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ELECTRIFICATION OF ROAD TRANSPORT – AN ANALYSIS OF THE ECONOMIC PERFORMANCE OF ELECTRIC TWO-WHEELERS

Abstract

Air pollution is a major problem in our current society, PM, NO_2, O_3 and CO cause health problems while CO_2 emissions have environmental impacts. One of the largest emitters is the transport sector. To reduce pollution by passenger transport, the EU has mapped a strategy to increase electric-based transport. In the EU the emissions from the extra electricity generation that is needed for electric transport are lower that the emissions for the currently used fossil fueled transport options. Studies show that electric cars are too expensive to compete with internal combustion engine (ICE) vehicles. Electrification via electric two-wheeler (ETW) technology could be an option, especially in urban regions, however little research has been done on ETWs in the EU. We enhance the knowledge base for policy makers by researching (i) the learning rate for e-bikes and bicycles and finding the future price of e-bikes until 2025 using the experience curve analysis, (ii) the current economic viability of ETWs based on total cost of ownership (TCO) [€/km] from a consumer's perspective, (iii) which vehicles the e-bike substitute. We do this to compare the substitution choices of e-bike consumers in the Netherlands with consumers in China and to find the main competitors of the e-bike in the Netherlands.

We find that (i) the learning rate is 1.0% ± 1.7% for average e-bike prices [€] and 7.9% ± 2.3% for specific e-bike prices [€/kWh] showing a decline in prices for e-bikes. For bicycles we found a learning rate of -36% ± 111% indicating a rise in bicycle prices. These learning rates are significantly lower than those found for battery electric vehicles (BEV) (23% ± 5%) and for energy demand technologies in general (18% ± 9%). We find that e-bike prices will decrease by 3% from €1614,- ± 674 in 2012 to €1561,- ± 609,- in 2025 and the specific price of e-bikes will fall by 17.8% in the same time period from €5813,- ± €2854,- per kWh in 2012 to €4779,- ± €2629,- per kWh in 2025. For the economic analysis (ii) we find that e-bikes are the cheapest option among ETWs with a cost of €0.10 ± €0.05 per km, compared to €0.31 ± €0.14 per km for electric scooters and €0.45 ± €0.21 per km for electric motorcycles. These prices indicate that e-bikes are relatively cheap, similar to the cost of public transport, only slightly more expensive than bicycles (€0.06 ± €0.03) and much cheaper than cars (€0.32 ± €0.15), scooters (€0.23 ± €0.11) or motorcycles (€0.31 ± €0.15). From a consumer perspective only e-bikes are a financially viable option (for large scale use). However it is believed that as prices of batteries decline electric-scooters, and later electric motorcycles will become economically viable as well. Compared to China, all vehicle options are more expensive in the Netherlands. However the relative cost distribution between the Netherlands and China is similar. (iii) From our questionnaire we can conclude that in the Netherlands e-bikes are predominantly used to replace cars (33% of km) and bicycles (33% of km). This is probably due to the convenience of the e-bike compared to the bicycle and the car. These findings however contradict earlier research performed on e-bikes in China, where e-bikes mostly replace public transport use. From the results we can conclude that e-bikes are a viable option to reduce congestion and parking problems in cities. Overall an increase in e-bike use will increase electricity consumption but probably lower harmful air pollutant emissions, especially in urban areas. It will probably also reduce CO_2 emissions. We expect that the CO_2 emission reduction by replacing cars, is greater than the increase of CO_2 emissions by replacing bicycles. This analysis is done based on data for the Netherlands and is probably representative for other densely populated regions with a bicycling culture and similar geographical characteristics, e.g. (cities in) Denmark, Germany, Switzerland and Belgium.

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LIST OF ABBREVIATIONS AND UNITS

$€_{2012}$	-	Euro's deflated to the base year 2012
10M	-	10 Million
a	-	Year
ACEM	-	European Association of Motorcycle Manufacturers
ANWB	-	Algemene Nederlandse Weggebruikers Bond (General Dutch Road-Users Association)
B	-	Benefits
BEV	-	Battery Electric Vehicle
BSEB	-	Bicycles Style Electric Bike
C	-	Cost
CBS	-	Centraal Bureau voor de Statistiek (Central Bureau for Statistics)
cm3	-	Cubic-centimeter
CO	-	Carbon Mono-oxide
CO_2	-	Carbon Dioxide
CP	-	Cost of Production
D	-	Distance Driven (per year)
DL	-	Deutschland/Germany
EC	-	European Commission
ETRA	-	European Twowheel Retailers' Association
ETW	-	Electric Two-Wheelers
EU	-	European Union
Excl.	-	Excluding
gCO_2	-	Gram of Carbon Dioxide
GTW	-	Gasoline Fueled Two-Wheeler
I	-	Investment
ICE	-	Internal Combustion Engine
IIASA	-	International Institute for Applied System Analysis
IT	-	Italy
km	-	Kilometer
km/h	-	Kilometer per hour
kW	-	Kilowatt
kWh	-	Kilowatt-hour
L	-	Lifetime
Li	-	Lithium
LR	-	Learning Rate
Mt	-	Megatonnes
NGO	-	Non-Governmental Organization
NiMH	-	Nickel-Metal hydride
NL	-	The Netherlands
NO_2	-	Nitrogen Dioxide
NPC	-	Net Present Cost
NPV	-	Net Present Value
O_3	-	Ozone
OECD	-	Organization for Economic Co-operation and Development
P	-	(Cumulative) Production
PBP	-	Pay-Back Period
PM	-	Particle Matter
PTW	-	Powered Two-Wheeler
r	-	Discount Rate

SSEB	-	Scooter Style Electric Bike
TCO	-	Total Cost of Ownership
UK	-	The United Kingdom
USA	-	The United States of America
VAT	-	Value Added Tax

1 INTRODUCTION

Currently, one of the major environmental problems is air pollution from transport (EEA 2011). In 2009 transport was responsible for 19% of global primary energy use and 23% of global anthropogenic CO_2 emissions (IEA 2009). The CO_2 emissions contribute to global warming while other emissions (PM, NO_2, O_3, CO) cause health issues, e.g. heart lung diseases, damage to the nervous system and leukemia (EEA 2011, EU Green Cars Initiative 2012). On-road transport alone is expected to be the largest contributor to anthropogenic climate forcing in 2020 (Unger 2010).

In the European Union, transport is responsible for about a quarter of the anthropogenic CO_2 emissions, making it the second largest CO_2 emitting sector after the energy generation sector. The European transport sector is also responsible for the emission of 4.5Mt of NO_x and ~0.5Mt of PM per year (EEA 2011). Road transport alone contributes about one-fifth of the EU's total emissions of CO_2 (Figure 1; Hill et al. 2012). Road transport can be divided into passenger (70% of CO_2 emissions) and freight transport (30% of CO_2 emissions) (Borken-Kleefeld 2010). In Europe passenger road transport accounted for over 500 Mt of CO_2 emissions in 2007 (EET 2008). In 2005, road transport contributed 40% to the European NO_x emissions and was responsible for 30% of the economy-wide PM emissions (Vestreng et al. 2008, Krzyzanowsky 2005).

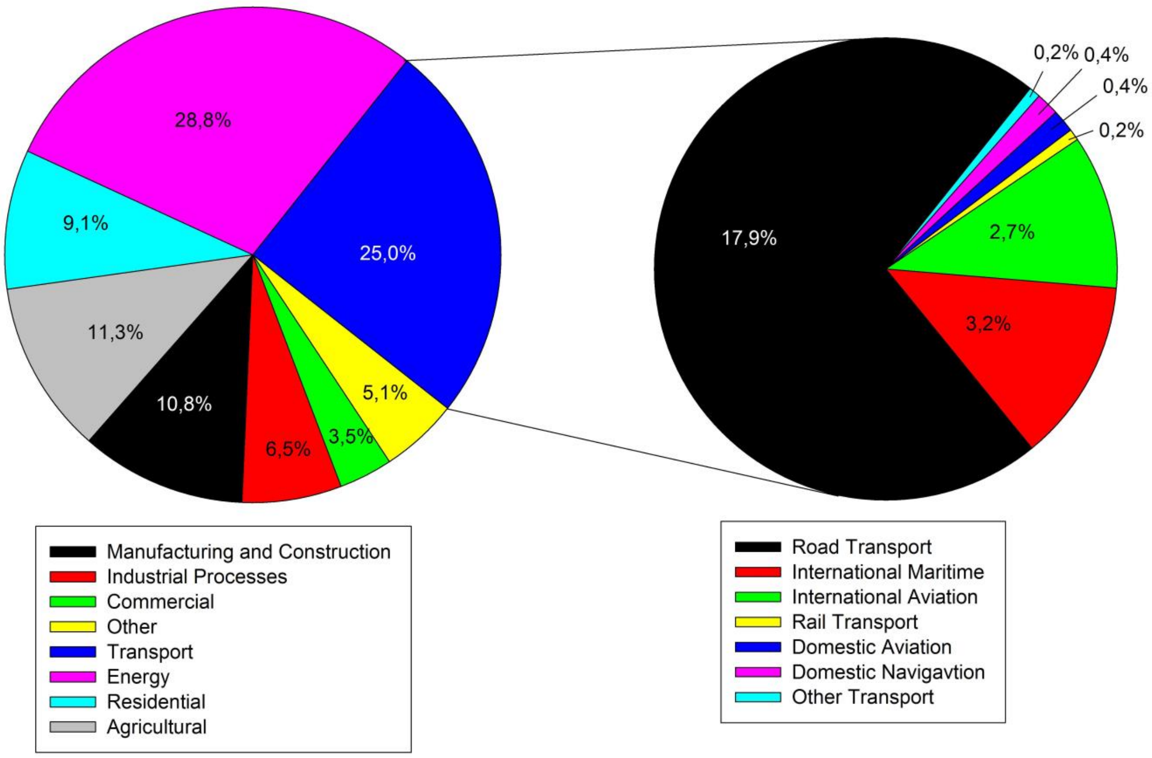

FIGURE 1: ANTHROPOGENIC CO_2 EMISSIONS OF THE EU-27 IN 2009 (DATA SOURCE: HILL ET AL. 2012)

In order to reduce the CO_2 and pollutant emissions and to ensure security of fuel supply, the European Union indicated the electrification of road transport to be one of the key objectives in realizing a sustainable energy and transport system (EU Green Cars Initiative 2012).

Research on the electrification of road transport focused on the electric automobile market. The research shows that electric cars have inadequate performance (limited drive range, long recharging time), are lacking the required infrastructure (charging stations) and are more expensive than comparable ICE cars (Lee and Lovellette 2011). These differences make the electric car unsuitable for large scale implementation in the near future (Lee and Lovellette 2011). An alternative option to pursue the electrification of road transport are electric two-wheelers (ETW) such as e-bikes, electric mopeds and scooters and electric motorcycles.

Electric two-wheelers could replace several combustion-driven vehicles such as cars in urban environments, conventional scooters but also bicycles and city-bound public transport. The tailpipe emissions of these combustion fueled vehicles have a negative effect on the health of the population. Reducing these emissions would be beneficial to general health and increase life expectancy and overall living standards of society (EEA 2011). Electric two-wheelers have no tailpipe emissions and need far less road surface for transport as well as for parking compared to cars. These aspects enable a reduction of congestion on the roads and parking problems in the city. However, ETWs could also replace conventional bicycles. This would cause an increase of emissions due to increased electricity use (TNO 2010). However, the elderly and disabled people could be inclined to keep mobile when a conventional bicycle would otherwise become too strenuous (Parker 2011).

Compared to electric cars, electric two-wheelers have received less attention from the scientists. A simple Google scholar search for “electric car” yields 2,180,000 results while searches for “electric two wheeler” yields 111,000 results, “electric bicycle” 84,700 results, “electric motorcycle” 40,600 results and “electric scooter” 15,400 results.

Research into ETW has been focused predominantly on the Asian market, in particular China where ETWs have gained a significant market share. Ninety percent of the world’s ETWs are produced and sold in China (Figure 2; Weinert *et al.* 2007, ADB 2009, Cherry 2009). Experts estimate that between 120-150 million ETW are on the road in China alone, compared to 450 million conventional bicycles, 98 million cars and 102 million conventional powered two-wheelers (Weinert 2007, China Daily 2011).

In 2006 approximately 33 million PTWs were being used in Europe, including 12.9 million mopeds (ACEM 2010). The PTWs contribution to European road transport emissions is ~2% while the contribution to CO_2 emissions is predicted to remain stable around 1.3% of passenger transport, ~6.5 Mt of CO_2 per year (EET 2008, ACEM 2010). ETW emit less pollutants to the atmosphere compared to fossil fuel propelled vehicles; the electricity generated to power the ETW does however emit CO_2 and other pollutants (Cherry 2008, WikiMobi 2013). On a well-to-wheel basis, ETW emit up to 80% less CO_2 than comparable gasoline fueled two-wheelers (GTW) (Weinert 2007, Den Boer et al. 2008, WikiMobi 2013). In the Netherlands 20% of bicycle sales are electric bicycles, in Germany this is 10%. Value wise, electric bicycles account for approximately double the percentage (EPOMM 2013). As the market is very young the amount of ETW in the EU is difficult to determine. In the EU over 1 million ETW were sold in 2012 from 300,000 in 2008 (EPOMM 2013). Our educated guess is that around 3-4 million ETW are on the road in the EU, including bicycles.

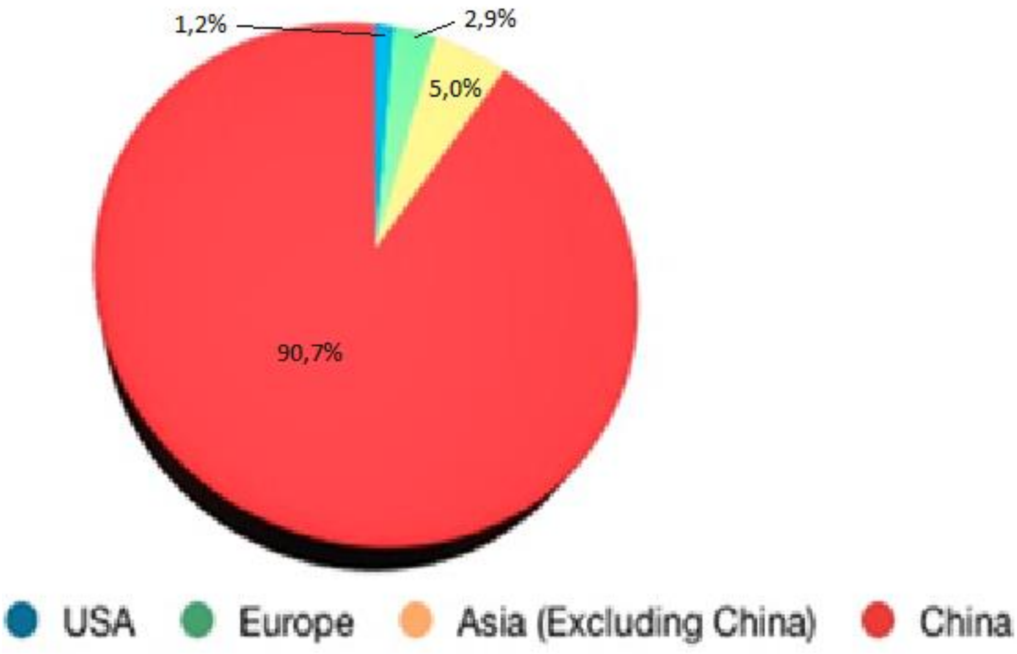

FIGURE 2: WORLD E-BIKE SALES 2012 (ADAPTED FROM: EBG 2013)

In order to enhance the electrification of road transport EU policy makers need to be well informed about current and future prices, cost of operation for consumers, market development, environmental impacts, infrastructure, use patterns and potential obstacles for implementation of ETW. This thesis will focus on costing and provides a detailed analysis on the technological learning and the cost-benefit performance of electric two-wheelers as compared to other transport options. This thesis will also look at the rebound shift in Northern Europe; which vehicles the electric bicycle competes with. This adds insight in the substitution options for the electric bicycle and could enable policy makers to create more specific and effective policy with regards to transport.

