was made in order to investigate the increasing market share of the E-bike. The analysis includes the internal strengths and weaknesses and the external opportunities and threats of the E-bike. [15] Table 4 provides an overview of the SWOT analysis; it will be further addressed throughout this chapter.

Table 4, SWOT analysis E-bike in comparison to car

<table>
<thead>
<tr>
<th></th>
<th>Helpful</th>
<th>Harmful</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Strengths</strong></td>
<td><strong>Weaknesses</strong></td>
</tr>
<tr>
<td>Internal</td>
<td>low energy use</td>
<td>theft sensitivity</td>
</tr>
<tr>
<td></td>
<td>price (and fuel costs)</td>
<td>battery charge time</td>
</tr>
<tr>
<td></td>
<td>usability</td>
<td>battery cycle life (recharges)</td>
</tr>
<tr>
<td></td>
<td>personal exercise</td>
<td>battery weight</td>
</tr>
<tr>
<td></td>
<td>no direct emissions</td>
<td>indirect emissions (environment)</td>
</tr>
<tr>
<td></td>
<td>flexible (parking)</td>
<td>comfort</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External</td>
<td>alternative for short trip car travel (2-30 km)</td>
<td>image “elderly” &amp; status</td>
</tr>
<tr>
<td></td>
<td>collective/ company e-bike for/ after public transport</td>
<td>traffic (un)safety</td>
</tr>
<tr>
<td></td>
<td>innovation battery and technology</td>
<td>bad weather</td>
</tr>
<tr>
<td></td>
<td>public charge and parking facility</td>
<td>trade-off with public transport</td>
</tr>
<tr>
<td></td>
<td>mobility management</td>
<td>habit car use</td>
</tr>
<tr>
<td></td>
<td>e-bike training</td>
<td></td>
</tr>
</tbody>
</table>

The SWOT analysis shows the E-bike use in comparison to car use. When the E-bike would be compared to the conventional bicycle it would perform better on comfort, personal exercise and travel speed. The E-bike would perform worse on energy use, indirect emissions and price.

3.4.1 Strengths

A great advantage of the E-bike is a lower energy use compared to car. [11]. The battery can be removed from the E-bike in order to charge it indoors. A conventional wall outlet is suitable to fully charge the battery in 2-6 hours (depending on the battery capacity). An average E-bike consumes plug-to-wheel 1.8 kWh/ 100 km [16]

“With an electricity price of €0.22/kWh the required energy for driving is €0.40 per 100 km.”

The average speed of an E-bike is higher than the conventional bicycle. Therefore in the theory it would travel a larger distance in the same amount of time. Table 5 shows the average cycling speed for different configurations. [17] It shows that the average cycling speed is relatively low in city centers (V5). This accounts for the electric versions as well as for the conventional bicycle. The cycling speed in crowded cities is even lower, 5-8 km/h, because of many interruptions by traffic lights and intersections. Since Groningen has a relatively well developed cycling infrastructure the average speed in city centers is estimated at 10 km/h. The average cycling speed will increase when the E-bike is used and quality of cycling infrastructure improves (V2 till
When the quality of conventional cycling paths is improved according quality standards they are called “bike route plus” or “bike highways”. The quality standards for a bike route plus are shown in appendix 13.4. The average speed of the conventional bicycle will not be higher than 18 km/h under the best circumstances.

<table>
<thead>
<tr>
<th></th>
<th>Average speed (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1 (E-bike + bike route plus)</td>
<td>24</td>
</tr>
<tr>
<td>V2 (E-bike + conv. bike route)</td>
<td>20</td>
</tr>
<tr>
<td>V3 (conv. bi + bike route plus)</td>
<td>18</td>
</tr>
<tr>
<td>V4 (conv. bi + conv. bike route)</td>
<td>15</td>
</tr>
<tr>
<td>V5 (city center)</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 5, Average speed E-bike for different situations in km/h [17]

The above presented data show that improving cycling infrastructure (V3) has a large impact on the average cycling speed. Therefore the traveled distance will be 20% higher in the same amount of time. The effect is even larger when the E-bike is applied (V1&2). The traveled distance in this case will be 33%-60% higher than by conventional bicycle. One should notice however that the effect on average cycling speed is strongest for trips outside the city center. The effect of the cycling speed on the range of cycling in region Groningen-Assen is shown in appendix 13.1. E-bike usage has consequences for the environment; it is addressed in the next chapter in detail.

Finally E-bike use offers advantages for human health [8]. The additional exercise has positive effects on human health. One should notice however that it is important which modality was used previously. A conventional bicycle will result in more personal exercise than an E-bike. Moreover, the reduction of local air emissions has a positive effect on human health. The positive health effect can be stronger when the E-bike stimulates people to go cycling more often and travel larger distances.

3.4.2 Weaknesses

The E-bike has a number of weaknesses. The extra total weight has consequences for the usability of the E-bikes. The removable battery and electric motor result in 5-10 kg additional weight on the E-bicycle. Therefore it is 25-50% heavier than the non-electric version. The E-scooter has a total mass of 60-120 kg (including battery). Additional weight is an issue since the 15 kg battery can be removed in order to carry it indoors. [18]

The e-bike is a costly product. Prices for E-bicycles range between €1,000 and €3,000. Therefore an E-bicycle is up to three times as expensive as the conventional bicycle. For E-scooters the difference is less. The prices of electric scooters range from €1,500 and €3,500. Therefore the price of E-scooters is comparable with the combustion engine types. High costs make the E-bike sensitive for theft; therefore security measures are installed. The battery is locked and can be removed with a key. Also the control panel on the steering wheel is removable. The E-bike is only operational when the control panel is attached to the steer or with an ignition key.
3.4.3 Opportunities

The E-bike can profit from external opportunities. The E-bike might prove a good alternative for short distance trips for commuting traffic. One of the opportunities is the development of cycling infrastructure. Another opportunity is the development of cycling facilities in combination with public transport. Therefore the E-bike can be used before or after public transport. Charge facilities, E-bike rentals and safe parking facilities at stations are options. Another opportunity is the advancement of battery technology. Prices of lithium ion batteries have gone down; now it is used instead of the lead acid battery. Finally mobility management can offer opportunities for the E-bike.

3.4.4 Threats

External threats are found within perception of (potential) users. A market research from 2008 shows that 80% of the respondents find the E-bike for “physically disabled people” and 75% find it “something for the elderly”. Only 11% of the respondents find the E-bike something for “commuters”. [6] Ever since, the E-bike market developed and its market share increased substantially (Figure 5), it is likely that the image is changing. The bicycle in general is known as a modality on which commuters are independent, flexible and on time. The bicycle is perceived less strong on comfort, convenience, speed and safety when compared to car and public transport. [8] The fact that the bicycle scores less on convenience and comfort is related to bad weather and the fact that people arrive "sweaty" at work on a conventional bicycle. Finally, a threat for the E-bike is the development of public transport and car infrastructure. There is a tradeoff with conventional bicycle users, public transport users and car users.

The SWOT analysis has been summarized in Figure 6. E-bike use contributes to: the reduction of local air emissions, improving accessibility of cities, more personal exercise, mitigating noise nuisance and smart space usage [8]. These issues are summarized in the top triangle. The bottom triangle shows incentives for E-bike usage on six cohesive areas.
bike designs result in different user groups and the image that the E-bike is “something for the elderly” is expected to change. Moreover, further technical developments will strengthen the position of the E-bike and gradually reduce prices.

3.5 Conclusion
The analysis of the E-bike results in a number of conclusions. Cycling usage is relatively high in the Netherlands, but large differences occur between regions. Well-developed cycling infrastructure and cycling culture in region Groningen-Assen, results in a relatively large bicycle usage. Therefore region Groningen-Assen is suitable for the large scale introduction of the E-bike. Moreover this region can be used as an example for other regions in the Netherlands. Currently the E-bike market share increases and this trend will continue after 2011. E-bike prices (and batteries) are expected to go down gradually. The image that electric cycling is something for “elderly” is changing. The E-bike in combination with bike route plus has a positive effect on cycling speed and comfort. The traveled distance per time unit on bike route plus with E-bike is 33-60% higher than with a conventional bicycle on conventional cycling path.

This chapter shows the E-bike is entering the personal mobility market quickly. The development can be explained by a number of advantages over conventional modes of personal mobility. The E-bike offers advantages concerning accessibility and environment.
4 ENVIRONMENTAL IMPACT E-BIKE

The previous chapter concludes that the E-bike has among others many advantages concerning the environmental impact. The E-bike is promoted as “zero emission” and “sustainable”, this would suggest that it is environmentally friendly. Still the E-bike has an environmental impact during its life cycle. Moreover LCA studies show that production and waste phase cannot be neglected. A substantial environmental impact of the E-bike is related to the use of Lithium-Ion batteries [20].

4.1 Relevant emissions

Local air emissions and CO₂ emissions are part of the “planet part” of sustainable mobility as shown in Figure 3. There are many different air emissions; some are more relevant than others for urban mobility. This chapter will address direct and indirect energy use and CO₂, SO₂, NOx and particulate matter (PM) emissions for car, bus, bicycle and E-bike. Mentioned emissions are closely related to energy use. The effects of local air emissions on environment and public health are shown below.

