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Cost-Benefit Analysis of *Cycle to Work Scheme*

- Implemented in Jönköping Municipality, 2016

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Abstract

In a response to negative externalities such as GHG emission, health costs, infrastructural costs, noise and air pollution etc. caused by motorised transportation international organizations and governments have started promoting shifts towards active transportation such as walking and cycling. This study use a CBA-framework to evaluate a cycle to work-scheme implemented in Jönköping municipality in 2016. The scheme allowed all municipality employees to lease bicycles or e-bikes for a three year period and pay for them through a salary sacrificing arrangements, after the three year were over the participants could either buy the vehicle at market value or return it free of charge. Eleven parameters were included in the CBA, the internalisation through taxation/fees of some of the effect for some parameters were taken into consideration as well as the shorter Swedish bicycle season (31 weeks on average). The result indicate a benefit-cost ratio of 6.21:1, meaning that C2W scheme is a cost efficient method of increasing AT usage.

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Abbreviations

AT- Active transport
GHG - Greenhouse gas
GWP- Global warming potential
LCA - Life cycle analysis
MCF/MCPF - Marginal costs of public funds
MEB - Marginal excess burden of taxes
MET- Metabolic equivalent of task
NCD - Non communicative disease
NVV - Naturvårdsverket
PA - Physical activity
VSL - Value of statistical life
VTTS - Value of travel time saved
WHO - World health organization

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1. Introduction

The accelerating pace at which the planet is heating has become an ever-increasing global threat (NASA, 2016). Scientists attribute the worrisome development to the increasing emission of greenhouse gases (GHG). Due to anthropological activity producing an excess of GHG, primarily during the last decade, the atmospheric concentration of carbon dioxide, methane and nitrous oxide are unprecedented in the last 800,000 years (IPCC, 2014). The impact on people and ecosystems are immense; changes in hydrological systems which affect water resources negatively in terms of both quantity and quality, reductions in crop yields, ocean acidification and extreme weather including; droughts, floods, hurricanes and wildfires are some of the effects that are to some extent already taking place but without a change in GHG emissions are expected to worsen (IPCC, 2014). A continuation of GHG emissions at similar rate will have a severe and irreversible effect on the way we live our lives today as well as the ability for future generations to live theirs. To avoid worsening climate effects and capping the global average increase in temperature at 2 degrees, the International Panel on Climate Change (IPCC) advises a decrease in GHG emissions with 40-70% by 2050.

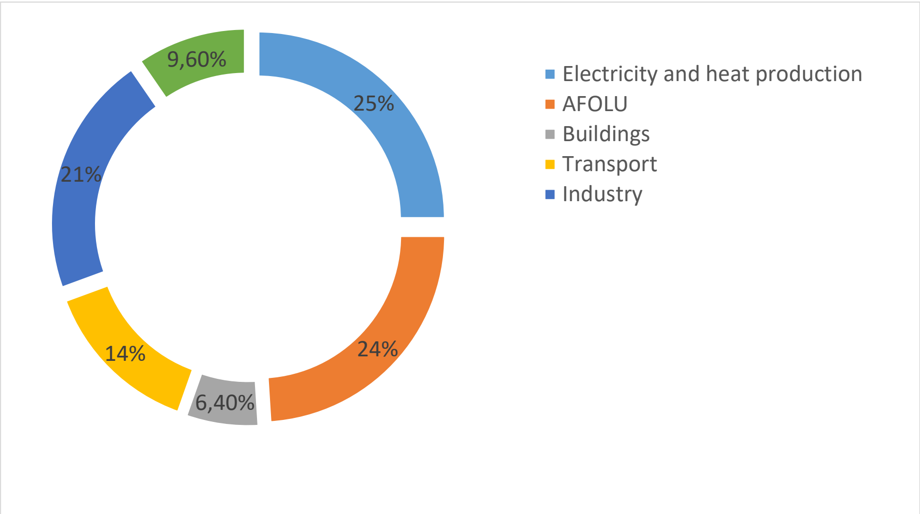

Figure 1: The world's economic sectors; electricity and heat production, agriculture, forestry and other land use (AFOLU), buildings, transport, industry and other; and their respective percentage of CO_2 emission. (IPCC, 2014)