This thesis addresses the following research question:

How will the price of an electric bicycle develop in Europe until 2025 and how do the costs of use of electric two-wheelers relate to other transportation options, car, bus, train, conventional bike, conventional scooter and motorcycle based on Dutch transport modes and what is/are the ETWs main competitor(s) out of these options?

The research questions can be addressed by answering the following the sub-questions:

- What is the learning rate of electric bicycles in Europe?
- What are the predicted costs of electric bicycles in (2025) the future?
- What is the learning rate of conventional bicycles?
- What are user costs of electric two-wheelers (bicycle, scooter, motorcycle) compared to other modes of transportation?
- What is the TCO (total cost of ownership) of an electric two-wheeler compared to a car, conventional scooter, conventional bicycle and public transport?
- Which and how much does the electric bicycle replace other vehicles?

The analysis of technological learning provides insight into the price dynamics of electric two-wheelers and allows price forecasting until 2025. The difference in cost of use between electric two-wheelers and other transportation options can show the economic viability of the different ETWs (bicycles, scooters and motorcycles). By interviewing ETW owners the substitution choices of consumers can be shown.

This thesis will increase the knowledge about prices of electric bicycles, especially in the EU. A more complete overview of (future) ETW pricing and cost of use in combination with the substitution options of electric bicycles will enable policy makers to determine if, and what kind of, policy is needed regarding electric two-wheelers and the electrification of road transport. The interview will give insight into use pattern and rebound effects of e-bike users, this knowledge can show policy makers what the main substitution options are for electric bicycles.

This report contains four parts; It starts with the methodology, Section 2, followed by an overview of the electric bicycle market in Section 3. Section 4 contains the results of the experience curve analysis, the cost benefit analysis and the interview. The results are discussed in Sections 5. Section 6 relays the conclusions of this report.

2 METHODOLOGY

2.1 RESEARCH BOUNDARIES AND DEFINITIONS

There are many ways something or someone can be transported; via pipelines, through the air, over water or over land. All these ways of transport can be further specified, e.g., water transport can be distinguished into transport over sea or through rivers or canals. Land transport can be separated into rail, road and off-road transport. This thesis will focus on road transport, specifically on passengers road transport. Passenger road transport can be divided into transport by heavy-duty vehicles (busses), light-duty vehicles (cars), and two-wheelers (bicycles , scooters and motorcycles; Figure 3).

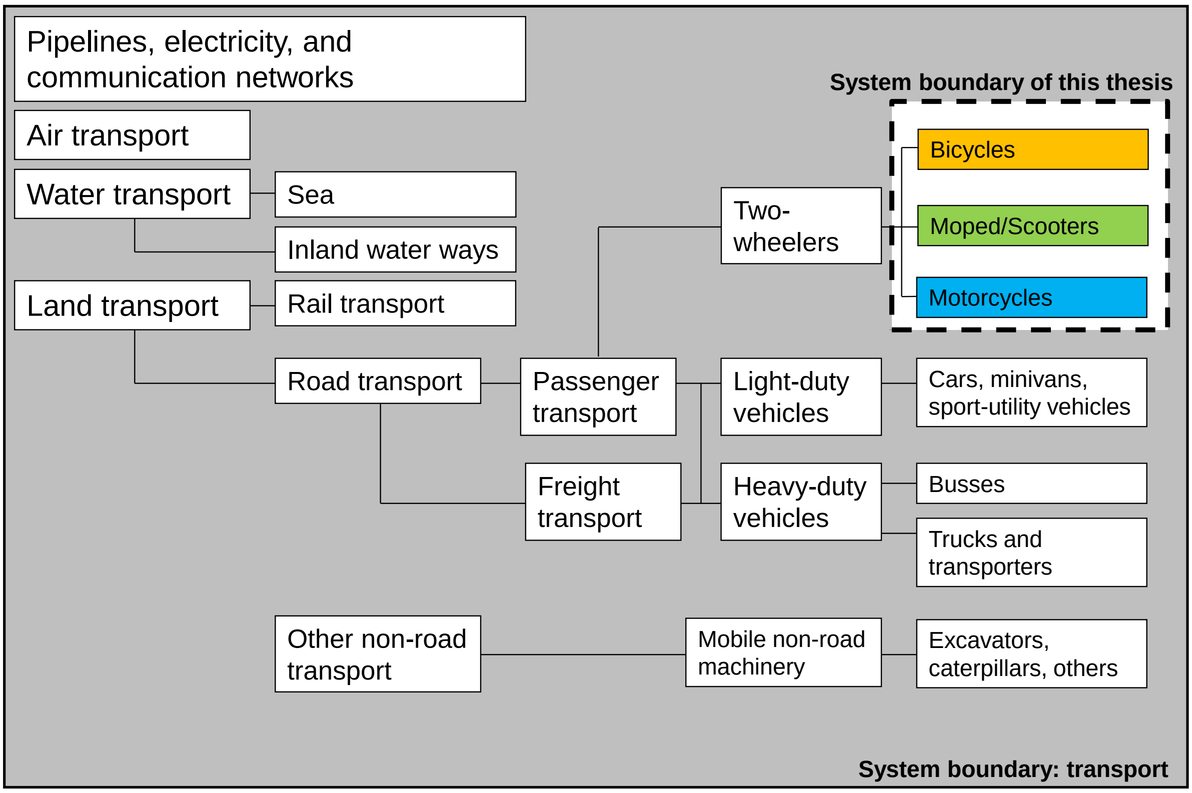

FIGURE 3: THE SYSTEM BOUNDARIES OF TRANSPORT AND THE SELECTION OF TRANSPORT FOCUSSED ON IN THIS THESIS

Of the total passenger road transport, this thesis focuses on conventional and electric two-wheelers. We exclude three- and four-wheelers, from our analysis, as well as vehicles with propulsion methods other than electric or gasoline based internal combustion engines such as vehicles equipped with fuel cells, diesel engines, and hydrogen propulsion. Although we exclude three-wheelers from our analysis, literature does not specify if the production data stated for two-wheelers include or exclude three-wheelers. It is possible that the data that we used to base our analysis on do include three-wheelers. We also exclude specialist and/or specific two-wheelers (e.g. high performance electric mountain bikes or racing bikes) from our analysis.

We base our categorization of two-wheelers on EC (2002) that classifies vehicles based on their maximum power and speed (Table 1). One exception is made here for bicycles. EC (2002) is not applicable to vehicles with pedal assistance with a maximum power of 0.25 kW and a maximum speed of 25 km/h. We use this description to categorize bicycles and electric bicycles, with the difference that bicycles are 100% human propelled and electric bicycles have an assisting electric motor.

TABLE 1: CATEGORIZATION OF TWO-WHEELERS BASED ON EC (2002)

Category	Speed (km/h)	Internal Combustion Engine size (cm³)	Electric Engine Power (kW)	Specifics
1. **Bicycles***	0 - 25	-	-	Pedals
2. E-bikes*	0 - 25	-	0 - 0.25	Pedals
3. **Mopeds/Scooters**	0 - 45	0 – 50	0 – 4	-
4. **Motorcycles**	> 45	> 50	-	-

*Excluded from EC (2002)

We focus mainly on e-bikes, e-bikes are far more abundant than electric scooters and electric motorcycles and the market for e-bikes in Europe is at the moment greater than that for other ETWs (GoPedelec 2012). From here on out we use the term "e-bike" instead of electric bicycle, (electric) pedelec, E-PAC or any other name. E-bike indicates a bicycle with an assisting electric motor with a maximum of 0.25kW. As there is little to no distinction made between bicycle style e-bikes (BSEB) and scooter style e-bikes (SSEB) in China, making it impossible for us to differentiate between e-bikes and electric scooters for China. Based on our best guess we assume both BSEB and SSEB to be e-bikes within our categorization.

2.2 DATA SEARCH

We start by collecting price and production data of electric and conventional two-wheelers, followed by a data search for the cost-benefit analysis. Table 2 shows the main sources for the identified data.

Production data for e-bikes were scattered over papers, reports, internet articles, and market blogs. Many papers and reports mentioned e-bike sales or production in China for only a few years (Weinert 2007, Cherry 2009). By combining multiple sources we could obtain a full data series for production of e-bikes in China and Japan and by extrapolation for the world from 1998 to 2012. For electric scooters and electric motorcycles, we are not able to collect the necessary production data. The literature sources yield no time series data on the production of e-scooters or e-motorcycles. Contacting branch organizations (ETRA, ACEM, Colibi, etc), searching statistical databases (CBS, Statline, Eurostat, China statistics, etc.), retailers and producers (Yahama, Giant, Qwic, etc.), NGO sites (IIASA, ExtraEnergy), automotive help services (NL, USA, Australia, Canada, etc.) and several two-wheeler museums (in the UK, Japan, USA, Australia, etc.) did not provide useful data regarding world production of electric scooters and electric motorcycles. The search for production data of conventional bicycles was less troublesome and we find complete series from 1950 until 2008 (Worldwatch 2008).

Next to historic production data, several sources predict the future market size for ETWs (Bento 2012, Navigant 2013, EBG 2013, Fastcoexist 2013). Continuing on the historic data collection we focus mainly on the E-bike production predictions.

The predictions about the future production of e-bikes differ significantly from each other. The only found scientific and therefore most credible source (Bento 2012) estimates a production of 179 million e-bikes per year worldwide in 2016, with 172million of those produced in China (Bento 2012). This would mean a compounded growth of production of more than 50% per year from 2012 to 2016. As the average growth per year has been 15% since 2006 (RiC 2011, GoPedelec 2012), we assume that Bento (2012) overestimates the future e-bike production. We also find data predicting sales of around 49 million e-bikes per year in 2018, of which 42 million in china (Navigant 2013, EBG 2013, Fastcoexist 2013. Lack of money prevents us from purchasing the original report (Navigant 2013) and the data we use is obtained via 2nd hand data sources and press releases. The data indicate a market growth of 7.5-10% per year, depending on the source (Navigant 2013, EBG 2013, Fastcoexist 2013). Literature also predicts that 10-15 million electric scooters and motors will be sold per year in 2018 (Navigant 2013, EBG 2013).

Besides production data, we also collect price data to base our experience curve analysis and cost-benefit analysis on. We use the same sources as stated for the production data. In general, we found it difficult to identify the prices of all ETWs dating back before 2011. As we only find production data of e-bikes we will focus the price data also on e-bikes. Websites of retailers are updated each year to incorporate the latest prices and old pricing is discarded. Producers do not want to disclose their prices for reasons of competition. The scientific literature often gives prices of only 1 specific vehicle or a general estimate of price (Miller 1999, Weinert et al. 2007). We could only find data from before 2011 for a few countries: The USA (few estimates 1997, 1999 and 2012; Miller 1999, Marshman and Benjamin 2012), Japan (2 prices of specific e-bikes 1990, and a general price range of 2006; ADB 2009-2), China (inaccurate estimates of price for several years between 1999 and 2007, ranging from $125 to $375 in the same year and with the exact same estimates for 2003 through 2007 (Weinert et al. 2007), and Europe.

We cannot provide valid data series for China, Japan, the USA and South-East Asia as we cannot find the necessary price data. Because of the meager data findings, we can also not construct a complete time series of price data for electric scooters or motorcycles in Europe. We do however identify a time series of price data, 1999-2012, for e-bikes by combining data for Germany and the Netherlands. The data for the German e-bike prices range from 1999-2008 while the Dutch e-bike data ranges from 2009-2012. These markets combined cover more than 50% of the total European e-bike sales (Colibi 2012). We find the average price for conventional bicycles in: the Netherlands, Germany, Italy and the United Kingdom from 2000-2011 (Colibi 2012).

Due to the lack of data we decide to forgo a worldwide experience curve but instead establish only experience curves for e-bikes sold in Germany and the Netherlands.

TABLE 2: OVERVIEW OF MAIN DATA SOURCES

Type of Data	Most relevant sources	Predominant Focus
Global bicycle production	- Worldwatch (2008)	- Global
Global e-bike production	- GoPedelec (2012) - Weinert et al. (2007) - Nagvigant (2013) - RIC (2011) - RIC (2013)	- Europe - China - China - China - China

	- Bento (2012) - EBG 2013 - Fastcoexist 2013	- Global - China - Global
Dutch e-bike prices	- Consumentengids (2008-2012) - Telegraaf (2011) - EFO (2013) - Orienteer (2013)	- The Netherlands - The Netherlands - The Netherlands - The Netherlands
German e-bike prices	- ExtraEnergy (2013)	- Germany
European bicycles prices	- Colibi (2012) - MiC (2012)	- Europa - NL
Dutch data fot the cost-benefit analysis	- NS (2013) - 9292OV (2013) - MiC (2012) - TNO (2010) - Bovag/Rai (2013) - CBS (2013) - ANWB (2013)	- Train ticket pricing - Bus, Tram, Metro Pricing - Two-wheeler data - Bicycle data - Car data - Travel distance - Taxation + Insurance
Chines data cost-benefit analysis	- Weinert (2007)	- Car, Scooter, Bicycle, E-Bike costs in China.

Next to the search for production and price data, we create a questionnaire (Appendix 4) to identify which modes of transport consumers substitute in the Netherlands when purchasing an ETW. We compare the identified use patterns with results from literature. We distribute 100 questionnaires over 21 different shops that sell e-bikes and/or electric scooters. 12 of the shops are located in Utrecht and Amsterdam, the other 9 shops are located in the smaller towns and villages surrounding Utrecht. We choose this experimental design to minimize bias caused by different use patterns due to geographical location and to identify potential differences in use patterns between customers living in urban and rural environments.