- Anthropogenic carbon (CO₂) emissions are the largest cause of global warming. The mobility sector has a large share in the total production of CO₂ emissions in the Netherlands.
- Nitrogen oxide (NOx) is emitted during high temperature combustion of fuel e.g. in engines. The effect of NOx emissions are among others smog and acidification (acid rain).
- Sulfur dioxide (SO₂) is emitted during the combustion of petroleum and coal. SO₂ is the main cause of acidification.
- Particulate matter or fine dust (PM) is a form of air pollution caused by burning fuels and wearing of tires, road surface and brakes. The PM problem is mainly caused by natural sources (55%); transport is one of the largest anthropogenic sources (17%). The main effects concern human health. There are 3 types of PM emissions which are measured in micrometer: PM 10, PM 2.5 and PM 0.1; respectively 10, 2.5 and 0.1 micrometer. The smaller the size of particles is, the bigger the consequences for human health. The particles can easily enter the human bloodstream and cause among others heart diseases, respiratory diseases, bronchitis and asthma.

4.2 E-bike compared to car, bus and bicycle

Accurate emission data is available for car and bus in the Netherlands. For the E-bike however, accurate data for the Dutch situation is missing. A number of studies have been conducted on the environmental impact of E-bikes in China. In order to compare Chinese data to Dutch data the different data sets will be modified. The main difference is the energy mix for electricity production. The biggest difference is to be found in the dependency on natural gas in the Netherlands and the dependency on coal in China. The emissions will be derived from the direct and indirect energy usage of E-bike. It is assumed that the energy necessary to produce and use an E-bike in China is similar to an E-bike in the Netherlands. Also it is assumed that the energy required during production is electricity.
Five steps were conducted in order to compare the E-bike with car, bus and bicycle.

1. Energy use vehicle direct and indirect
2. Emissions vehicle
3. Emissions during fuel processing
4. Emissions during electricity production
5. Environmental impact battery

4.2.1 Energy

The E-bike is equipped with an electric engine and a battery. An average E-bike consumes plug-to-wheel 0.065 MJ/km [16]; this is direct energy. The indirect energy, on the other hand, is necessary for production of the E-bike and production of electricity. Total energy use of the E-bike is shown in Table 6, with an assumed lifespan 50,000 km.

**Table 6, Total energy use bicycle, E-bicycle and E-scooter (MJ/km)**

<table>
<thead>
<tr>
<th></th>
<th>MJ/km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycle (conventional)</td>
<td>0.176</td>
</tr>
<tr>
<td>Bicycle (electric)</td>
<td>0.274</td>
</tr>
<tr>
<td>Scooter (electric)</td>
<td>0.356</td>
</tr>
</tbody>
</table>

Above presented data was compared to car and bus as shown in Graph 1. It shows that the energy usage of E-bike is substantially lower than for car and bus. Results are shown in passenger per kilometer (pax-km). Results depend greatly on the average number of passengers assumed. Average number of passengers for Dutch commuter traffic during rush hour is applied. Total energy includes direct energy, tank to wheel (TtW) for patrol and plug to wheel for electric (PtW), and indirect energy, well to tank (WtT) and production vehicle.

![Graph 1](image-url)  
*Graph 1, Direct and indirect energy use commuter traffic (MJ/pax-km), in city, average number of passengers car 1.16 and bus 13, including production vehicle, indirect fuel WtT and direct fuel TtW*
4.2.2 Emissions

Data about the total emissions for car and bus in the Netherlands are available. The total emissions of the E-bike however, depend greatly on the local energy mix for the production of electricity. Table 7 shows the emissions of the conventional electricity production in the Netherlands for 2005, 2010 and 2020. The Dutch energy mix was: 60% gas, 25% coal, 11% nuclear and 4% misc. in 2005. The table shows that only NOx emissions have decreased since 2005. CO$_2$, PM and SO$_2$ emissions did not change over the years and are not expected to do so up to 2020. The share of renewable electricity which is sold in the Netherlands is not included in Table 7. It is the user's own choice to buy renewable electricity. The use of renewable electricity will substantially reduce CO$_2$ emissions by more than 90% to 10g CO$_2$/MJe [20]. However, renewable energy sources are not unlimited available.

Table 7, Prognosis emission conventional electricity production Netherlands 2005 (incl. mining and transport resources), [21]

<table>
<thead>
<tr>
<th>Year</th>
<th>Unit</th>
<th>CO$_2$</th>
<th>NOx</th>
<th>PM</th>
<th>SO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>g/MJ</td>
<td>170</td>
<td>0.211</td>
<td>0.0061</td>
<td>0.0832</td>
</tr>
<tr>
<td>2010</td>
<td>g/MJ</td>
<td>170</td>
<td>0.173</td>
<td>0.0061</td>
<td>0.0832</td>
</tr>
<tr>
<td>2020</td>
<td>g/MJ</td>
<td>170</td>
<td>0.173</td>
<td>0.0061</td>
<td>0.0832</td>
</tr>
</tbody>
</table>

The absolute amount of renewable electricity produced in the Netherlands is increasing, but since the amount of conventional electricity production increases as well the share of renewable is steady. The development of the energy mix of the Netherlands and the share of renewable electricity is shown in Figure 14 in appendix 13.3.
An overview of emissions of car, bus bicycle and E-bike per passenger kilometer is shown in Graph 2.

![Graph 2](image)

Above presented data shows that the E-bike performs well on CO\textsubscript{2}, NO\textsubscript{x} and PM emissions. However, SO\textsubscript{2} emissions of E-bike usage are much higher than for car and bus usage. The reason is SO\textsubscript{2} emissions for power generation. The most relevant environmental impact concerning SO\textsubscript{2} is acidification. Total acidification is a tradeoff between the absolute amount of SO\textsubscript{2} and NO\textsubscript{x} emissions. A complete scenario analysis for region Groningen-Assen will be addressed in chapter 8.

4.3 Battery and environmental impact

Another important determinant of the total life cycle environmental impact of E-bikes is battery usage. The electric power for the E-bike is stored in a battery. Every battery has its particular strengths and weaknesses. “There is no black and white concerning batteries” [22]. A battery in general is slow to fill, holds relatively little capacity and has a defined life span. Manufacturers have to make choices concerning battery characteristics. There is always a tradeoff between price, cycle life (recharges), load capability and weight. There are advances in battery technology, but progress cannot keep up with fast developments in microelectronics and electric mobility.
The energy and power storage characteristics of batteries critically impact the commercial viability of these emerging technologies [23].

Batteries for E-bikes use a cathode (positive electrode), an anode (negative electrode) and electrolyte as conductor. Figure 7 shows that the cathode is a metal oxide and the anode consists of porous carbon. During discharge, the ions flow from the anode to the cathode through the electrolyte and separator; charge reverses the direction and the ions flow from the cathode to the anode.

![Battery diagram](image)

Figure 7, Battery technology E-bike

The first models of E-bikes where equipped with lead acid batteries. Recent E-bike models are equipped with lithium ion batteries. Table 8 shows the characteristics of lead acid and lithium ion batteries. The advantage of lithium ion batteries is that they can be recharged more often and they have a higher energy to weight ratio. [20] Also, the lithium-ion battery requires little maintenance, there is no memory effect, little self-discharge and no scheduled cycling is required to prolong battery life cycle [24]. The biggest drawback of lithium ion batteries is the price; it is more expensive than the same type lead acid battery [20]. Moreover, like any other battery available, it ages.

<table>
<thead>
<tr>
<th></th>
<th>Valve Regulated Lead Acid</th>
<th>Lithium -Ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost ($)</td>
<td>130</td>
<td>500</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>26</td>
<td>8</td>
</tr>
<tr>
<td>Lifetime (yr)</td>
<td>1.5-3.0</td>
<td>3.0-9.0</td>
</tr>
<tr>
<td>Volume (L)</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Energy density (Wh/L)</td>
<td>86</td>
<td>170</td>
</tr>
<tr>
<td>Cycle life (recharges)</td>
<td>300</td>
<td>800</td>
</tr>
<tr>
<td>Life Cycle Costs (€/kWh/recharge)</td>
<td>0.43</td>
<td>0.70</td>
</tr>
</tbody>
</table>

Table 8, Characteristics E-bike batteries, [20]

---

1 0.69724 USD EUR Exchange rate 31-12-2009
Recent developments are found in the variation of the electrode materials and nanotechnology. New generation batteries are described as one of the most significant examples of the contributions of nanotechnology in the energy sector [25]. The expensive cobalt is for example replaced by the iron phosphate or manganese. The latter one is a favorable option for electric mobility because of low costs, easy production, thermal safety and manganese is well abundant in nature [24].

4.3.1 Environmental impact lead acid battery

The first types of E-bikes where equipped with lead acid batteries. In China, the biggest E-bike using country, 95% of the E-bikes were equipped with lead acid batteries in 2009. The batteries have a life span of 1-2 years or 10,000km. Therefore 5 batteries are used per average lifetime of an E-bike. In most industrialized countries, lead recycling rates exceed 90%. Nonetheless, lead is emitted into the environment in four processes: mining and smelting ore, battery manufacturing, recycling used batteries and non-recycled lead entering the waste stream. Lead is a neurotoxin causing various health issues like a high incidence of developmental disorders, low IQ and even premature mortality. These problems occur mainly in communities neighboring lead mines, smelters, battery producers and recyclers. A battery composed of 100% recycled lead emits 3% of its lead mass into the environment. A battery composed of 100% virgin material emits 5% of its lead content into the environment. [16] Lead loss is more relevant for E-bikes than for other modes of transport since the batteries are replaced more often than e.g. on buses. These problems are partly prevented due to the switch to lithium ion batteries on E-bikes in the Netherlands.