The world's economic activity that is responsible for almost all CO_2 emission can be divided into six primary sectors seen in figure 1 above. Despite some sectors emitting more than others a change is needed in all to accomplish the ambitious goals of a CO_2 concentration not higher than 450-500 ppm, at which it is likely that the temperature does not rise more than 2 degrees above pre-industrial levels. One sector not expected to meet the demand of change is the transport sector. Instead, due to the growing numbers of passenger and freight transportation the emissions of GHGs is estimated to increase by 50% by 2030 and more than 80% by 2050 despite the potential of GHG decrease in the sector being deemed as high (IEA, 2009; IPCC, 2014). Many influential organizations, the World Bank, UN, WHO and the EU have recognized the importance of emission decrease in the transport sector and promote various methods of decrease emission and, to the extent possible, create a modal shift from motorised transportation, towards more sustainable active transport (AT) such as cycling and walking (Dill et al 2009; Cavill et al 2006; WHO, 2002; European commission, 2018).

In Sweden, the transport industry (primarily passenger vehicles) produced one third of all GHG emissions, but unlike globally, the emission are slowly decreasing (NVV, 2017). The decrease is not due to a reduction in numbers of automobiles or average mileage driven, which both have increased but rather substitution for more fuel-efficient vehicles. Nonetheless, to be in line with the set environmental goals the transition is not fast enough and the Swedish government much like other organizations maintains that a decrease in passenger cars as well as freight transportation is necessary. This ambition is included in the government's environmental plan, where the importance of decreased motorised transportation is highlighted in 4 out of 16 environmental goals (Miljömål, 2018).

AT had been suggested as part of the solution to the increasing GHG emissions from the transportation sector, but it has also been previewed as part of the solution to the problems that the increasingly sedentary modern lifestyle cause. The recommended amount of weekly moderately intense aerobic physical activity is 150 min, but in 2016, 28% of the world population (1.4 billion) were below this and estimated to be “at risk of developing or exacerbating diseases linked to inactivity” (WHO, 2010; Guthold et al, 2018). In Sweden the numbers are slightly more encouraging but still 21.5% of all men and 24.7% of all women do not move sufficiently enough to avoid negative health effects (Guthold et al, 2018). Physical inactivity is now one of the leading causes behind an increase of a variety of non-transferable diseases (NCDs) such as cardiovascular diseases, diabetes, colon cancer, high blood pressure, osteoporosis, lipid disorders, depression and anxiety (WHO 2002; Hallal et al, 2012; Thorp et al, 2011). The cost for the increase in NCD is not only in human suffering but the social cost for medical assistance is considerable. A large study including 142 countries conservatively estimated that in 2013 the worldwide health care system cost for physical inactivity was $53.8 billion as well as related deaths contributed to $13.7 billion in productivity losses and 13.4 billion disability adjusted life years (DALY) (Ding et al, 2016).

Increased AT has been proposed as part of the solution to the negative externalities caused in part by motorised transportation. But in addition to having impacts on the climate and activity levels motorised transportation cause additional externalities for which the first hand consumer does not bare full cost. Externalities such as congestion, noise and other environmental unfriendly pollutants, space consumption, accident costs and road wear. As a result increased AT is recommended from the absolute top political organs down to local municipality levels. The measures to encourage AT and discourage motoring comes in many forms with varying results, but since the governmental resources are limited the cost needs to be carefully measured against the benefits.