Using the questionnaire results a rough estimate on the impact of CO_2 emissions and electricity generation is made.

2.3 DATA ANALYSIS

2.3.1 EXPERIENCE CURVE

The price of products generally declines with increasing experience, i.e., the cumulative production of a product in time. Manufacturers acquire experience through several mechanisms including:

- Learning by doing,
- Economies of scale,
- Factor substitution,

- Technological innovation.

Together these mechanisms are called “technological learning”. To capture the combined effect of technological learning so called experience curves can be established (BCG, 1968). Experience curves model the production cost of a product as power-law function of cumulated production as:

$$CP1 = CP2 * \left(\frac{P2}{P1}\right)^{b}$$

Where CP1 is the cost at point 1 [$€_{2012}$], CP2 is the cost at point 2 [$€_{2012}$]. P1 is the cumulative production at point 1 [units], and P2 the cumulative production at point 2 [units], and b is the experience index. The experience index (b) is specific to a technology.

The experience index can be used to calculate the technology-specific learning rate (LR), that is the decline in costs per doubling of cumulative production:

$$LR = 1 - 2^{b}$$

If the experience index is known future costs can be predicted based on estimated future production and historic production costs.

We use the experience curve to find the learning rate for average price [€] of e-bikes and the specific price. The specific price [€/kWh] is the price of the e-bike per unit of battery storage capacity (kWh). To determine the specific price for the power of the electric motor is not useful as the power is limited to 0.25 kW for e-bikes (EC 2004).

We base the experience curve analysis on consumer prices instead of production costs. This is a wide spread and generally accepted approach as production costs are often not available (Weiss et al. 2009), we discuss the resulting uncertainties in the discussion. Price margins vary, VAT rates and inflation differ between countries. To minimize the uncertainty we correct for VAT rate and for inflation. We do this by subtracting the VAT of the price (EC 2013) and by deflating the price to the 2012 base year (WorldBank 2013) prior to the analysis (for all data see Appendix 1).

We apply the experience curve analysis to e-bikes sold in Germany and the Netherlands between 1999 and 2012. As the Netherlands and Germany are both experiencing approximately the same market development and the prices between the countries do not vary a lot (Colibi 2012, GoPedelec 2012), we assume the markets to be similar enough to valid this analysis. We also determine the learning rate of bicycles for several countries in the EU.

The data search (section 2.2) provides us with a complete production overview from 1951-2008. Based on the average growth of bicycle production in the last 20 years we use a growth rate of 1% to extrapolate the production data of bicycles between 2009 and 2012.

Using the data found as shown in section 2.2, we determine the global production of e-bikes by dividing world production into 3 regions: China, Japan and the rest of the world. Our best educated guess is that China produced 93% of the e-bikes produced in the regions China and the rest of the world (Figure 2, Figure 4, Weinert et al. 2007, EBG 2013). By adding Japanese production data to the estimate for production in China and the rest of the world we get our estimate of the total world production.

For the experience curve analysis we need to know the speed at which the e-bike and electric two-wheeler market will develop. As shown in section 2.2, estimates in literature vary widely.

Based on the data (section 2.2), we make an educated guess and use a growth of 4% in 2012, 6% in 2013 and 8.5% from 2014 on. The resulting numbers are consistent with indicated estimates in literature (Navigant 2013, EBG 2013, Fastcoexist 2013, Bento 2012).

2.3.2 COST-BENEFIT ANALYSIS

We calculate the cost of ownership (TCO) [€/km] for the e-bike, electric scooter, electric motorcycle and the other transportation modes as:

$$TCO = \frac{NPC}{D * L}$$

Where NPC is the net present cost [$€_{2012}$], D is the yearly distant driven [km/year] and L the average lifetime of the vehicle [year].

The net present cost represents the economic value of an investment:

$$NPC = -I - \frac{C}{\alpha}$$

Where I is the investment [€], C are the costs [€] and α is the annuity factor [%].

$$\alpha = \frac{r}{1-(1+r)^{-L}}$$

Where r is the discount rate [%].

For vehicles that are owned by the consumer we take the investment to be the purchase price. When the consumer only uses the vehicle (public transport) the investment represents the administrative costs needed to travel with public transport (buying a travel pass, OV-chipcard in the Netherlands). C are the yearly costs for owning and/or using the vehicle. For vehicles that could be owned by consumers (bike, car, scooter etc.) the costs are: maintenance costs, fuel/electricity costs, insurance and road tax. For public transport the costs are the ticket price and maintenance, where maintenance consists of the purchase of a discount subscription and write-off on the OV-chipcard, we take 10% of the original investment for this.

We compare the cost-benefit analysis for the Netherlands to that of China. To incorporate inflation we deflated the costs of use for China, which we found in literature, to 2012 (Jamerson and Benjamin 2005, Cherry and Cervero 2006, Ulrich 2006, Weinert 2007). This gives an insight into the similarities and the differences of price between the Chinese and the European e-bike market.

Afterwards, we make a substitution calculation based on the average use pattern to see if electric two-wheelers are economically viable from a consumers perspective. We calculate the pay-back periods (PBP; Blok, 2007) to see how much time it takes consumers to earn the money back. We calculate the PBP [Year] by taking the average price of an e-bike and dividing it by the benefits in operation (difference costs compared to the other vehicle) per year. This is done using the equation:

$$PBP = \frac{I}{B}$$

Where B are the benefits [€/year].

Benefits are possible if an electric two-wheeler is used instead of a different, more expensive, transportation method. We calculate the benefits for a consumer buying and using an e-bike by using the equation:

$$B = (TCOvehicle\ replaced - TCOebike) * km\ replaced\ per\ year$$

We determine the benefits by using the data obtained by the questionnaire. We do not include changes in the TCO for the original vehicle, due to the change in use pattern, in the calculation. The inclusion of these changes will make the calculations far more complicated while the added benefit of certainty is, at best, minimal. It is assumed that the extra lifetime of the vehicle (less use) will weigh against the higher fixed costs per kilometer and that therefore the cost per kilometer of the vehicles remains constant. We perform the calculations for the most common personal transport modes: cars, busses, trains, metro or trams, bicycles, scooters, e-bikes, electric scooters and electric motorcycles.

To determine the uncertainty of the TCO we follow the error propagation approach of Lindberg (2000). As Lindberg (2000) does not provide an uncertainty calculation for errors in powers we make an exception for the error calculation of α. We determine the error in α by changing the values for 'discount rate' and 'lifetime' from favorable to unfavorable for the consumer. We use the values 5%, 7.5% and 10% as discount rate with 7.5% for the default calculations. For lifetime we assume an uncertainty of 33% of the original lifetime of the vehicle. We then determine the error in α by taking the highest discount rate and the lowest lifetime and visa versa and determine the standard deviation based on the obtained values. The used value's and errors are shown in Table 3.

TABLE 3: OVERVIEW OF DATA FOR THE COST-BENEFIT ANALYSIS (VARIOUS SOURCES)

	Investment [€]	**SD**	**α [%]**	**SD**	**Fuel Cost [€/year]**	**SD**
Car	24000	7200	0.1093	0.0382	1680	336
Bus	10	0	0.0794	0.0277	165	70
Tram/Metro	10	0	0.0794	0.0277	87.5	30
C-bike	650	195	0.1707	0.0597	0	0
Train	60	0	0.0794	0.0277	200	100
E-bike	1920	800	0.1707	0.0597	5.44	1.09
Scooter	1500	450	0.1707	0.0597	90.00	18
E-scooter	3100	1000	0.1707	0.0597	8.80	1.76
C-Motorcycles	7087	1896	0.0980	0.0343	222.0	44.4
E-motorcycles	11555	3129	0.1292	0.0452	40.70	8.14

	Maintenance [€/year]	**SD**	**Insurance & Taxation [€/year]**	**SD**	**Lifetime [year]**	**Distance [Km/year]**
Car	2400	360	1020	51	16	14000
Bus	1	0.15	0	0	40	500
Tram/Metro	1	0.15	0	0	40	250
C-bike	30	4.5	40	2	8	2400
Train	51	7.65	0	0	40	1000
E-bike	40	6	55	2.75	8	3000
Scooter	125	18.75	150	7.5	8	2000

E-scooter	100	15	200	10	8	2000
C-Motorcycles	750	112.5	565	28.25	20	3700
E-motorcycles	500	75	565	28.25	12	3700

3 OVERVIEW OF THE ELECTRIC TWO-WHEELER MARKET

In 1895 the first e-bike model was patented in the USA by O. Bolton Jr (Patent 1895). Two years later, in 1897, Hosea W. Libbey was granted a patent for an electric bike with two electric batteries. This model has in recent years been reincarnated by Giant as a model for one of their e-bikes (Patent 1897, Wikipedia 2013). In the following years, several e-bike patents were applied for, however, the e-bike was outperformed by the internal combustion engine and development of the electric bike came to a standstill as the internal combustion engine was preferred for all vehicles (Wikipedia 2013, Raleigh 2013). We assume electric scooters and motorcycles were not developed in the 19th century, lack of power and battery capacity prevented this, the extra weight and size of the vehicles would even further diminish performance.

There was little activity regarding e-bikes until the 1980's when a short lived out roll of e-bikes was experimented with in China. During a few years in the late 1980's 10,000 to 20,000 e-bikes a year were produced in China. This introduction failed due to low quality battery technology and high costs; the electric vehicles could not compete with the cheaper gasoline-fueled motor scooters (Weinert 2007, Weinert et al. 2007).

The introduction of e-bikes also took place in other countries during the early 1990's, mainly due to government influence, again this out roll was short lived. Despite subsidies, electric two-wheelers could not compete with the cheaper gasoline fueled counterparts. An exception was Japan where the e-bike managed to create a market for itself (Weinert 2007, Weinert et al. 2007).

3.1 GLOBAL OVERVIEW

Today e-bike production is growing rapidly. E-bike production has risen from a few tens of thousands in 1995 to an estimated 34 million globally in 2012 (RIC 2013). The increase in production since 1998 is largely due to Chinese stimulation of their internal market. When compared to the yearly production of cars (i.e., 84 million; OICA 2013), bicycles (i.e., an estimated 106 million; Worldwatch 2008) and motorcycles (i.e., just over 41 million in 2006; OECD), it is apparent that e-bikes are successfully competing with other transport options. We could not find precise data on electric scooter and electric motorcycle production. However, they are low compared to the conventional options (cars, motorcycles, scooters), residing in niche markets, production is expected to grow towards 2015 and on (Evon 2011). Figure 5 shows the global e-bike production compared to global car and bicycle production.

In 2006 ~96% of all electric two-wheelers (including mainly e-bikes but also electric scooters and motorbikes) were sold in China (Figure 4), since then the market outside of China has increased significantly and while China is still very much the largest market, it is no longer the only market (Figure 2;Weinert 2007, Weinert et al. 2007). In recent years, the e-bike market has expanded abroad and started to pop-up in other countries. The main markets outside of China are: Europe, Japan, the United States of America, India and South-East Asia (Weinert 2007, Weinert et al. 2007, EBG 2013, Parker 2011, GoPedelec 2012).

China is the largest producer and consumer of e-bikes with an e-bike production in 2012 of over 30 million. Japan is the oldest e-bike market with steadily increasing sales since the early-to-mid 1990's reaching e-bike sales of 430,000 in 2011 (Parker 2011, GoPedelec 2012). The USA has, as the largest economy in the world, a potentially substantial e-bike market. However only 170,000 e-bikes were sold in the USA in 2012. Asia without China has a huge potential e-bike market. With comparable economies to China experts assume the same potential for e-bikes in these countries, as has been shown to exist in China (Chiu 1999, ADB 2009). Europe has currently the 2nd largest market (over 1 million sales in 2012) and rapidly expanding, producing and selling the highest quality e-bikes (GoPedelec 2012).

Electric scooters and electric motorcycles are less popular than e-bikes. Electric scooters and electric motorcycles cannot compete with their fossil fueled counterpart (ADB 2009). All over the world electric scooters and electric motorcycles are either substantially more expensive or have lower performance than fossil fuels scooters and motorcycles. The only exception is perhaps China (Navigant 2013). According to literature, electric scooters and electric motorcycles have a consistent growing market, however until now the market has not been profitable (Navigant 2013). To get a better overview we will discuss each market individually in sections 3.2-3.6.

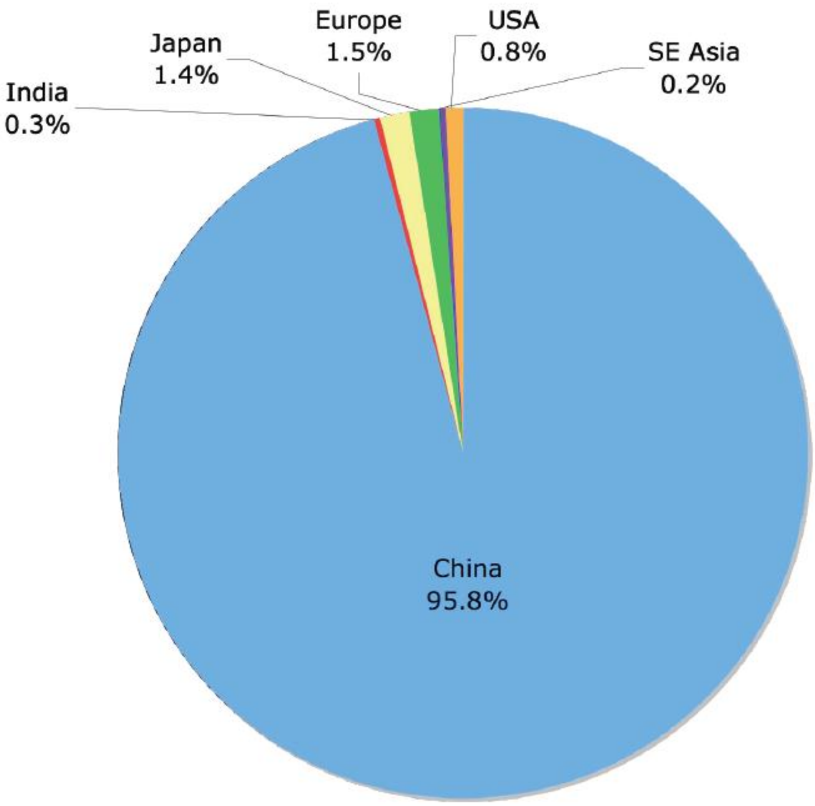

FIGURE 4: MARKET SHARE OF E-BIKES IN 2006 (DATA SOURCE: WEINERT 2007)