4.3.2 Environmental impact lithium ion battery

Nowadays most E-bikes are equipped with lithium-ion batteries in the Netherlands. A life cycle analysis was conducted at EMPA in order to calculate the share of the lithium ion battery in the total environmental impact of electric mobility. This case addresses an electric car (BEV) which has larger batteries than the E-bike. The share of the total environmental impact of E-mobility caused by the battery (measured in Ecoindicator 99 points) is 15%. More information about “Ecoindicator 99” and a life cycle analysis (with simapro) of different modalities can be found in appendix 13.1. The impact caused by the extraction of lithium for the components of the Li-ion battery is less than 2.3% (Ecoindicator 99 points). The major contributor to the environmental burden caused by the battery is the supply of copper, aluminum and manganese for the production of the anode and the cathode, plus the required cables and the production of the battery management system [24] [8]. The lithium ion battery is an important determinant for the total environmental impact of battery electric vehicles. Despite the fact that above mentioned life cycle analysis includes an electric car it still emphasizes the large effect of batteries on the total environmental impact electric mobility. Therefore recycling of copper, aluminum and manganese is essential for reducing the environmental impact of the E-bike.
4.4 Conclusion

This chapter concludes that the E-bike consumes energy and produces emissions, more per passenger kilometer than the bicycle, less than bus and car. Therefore every car and bus movement which is replaced by an E-bike movement contributes to the mitigation of emissions of traffic in general. The well-to-wheel energy use of a conventional car is 10-15 times as large as those of an E-bike. The use of renewable electricity to power the E-bike will substantially reduce CO₂ and SO₂ emissions. However, the emissions of conventional electricity production will not change substantially between 2012 and 2020.

The lithium ion batteries have most favorite characteristics for large scale implementations. The lithium ion battery has a large impact on the life cycle environmental impact of an E-bike. Mainly material usage for anode, cathode and electrolyte determine total environmental impact of battery. It underlines the necessity of battery material recycling. Variation of battery materials and nanotechnology will substantially improve battery characteristics in the future.

The E-bike will replace other modalities for commuter traffic; it will be addressed in the next chapter. E-bike use results in substantially higher SO₂ emissions and therefore acidification. The total acidification depends on NOx emissions as well. Finally the total environmental impact (including acidification) of E-bike use on commuter traffic will be addressed in the scenario analysis for region Groningen-Assen in chapter 8.
5 MODALITY CHOICE COMMUTER AND INCENTIVES

The effect of E-bike usage on accessibility and local environments depends greatly on the number of people who will switch modalities and which modalities were used previously. The aim is to persuade car users to start bicycling. The SWOT analysis in paragraph 0 shows that the E-bike has a number of strengths and a number of weaknesses compared to car use. Mode choice of the commuter however is more complex and involves psychological issues as well.

Publications show that mode choice for the conventional bicycle has been a topic for research for decades. These studies are a solid basis for this thesis since there are many similarities between the conventional bicycle and the E-bike. Within these studies there are subjective factors and objective factors. The subjective factors have a close link to behavioral sciences. The objective factors are determined by traffic characteristics, infrastructure and spatial planning. This chapter comprises the modality choice of commuters in detail. The first paragraph shows results of a model study on modality choice for commuters. A complete overview of factors for E-bike usage was made based on literature and expert interviews. The second paragraph includes the psychological approach to modality choice. The final paragraph describes incentives for E-bike usage. “Although cycling is an option for many commuters, a considerable number of them choose to use other forms of transport”. [15]

5.1 Mode choice model E-bike

Chapter 3 concludes that cycling offers many advantages for accessibility and local environment. Still many commuters do not consider cycling to be an option. Mode choice is in many cases not a rational consideration of all optional modes for commuting, but is largely influenced by habits, attitudes and norms. Moreover travel time and safety are important factors in the consideration to commute by bicycle. [15] A few factors for E-bike usage are not included or overlooked in conventional mode choice studies. A literature review suggests that additional research is necessary on the influence of environment (weather, hills and wind) and built environment (parking facilities, traffic lights) on modal choice. An overview of all relevant factors to determine E-bike usage is shown in Figure 9.

In order to find factors which influence the use and possession of E-bikes by commuters, an extensive model study was conducted. A model study [26] focused on creating a comprehensive model of the use and possession of E-bikes in the Netherlands. The aim of this study was to find a statistical relation between different factors of influence and the possession and use of E-bikes. This study succeeded in quantifying some of the factors by conducting interviews and a literature study. The first part of this study aimed at creating a possession model. It used data from market research from 2007; it succeeded into quantifying six factors and proved to form a statistical relation to E-bike possession.

Factors E-bike possession [26]
1. Knowing someone with an E-bike. When close friends or relatives own an E-bike the change is higher that someone will buy one themselves. 41%
2. Age, the older the greater the chance someone buys an E-bike. 16%
3. Travel distance, the larger the cycling distance the greater the chance that someone owns an E-bike. 16%
4. Physical health, the healthier someone is, the smaller the chance they own an E-bike. 15%
5. Gender, women own an E-bike more often than men. 9%
6. Extend to which someone has an active attitude, less active people have a smaller chance to own an E-bike. 3%

Factors which could not be quantified in above mentioned study were ethnicity, extend into which an E-bike is considered something for elderly, movement motives, capital costs E-bike, design E-bike, extend of urbanization and the mode of transport people are used to.

Future owners of E-bikes where assessed in an interest model [26]. The model shows a relation between factors and interest in buying an E-bike among non-owners. The factors and weight are shown below.

- Age 32%
- Knowing someone who owns an E-bike 31%
- Physical health 27%
- The extend into which an E-bike is considered something for elderly 10%

This model shows that different factors are relevant for the interest model than for the possession model. In this case “travel distance”, “gender” and “extend to which someone has an active attitude” are not relevant for the interest in the E-bike.

A mode choice model was created [26] including the use factors. The model shows that for short distances the bicycle and electric bicycle are preferred instead of car and public transport. For longer distances the car and public transport are more preferred. However, the data proved insufficient in order to model changes in mode choice behavior after the introduction of the electric bicycle. The use factors where determined by interviews with experts and are shown below.

- Extend to which someone has an active attitude, the more active people are, the higher the chance of using an E-bike.
- Movement motives, commuters use the E-bike daily and recreational incidental.
- Travel distance, a distance between 10-20 km is travelled more often than other distances.
- Availability of secure parking facilities for bicycles at destination, when secure parking facilities are available at the destination, the chance of using an E-bike increases.
- Climate and weather, with good weather and in summer time the chance of using an E-bike is higher than with bad weather and in winter time.
- Habits concerning mode choice, habits play an important role in the mode choice behavior of people.

5.2 Psychological approach to mode choice

The model of E-bike usage in Figure 9 also includes factors derived from the psychological approach to modality choice. Many studies on modality choice appear to be based on the assumption that travel is a cost to be minimized and decisions are based on weighing the instrumental costs and benefits of various travel options. However, modality choice proves more complex. “Travel may have a positive utility of its own which is not necessarily related to reaching a destination.” [27]
By including psychological issues a distinction occurs between affective and instrumental factors.

- Affective factors: relaxation, no stress, excitement, control, freedom.
- Instrumental: environment, costs, health and fitness, convenience, predictability, flexibility.

This distinction is applied as well in a study by Linda Steg. Modal choice is determined by: social demographic characteristics, objective factors and subjective factors, as shown in Figure 8 [28]. The behavior (modality choice) is determined by socio and demographic characteristics. The preference to commute by car is e.g. higher when children are dropped off at school on the way to work [12]. Secondly general- and individual objective factors are relevant. Finally subjective factors determine the behavior.

![Socio-demographic characteristics diagram](image)

**Figure 8, Mode choice behavior of commuters, [28]**

Psychological research shows that for work journeys, respondents tend to attach more importance to objective aspects and especially to convenience than to subjective factors. For leisure journeys, however, respondents appear to attach almost equal importance to instrumental and affective aspects, particularly flexibility, convenience, relaxation, a sense of freedom and “no stress”. [29] It means that the purpose of a movement is an important factor.

The results of the earlier mentioned studies are combined in Figure 9. It presents relevant factors concerning mode choice of the E-bike for commuters. Different factors determine “intended E-bike use”. The factors are divided in objective factors and subjective factors. Finally there is a difference between intended E-bike use (wanting to commute by E-bike) and actual E-bike use (actually commuting by E-bike). Therefore the actual E-bike use is determined by the factors surroundings and habits.
Figure 9, Factors E-bike usage
5.3 Incentives for E-bike usage

The model in Figure 9 shows that E-bike usage is determined by a large number of factors. Therefore single sided incentives will prove ineffective. A balanced package of incentives contains cycling infrastructure, public cycling facilities and mobility management.