1.1 Aim and delimitations

In an attempt to address the negative externalities caused by passenger transportation Swedish governmental agencies at all levels have started to implement measures to increase active transportation modes. One example of this is the cycle to work-scheme (C2W) implemented by Jönköping municipality in 2016. The scheme allows municipality employees to lease bicycles or e-bikes for a three year period and pay for them through a *salary sacrificing arrangement.* After the three years the participants can either buy the vehicle at the current market price or return it. This study aims to calculate all private as well as social costs and benefits of the implementation in an attempt to determine if it is economically justified. There is a lack of such evaluations, internationally but particularly within a Swedish context, given winter conditions and internalisation of externalities through taxation. It also, unlike any other study found, includes e-bikes (electric bicycles) which have been popular for a long period of time in other parts of the world but are a rather new transportation mode in Sweden and therefore somewhat lacks evaluation.

The study is limited to a smaller sized city, Swedish seasonal cycling conditions and Swedish tax policy. It is also limited to a 12 year long period (2016-2024) based on the life expectancy of a bicycle. Since the evaluation is medias res, meaning that the evaluation takes place before completion of the implementation, the full effect is not calculated. The result presented here is only a part of the total outcome from the complete implementation, and should be treated as such.

1.2 Structure

The thesis consists of ten sections in total; section two is meant to give the reader a deeper background of the history of transportation vehicles, travel behaviour and political approach. In section three an overview of the previous literature on this is presented. In section four the CBA framework is presented and criticism and limitations with the framework is discussed. Section five is where the reader will gain information about the case study in question, as well as the counterfactual and data collection. In section six, the parameters included in the CBA are presented; how they are measured and to some extent the limitations of these measuring methods. The parameters from section six are then applied to the case study in section seven, where the costs and benefits from the implementation are presented. Section eight and nine tests and discusses the findings from previous section and lastly the findings are concluded in section ten.

2. Background

Historically, the bicycle have had a longer time to make an impact on human life than the automobile. When the first blueprint for the bicycle originated is still a matter of discussion but the first documented bicycle then known as a “draisine” was constructed by Baron Karl von Drais in 1817 (Herlihy, 2006). Since then it has had many different names and designs, but it was not until 1885 when the first “safety bicycle” was produced the bicycle became a commercial hit. The vehicle was cheap, light weight, safe and offered extended opportunities of mobility. Only a few years later it was the most popular mode of transportation in Europe and America (Herlihy, 2006). The bicycle remained its popularity in Europe during the first part of the 20th century whilst in America the automobile made its debut and flooded the market (Herlihy, 2006). In Sweden bicycling remained popular until the 1950s when the automobile took over, but after 20 years of low demand, in the 1970s the bicycle return to the public eye and bicycling started increasing again (Miljöbarometer, 2018). During the last 20 years bicycling in Sweden had decreased but this trend has stagnated the last couple of years and its popularity remain rather constant. (Trafikanalys, 2015; Regeringskansliet, 2017)