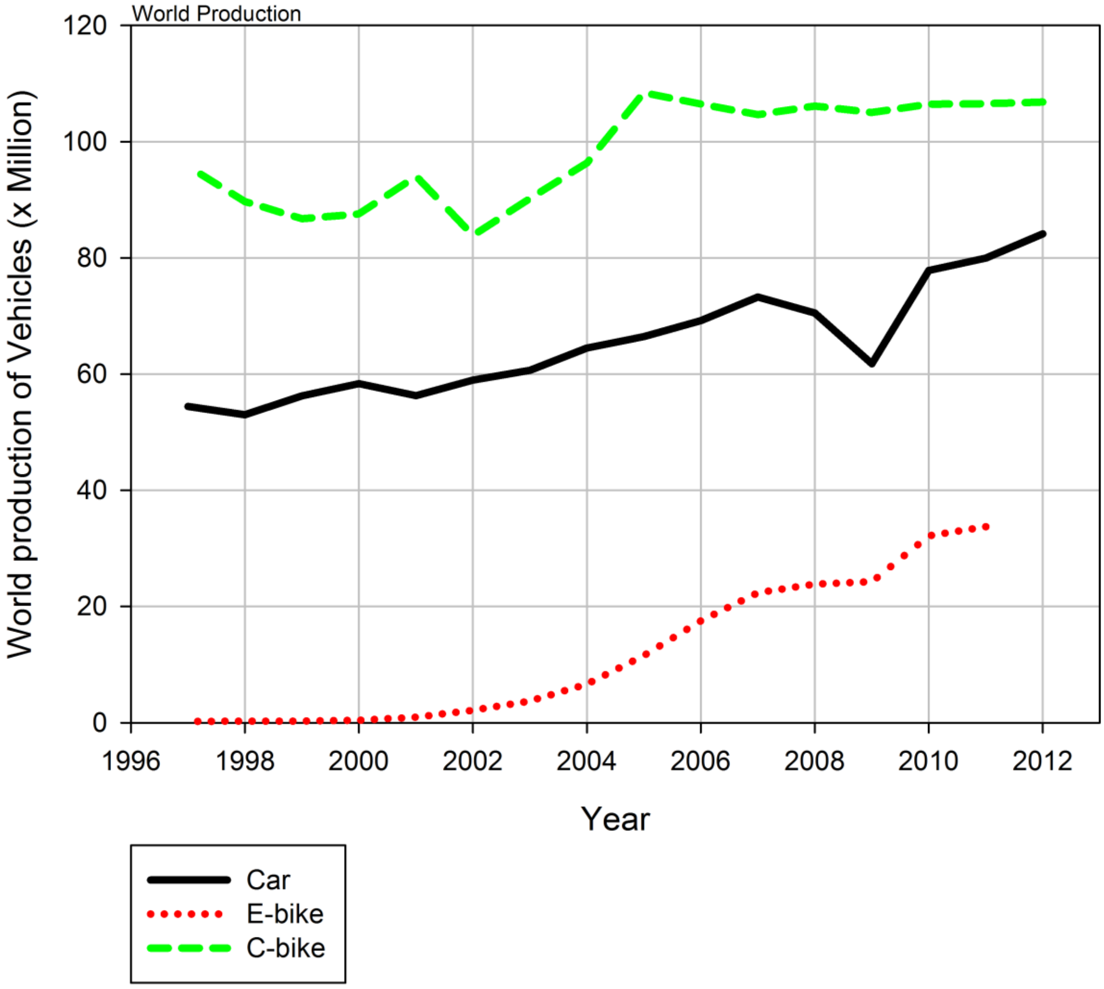

FIGURE 5: WORLD PRODUCTION OF VEHICLES 1997-2012 (SOURCES OF BICYCLES AND E-BIKES IN TABLE 3. DATA SOURCE FOR CARS: OICA (2013))

3.2 CHINA

Development did not stop after the first failed attempts to bring e-bikes and electric scooters to the market. In 1991, the Chinese national science board named electric two-wheelers as one of 10 technology projects during its 9th 5-year plan period (Gou 2000). It became clear that electric vehicles had political support as in 1995 the Chinese prime minister Li Pong declared support for electric vehicles. In that same year a beta-test was held with electric two-wheelers and the next year the first national forum on electric two-wheelers was held (Gou 2000, Weinert 2007, Weinert et al. 2007).

The political support for electric two-wheelers did not only result in support for R&D, also a restriction on gasoline fueled two-wheelers was put in place. In 1996 Shanghai suspended license granting to gasoline-powered vehicles for downtown Shanghai. The Mayor declared to "gradually eliminate gasoline-powered assist vehicles and develop and promote electro-assist technology" this was done to diminish congestion and reduce local pollution (Gou 2000, Weinert 2007, Weinert et al. 2007).

In the following years, many large and medium cities banned the sale of gasoline-powered scooters (Gou 2000, Weinert et al. 2007). In 1999, national electric two-wheeler standards were passed, creating uniform specifications for bicycle style electric bikes (BSEB) and scooter style electric bikes (SSEB). While there are some irregularities (a few cities banning electric two-wheelers to promote public transport or cars) the overall trend is to promote e-bikes, This helps to push the e-bikes to claim a substantial portion of the market and sales have risen tremendously from 1998 on. After the 2003 SARS outbreak, many people changed from public transportation to e-bikes creating an explosion of e-bike sales. In 2005 annual domestic sales reached 10 million and they grew to ~30 million in 2010 (Gou 2000, Weinert 2007, Weinert et al. 2007, RiC, EBG).

One caveat has to be placed with Chinese e-bikes. Chinese regulation states that there is no licensing required if an e-bike has working pedals and a maximum speed of 20 km/h. However there is little evidence of enforcement of this regulation and literature suggests that many e-bikes would be classified as electric scooters in the EU (Rose 2011). Experts believe the ETW market to continue to grow in China with the e-bike as the most popular option. However, electric scooters and electric motorcycles are predicted to follow in the e-bikes footsteps and grow substantially in the coming decade (Navigant 2013).

3.3 JAPAN

Japan's e-bike market has been growing steadily since the early 1990's. A total of over 4 million e-bikes have been sold in Japan with record sales of 430,000 in 2011 alone (GoPedelec 2012). In the 1990's the Japanese e-bike market was the largest in the world, until 2000 when China's e-bike sales surpassed Japans. In recent years Europe e-bike sales have also surpassed the Japanese making the Japanese e-bike market the 3rd largest in the World (Weinert 2007, GoPedelec 2012). In Japan, the e-bike is seen as a transport aid and often used by handicapped people; the elderly and people with an affliction like: arthritis, osteoporosis etc. (Parker 2011, Parker n.d.).

The regulation of e-bikes in Japan classifies e-bikes only as bicycles if the electric motor works proportional to the physical work delivered, meaning that unassisted riding is impossible (Parker 2011, Parker, Rose 2011, GoPedelec 2012).

3.4 ASIA WITHOUT CHINA & JAPAN

In South-East Asia, (electric) two-wheelers are also used as a main transport vehicle. Different from China is the fact that gasoline-fueled scooters are still in competition with the electric two-wheelers. In South-East Asia, GTW have not been banned from the cities and this creates a barrier for the developing electric two-wheeler market. Also the public opinion appears to be negative towards electric two-wheelers. The negative opinion is based on previous experience, early models did not live up to their expectations of performance and quality. The currently imported ETW are low quality vehicles from China and do not perform adequately under local conditions and also have little after-sales support (ADB 2009). The negative public opinion combined with the performance differences, ETWs are less powerful and have limited range compared to GTW, hinders the growth of the electric two-wheeler market (ADB 2009). Unfortunately we could not find reliable sales numbers, only statements that both e-bikes and electric scooters and electric motorcycles have yet to gain a significant market share.

3.5 UNITED STATES OF AMERICA

The e-bike market in the U.S.A. has trailed the emerging European electric two-wheeler markets (Leva 2012). The USA have lagged behind because of an inherent life style choice; the USA are not a cycling nation. Cycling is seen as a recreational activity and accordingly much of the e-bike market focuses on the off-road and recreational cyclists (Patil 2009). These circumstances caused the sales to lag behind compared to other western countries and experts estimate that the e-bike market in the USA is comparable to the EU around 2004 (Leva 2012). The e-bike sales in the USA (around 170,000 units; Bike-Eu 2012) are considerably lower than comparable western countries: Japan (~430,000/a) and Europe (>1million/a) (Goodman 2009, Rose 2011, GoPedelec 2012, Colibi 2012). The electric scooter and electric motorcycle market in the USA are in their early stages. There are only two U.S. manufacturers (Zero Bikes and Bramo).

3.6 EUROPE

While e-bikes have only recently started to gain popularity with consumers they have been in Europe since the early 1990's. In 1992, Antec was the first producer to introduce e-bikes to Europe (Antec 2013). The 10 years that followed the e-bike market did not grow much although efforts were made by governments to expand the e-bike and electric scooter market the e-bike was perceived as a vehicle for disabled people (Vermie 2003). This image started to change around 2002-2003. Other producers, like Sparta with the Sparta ION, started to make and sell e-bikes and slowly the e-bike started to gain popularity with consumers (Sparta 2013).

Since then the European e-bike market has increased significantly. E-bike sales have risen from 190,000 a year in 2006 to just over a million in 2012. Sales are highest in the Netherlands and Germany, representing over 50% of the European market (Weinert 2007, Weinert et al. 2007, Colibi 2012). Compared to 12 million cars sold in 2012 and just under 20 million bicycles sold in 2011 it is apparent that e-bikes are gaining a part of transport (Jolly 2013, Schaik 2013)

Today the e-bike is not just for disabled people but also for commuters living within 20km of their work; for instance, mothers that bring their children to school on the bike (GoPedelec 2012, ACEM n.d.). Recently, car manufacturers started to enter the e-bike and electric scooter market by partnering with current producers. They see the potential of electric transportation and want to be a part of the market (Tweewieler 2013, FietsVAK 2013). As more commuters transfer to electric two-wheelers retailers find that the need for speed increases (FietsVAK 2013). Producers and retailers would like to accommodate this trend by delivering bicycles that can go up to 50 km/h. However, European regulation does not allow this (FietsVAK 2013, EC 2002). Electric scooters do not have this restriction but the weight of a scooter limits the range, and the need for a license to operate a scooter is creating a barrier. The commuter market is seen as important, making the electric two-wheeler a competitor of the car (Tweewieler 2013, Bike-EU 2013, FietsVAK 2013).

The electric scooter and electric motorcycle market in Europe is still in its infancy. The PTW market in Europe in general is in decline. In 2011 1.7 million PTW were sold in Europe against 2.7 million 2007. Of the PTW less than 1% of all sales is due to electric scooters and electric motorcycles. Many of these electric scooters and motorcycles are sold in the southern European countries like Spain and Italy (Euractive 2012, Webbikeworld 2013).

4 RESULTS

We begin by presenting the results of our experience curve analysis in section 4.1, followed by the results of the cost-benefit analysis for ETWs compared with other transport options in Section 4.2. Afterwards we present the results of the questionnaire in Section 4.3.

4.1 EXPERIENCE CURVES

We find for the average price of e-bikes (Figure 6) a learning rate of 1.0 ± 1.7% with a R^2 of 0.14, see appendix price data for exact data. We find that the average purchase price, excl. VAT, of an e-bike in 2012 is €1614,- ± 674,-. And via extrapolation we find that the price will be; €1598,- ± 604,- in 2015, €1578,- ± 606,- in 2020 and €1561,- ± 609,- in 2025. This is a drop in price of just over 3% until 2025.

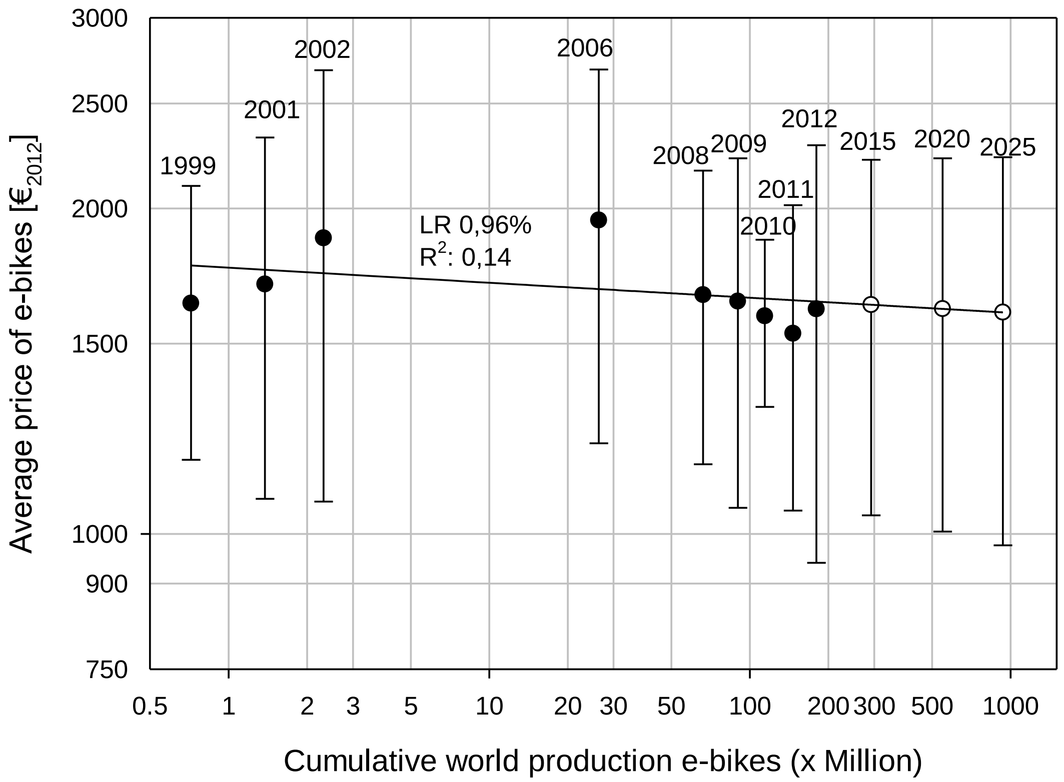

FIGURE 6: THE EXPERIENCE CURVE OF E-BIKES BASED ON DUTCH AND GERMAN E-BIKE PRICES; PRICE DEFLATED TO 2012

The experience curve for the specific price of e-bikes (Figure 7) shows us a learning rate of 7.9% ± 2.3% with a R^2 of 0.87. We find that the average price of e-bikes per kWh of battery power (or specific price [€/kWh]) is €5813,- ± €2854,- per kWh in 2012 and via extrapolation we calculated that this will drop to €5489,- ± €2789,- per kWh in 2015, €5092,- ± €2703,- per kWh in 2020 and €4779,- ± €2629,- per kWh in 2025.