A strong incentive and a precondition for additional E-bike use by commuters is qualitative cycling infrastructure. A complete and high quality cycling network will contribute to more comfort, higher travel speed and more safety. The quality standards for bike route plus are shown in appendix 13.4. [12]

Other strong incentives are public cycling facilities. The E-bike is a costly product and therefore theft sensitive; secure parking facilities are important. The facilities will be most effective at public transport knots, P+R locations and work locations. The design characteristics of E-bike are slightly different from the conventional bicycle; modern design E-bikes are bigger and heavier. Therefore parking facilities should be more spacious and the extra weight can result in difficulties in multi-level parking facilities. Finally charge facilities are important. Charging the battery can take up to 8 hours. Therefore it is desirable to charge the battery during parking.

Finally mobility management focused on car commuter is a strong incentive. Mobility management comprises a number of incentives which take place at companies. The most sustainable option for commuter travel is no travel at all. Therefore time and place independent working (video conferencing and working at home) is a good option. When travel is necessary the E-bike is a sustainable option; there are a number of incentives [30].

- Minimize car parking spots and transform to bicycle parking
- Secure bicycle parking
- Analyze travel patterns of employees and formulate clear policy on desired mode choice
- Promotion campaigns aiming at breaking habits of employees, new employees are more sensitive for change and will persuade others to follow behavior [31]
- Test drive on E-bike, changing image of E-bike
- Fiscal advantages for buying an E-bike
- Company E-bikes for work-work journeys (for promotional purposes as well)
- Charge facilities
- Locker for clothes etcetera, shower and dressing room at work location

5.4 Conclusion

This chapter concludes that mode choice behavior for commuters is complex. It is hard, if not impossible to model mode choice sufficiently. Modality choice of the commuter is determined by objective and subjective factors. Therefore behavioral sciences are relevant in order to grant a good understanding of the modality choice of the commuter. Given the many factors, single measures to change behavior are ineffective. A balanced package of incentives contains cycling infrastructure and public cycling facilities. Finally different target groups and situations demand tailor made incentives. Mobility management is an effective measure to persuade the car commuter in particular to start using the E-bike.
6 EFFECT E-BIKE ON ACCESSIBILITY

The main focus of this chapter is “accessibility”. Accessibility is defined in this study as the time necessary and circumstances in which a commuter reaches its destination. Within accessibility, one would try to optimize the circumstances of travel and minimize the amount of time. Relevant issues are: the flow of traffic, average speed, lost time in traffic and car parking. Accessibility in this study does not include livability of the city center or economic development of the region. This chapter includes a literature review on the effect of E-bike use and cycling infrastructure on accessibility. Findings are based on traffic models, traffic counts and market research and show that E-bike use and cycling infrastructure have positive effects on accessibility of a compact Dutch city.

6.1 Traffic model studies

In order to analyze the effect of E-bikes on accessibility studies with traffic models have been conducted. Mobility consultancy Goudappel Coffeng did a study on the effect of bike route plus and the use of E-bicycles on mobility in the Netherlands; results are shown in Table 9. [17] The average total Dutch situation was calculated with the national traffic model for 2020; it does not address commuter traffic in particular. The number of movements is based on an average Dutch work day. Since the current traffic models do not include knowledge about E-bikes assumptions where made. As input for this case a number of new cycling roads were inserted. Also the average cycling speed went up from 15 to 18 km/h for the bike route plus and results in 1.3% more bicycle movements as shown in the second column. The last column shows a scenario including a large availability of the E-bike; the average speed increases from 18 to 24 km/h. The result is 3.3% more bicycle movements. Additional cycling movements replace car and public transport movements. The scenario including the E-bike results in 1.6% less car movements and 2.7% public transport movements.

<table>
<thead>
<tr>
<th></th>
<th>Change (%)</th>
<th>Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>no. movements</td>
<td>no. movements</td>
</tr>
<tr>
<td>With bike route plus</td>
<td>-0.7%</td>
<td>-1.6%</td>
</tr>
<tr>
<td>(15-&gt;18 km/h)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>With bike route plus</td>
<td>-0.9%</td>
<td>-2.7%</td>
</tr>
<tr>
<td>and E-bike</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(15-&gt;24 km/h)</td>
<td>+1.3%</td>
<td>+3.3%</td>
</tr>
</tbody>
</table>

Table 9, Effect of bike route plus and E-bike on accessibility and CO₂ emissions on average work day Netherlands

The above mentioned study shows that it is hard to achieve an increase in the number of bicycle movements in Dutch traffic in general. In order to investigate the effect of a substantial increase of bicycle movements Fietsberaad and DHV did a study “sensitivity analysis effects cycling policy”. [32] The study is based on a reference case for 2020 in the city of Alkmaar with 94,000 inhabitants. The small autonomous increase in traveled kilometers by cars will result in an explosive development of lost time in 2020. The study investigates the effect on accessibility as a result of 10% more bicycle movements and 10% less bicycle movements as shown in Table 10.
Table 10, Effect of 10% more and 10% less bicycle movements on mobility in compact Dutch city during evening rush hour, in relation to reference 2020 [32]

<table>
<thead>
<tr>
<th></th>
<th>Bicycle movements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10% more</td>
</tr>
<tr>
<td>No. car movements</td>
<td>-6%</td>
</tr>
<tr>
<td>No. car departing from city centre</td>
<td>-25%</td>
</tr>
<tr>
<td>Lost time (min.) per vehicle</td>
<td>-15%</td>
</tr>
<tr>
<td>Average speed motor vehicles</td>
<td>+8%</td>
</tr>
</tbody>
</table>

Four different models were used: static model (Questor), dynamic model (Dynasmart), micro simulation (Aimsum) and environment model (Questor environment). The study concludes that 10% more cycling trips have the largest effect on mitigating parking problems in the city center (car departing from city center). The effect on car parking in city center is large because mainly short distance car trips are replaced by bicycle. The effect on car parking e.g. at remote business parks is less because these sites are less attractive for bicycle. Moreover 10% more cycling trips result in 15% reduction of lost hours for car trips and the average speed increases by 8%. Measures to promote bicycle usage were addressed in paragraph 5.3.

6.2 Traffic counts

A study focused on the effect of the upgrade of five cycling routes in the Netherlands. The upgrade (bike route plus) includes improvement of road surface, wider lanes, improvement of intersections with right of way for cyclists and road lighting. The upgraded corridors have been evaluated by an inquiry among cyclists and by traffic counts on the routes [33]. The inquiry shows factors which promote cycling the most, according to former car users.

- Personal exercise
- Travel distance
- Number of interruptions of the route by traffic lights and intersections
- Costs of car use
- Quality of road surface
- Separation between car and cycling traffic
- Lighting of route

Out of the cyclist on the improved corridors 8% was a previous car user. The previous car users mention personal exercise, health and the improved cycling infrastructure as the major reasons for the switch. Previous to this study, car commuters in the particular areas where asked if they would switch to the bicycle when the infrastructure would be upgraded, 5% answered yes. The results show that eventually 1% did in fact make the switch. The discrepancy could be caused by the fact that the desired upgrade of corridors is not always possible and that a switch could take more time. [33]

Also traffic counts were conducted to assess the effect of the measures on cycling intensity. Traffic counts started in 2007 with the original situation, and continued till after the upgrade was finished in 2008 and 2009. The number of counted cyclist showed an increasing trend of 17% per year on the 10 km corridor between Rotterdam and Delft. A clear trend was visible on the 10-15 km corridor between Utrecht and Maarssen/ Breukelen as well; the daily number of cyclists increased by 8% per year. The corridor Den Haag and Zoetermeer did not show a clear trend, but the number of cyclists was 32% higher in 2009 than in 2007. The other corridors did
not have significant results because traffic counts were interrupted by local circumstances. [33] It would be interesting to continue traffic counts to see if the trends will continue or how long it will take till the trend breaks.

6.3 Market research E-bike

Previous paragraphs showed the effect of upgraded cycling infrastructure and E-bike use in the Netherlands in general. This paragraph will focus on possession of E-bikes, interest in buying an E-bike and modal split of commuter traffic in the Netherlands. [6] A market research assumes a large availability of the E-bike (50%). In total 1,448 respondents participated in a panel and filled out a survey. The survey shows that 1.9% of commuters were in possession of an E-bike in 2007. Out of the interested people 20% would like to buy an E-bike based on environmental reasons. Reasons to not buy an E-bike are: wanting to pedal on own strength (58%), people do not consider themselves to fit the target group and the E-bike is too expensive (28%). Owners of E-bike were also asked about their experience. Around 91% of the commuting owners are satisfied with their E-bike, 7% is not satisfied and 2% is neutral. Main reasons for dissatisfaction are driving range (79%), battery charge time (63%), maintenance costs (60%) and total weight of Ebi (60%). Obviously this market research is from 2008. Battery technology has advanced since. Also this study includes perceptions of the respondent and not the effects in real life.

The effect of E-bike possession on the travel behavior of commuters was part of the research as well. The commuting users of E-bike indicate that they cycle faster (75%) and that they cycle larger distances (77%). Only 22% of commuting E-bike users said they cycle to work more often. The effect of E-bike use on the average speed is shown in Figure 10.