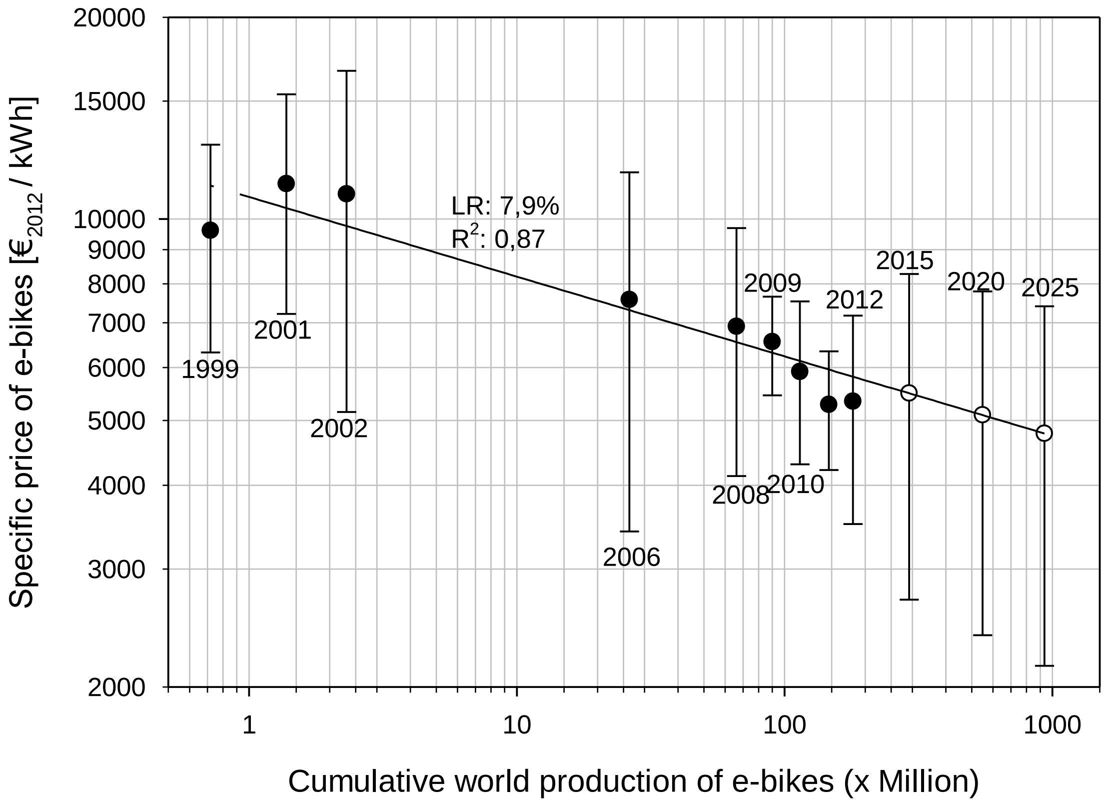

FIGURE 7: SPECIFIC EXPERIENCE CURVE BASED ON BATTERY POWER AND PRICE OF E-BIKES IN THE NETHERLANDS AND GERMANY; PRICE DEFLATED TO 2012

The experience curve results for conventional bicycles in the Netherlands, Germany, Italy and the United Kingdom (Figure 8) suggest that the average price of bicycles has risen over the last decade in the Netherlands, Germany and the United Kingdom, while the average price of bicycles in Italy has dropped (Table 4).

TABLE 4: LEARNING RATES FOR BICYCLES IN FOUR EUROPEAN COUNTRIES

	Learning Rate	R^2
The Netherlands	-37% ± 21%	0.64
Germany	-50% ± 38%	0.50
Italy	31% ± 44%	0.12
The United kingdom	-126% ± 95%	0.61
The EU combined	-36% ± 111%	0.01

The experience curve also shows that from 2006 to 2008 the average price of bicycles in all countries rises significantly.

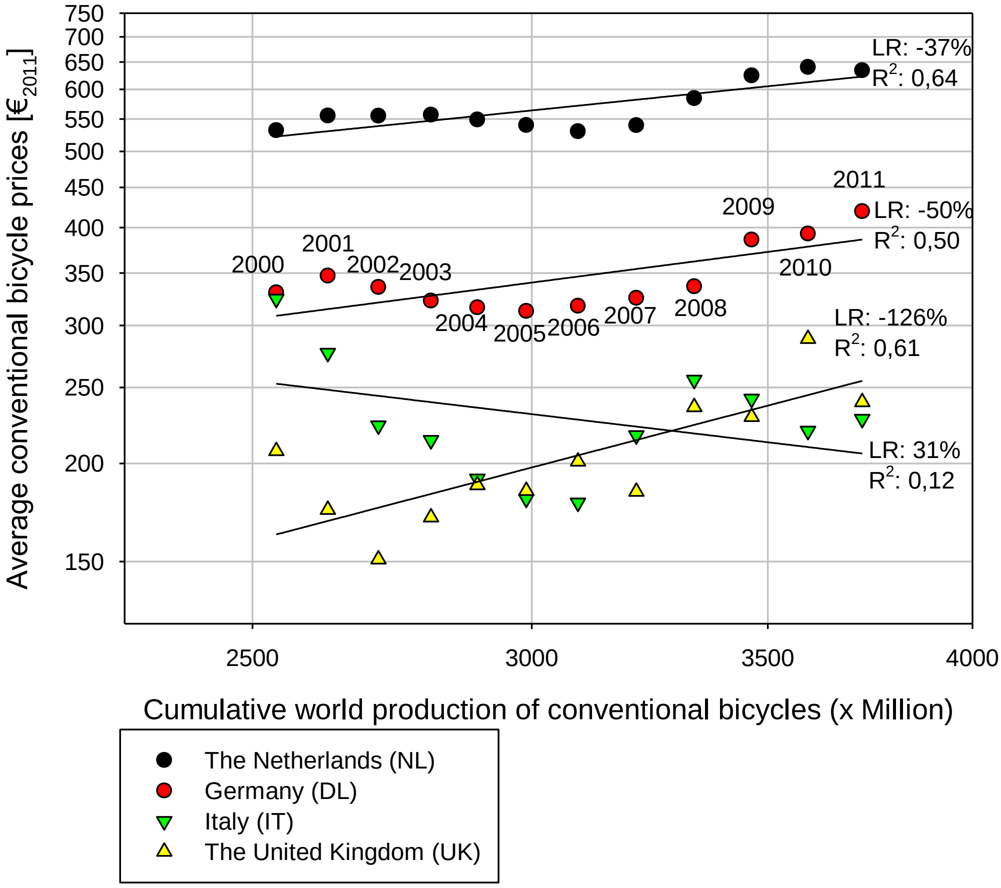

FIGURE 8: EXPERIENCE CURVE FOR CONVENTIONAL BICYCLES IN ITALY, THE NETHERLANDS, GERMANY AND THE UNITED KINGDOM; PRICE DEFLATED TO 2012

The experience curve for the Netherlands (figure 9) shows us an increase of prices between 2006 and 2010. The other countries analyzed show similar price increases, this increase in bicycle price will be discussed in section 5.1.1.

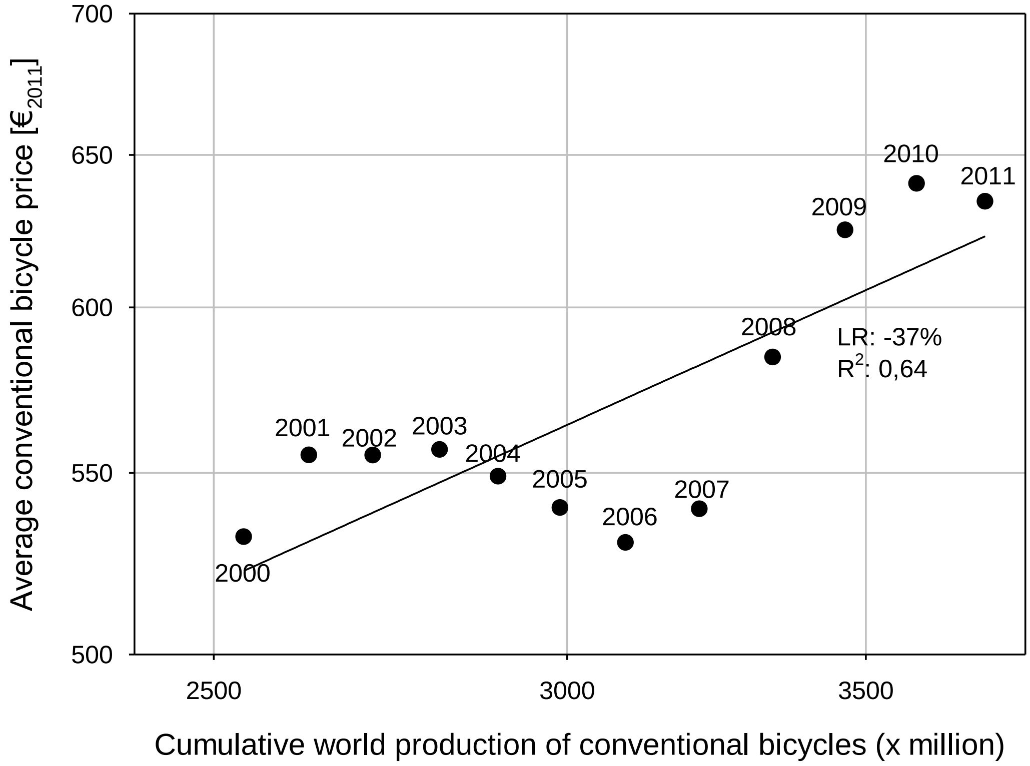

FIGURE 9: EXPERIENCE CURVE PLOTTED FOR CONVENTIONAL BICYCLES IN THE NETHERLANDS; PRICE DEFLATED TO 2012

4.2 COST-BENEFIT ANALYSIS

The TCO and NPC for e-bikes and several other vehicle options in the Netherlands are shown in Table 5 and in Figure 10, The results show the cost of use for the Netherlands (2012) and China (2007).

TABLE 5: THE TCO AND NPC OF SEVERAL VEHICLE OPTIONS IN THE NETHERLANDS IN 2012

	TCO [€/km]	NPC [€]
Car	-0.32 ± 0.15	-70622 ± 18401
Bus	-0.11 ± 0.06	-2101 ± 1146
Tram/Metro	-0.11 ± 0.06	-1125 ± 543
C-bike	-0.06 ± 0.03	-1060 ± 244
Train	-0.08 ± 0.04	-3221 ± 1679
E-bike	-0.10 ± 0.05	-2516 ± 828
Scooter	-0.23 ± 0.11	-3638 ± 887
E-scooter	-0.31 ± 0.14	-4909 ± 1188
C-Motorcycles	-0.31 ± 0.15	-22756 ± 5939

E-motorcycles	-0.45 ± 0.21	-20108 ± 4375

Table 5 shows that e-bikes are the 3rd cheapest option when we look at TCO and NPC, after trains (2nd cheapest) and bicycles. Cars have the highest negative NPC and they are the 2nd most expensive per kilometer.

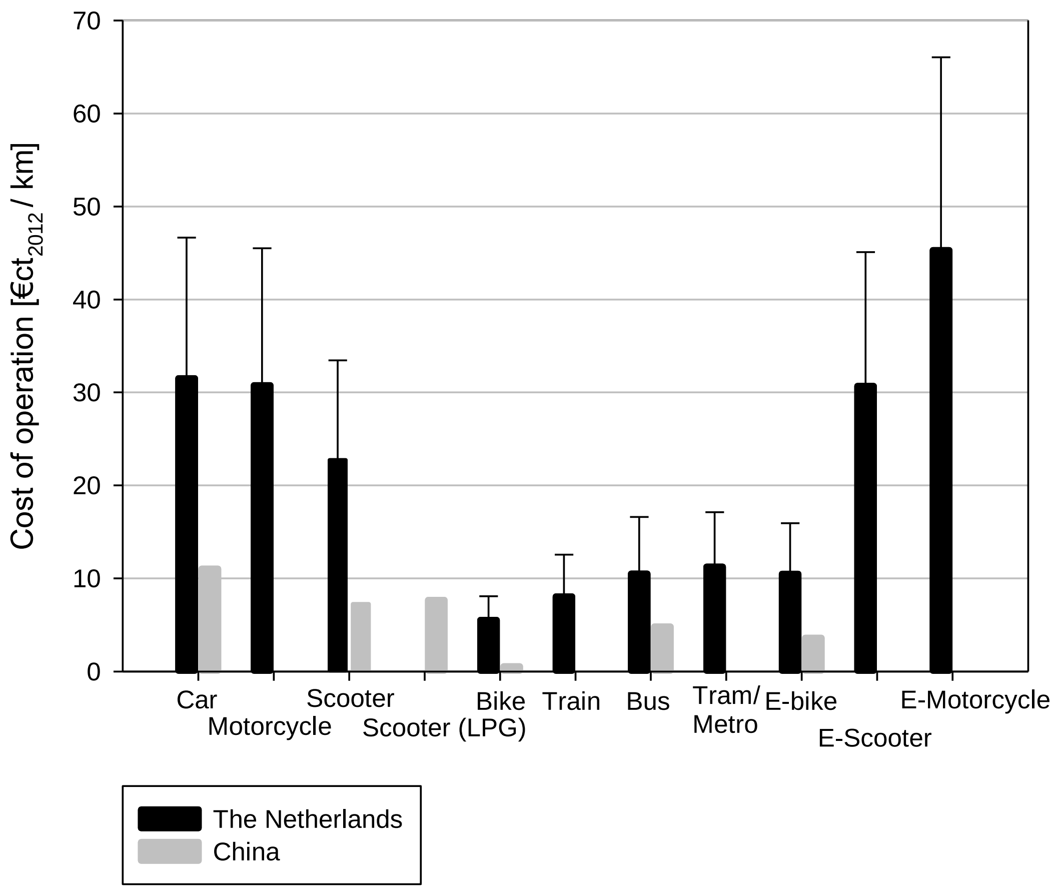

FIGURE 10: COMPARISON OF THE COST OF USE BETWEEN THE NETHERLANDS AND CHINA; DEFLATED TO 2012

The costs of use are lower in China but the general relation of costs between the vehicles is very similar. The car is the most expensive option and the bicycle is the cheapest. Public transport (e.g. trains) are in the same cost range per kilometer as e-bikes, while scooters are a bit more expensive.

Table 6 shows the PBP of the e-bike for the different transport options.

TABLE 6: OVERVIEW OF THE PAY-BACK PERIOD FOR THE E-BIKE WHEN REPLACING A TRANSPORT OPTION

Vehicle replaced	Pay-back period [Year]
Car	3,0
Bus	3406,9
Tram/Metro	84,0

C-bike	-
Train	-
Scooter	5,2
E-Scooter	3,2
C-Motorcycles	3,2
E-motorcycles	1,8

4.3 QUESTIONNAIRE

Out of the 100 questionnaires 22 were returned (Table 7); 13 from shops located in Utrecht and Amsterdam , 9 from shops located outside of Utrecht. Out of these, 55% were provided by women, 27% by men, and the remaining 18% by unidentified persons. The average age of the respondents is 53 years, however only 23% of the respondents answered this question. On average people ride 75 km on their e-bike per week, however city dwellers ride more (85 km/week) on their e-bikes than people from towns (60 km/week).