![Figure 10, average speed per type bicycle (km/h)](image)

With results from above presented market research it is possible to evaluate the potential of the electric bicycle for commuter traffic. The market research shows that the average trip distance on an E-bike is 9.8 km compared to 6.3 on a conventional bicycle. This would suggest that the range of an E-bike is 56% higher than for a conventional bicycle. In Graph 3 the modal split of the conventional bicycle is shown for various trip distances. The study assumes that the bending point (at 4 km) is 56% higher for an E-bike, resulting in a shift of the modal split to the right, the marked area. Next, three options are shown for the development of E-bike modal split over various trip distances.
The marked area shows different options for the modal split of the E-bike. The average speed on an E-bike is higher for long distance trips between 5 and 20 km; especially outside the city center. Therefore the complete red marked area will represent the modal split for E-bike. During the interviews this graph was presented. All experts consider Graph 3 to represent the development of the modal split for E-bikes [3,11,13,14,31,34-36]. Upgrading cycling infrastructure will result in larger modal split for the E-bike. However, additional E-bike use means other modalities will be substituted.

Table 11, Substitution of other modalities by the E-bike for commuter traffic [6]

<table>
<thead>
<tr>
<th>Bicycle</th>
<th>Car</th>
<th>Public transport</th>
<th>Motorbike/ scooter</th>
<th>No substitution</th>
</tr>
</thead>
<tbody>
<tr>
<td>33%</td>
<td>16%</td>
<td>8%</td>
<td>5%</td>
<td>38%</td>
</tr>
</tbody>
</table>

The market research also addressed the substitution of other modalities by the E-bike as shown in Table 11. When respondents answered “always” on the question “how often the E-bike was used for commuting”, it was considered substitution. When respondents answered “occasionally” or “regularly” it was considered no substitution; shown in the last column. Therefore 38% of the cases were considered no substitution. Nevertheless, in the remaining 62% of the cases the E-bike did substitute other modalities completely. The E-bike is a substitute for other modalities as follows: the conventional bicycle (53%), car (26%), public transport (13%), motorbike/ scooter (8%).

The final step is to show the current and potential cycling trips (assuming a large availability of the E-bike) [6]. The market research concludes that the total number of commuting cycling trips potentially increases with 4-9%. The number of conventional cycling trips reduces and the number of E-bike trips increases. More details can be found in appendix 0.
6.4 Conclusion

This chapter shows that improvement of cycling infrastructure results in more cycling movements and better accessibility. Traffic counts at upgraded cycling routes result in all cases in more cycling movements per day; in some cases up to 17%. The use of E-bikes can enhance the above mentioned effects. Model studies, traffic counts and market research show an increase in the number of cycling movements, decrease in the number of car movements, better traffic flow, higher average speeds for commuter traffic and less parking problems in city center. The E-bike results in a shift of the modal split; size and cause of the modal shift differs per situation and the applied research method. The effect of large availability of the E-bike on number of cycling movements for commuters ranges between 4-9% according market research. The traffic model study shows 1.3-3.3% more cycling movements for traffic in general.

The bicycle is a popular modality for short trips. When E-bike use increases, other modalities are substituted. The share of the bicycle for commuter traffic in the modal split will decrease from 52% to almost zero between respectively 4 km and 20 km trip distance. The range will be 56% higher with an E-bike compared to the conventional bicycle. The E-bike is a substitute for other modalities as follows: the conventional bicycle (33.3%), car (15.9%), public transport (8.1%), motorbike/ scooter (4.6%) and 37.4% was no complete substitution.
Groningen is a compact city; it is relatively densely populated in comparison to the surrounding rural area. Most industrial areas, work areas, schools and facilities are concentrated in the city of Groningen. As a result commuting traffic travels up and down every day. Details about the origin of commuters and the modal split are shown in Table 12. The first ring of origin of commuters has a large share in the modal split 70%; it shows a large potential for the E-bike.

Table 12, Daily commuting traffic city Groningen, origin and modal split for 2020, [37]

<table>
<thead>
<tr>
<th>Origin commuters</th>
<th>Commuters 2020</th>
<th>% increase 2004-2020</th>
<th>Modal split (share modalities % in total commuters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st ring &lt;15 km from city center</td>
<td>190,000</td>
<td>38</td>
<td>70</td>
</tr>
<tr>
<td>2nd ring 15-40 km from city center</td>
<td>178,000</td>
<td>35</td>
<td>80</td>
</tr>
<tr>
<td>3rd ring &gt;40 km</td>
<td>62,000</td>
<td>43</td>
<td>67</td>
</tr>
<tr>
<td>Total</td>
<td>430,000</td>
<td>40</td>
<td>75</td>
</tr>
<tr>
<td>Commuters city – city center</td>
<td>175,000</td>
<td>10</td>
<td>35</td>
</tr>
</tbody>
</table>

An increase of 40% in traffic movements from and to the city of Groningen was calculated in 2020 as compared to 2004. This calculation was conducted with the “regional traffic model” [38]. Daily 320,000 commuters went into and out of the city of Groningen in 2004, in 2020 it will be 430,000 people. Table 13 shows daily commuter traffic and the location of origin in more detail.

Table 13, Daily commuters between Groningen and regions 2020, [39]

<table>
<thead>
<tr>
<th>Region</th>
<th>Commuters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leek/ Roden</td>
<td>27,000</td>
</tr>
<tr>
<td>Haren</td>
<td>26,700</td>
</tr>
<tr>
<td>Hoogezeand/ Sappemeer</td>
<td>19,500</td>
</tr>
<tr>
<td>Assen</td>
<td>13,000</td>
</tr>
<tr>
<td>Zuidlaren</td>
<td>9,585</td>
</tr>
<tr>
<td>Bedum</td>
<td>8,600</td>
</tr>
<tr>
<td>Ten Boer</td>
<td>7,150</td>
</tr>
<tr>
<td>Winsum</td>
<td>5,480</td>
</tr>
</tbody>
</table>

In order to mitigate accessibility problems, there is a detailed accessibility program for region Groningen-Assen, as shown in Figure 11. The aim of this program is to guarantee good and safe accessibility of the region on behalf of economic development. The program includes development of public transport and park and ride (P+R) locations. Cars can be parked at the P+R locations, next people are taken into the city center by bus or train. The timetable of current train and bus lines will become more frequent in the short future. Newly planned tram and bus lines will depart e.g. 4 or 6 times an hour when in the current situation it was twice an hour. Another part of the accessibility program is the construction of two new inner city tram lines (tram phase 1). The final step of the accessibility program is to extend the public transport network to surrounding villages by trams (tram phase 2). The tram will in some cases run on current railway tracks, in other cases on new tracks. [39]
There are limits concerning car traffic due to the lack of space for parking and infrastructure. Further development of car infrastructure will be insufficient in order to limit congestion. Moreover, the southern part of the belt road of Groningen has been a traffic bottleneck for years (A28 and A7). The local government has radical plans to improve this part of the belt road, including tunnels and multi-level crossings. The construction however, will take many years and cause additional congestion for car traffic. Major car traffic corridors are shown on Figure 11 indicated by blue arrows.

![Accessibility program region Groningen-Assen](image-url)
Key characteristics for an integral public transport network: [40]

- No different modalities on similar travel relation/ corridor
- Clock tight departure times
- Good connections and consequent
- Both travel ways similar travel time and (modality) switch time
- Development of public transport knots (bus, tram, train and P+R)

An important part of the accessibility program is the knot principle (Figure 11). Throughout the region there will be various public transport knots assigned. At these locations trams, trains and buses from all directions meet at the same time. Therefore parallel connections are not necessary and exploitation is more efficient. Other characteristics of the public transport knot are park and ride (P+R) and bicycle facilities. The knots are positioned on intervals of 15 minutes travel time. The result is a frequent, efficient and conveniently arranged public transport network. [40]

As part of the accessibility program the local government is promoting cycling. One of the measures is to improve the current “main” cycling routes, as shown in Figure 12. The “main” cycling routes are the connection between work and residential areas and are in some cases individual cycling paths and sometimes on other roads. Region Groningen-Assen has plans to upgrade the “main cycling paths” to “bike route plus” or “bike highways”.

![Image of a map showing public transport routes]

*Figure 12, Main cycling paths 2005, [41]*

The integral public transport network in combination with the development of car infrastructure, cycling infrastructure and park and ride should guarantee good accessibility in the future. Different modalities will strengthen each other by the application of the knot principle and there
is a big opportunity for the E-bike. The potential of the E-bike for corridors in region Groningen-Assen is shown in paragraph 7.1. The total environmental impact of different scenarios for 2020 on system level will be addressed in the next chapter.

7.1 Potential E-bike corridors region Groningen-Assen

A number of villages are located close to the 15 km range from the city center of Groningen. This paragraph shows a calculation of the E-bike potential for commuting traffic on those corridors. The potential is determined by four parameters. The modal split of the E-bike is derived from Graph 3, it depends on the distance from a village to the specific work location. The other three parameters are based on personal experience and during a session with Kees Anker (region Groningen-Assen) and Ben Boersma (slimmer reizen & werken). Every parameter has been given a specific weight within the equation. The results are shown in 7.1.2. High number relates to high E-bike potential for the specific corridor.

7.1.1 Input

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Positive/ negative</th>
<th>Weight (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>sMS</td>
<td>Modal split E-bike (Graph 3) in relation to distance</td>
<td>+</td>
<td>5</td>
</tr>
<tr>
<td>qCI</td>
<td>Quality cycling infrastructure</td>
<td>+</td>
<td>4</td>
</tr>
<tr>
<td>CA</td>
<td>Attractiveness by car for work location</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>PTA</td>
<td>Attractiveness by public transport for work location</td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

Table 14, Parameters model E-bike potential corridors region Groningen-Assen

\[
E = \frac{(sMS \times n_{sMS}) + (qCI \times n_{qCI})}{(CA \times n_{CA}) + (PTA \times n_{PTA})}
\]

<table>
<thead>
<tr>
<th>Work location</th>
<th>Share commuter traffic</th>
<th>PTA</th>
<th>CA</th>
<th>qCI</th>
</tr>
</thead>
<tbody>
<tr>
<td>City center</td>
<td>17,0</td>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Central train station</td>
<td>9,0</td>
<td>5</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>UMCG hospital</td>
<td>5,0</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Kardinge</td>
<td>9,0</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Station noord</td>
<td>4,0</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Zernike</td>
<td>7,0</td>
<td>4</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Europapark</td>
<td>17,0</td>
<td>2</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Bedrijven oost</td>
<td>9,0</td>
<td>1</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Martini hospital</td>
<td>12,0</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Hoogkerk</td>
<td>11,0</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 15, Input model E-bike potential corridors region Groningen-Assen

7.1.2 Results

Table 16 shows the results of the E-bike potential model for different corridors within region Groningen-Assen. A high value or green color means the potential for the E-bike is high for commuting traffic on the corridor. This overview can assist policy makers to promote E-bike use most effectively.
<table>
<thead>
<tr>
<th>Work areas</th>
<th>Villages</th>
<th>Zuidhorn</th>
<th>Leek</th>
<th>Haren</th>
<th>Zuidlaren</th>
<th>Vries</th>
<th>Winsum</th>
<th>Bedum</th>
<th>Ten Boer</th>
<th>Hoogeand/Sappemeer</th>
</tr>
</thead>
<tbody>
<tr>
<td>City center</td>
<td></td>
<td>10</td>
<td>5</td>
<td>23</td>
<td>4</td>
<td>3</td>
<td>8</td>
<td>14</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Central train station</td>
<td></td>
<td>8</td>
<td>5</td>
<td>21</td>
<td>4</td>
<td>3</td>
<td>6</td>
<td>9</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>UMCG hospital</td>
<td></td>
<td>11</td>
<td>6</td>
<td>26</td>
<td>5</td>
<td>4</td>
<td>9</td>
<td>14</td>
<td>12</td>
<td>7</td>
</tr>
<tr>
<td>Kardinge</td>
<td></td>
<td>4</td>
<td>2</td>
<td>7</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>10</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>Station noord</td>
<td></td>
<td>9</td>
<td>3</td>
<td>18</td>
<td>3</td>
<td>3</td>
<td>8</td>
<td>12</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Zernike</td>
<td></td>
<td>11</td>
<td>3</td>
<td>11</td>
<td>3</td>
<td>3</td>
<td>7</td>
<td>9</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Europapark</td>
<td></td>
<td>5</td>
<td>2</td>
<td>14</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>6</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Bedrijven oost</td>
<td></td>
<td>4</td>
<td>2</td>
<td>11</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>10</td>
<td>18</td>
<td>7</td>
</tr>
<tr>
<td>Martini hospital</td>
<td></td>
<td>6</td>
<td>6</td>
<td>21</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Hoogkerk</td>
<td></td>
<td>14</td>
<td>9</td>
<td>13</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Av. potential</td>
<td></td>
<td>8</td>
<td>4</td>
<td>16</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>10</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Av. distance (km)</td>
<td></td>
<td>12.7</td>
<td>16.8</td>
<td>7.5</td>
<td>18</td>
<td>20.2</td>
<td>15.1</td>
<td>11.4</td>
<td>12.1</td>
<td>16.5</td>
</tr>
</tbody>
</table>

Table 16, Results model E-bike potential corridors region Groningen-Assen
8 SCENARIO ANALYSIS REGION GRONINGEN-ASSEN

Previous chapters show that E-bike use has a positive effect on accessibility; a better flow of commuter traffic, the mitigation of parking problems, higher average speed and less lost time in traffic. Moreover the energy use and total air emissions of single E-bike movements are lower than for car and bus movements; but higher than conventional bicycle. When the E-bike is introduced on a large scale for commuter traffic in region Groningen-Assen it will replace other modalities. A spreadsheet model was created to analyze different scenarios on system level in order to find out how increased E-bike use will affect the total environmental impact of commuter traffic in region Groningen-Assen.

8.1 Scenario input

The scenario analysis includes direct and indirect energy use for car, bus, bicycle, electric bicycle and electric scooter. Also direct and indirect emissions are included; CO$_2$, NOx, PM and SO$_2$ as shown below. The results show direct and indirect energy and emissions and the total acidification potential of NOx and SO$_2$ together.

Table 17, Direct and indirect energy and emissions

<table>
<thead>
<tr>
<th>Energy</th>
<th>Emissions (CO$_2$, NOx, PM and SO$_2$) during:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Fuel (tank-wheel/ plug-wheel)</td>
<td>Operation</td>
</tr>
<tr>
<td>Indirect Production fuel (well-tank)</td>
<td>Production vehicle</td>
</tr>
<tr>
<td>Production electricity</td>
<td>Production fuel/ electricity</td>
</tr>
</tbody>
</table>

Within this study indirect energy use does not include infrastructure, maintenance and disposal (lead pollution). Error! Reference source not found. shows direct and indirect energy use, CO$_2$, NOx, PM and SO$_2$ emissions per kilometer per vehicle. It shows data for the average Dutch situation for commuter traffic in cities. Data for the E-bike were derived from Chinese data.

Table 18, Direct and indirect energy use, CO$_2$, NOx, PM and SO$_2$ emissions per km per vehicle

<table>
<thead>
<tr>
<th></th>
<th>Energy MJ/km</th>
<th>CO$_2$ g/km</th>
<th>NOx g/km</th>
<th>PM g/km</th>
<th>SO$_2$ g/km</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Direct</td>
<td>Indirect</td>
<td>Direct</td>
<td>Indirect</td>
<td>Direct</td>
</tr>
<tr>
<td>Car CE</td>
<td>3,490</td>
<td>0,873</td>
<td>252,0</td>
<td>63,00</td>
<td>0,560</td>
</tr>
<tr>
<td>Bus CE</td>
<td>14,530</td>
<td>3,633</td>
<td>1079,0</td>
<td>269,75</td>
<td>11,750</td>
</tr>
<tr>
<td>Bicycle</td>
<td>0,176</td>
<td>0,022</td>
<td>0,044</td>
<td>0,034</td>
<td>0,018</td>
</tr>
<tr>
<td>E-Bicycle</td>
<td>0,076</td>
<td>0,198</td>
<td>0,034</td>
<td>0,034</td>
<td>0,018</td>
</tr>
<tr>
<td>E-Scooter</td>
<td>0,076</td>
<td>0,281</td>
<td>0,044</td>
<td>0,034</td>
<td>0,018</td>
</tr>
</tbody>
</table>

This analysis was conducted for region Groningen-Assen in particular. For this type of analysis it is very important that different modalities are realistic substitutes for each other. The E-bike is an alternative for car and bus movements for short distances only. Therefore commuter traffic within the range of 15 km from the city of Groningen was included. The spreadsheet model includes a number of parameters.
Parameters
- Energy use per vehicle per km: car, bus, bicycle, electric bicycle and electric scooter
- Emissions per vehicle per km: car, bus, bicycle, electric bicycle and electric scooter
- Emissions of local power generation, depending on the energy mix
- Daily no. commuters range 15 km from Groningen
- Assumed average distance work-home (10 km)
- Modal split commuter traffic
- Average number of passengers per modality
- Average detour factor per modality

Different scenarios were calculated with the model. The first scenario is the current situation for 2012. The second one represents the prognosis for 2020 with an increase in the number of commuters and modal split E-bike of 1%. The final one is the situation in 2020 with more commuters and 10% additional E-bike movements.

<table>
<thead>
<tr>
<th>Daily no. commuters</th>
<th>2012 current</th>
<th>2020 BAU +1% E-bike</th>
<th>2020 +10% E-bike</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>70%</td>
<td>70%</td>
<td>67.5%</td>
</tr>
<tr>
<td>Bus</td>
<td>10%</td>
<td>10%</td>
<td>7.5%</td>
</tr>
<tr>
<td>Bicycle</td>
<td>20%</td>
<td>19%</td>
<td>15%</td>
</tr>
<tr>
<td>E-bicycle</td>
<td>0%</td>
<td>1%</td>
<td>8%</td>
</tr>
<tr>
<td>E-scooter</td>
<td>0%</td>
<td>0%</td>
<td>2%</td>
</tr>
</tbody>
</table>

### 8.2 Scenario results

The model results are presented in Table 19. Daily energy use and emissions for commuter traffic within a range of 15 km from city Groningen were calculated for the three different scenarios. It shows that the energy use for SC3 is almost 4% lower than SC2; both direct and indirect energy. All emissions except SO$_2$ show substantial reductions. Indirect particulate matter (PM) emissions show an increase since the E-bike use results in a shift from petrol use to electricity usage. Total PM emissions are almost 4% lower in SC3 than SC2.