TABLE 7: OVERVIEW OF RESPONDENTS AGE, LOCATION AND MOVEMENT

Respondents	22			Response (%)
Sex	Male	6		
	Female	12		82%
	Unknown	4		
Age	Average Age	53	Years	23%
Location	City	13		100%
	Town	9		
Driven (wk)	Average Km	75	km/Week	
	City	85	km/Week	95%
	Town	60	km/Week	

TABLE 8: RESULTS OF THE QUESTIONNAIRE

Replaced by E-bike	Absolute replacement in numbers*	Replacement in percentage	Absolute amount of km replaced**	Kilometers replace in percentage
Car	9.00	28%	520.5	33%
Bus	2.00	6%	77.5	5%
Train	1.00	3%	0	0%
Metro/subway	1.00	3%	15	1%
Conventional Bicycle	8.00	25%	528.5	33%
Conventional Scooter	1.00	3%	40	3%
Old E-bike	1.00	3%	200	13%
Old Electric Scooter	0.00	0%	0	0%
Additional Transport	5.00	16%	146	9%

Other	4.00	13%	56	4%
Total:	32.00	100%	1.584	100%

*People could indicate multiple vehicles that the e-bike would replace
** People were asked to indicate how many kilometers they would use their e-bike per week

E-bikes replace many different vehicles but there are two main competitors cars and bicycles. 28% of the respondents use their e-bike to replace their car and 33% of all kilometers driven on an e-bike is done instead of driving those kilometers in a car. 25% of the respondents use their e-bike to replace their bicycle and again 33% of all kilometers driven on an e-bike is done instead of driving those kilometers on a bicycle. This means that 2/3 of all kilometers driven on an e-bike replace kilometers previously driven in a car or on a bicycle. The e-bike is not often used to replace public transport (trains, busses, trams and metro's). Only 6% of the kilometers driven on an e-bike is done instead of using public transport. 16% of the respondents will use the e-bike to increase their mobility. This contributes 9% to the total amount of e-bike driven kilometers.

We determine the CO_2 emissions impacts that arise from the electricity and fuel use during the use phase of the vehicles. The emissions contributed to the production, maintenance and end-of-life disposal are not considered. Based on the data in Tables 8 and 9 we determine that e-bikes emit less CO_2 than any of the alternative motorized transport modes. Using a 3500 km per year driven distance for the e-bike this results in an extra electricity generation of 51.5 kWh per e-bike per year. In the Netherlands, where the generation of a kWh of electricity causes the emissions of 450 gram of CO_2 (EEA 2009) this would come to an emission of just over 23 kg of CO_2 per e-bike per year. Over the same distance the average European car would emit 462.7 kilograms of CO_2 (EEA 2013), the average Dutch car would emit 413.7 kilograms of CO_2 (EEA 2013).

In order to calculate the reduced CO_2 emissions caused by the use of the e-bikes we use the values obtained by the questionnaire (Table 7 and Table 8). Of the 3500 kilometers driven on e-bikes 33% is done instead of in cars, 33% instead of on bicycles, 9% is additional transport. For the 4% of driven kilometers that replace unknown vehicles (the option "other" in the questionnaire) we assume that these replaced vehicles replace do not emit any CO_2. And we assume the other 21% to be CO_2 neutral compared to the e-bike. The last two assumptions are an underestimation of reality.

The extra electricity that needs to be generated to power the e-bikes, based on 250.000 e-bike sales for the Netherlands, is 12.9 MWh/year. The amount of CO_2 effect in the Netherlands for the same 250,000 e-bikes is: for the replacement of the cars a 32.55 kilotonnes reduction of CO_2 emitted; for the replacement of the bicycles a 1.93 kilotonnes increase of CO_2 emissions; for the additional movements and the "other" option replacement a 0.75 kilotonnes increase of CO_2 emissions. In total this comes to a reduction of 29.9 kilotonnes of CO_2 for the Netherlands.

TABLE 9: OVERVIEW OF DATA USED FOR CO_2 IMPACT CALCULATIONS (VARIOUS SOURCES)

Vehicle	Electricity use [kWh/km]	CO_2 emissions [gram/km]	Source	Remarks
Car		132.2 (EU average)	EEA (2013)	

		118.2 (NL average)		
Train		35	NS (2013)	Based on Dutch data
Bus		65	NS (2013)	Based on Dutch data
Tram/Metro		35	NS (2013)	Based on Dutch data
Bicycle		0	-	No motor
E-bike	0.0103	6.6	GoPedelec (2012) EEA (2009)	Based on: Charging efficiency 70% (estimate), 450 gram CO_2/kWh electricity and range of 97km/kWh. Based on Dutch data

5 DISCUSSION

5.1 DISCUSSION OF METHODOLOGY

5.1.1 EXPERIENCE CURVE ANALYSIS

Strengths

The experience curve shows us that while prices do not decline rapidly for e-bikes, a learning rate of just 1.0% ± 1.7%, they are subject to technological learning. The learning rate of 7.9% ± 2.3% for specific price shows us this. The learning rates we found are smaller than those found for energy demand technologies in literature (Weiss et al. 2009-2). Average learning rates for energy demand technology are 18% ± 9%. The difference could be related to some of the assumptions we have had to make in our thesis.

A strong point of our thesis is the collection of price data for e-bikes and the creation of an experience curve for e-bike technology as this has not been done before for e-bikes. We found that scientific literature on e-bikes often gives a rough estimate of the price or the price of e-bikes for a single year is given. We provide a history of e-bike prices and quantified future prices. By doing so we create a database that can be used for further research. Possible uses for the database can be to compare (price) development in transport technologies, or to gain insight in the innovation trajectory of a new technology. The database can also be used in later studies on price development of e-bike or electric transport or for the comparison of price development between the EU and China.

The large number of doublings in combination with a substantial cumulative production and a large coverage of the production indicates a reliable experience curve plot and learning rate. The time period of 1999-2012 we use for the e-bike experience curve analysis covers seven doublings and over 99% of the total e-bike production. In 1999 the cumulative production of e-bikes in the world was less than 1 million. Now, at the beginning of 2013, cumulative e-bike production is around 200 million.

Uncertainty and limitations

In this thesis we did not look at the different battery technologies used for e-bikes. This can cause an overestimation of cumulative production. In Europe, almost every e-bike uses advanced technology batteries (Li-ion, NiMH) (Consumentenbond 2009-2012, ExtraEnergy 2013). If we leave out all lead battery powered e-bikes from the cumulative production the production would be significantly smaller and the learning rate we would have found would be higher. The assumption of no difference in battery technology between China and Europe could result in an underestimation of the learning rate for both the average price and the specific price. If the production of e-bikes was separated on battery technology used the total cumulative production would be lower while the price decline would be similar. This would result in a higher learning rate. However, we found no way to distinguish the amount of difference in production between battery technology based on the literature of production. The same applies to the change in battery technology in the EU. At the start of our analysis many batteries were NIMH based while in 2012 the e-bike batteries are mostly Lithium based.

As most of the price data for e-bikes is obtained from consumer test organizations (Consumentengids 2009-2012, ExtraEnergy 2013) bias is possible if these organizations over represent particular market or price segments. However, limited resources prevented us from investigating whether this is indeed the case. From personal experience we know that for other products (e.g. bicycles, car insurance, bicycle locks) the data source for most of the Dutch data, the consumentengids, tests a wide range of prices. We believe this to be true for the e-bike as well. For the German data this is not known. This limitation also affects the cost-benefit analysis.

Also, we assume that the e-bikes in China are all categorized similar to European e-bikes. However, some Chinese e-bikes may include vehicles that perhaps would be categorized as electric scooters in Europe. If this is the case it would influence reliability for the comparison of the cost-benefit analysis and for the estimates of cumulative production for e-bikes. However, we cannot differentiate between the “scooters” and the “bikes” in China and as the technology used for both is the same (the only difference is power) we think this makes no difference towards the experience curve data that is used.

In order to create a complete time series of price data we combined data from the Netherlands and Germany. There is a possibility that this influences the results. It is our guess that markets in countries can differ regarding prices, margins for retailers, public opinion for the products , the stage of market development and cultural differences. These are all factors why ideally we would have preferred not to make the combination. However, without the combination no analysis could be made since the time series are too short per country. There are arguments for the combination of the countries. When we look at the bicycles price (2000-2011) we see that the price development is almost identical (German prices are a bit lower) but the price rise and decline happen at the same moments and are of similar magnitude (Figure 8; Colibi 2012). The stage of market development seems to be equal. When we look at the numbers we see both countries are forerunners in the EU with far higher e-bike sales than the other countries. Because of these similarities in the market, we thought it plausible to combine the data. If German e-bike prices were lower than the Dutch in the period of 1999-2008 (the German data range), as was the case with bicycle prices, the effect could be that the prices could drop faster in the future than predicted by the experience curve analysis. However, as there is no overlap in the Dutch and German e-bike price data and we simply do not know if German e-bike prices are lower than Dutch e-bike prices.

The use of price data from the Netherlands and Germany means that our experience curve analysis may have limited validity for other countries. The results are therefore most applicable for countries with a similar (e-)biking market like other Western countries with a cycling background. When extrapolated to other countries that do not have similar characteristics it should be noted that technological learning might occur at a different rate. An extra point of attention is the use of sales prices instead of production costs to base our experience curve on. This adds to the uncertainty as retail prices do not always reflect production costs. Market effects have an influence on the price but not on the production cost and margins may be different for different retailers or between countries.

To make the experience curve analysis we assume future production. The assumed future e-bike market is based on average growth rates given in literature; 7.5-10%. With the current e-bike market growth near to 5% we decide to use a growth rate under the average of the literature. We use a 8.5% growth rate. The overall trend in the e-bike market is still up but with lower growth rates than before and assuming the electric scooter and electric motorcycle markets will grow and compete with e-bikes in future years. All data suggest that electric scooters and electric motors will be gaining a substantial market percentage in the coming years (Navigant 2013). Literature suggests that 10-15 million electric scooters and electric motorcycles will be produced per year in 2018 (Navigant 2013, EBG 2013). In the past there have been dramatic increases and decreases of growth within 1 or 2 years and years of 5% growth have alternated 20+% growth rates. This could happen again in the future. The estimates on future sales hinge on many assumptions like price of fossil fuels, economic prosperity, electricity prices, development in battery technology, possible environmental policies, etc. These make it difficult to predict the future production.

For the experience curve of bicycles less than 40% of cumulative production is used for the analysis. The time period covers less than one doubling of cumulative production of bicycles, the increase in cumulative production is about 50%. These facts contribute to a possible variance in the results.

5.1.2 COST-BENEFIT ANALYSIS

Strength

A strong point of the thesis is that the cost benefit is done for all ETWs and many vehicle options. This creates a similarity in the calculations that could be absent when the costs for the vehicles are taken from different literature sources. All assumptions are similar and the same methods are used to determine the costs. If data from different literary sources are used they could cause bias. Different approaches and assumptions could have been taken to calculate the costs resulting in a comparison based on dissimilar assumptions.

Uncertainty and limitations

We base the cost benefit analysis on Dutch data. There is a possibility that the data obtained does not relate to other countries and that the results are not valid outside of the Netherlands. We believe (as mentioned in section 5.1.1.) that the results are valid for countries with similar characteristics like Germany, Belgium and Denmark.

5.1.3 CONSUMER QUESTIONNAIRE

Strengths

Our questionnaire asks consumers of e-bikes about their choices and expectations as they buy their (first) e-bike giving valuable information about what they think when purchasing an e-bike. For the questionnaire we interviewed consumers at the time they purchase their e-bike, this is a strength of the thesis. Normally interviews are either held with potential e-bike consumers (GoPedelec 2012) or e-bike owners (Weinert 2007, Chiu 1999). This creates an uncertainty because potential buyers could give a socially desirable answer but not follow through with it. In the same way owners could use the e-bike differently than anticipated when buying and provide different answers than they would have at the time of purchase. Our interview shows what the consumer is thinking at the time of purchase giving a unique perspective. These insights could be compared to interviews held with e-bike owners to see if the expectations of the e-bike are met.

Uncertainty and limitation

A limitation of our questionnaire is that the sample of respondents remained small. This means we cannot make definitive statements about the obtained data as they could be subject to variance. It does however give an indication of the preferences of consumers at the moment they buy an e-bike.

There is also uncertainty of validity, the questionnaires were distributed in a densely populated area ('de randstad' in the Netherlands) and the results could be influenced because of this. Distances are smaller than in sparsely populated regions. Therefore, the e-bike could be seen as a more viable option than it would if the distances between cities or home and work were larger. This could already become a bit apparent when we look at the distance traveled in the city and outside of the city. The e-bikes are used more and drive more km in the city.

5.2 DISCUSSION OF RESULTS

5.2.1 LEARNING RATES OF E-BIKES

The learning rate of 1.0% ± 1.7% for e-bikes in the Netherlands and Germany (Figure 6) suggests little decline in the average purchase price between 1999 and 2012. However there is a distinct learning rate of 7.9% ± 2.3% for the specific price (Figure 7). These learning rates are significantly lower than those found for BEV 23% ± 5% and energy demand technologies in general: 18% ± 9% (Weiss et al. 2009-2). The drop in specific price indicates that there is technological learning. However, e-bikes may not become much cheaper as the technology in the e-bikes is constantly upgraded to increase performance, this can be seen by the increasing range of the e-bikes (Consumentengids 2009-2012, ExtraEnergy 2013, FietsVAK 2013).

The cost buildup of e-bikes differs from a conventional bicycle only by the battery and electro motor. As bicycle prices seem to be rising it is possible that batteries have a higher technological learning than the one found for the specific price. As the battery is the most expensive part of an e-bike, accounting for 30-70% of the costs of the bicycle (FietsVAK 2013), this is a distinct possibility. And when the price of battery technology drops other electric vehicles will become economically viable and could gain a larger market share. The success of the e-bike could create the possibility for battery technology to develop so that it can be used in other electric vehicle options.

E-bikes are a relatively new technology. Therefore, it is possible that the reason for the lack of price decline is that consumers prefer performance increase over price decrease. Innovation theory states that emerging technologies often first compete on performance and differentiation. Later on, only after the technology has reached a level of performance that fits most people's needs the competition on price becomes the dominant form of competition (Christensen 2003). We think another possible cause could be that because the e-bike market is growing rapidly the demand is greater than the supply and this keeps prices high. This could mean that there will be a tipping point for e-bikes when price becomes more important than performance or the supply will catch up with demand. If this happens the price will probably start dropping faster than indicated by the experience curve of average price.