**Table 19, Results scenarios daily energy usage and emissions for commuter traffic**

<table>
<thead>
<tr>
<th>Modality</th>
<th>Energy (TJ)</th>
<th>CO$_2$ (ton)</th>
<th>NOx (ton)</th>
<th>PM (ton)</th>
<th>SO$_2$ (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Direct</td>
<td>Indirect</td>
<td>Direct</td>
<td>Indirect</td>
<td>Direct</td>
</tr>
<tr>
<td>SC1 2012</td>
<td>5.061</td>
<td>1.328</td>
<td>365</td>
<td>91</td>
<td>0.959</td>
</tr>
<tr>
<td>SC2 2020 BAU</td>
<td>5.658</td>
<td>1.485</td>
<td>409</td>
<td>102</td>
<td>1.073</td>
</tr>
<tr>
<td>SC3 2020 E-bike</td>
<td>5.415</td>
<td>1.445</td>
<td>390</td>
<td>97</td>
<td>0.990</td>
</tr>
<tr>
<td>% change SC2&amp;3</td>
<td>-4.30</td>
<td>-2.65</td>
<td>-4.56</td>
<td>-4.56</td>
<td>-7.69</td>
</tr>
<tr>
<td>% change SC2&amp;3 total</td>
<td>-3.95</td>
<td>-4.56</td>
<td>-7.48</td>
<td>-3.83</td>
<td></td>
</tr>
</tbody>
</table>

SO$_2$ emissions in SC3 are substantially higher than in SC2. The reason is one kilometer on E-bike results in almost ten times as much SO$_2$ emissions compared to the same kilometer in a car with one passenger. The most relevant environmental impact concerning SO$_2$ is acidification. However, total acidification is a tradeoff between the absolute amount of SO$_2$ and NOx emissions. NOx emissions in SC3 are lower than for SC2. Total acidification is determined by the following comparison. The acidification potential (AP) is given for different substances [42].
Total acidification [kg SO₂-equiv.] = \( (AP_{NOx} \text{ [kg SO₂-equiv./kg]} \cdot m_{NOx}[kg]) + (AP_{SO2} \text{ [kg SO₂-equiv./kg]} \cdot m_{SO2}[kg]) \)

- \( m \) = mass of substance [kg]
- \( AP_{NOx} = 0.70 \text{ kg SO₂-equiv./kg} \)
- \( AP_{SO2} = 1.00 \text{ kg SO₂-equiv./kg} \)

Total acidification for SC2 is 961 kg SO₂-equiv. and SC3 is 893 kg SO₂-equiv.; a reduction of 7.11%. Therefore despite a substantial increase in SO₂ emissions due to additional electricity production for E-bike in SC3, the total acidification is lower than SC2.

### 8.3 Other possibilities to reduce environmental impact commuter traffic

The large scale introduction of the E-bike has positive effects on accessibility and environment. However, there are other possibilities to reduce the environmental impact of commuter traffic in region Groningen-Assen. A sensitivity analysis was conducted in order to compare the E-bike scenario (SC3) with three alternative scenarios. Scenarios 4-6 were calculated for 2020 and compared to SC2 (BAU 2020) as shown in Table 20.

- SC 4: cars average 10% more energy efficient; therefore -10% energy use and emissions pax/km
- SC 5: large share renewable electricity; 50% renewable, 44% gas, 6 other (nuclear)
- SC 6: Average number of passengers per car from 1.16 to 1.5, resulting in 23% less car movements

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Energy</th>
<th>CO₂</th>
<th>NOx</th>
<th>PM</th>
<th>SO₂</th>
<th>Acidification</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC4</td>
<td>-9.5%</td>
<td>-9.5%</td>
<td>-8.6%</td>
<td>-8.3%</td>
<td>-7.2%</td>
<td>-8.6%</td>
</tr>
<tr>
<td>SC5</td>
<td>0.0%</td>
<td>0.0%</td>
<td>-0.3%</td>
<td>-2.1%</td>
<td>-26.6%</td>
<td>-0.8%</td>
</tr>
<tr>
<td>SC3+5</td>
<td>-4.0%</td>
<td>-4.6</td>
<td>-7.9%</td>
<td>-7.0%</td>
<td>-29.7%</td>
<td>-8.3%</td>
</tr>
<tr>
<td>SC6</td>
<td>-21.4%</td>
<td>-21.6%</td>
<td>-18.3%</td>
<td>-18.8%</td>
<td>-16.2%</td>
<td>-18.2%</td>
</tr>
</tbody>
</table>

The scenario with 10% more E-bike movements (SC3) is compared to other reduction options for the environmental impact of commuter traffic in region Groningen-Assen. It shows that the improvement of the average energy efficiency of cars has a mayor effect on energy use and related emissions. Market forces and government policy in the future will determine into which extend cars will become more energy efficient.

The scenario with 50% renewable electricity in the Dutch energy mix (SC5) has a negligible effect on environmental impact since in SC5 the modal split of E-bike is only 1%. When SC3 is combined with SC5, modal split E-bike 10% and large share sustainable electricity, it results in substantial reduction of PM and SO₂ emissions.

Finally mayor effects on energy use as well as emissions occur with an average number of passengers per car of 1.5 instead of 1.16 (SC6). Carpooling offers a great reduction potential for energy use and emissions of commuter traffic. The effect of more passengers per car will be even bigger for long distance car movements (>15 km). Still it proves very hard to promote car sharing.
8.4 Conclusion

The scenario analysis shows that the E-bike offers advantages concerning energy use and emissions as an individual mode of transport and on system level. Local air quality is an important issue for region Groningen-Assen; therefore the direct emissions are most relevant. All mentioned direct emissions are lower in the scenario with a large share of E-bike usage. Moreover total energy usage (-4%) and the total acidification (-7%) are lower in the scenario with a large share of E-bike usage, despite additional SO₂ emissions.

Other options to reduce environmental impact of commuter traffic are included as well. The improvement of energy efficiency of cars and car sharing has substantial effects on energy use and emissions of commuter traffic. All scenarios, except carpooling, perform worse in absolute sense than the current situation in 2012. The reason is the increase in commuter traffic up to 2020. Finally different scenarios will strengthen each other and contribute to more sustainable commuter traffic in the region Groningen-Assen.
9 DISCUSSION

9.1 Environment
Concerning direct energy use it is a point of discussion if the battery is charged at night. The E-bike needs to be charged, which leads to an increase of electricity usage. However, such would not be the case under circumstances of electricity surplus, which would spilled otherwise. This offers opportunities for charging E-bikes in combination with smart grids. Moreover emissions will be substantially lower when renewable energy is used to charge the batteries.

During the analysis of emissions it appeared, that substitution of car-usage by E-bikes has additional advantages. The E-bike is a substitute for short distance car-trips when the car-engine is relatively cold. A cold engine consumes more fuel and produces more emission than a heated engine. Another advantage is that the amount of car kilometers that is “not traveled by bicycle” is higher than one would suggest based purely on traveled bicycle kilometers (detour factor). The traveled distance by bicycle of a trip of 2.5 - 5 km appears to be 17% shorter than by car; for longer distances even 35% shorter [43].

Emissions of bus and car were estimated with average occupation rate. When all seats are taken emissions per passenger km will be lower. In China the energy mix produces relatively more air emissions than the Dutch energy mix. Moreover in China the E-bike is fully electric, while in the Netherlands pedal assistance is the standard. One might argue that the more advanced E-bikes used in the Netherlands require more advanced technology which will contribute to the higher total environmental impact. On the other hand manual pedaling might reduce the energy use. Finally PM is emitted during the combustion of fuels, but by wearing of brakes, tires and road surface as well, this is not included. This type of PM is less harmful for human health than the PM from combustion of fuels.

9.2 Accessibility
Traffic counts show more movements closer to the city, but they do not produce a total number of movements. It might well be, that commuters use the bike route plus in favor of previous routes due to the upgrade. It is possible that people moving or changing work places have an influence on the intensities.

It is not sure if additional E-bike movements result in less car movements. It is likely that the extra space on the road is filled immediately by new car users or people who used to travel outside rush hours. The replacement of short distance car trips by E-bike trips will lower the pressure on belt roads. Therefore rat-run traffic in local neighborhoods will return to the belt road and the livability in neighborhoods will slightly improve. Also, the saved space for car parking has to be used partly for additional bicycle parking.

Model studies provide single-sided views of effects on accessibility since mode choice is determined by more factors than costs, distance and travel time. The analysis in this thesis included only cases where the E-bike is a substitute for 100%, but even when the E-bike is used a few times a week there are advantages as well.
9.3 Scenario analyses
The scenarios include car, bus, bicycle and E-bike. It would be interesting to expand the spreadsheet model by including train and tram. The latter one is interesting since the construction of tram lines in Groningen has started already. Another interesting development is the introduction of the electric car.

9.4 Opportunities for future research
An essential part of the total environmental impact is material use and waste management. These issues were mentioned briefly within this thesis. It would be very interesting to conduct a full life cycle analysis of an E-bike.

Another essential issue is E-bike use and traffic safety. There has not been proven a statistical relationship between E-bike usage and accidents. However, many accidents occur among elderly E-bike users. The lack of a distinctive sound and additional speeds are major reasons for unexpected traffic situations. It would be interesting to include the E-bike as a separate category in MON (Dutch mobility research) and in databases of insurance companies. This would provide accurate data on accidents in relation to E-bike use.

Another interesting development is the collection of trip data from E-bike computers. This data is collected by the manufacturers (Sparta) during service. It provides accurate data about trip distances, trip time and speed.

The energy use and emission data about the E-bike could be used in other models e.g. EAP. EAP can be used to calculate the total environmental impact of households (including personal mobility).
10 CONCLUSIONS

The electric bicycle and scooter are entering the personal mobility market quickly due to a number of advantages over conventional modes of personal mobility. The image that E-bikes are something for elderly is changing. The E-bike appears to be a cheap, clean and flexible alternative for the car. However, the E-bike is theft sensitive, traffic safety is an issue and it has a higher environmental impact than the conventional bicycle. The effect of E-bike use on the accessibility of a city and the quality of its environment depend on the change of habits of commuters starting to use an E-bike. Therefore behavioral sciences are needed to understand a commuter’s choice.

Mode choice for commuters is determined by objective and subjective factors. It is hard, if not impossible to model mode choice sufficiently. It shows that many factors determine the mode choice of commuter. Costs, traffic safety, image, weather, habits (car use), quality of cycling infrastructure, experience (spending time outside) and the quality of facilities are most relevant. A car user should be persuaded to choose public transport and the bicycle in order to reduce the environmental impact of personal mobility. Measures focusing at a single factor are ineffective due to the many factors at stake. A balanced package of incentives contains cycling infrastructure and public cycling facilities. Finally different target groups and situations demand for tailor made incentives. Mobility management is an effective measure to persuade the car commuter to switch in particular to E-bike.

Improvement of cycling infrastructure results in more cycling movements and better accessibility of a compact city. Traffic counts at upgraded cycling routes show in all cases more cycling movements per day; in some cases up to 17%. The utilization of E-bikes enhances the above mentioned effects. Model studies, traffic counts and market research show an increase in the number of cycling movements, a decrease in the number of car movements, a better traffic flow, higher average speeds for commuter traffic and less parking problems in city center. The E-bike results in a shift of the modal split. Size and cause of the modal shift differs per situation and the applied research method. Market research shows, that the effect of large availability of E-bikes on the number of cycling movements for commuters ranges between 4-9%. The E-bike appears to substitute for other means of transport for commuting traffic as follows: the conventional bicycle (33.3%), car (15.9%), public transport (8.1%), motorbike/ scooter (4.6%) and no complete substitution (37.4%).

The E-bike offers advantages concerning energy use and emissions compared to car and bus use. The scenario with 10% more E-bike use (modal split: 67.5% car, 7.5% bus, 15% bicycle and 10% E-bike) results in lower total energy use and emissions compared to a business as usual scenario (modal split: 70% car, 10 % bus, 19% bicycle and 11% E-bike). Alternative options to reduce environmental impact of commuter traffic were calculated as well. The use of E-bikes offers a substantial contribution to the reduction of the total environmental impact of commuter traffic. A substantial reduction of SO₂ emissions occurs in the scenario with renewable electricity and 10% E-bike usage. Moreover batteries have a large environmental impact due to scarce material use. Therefore further development of batteries and recycling of materials is important for sustainable personal transport.
An integrated public transport network in combination with the development of car infrastructure, cycling infrastructure and park and ride will guarantee good accessibility for region Groningen-Assen in the future. Different modalities will strengthen each other. In such infrastructural networks the E-bike will have its own role for commuter traffic.
REFERENCES


[38] RGA (2010). OV-bereikbaarheidsstrategie regio Groningen-Assen.


12 DEFINITIONS/ ABBREVIATIONS

- **Accessibility**: the time necessary and circumstances in which a commuter reaches its destination. Within accessibility, one would try to optimize the circumstances of travel and minimize the amount of time. Relevant issues are: the flow of traffic, average speed, lost time in traffic and car parking. Accessibility in this study does not include livability of the city center or economic development of the region.
- **Acidification**, acid rain causing harm to ecosystems and nature
- **CE**, combustion engine
- **CO₂ emissions**, anthropogenic carbon dioxide emissions
- **Commuter**, 1 person traveling from home to work and back
- **Commuting traffic**, traffic between residential areas and work locations with work as purpose
- **E-bicycle**, electric bicycle with pedal assistance
- **E-bike**, fully electric scooter (mofas type) and electric bicycle with pedal assistance
- **E-scooter**, electric scooter (mofas type)
- **LCA**, life cycle assessment
- **Lost time**, minutes lost in traffic jams
- **Modal split**, share of certain transport mode within total of movements
- **Mofas type scooter**, scooter with maximum allowed speed of 25 km/h, insurance and driving license required, no helmet
- **Movement**, moving from A to B, 1 commuter results in 2 movements
- **NOₓ emissions**, nitrogen oxide causing smog and acidification
- **Pax-km**, per passenger per kilometer
- **PM emissions**, particulate matter/ fine dust
- **SO₂ emissions**, sulfur dioxide causing acidification
13 APPENDICES
13.1 Range of current situation with E-bike and "bike route plus" region Groningen-Assen
13.2 LCA of various transport modes in Sima Pro

![Graph showing life cycle environmental impact of various transport modes](image)

Figure 13, Environmental impact SimaPro (CO2-eq/pax-km) for different stages of modality life cycle, relative and absolute, Netherlands, [21]

Eco Indicator 99

The total life cycle environmental impact however, is determined by many factors. In a life cycle analysis (LCA) the total environmental impact of different products can be compared. The life cycle of a product is divided in the production, use and disposal phase. There are always three different fields (spheres) of scientific knowledge required to make a LCA [44].

- Techno sphere, the description of the life cycle, the emission from processes, the allocation procedures as far as they are based on causal relations.
- Eco sphere, the modeling of changes (damages) that are inflicted on the environment.
- Value sphere, the modeling of the perceived seriousness of such changes (damages), as well as the management of modeling choices that are made in techno- and ecosphere.

The value sphere is a social one, the relative seriousness of certain emissions is subject to discussion. Product A for example emits SO$_2$ and causes acidification which has serious consequences for nature. Product B releases toxic emissions which causes risks to human health. A nature lover might be in favor of product B, while someone else might be in favor of product A. [44] In the discussion of seriousness three damage categories are most relevant: human health, ecosystem quality and resources. There are two methods available to determine how serious this damage is perceived by society. First the observation of actual behavior, this is basically how decisions of comparable issues are taken. The second method is questioning representatives of
society (panel) on the specific issue. The seriousness of damage categories is determined in the “EcoIndicator 99” [44].

13.3 Energy mix Netherlands 2009, total 113.5 TWh

![Energy mix Netherlands 2009](image)

Figure 14, Gross electricity generation Netherlands 2009 (TWh), [45]

13.4 Quality standards bike route plus
The driving lane of a bike route plus is wider than a “main” cycling path. A two way lane is upgraded to 3.5 meter wide and a one way lane to 2.5 meter wide. There should be at least 3 meter space between the lane for car traffic and bike route plus. [41] The bike route plus pays extra attention to shelter from passing car traffic and bad weather. Low and sustainable lighting (LED) offers a safe feeling along the route and limits light pollution for the area as much as possible. Turns are indicated by lights in the driving lanes. The number of intersections is minimized as much as possible.
13.5 Potential cycling trips due to E-bike usage

Table 21, Current and potential cycling trips (large availability E-bike) commuter traffic Netherlands total [6]

<table>
<thead>
<tr>
<th>Distance (km)</th>
<th>Current cycling trips</th>
<th>Potential minimum number cycling trips</th>
<th>Potential maximum number cycling trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2.5</td>
<td>310</td>
<td>310</td>
<td>310</td>
</tr>
<tr>
<td>2.5-5</td>
<td>208</td>
<td>229</td>
<td>229</td>
</tr>
<tr>
<td>5-7.5</td>
<td>130</td>
<td>186</td>
<td>186</td>
</tr>
<tr>
<td>7.5-10</td>
<td>41</td>
<td>41</td>
<td>60</td>
</tr>
<tr>
<td>10-15</td>
<td>47</td>
<td>47</td>
<td>83</td>
</tr>
<tr>
<td>15-20</td>
<td>14</td>
<td>14</td>
<td>32</td>
</tr>
<tr>
<td>20-30</td>
<td>10</td>
<td>10</td>
<td>17</td>
</tr>
<tr>
<td>Total</td>
<td>760</td>
<td>837</td>
<td>918</td>
</tr>
</tbody>
</table>

Theoretical additional cycling trips: 77 158
Theoretical additional E-bike trips: 116 237
Effective additional E-bike trips after correction “no substitution”: 72 148
Effective additional cycling trips after correction substitution conv. bicycle: 34 69