The continuing need for better and more powerful batteries stimulates battery development. We think this will further speed up the development and create a better competition position for vehicles with heavier batteries like the electric motorcycle and the electric car.

The negative learning rates of -36% ± 111 % for bicycles indicate that bicycle prices are rising. We cannot determine if the production costs are increasing or that market effects are the cause. When we look at the experience curve plot of bicycles for the Netherlands (the same holds for Germany) we can see a substantial (~20%) price increase from 2007 to 2010, this is also the time that e-bikes started to gain a market share in the Netherlands (and Germany). It could be that the entrance of the e-bike to the bicycle market is (partially) responsible. However, there are many other possible causes. It could be that the bicycles in Europe over the last years have become more sophisticated including LED lights, gears, composite materials, etc. These improvements might have increased the overall price or materials have become more expensive (FietsVAK 2013).

5.2.2 COST-BENEFIT PERFORMANCE OF E-BIKES

It has been made clear from the results that for electric vehicles the costs go up as the size and weight of the vehicle increases. This is probably caused by the need for more expensive battery's in heavier vehicles. Bicycles are cheaper than e-bikes, so why do consumers still buy the e-bike? E-bikes make it easier to travel short distances. The convenience is worth the extra money. Using this assumption we can explain the results we found from the questionnaire, section 5.2.3.

As with all technologies the consumers have to be willing to use the product. Culture is important in this aspect. The Netherlands and in lesser aspect Germany are bicycling countries. Bicycles are used mostly for short distance traveling. The attitude to the bicycle as a means of transport for all kinds of people is prevalent among large parts of society. This makes for an easier introduction of e-bikes compared to countries where bicycling is seen as a pastime for a specific class of people. Other important aspects are topography, infrastructure, average travel distance and population density. These could be very strong reasons why the e-bikes market has grown rapidly in the Netherlands and Germany but is still in an earlier stage in the surrounding European countries. However, there is a huge potential for the e-bike in the Western world.

If the transformation is made from bicycles and scooters to electric two-wheelers, the electric vehicle market will get a boost and grow. The ETW will create a demand for high power batteries and therefore also produce a supply of recyclable material. On the other hand, jobs could be lost in the current GTW industry. A growth of the ETW market could also stimulate other electric transport vehicles e.g. cars. Experience is gained about electric vehicles and performance is increased due to more R&D of electric propulsion. We think this would benefit the electric cars chances of capturing the automotive market.

5.2.3 CONSUMER QUESTIONNAIRE

From the questionnaire it is made clear that e-bikes in the Netherlands predominantly replace cars and bicycles. The e-bike also creates additional travel movements for 16% of the respondents; contributing 9% to all travelled e-bike kilometers. The extra mobility may increase the quality of life for these people. It does however increase pollution through electricity generation. The replacement of cars has a positive impact on the environment. The replacement by e-bikes of bicycles and the extra travel movements the e-bike creates have a negative impact on the environment. We believe that on average e-bikes reduce polluting emissions. It will however increase electricity consumption. E-bike use will move the pollution from highly dense populated areas, like cities, to the in general less populated areas surrounding electricity generation plants.

The questionnaire shows that on average people in the city ride more kilometers on their e-bike than people outside the city. Moreover, as users use the e-bike instead of a car it can be a useful option to diminish congestion and parking problems in cities. E-bikes need far less asphalted road to move and also far less space to be parked. With the 1 million and rising e-bike sales in Europe and 25% of e-bike consumers that replace their car it can potentially have a massive impact congestion in cities. We assume that the ease of parking in cities is one of the reasons why people substitute their car, however this is not based on evidence.

What is also remarkable is that according to our questionnaire in the Netherlands 11% of the respondents use an e-bike instead of public transport. However this results in just 6% of the kilometers driven on an e-bike. This is a contrast to China where the majority (up to 70%) changes from public transport to e-bikes (Weinert et al. 2007, Cherry and Cervero 2006). We believe that this is because in the Netherlands public transport is mostly used for trips over 10 km (NS 2013) while shorter distances are made on foot, by bicycle or by car. Our personal experience is that the extra time it takes to use public transport on short trips is seen as inconvenient and a bicycle, scooter or a car is preferred.

Surprisingly, the answers of the respondents showed that only 8 out of 22 indicated that they would substitute their bicycle. We would have believed that all respondents' bicycle use would be substituted by e-bike use due to the reduced effort. It is possible that the majority of the respondents do not own a bicycle. However, we find this unlikely, the Netherlands has a bicycle to inhabitants ratio > 1, with 18 million bicycles (MiC 2012). An explanation could be that many people do not think about replacing their bicycle when they buy their e-bike. They see it as an option to increase their travel distance or replace a different vehicle.

The uncertainty in the CO_2 reduction potential is significant, this is based on rough estimates and most likely has a large uncertainty. However, it does show the general size of the emission reduction potential for CO_2.

6 CONCLUSION

We started this thesis to enhance the knowledge base about ETWs for policy makers. We did this via an economic analysis of ETWs in Europe with a focus on e-bikes. We are finally able to answer the research question and the sub questions and we come to the following conclusions:

In this thesis we want to find the price of e-bikes in 2025 and the learning rate for e-bikes and for bicycles. Using the experience curve approach we find learning rates of 1.0% ± 1.7% for average e-bike prices and 7.9% ± 2.3% for the specific price of e-bikes. The 2012 e-bike price is €1614,- ± €674,-. With these learning rates the price of e-bikes will only drop 3% between 2012 and 2025 resulting in an average e-bikes price of €1561,- ± €609,-. The 2012 specific e-bike price is €5813,- ± €2854,-per kWh. With the calculated learning rates the specific price will drop to €4779,- ± €2629,- per kWh in 2025, this is a 17.8% drop. If the past growth rates of the global ETW market persist, we predicted a global production of 50 million e-bikes and over 10 million electric scooters and electric motorcycles before 2020.

For bicycles we find a European learning rate of -36% ± 111%. This European experience curve has a R^2 of 0.01 and is therefore unreliable. For the different countries the learning rates are: the Netherlands -37% ± 21%, Germany -50% ± 38%, Italy 31% ± 44% and the United Kingdom -126% ± 95%. This means that overall the prices for bicycles in the EU are rising. Price levels differ significantly per country therefore it is not possible to determine a future general price of bicycles in the EU.

We also wanted to see what the costs of ETWs are from a consumer perspective, and how they relate to other vehicle options. We found that for the total cost of ownership of ETWs the more power a vehicle needs the more expensive it becomes. The cost for an e-bike is €0.10 ± € 0.05 per kilometer, the cost for an electric scooter is €0.31 ± €0.15 per kilometer and the cost for an electric motorcycle is €0.45 ± €0.21. If we look at the net present cost of ETWs we find that an e-bike costs €2516,- ± €828,-, an electric scooter costs €4909,- ± €1188,- and an electric motorcycle costs €20108,- ± €4375,-.

If we compare this to the conventional transport options we see that each of the ETWs is more expensive to ride or drive than its conventional counterpart. The cost of use for a bicycle is €0.06 ± €0.03 per kilometer with a NPC of €1060,- ± €244,-, for scooters the cost of use per kilometer is €0.23 ± €0.11 with a NPC of €3638,- ± €887,-, and motorcycles cost €0.31 ± €0.15 per kilometer and have a NPC of €22756,- ± €5939,-

Our results further show that the cost for traveling with public transport are similar to that for the use of an e-bike. The cost of traveling with a train is €0.08 ± €0.04 and the cost for traveling with a bus, with the tram or metro is €0.11 ± €0.06. The NPC we found for travelling with public transport is: for the train €3221,- ± €1679,-, for the bus €2102,- ± €1146,- and for the tram or metro €1125,- ± €543,-.

Compared to cars, e-bikes are a lot cheaper to use. The TCO of a car we found is €0.32 ± €0.15 per kilometer. This is comparable to electric scooters but cheaper than electric motorcycles. The car with a NPC of €70622,- ± €18401,- has the highest total cost far higher than any of the ETWs or any of the other transport options.

Besides the pure economics we also wanted to find the substitution options for the e-bike, and what vehicles they replace. We find that the e-bike is mostly used to replace bicycles (33% of kilometers, 25% of people) and cars (33% of kilometers, 28% of people). A considerable amount of people (16%) also use the e-bike as an addition to their current transportation possibilities. This results in 9% of the kilometers driven. Based on the kilometers driven over

75% is done to either replace cars or bicycles or to extend the current amount traveled. It shows us that cars and bicycles are the main competitors of e-bikes and we believe that they compete on convenience and price. E-bikes are more expensive but more convenient than bicycles. Compared to cars e-bikes are less expensive and can be more convenient with regards to travel and parking in cities.

An increase in e-bike use will increase electricity consumption. However it will lower harmful air pollutant emissions, especially in urban areas. E-bike use can reduce CO_2 emissions. We calculated that the CO_2 emission reduction by replacing cars (118,2 gCO_2/km) is greater than the increase of CO_2 emissions by replacing bicycles (6.6 gCO_2/km). In order to reduce CO_2 emissions cars or public transport have to be replaced. Policy to promote this could help the reduction of CO_2. We concluded that the Netherlands reduced the CO_2 emissions of transport by almost 30 kilotonnes through one year of e-bike sales (250,000 e-bikes). The analysis is done based on data for the Netherlands, and is most representative for other countries with similar economical and geographical characteristics, e.g. (cities in) Denmark, Germany, Switzerland, Belgium.

Finally, we conclude that while prices will not drop significantly for ETWs there is technological learning and the market will continue to grow until 2025. The TCO of ETWs increase with their weight and power. E-bikes are the cheapest option of the ETWs and have costs comparable to public transport. E-bikes are more expensive that bicycles but cheaper to use than cars. From a consumer's point of view the e-bike is an economically viable option and is predominantly used to replace bicycles and cars. Electric scooters and electric motorcycles are more expensive and not a viable option for consumers at the moment. However, it is predicted that as the price of batteries drops electric scooters and electric motorcycles may gain in market share.

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APPENDICES:

PRICE DATA

TABLE 10: AVERAGE SALES PRICE OF CONVENTIONAL BICYCLES IN € SINCE 2000 (DATA SOURCES: COLIBI 2012, MIC 2012)

Year	NL	GER	IT	U.K.
	€	€	€	€
2011	745.52	495.00	270.00	280.00
2010	744.65	459.35	259.77	321.43
2009	726.00	445.93	279.62	246.76
2008	664.95	385.98	288.27	251.89
2007	602.86	366.96	239.24	192.26
2006	582.01	348.47	193.00	204.08
2005	578.69	341.05	191.80	182.89
2004	584.00	341.06	198.68	181.31
2003	579.63	344.08	215.80	160.99
2002	556.65	353.04	218.21	139.13
2001	529.67	361.06	262.47	158.33
2000	481.21	346.09	301.97	186.96

TABLE 11: VAT RATES PER COUNTRY PER YEAR (DATA SOURCE: EC 2013)

Year	NL	GER	IT	U.K.
2012	19.0%	19.0%	21.0%	20.0%
2011	19.0%	19.0%	20.0%	20.0%
2010	19.0%	19.0%	20.0%	17.5%
2009	19.0%	19.0%	20.0%	15.0%
2008	19.0%	19.0%	20.0%	17.5%
2007	19.0%	19.0%	20.0%	17.5%
2006	19.0%	16.0%	20.0%	17.5%
2005	19.0%	16.0%	20.0%	17.5%
2004	19.0%	16.0%	20.0%	17.5%
2003	19.0%	16.0%	20.0%	17.5%
2002	19.0%	16.0%	20.0%	17.5%
2001	19.0%	16.0%	20.0%	17.5%
2000	17.5%	16.0%	20.0%	17.5%

TABLE 12: PRICE AND BATTERY POWER OF E-BIKES 2012 (DATA SOURCES: CONSUMENTENGIDS 2009-2012, HALFORDS 2012, ORIENTEER 2013, ELEKTRISCHESCOOTERCLUB 2013)

Year	Brand	Model	Price	Battery power
			€	kWh
2012	Batavus	Socorro Easy	2400	0.36
	Batavus	E-go	1399	0.24
	Bikkel	ibee T2	1600	0.276
	Cumberland	Energy V6	699	0.192
	Cumberland	Connect N7	899	0.192
	Daimler	AG	2897	0.42

	Dutch ID	Sport Lady	2400	0.288
	Flyer	C8 De Luxe	3100	0.432
	Gazelle	Excellent Innergy	2600	0396
	Koga	E-Tour	3000	0.25
	MC	Elegance-E	2900	0.27
	Qwic	Trend^3	1850	0.36
	Qwic	Urban2	1380	0.216
	Raleigh	Dover Impulse	2100	0.558
	Sparta	Ion GLS+	2700	0.36
	Trek	L300+ Navigator	2200	0.30
	Union	Switch (Dames)	1199	0.252
	Union	Switch (Heren)	999	0.252
	Union	Ace	999	0.24
	Union	Elegance	1099	0.192

TABLE 13: PRICE AND BATTERY POWER OF E-BIKES 2011 (DATA SOURCES: TELEGRAAF 2011, CONSUMENTENGIDS 2009-2012, HALFORD 2012, ORIENTEER 2013, ELEKTRISCHEFIETS 2013, ELEKTRISCHEFIETSEN 2013, FIETS.123, 2013, ELEKTRISCHESCOOTERCLUB 2013)

Year	Brand	Model	Price	Battery power
			€	kWh
2011	Antec	Vela	2149	0.378
	Batavus	Intermezzo Easy	1850	0.266
	Batavus	Intermezzo Easy Royal	2499	0.36
	Bikkel	Ibee2	1599	0.276
	Cumberland	Energy V6	899	0.192
	Cumberland	Connect N7	999	0.192
	Flyer	T8	2850	0.432
	Flyer	C5	2499	0.312
	Gazelle	Orange Pure Innergy	1699	0.252
	Giant	Twist Go Double	2100	0.576
	Infineum	I-centiv	1799	0.225
	Kalkhoff	Tasman City E-Series	2399	0.43
	Koga	E-Runner	3000	0.36
	Montego	Elan	1549	0.27
	Powabyke	X-24	1299	
	Qwic	smart e3 urban	1499	0.36
	Rivel	Mingle	1649	0.24
	Sparta	E-motion C2	1650	0.24
	Sparta	E-motion C3	1749	0.24
	Trek	T500+	2300	0.32
	Union	Switch (Dames)	1399	0.252
	Union	Switch (Heren)	1399	0.252
	Union	Ace	1099	0.24
	Union	Elegance	1299	0.192

TABLE 14: PRICE AND BATTERY POWER OF E-BIKES 2010 (DATA SOURCES: CONSUMENTENGIDS 2009-2012, ELEKTRISCHEFIETS 2013, ELEKTRISCHEFIETSEN 2013, ORIENTEER 2013, KIESKEURIG 2013, GIANT 2013, BESTEPRODUCT 2013)

Year	Brand	Model	Price	Battery power

Year	Brand	Model	Price	Battery power
			€	kWh
2010	Adventure	Lithium	1400	0.18
	Batavus	Easy Weekend	2150	0.24
	Gazelle	Orange Innergy	2200	0.252
	Giant	Twist Go Double	2100	0.576
	Kalkhoff	Agattu Pedelec C	1900	0.26
	Qwic	Trend	1600	0.36
	Sparta	E-motion C2	1500	0.24
	Trek	Navigator T500	2200	0.26
	Union	Switch	1600	0.252

TABLE 15: PRICE AND BATTERY POWER OF E-BIKES 2009 (DATA SOURCES: CONSUMENTENGIDS 2009-2012, STRUIJK 2013, GAZELLE 2013, KIESKEURIG 2013, ELEKTRISCHEFIETSEN 2013)

Year	Brand	Model	Price	Battery power
			€	kWh
2009	Batavus	Padova Easy Supreme	2200	
	Gazelle	Orange Innergy	2150	0.252
	Giant	Twist Comfort Lite	1700	0.234
	Koga	Tesla	2800	
	Sparta	ION Comfort GL	2300	0.264
	Union	Volta	700	
	Union	Switch	1500	0.252

TABLE 16: PRICE AND BATTERY POWER OF E-BIKES 2008 (DATA SOURCES: KAMPIOEN 2008, STRUIJK 2013, GAZELLE 2013, KIESKEURIG 2013, ELEKTRISCHEFIETSEN 2013)

Year	Brand	Model	Price	Battery power
			€	kWh
2008	Adventure	XT 10Ah	1000	
	Avancer	Support	1060	
	Batavus	Padova Easy	2100	0.264
	Flyer	T8	2700	0.312
	Gazelle	Easyglider	2100	0.187
	Giant	Twist 1.1	1900	
	Harbin	Evergreen	1300	0.36
	Hudson bike	Alu Touring	1990	
	Koga miyata	Tesla	2700	
	Schwinn	Transit	1870	
	Sparta	ION m-gear	2100	

TABLE 17: PRICE AND BATTERY POWER OF E-BIKES 2006 (DATA SOURCE: EXTRAENERGY 2013)

Year	Brand	Model	Price	Battery power
			€	kWh
2006	eGO	Helio	1690	0.816
	Euromoto	binbike	1850	0.54
	Flyer biketec AG	T8 Premium	2790	0.24
	Gazelle	Easy Glider	1999	0.172
	Giant	Twist	1699	0.156
	heinzmann	estelle elegance	2554	0.342

	Helkama Velox Oy	jubilee	1940	0.173
	Hercules	Emove tourer RT	2099	0.24
	Lohmeyer	mistral-e	4495	0.24
	Sachs bikes	alu-touring	1899	0.36
	schachner	citybike	1399	0.324
	Shanghai eZee	eZee Sprint	1400	0.324
	Sparta	Ion m-gear	1999	0.24

TABLE 18: PRICE AND BATTERY POWER OF E-BIKES 2002 (DATA SOURCE: EXTRAENERGY 2013)

Year	Brand	Model	Price	Battery power
			€	kWh
2002	Aprilla	Stufe	1399	0.256
	biketec	flyer deluxe f6	3400	0.18
	Giant	lafree twist	1425	0.137
	heinzmann	estelle comfort	1839	0.18
	KMT	life blitz	1699	0.2141
	Roll tech	City Full	2195	0.35
	schachner	easy boarding	1307	0.164
	Velocity	Dolphin	3800	0.166
	Yamaha	XPC 26 deluxe	1406	0.157
	Yamaha	easy super	1891	0.138

TABLE 19: PRICE AND BATTERY POWER OF E-BIKES 2001 (DATA SOURCE: EXTRAENERGY 2013)

Year	Brand	Model	Price	Battery power
			€	kWh
2001	biketec	flyer deluxe f6	3574	0.18
	Epple	mainau elegance	1449	0.0864
	Giant	Lafree E-race	1409	0.144
	Giant	lafree twist	1425	0.144
	hartje	victoria ausburg	1499	0.0864
	heinzmann	estelle comfort	1839	0.18
	KMT	life blitz	1687	0.2184
	kynast	e0bike luxus	1500	0.12
	Sachs bikes	elo touring	1473	0.168
	schachner	easy boarding	1256	0.18
	velocity	Dolphin blackpowder	2846	0.168
	Yamaha	XPC 26 deluxe	1406	0.168
	Yamaha	easy super	1891	0.168
	Yorker	city	1528	0.192

TABLE 20: PRICE AND BATTERY POWER OF E-BIKES 1999 (DATA SOURCE: EXTRAENERGY 2013)

Year	Brand	Model	Price	Battery power
			€	kWh
1999	AC-Power-Bike		3324	0.432
	Easy	E	4380	0.168
	Estelle	Classic Sprinter	3065	0.168
	Estelle	Classic	2950	0.168

Flyer	Classic	5431	
KTM	city Blitz	2990	0.2184
Kynast	E-bike	2398	0.12
Mercedez-Benz	hybrid-bike	3250	0.12
Merida	Power Cycle	2695	0.168
Patria	E-wing	3848	0.12
Radius	C4	4699	0.144
Sachs bikes	Elobike classic	2499	0.168
Sanyo	Pedelec	2200	0.12
UNA	E	3800	0.168
Velectron	Velo de ville	2399	0.12
Velocity	Dolphin	4680	
Wavey	E	3990	0.32
Yahama	PAS XPC	2390	0.12
Yahama	Easy	2490	0.168

TABLE 21: DEFLATION RATES PER YEAR STANDARDIZED FOR 2012 (DATA SOURCE: EUROSTAT 2013)

Year	NL	GER	IT	U.K.	China
2012	1	1	1	1	1
2011	0.987724279	0.991979892	0.987461607	0.974631454	0.92804
2010	0.977379924	0.982849941	0.983735585	0.948393071	0.869895
2009	0.976430147	0.971453832	0.963606348	0.936079881	0.875088
2008	0.956074945	0.963994764	0.939799732	0.908483634	0.811786
2007	0.938723109	0.948530533	0.918007546	0.888840441	0.754434
2006	0.922418447	0.945580205	0.902594842	0.863764395	0.726916
2005	0.900551136	0.939770432	0.886486521	0.843556696	0.69943
2004	0.894002025	0.929813035	0.865775484	0.822303028	
2003	0.874939548	0.919722468	0.839590602	0.802601938	
2002	0.842701437	0.9067446	0.813493411	0.784614224	
2001	0.801817739	0.896652919	0.790737935	0.771994458	
2000	0.770073861	0.902722177	0.775651532	0.766882878	
1999	0.756614663	0.900992528	0.76198312	0.751373331	
1998	0.742421344	0.89570975	0.742223105	0.736295737	

TABLE 22: PRODUCTION DATA OF BICYCLES, E-BIKES AND CARS PER YEAR; 1950-2012 (DATA SOURCES: WEINERT 2007, WEINERT ET AL. 2007, WORLDWATCH 2008, ADB 2009-2, CHERRY 2010, PARKER N.D., RIC 2012, YAM 2011, BHARAT 2012, SEN 2012)

Year	bicycles+E-bikes	E-bikes China	E-bike Japan	Cars	E-bike World[a]
	[units]	[units]	[units]	[units]	[units]
2025		89987140[a]			97812109
2024		82937456[a]			90149409
2023		76440052[a]			83087013
2022		70451661[a]			76577892
2021		64932406[a]			70578702
2020		59845536[a]			65049495
2019		55157176[a]			59953452
2018		50836107[a]			55256638
2017		46853554[a]			50927777
2016		43182999[a]			46938043
2015		39800000[a]			43260869
2014		36682027[a]			39871769
2013		33808320[a]			36748174
2012		32198400[a]		84141209	34998261
2011		30960000	430000	79989155	33720323
2010		26000000	370000	77857705	32133441
2009		22200000	350000	61791868	24220968
2008	130000000	21880000	300000	70520493	23826882
2007	127000000	20500000	285000	73266061	22328011
2006	124000000	16000000	280000	69222975	17484301
2005	120000000	10500000	230000	66482439	11520323
2004	103000000	6000000	185000	64496220	6636613
2003	94000000	3250000	215000	60663225	3709624
2002	86000000	1800000	185000	58994318	2120484
2001	95000000	700000	180000	56304925	932688
2000	88000000	250000	135000	58374162	403817
1999	87000000	100000	150000	56258892	257527
1998	90000000	40000	210000	52987000	253011
1997	96000000		225000	54434000	200000
1996	103000000		120000		120000
1995	102000000	100	80000		80108
1994	99000000		25000		25000
1993	99000000				
1992	96000000				
1991	91000000				
1990	95000000				
1989	105000000	10000			10000
1988	98000000	20000			20000
1987	84000000	10000			10000
1986	79000000				
1985	76000000				

1984	74000000
1983	69000000
1982	65000000
1981	62000000
1980	54000000
1979	51000000
1978	49000000
1977	47000000
1976	43000000
1975	52000000
1974	52000000
1973	46000000
1972	39000000
1971	36000000
1970	25000000
1969	24000000
1968	23000000
1967	22000000
1966	21000000
1965	21000000
1964	20000000
1963	20000000
1962	20000000
1961	20000000
1960	19000000
1959	18000000
1958	17000000
1957	16000000
1956	15000000
1955	14000000
1954	13000000
1953	12000000
1952	11000000
1951	11000000
<1951	125000000[a]
	Values with an [a] are extrapolated or estimations

The questionnaire was placed in multiple scooter and bicycle shops that sold e-bikes and/or electric scooters. The questionnaire in Dutch was placed in the shops that were willing to participate. When a bike/scooter was sold the customer was asked to fill in a questionnaire.

The shops that were willing to participate:

TABLE 23: OVERVIEW OF SHOPS THAT PARTICIPATED IN THE INTERVIEW AND THEIR LOCATION

Name of the shop	Location
ScootStore	Amsterdam
Tromm	Amsterdam
B.v.D. Tweewielers	Amsterdam
B.v.D. Tweewielers	Amsterdam
Juizz	Amsterdam
C. van Weelden	Bilthoven
Bakker2Wielers	Bilthoven
Matrabike	De Bilt
Wierda Scoots and Bikes	De Bilt
Profiel Rene fietsen	De Bilt
FietsPlus	Driebergen
Pronto Scooters	Soest
Ton van den Ijssel	Utrecht
Van Meerten Tweewielers	Utrecht
Snel Tweewielers	Utrecht
Prijssnijder	Utrecht
Banierhuis	Utrecht
Banierhuis	Utrecht
Profile Kok fietsen	Utrecht
Het Rijwiel Paleis	Zeist
Tweewielercentrum van Dijk	Zeist

In each of the shops several of the Dutch questionnaires were placed. The questionnaire is shown below (Dutch and English):

Dutch version of the questionnaire:

Dank u voor the invullen van deze korte vragenlijst. De antwoorden op de vragen zullen gebruikt worden voor een onderzoek van de Universiteit van Utrecht naar elektrisch vervoer. De antwoorden worden volledig geanonimiseerd en niet gebruikt voor commerciële doeleinden.

Leeftijd: Geslacht: Man/Vrouw

1: Welk voertuig heeft u gekocht?

0 Elektrische fiets
○ Elektrische Scooter

2: Hoeveel kilometer gaat u gemiddeld fietsen/scooteren per week?

3: Welk transportmiddel vervangt u door op de elektrische fiets te rijden? (meer antwoorden mogelijk)

0 Auto
0 Bus
0 Trein
0 Tram/Metro
0 Gewone fiets
0 Scooter
0 Oude elektrische fiets
0 Oude elektrische scooter
0 Het is een toevoeging, geen vervanging.
0 Anders, namelijk: ....

4: Welk percentage, van de kilometers die gemaakt gaan worden op de elektrische fiets/scooter, vervangt het een ander vervoersmiddel. Mocht u een oude elektrische fiets/scooter vervangen kunt u dit dan aangeven voor uw eerste elektrische fiets/scooter?

(Bv. U gaat 40km p.w. op de elektrische fiets rijden, voorheen reed u 20 km hiervan in de auto en 20 op een gewone fiets, dan vervangt de elektrische fiets 50% een auto en 50% een gewone fiets.)

..... % Auto
..... % Bus
..... % Trein
..... % Tram/Metro
..... % Gewone fiets
..... % Gewone scooter
..... % Het is een toevoeging, geen vervanging.
..... % Anders, namelijk:.....

The English Version of the questionnaire:

Thank you for answering this short questionnaire. The answers will be used for research purposes by the University of Utrecht in the Netherlands. The answers will be treated confidentially and will not be used for commercial purposes.

Age: Sex: Male/Female

1: What vehicle have you bought?

o Electric Bicycle (Pedelec)
o Electric Scooter/Moped

2: How many kilometers a week will be using your electric bicycle/scooter?

3: Which transport vehicle do you replace by using the electric bicycle/scooter? (multiple answers possible)

- Car
- Bus
- Train
- Tram/Metro/Subway
- Common bicycle
- Common scooter
- Old electric bicycle
- Old electric scooter
- It is an addition, not a replacement
- Different option: …….

4: Of the kilometers that you will be using the electric bicycle/scooter, what percentage will it replace a different transport option. If you replace an old electric bike or scooter, could you indicate this for your first electric bicycle or scooter?

(E.g. You will drive 40 kilometers on your electric bike, before you drove 20 of those kilometers in a car and 20 in a bus. Then the electric bicycle replaces for 50% a car and 50% a bus.)

….. % Car
….. % Bus
….. % Train
….. % Tram/Metro/Subway
….. % Common bicycle
….. % Common scooter
….. % It is an addition, not a replacement
….. % Different option: …….

TABLE 24: OVERVIEW OF ELECTRIC SCOOTER PRICES (DATA SOURCES: ABD 2009, PARKER N.D.)

Year	Vehicle	Viet Nam [đ]	India [₹]	Taiwan [US$]
2000	E-scooter			1700 - 2000
2008	E-scooter	8 - 16 Million	15 - 40.5 Thousand	

TABLE 25: OVERVIEW OF E-BIKE PRICES (DATA SOURCES: ACEM N.D., PARKER N.D., MILLER 1999. WEINERT ET AL. 2007, ACEM 2010, PARKER 2011)

Year	Vehicle	China [US$]	Japan [US$]	USA [US$]	Australia [NZ$]
1989	E-bike		1600[a]		
1990	E-bike		3550[b]		
1997	E-bike			1100	
1999	E-bike	310 - 380		325 - 1500	
2000	E-bike	250			
2002	E-bike				2000
2003	E-bike	125 - 188			
2005	E-bike		700 - 2000		
2006	E-bike	125 - 375	700 - 2000		
2007	E-bike	125 - 325			

[a] New Zealand Dollar
[b] Australian Dollar