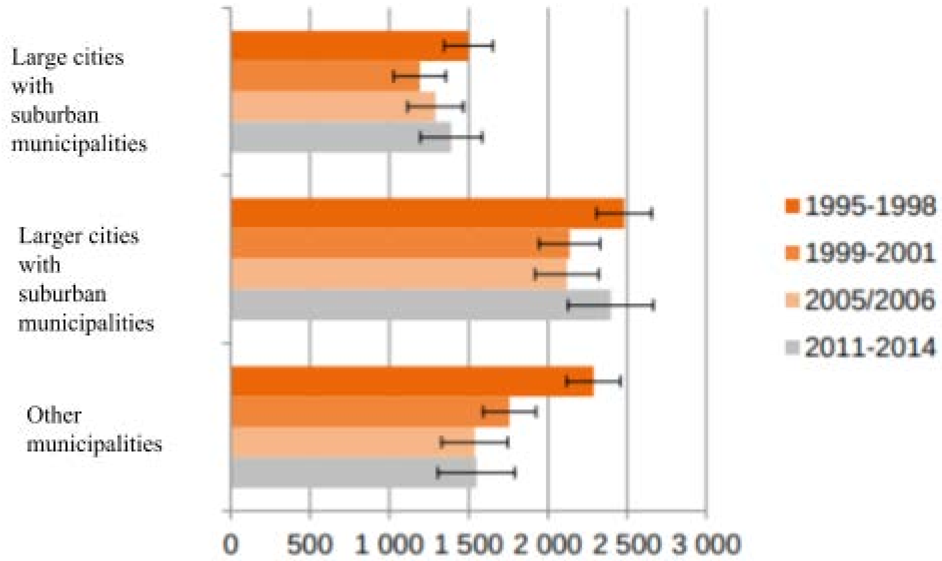

Figure 2: Total distance cycled in Sweden each day (1000 km), 1995-2014 (Trafikanalys, 2015)

The e-bike has an equally long history in theory but since the design demands more advanced technology it was for a long time limited by the heavy electrically driven wheels and low range battery and not until the invention of lighter batteries in the 1990s it became a commercially sold item (Electricbikereport, 2016). In Sweden e-bikes had a slow start and it was not until 2015 that sales grew to significant size, and by 2018, 12% of the total market of bicycles was e-bikes and 38% of all Swedish individuals could see themselves purchasing one (Svensk cykling, 2018). In modern times however, neither the bicycle or the e-bike can compare to the impact of the automobile; in 2015 there were almost a billion automobiles in operation worldwide (Statista, 2018). In Sweden the number of automobiles have steadily increased since 1943 and in 2017 there were 4.8 million automobiles in total (SCB, 2018).

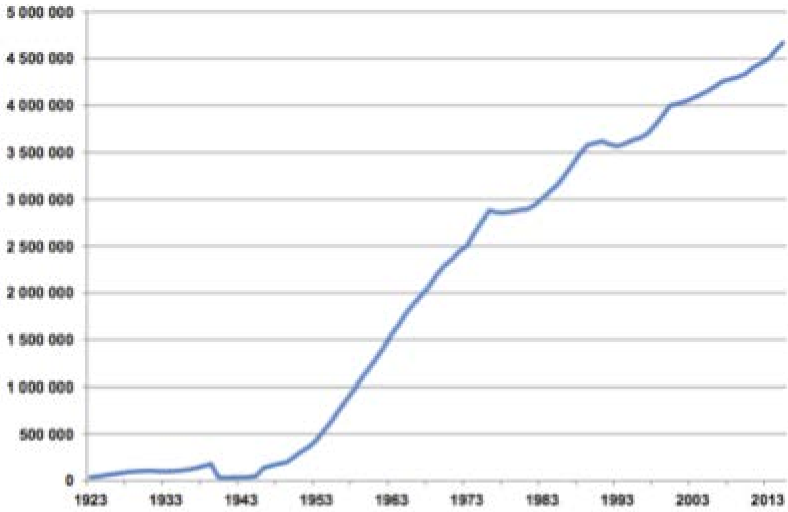

Figure 3: automobiles in Sweden (1923-2014) (SCB, 2018)

The field of travel behavior offer several economical, psychological and sociological suggestions as to what the driving forces behind choice of transportation mode are. On a macroeconomic scale the rate of increase in driving shows correlation with GDP growth as well as a decrease with economic recessions and increased fuel prices, indicating that economics is highly influential on our travelling habits (ACEA, 2018). In addition there is extensive research suggesting various psychological reasons for our travel choices, such as; pre-existing attitudes, "perceived barriers to behavior", habits or affective motives (Anable, 2004). There is also evidence that we have an irrational bias towards automobiles and that they exhibit "travel mode stickiness" meaning that once an individual has chosen automobiles as a first choice they are inclined to change this decision (Innocenti et al, 2013). The underlying individual factors for choice of transportation mode are many, but there are also other practical reasons why someone would choose one transportation mode over another such as large variation in altitude, the possibility of combining transportation modes, well-functioning and maintained cycling infrastructure.

Historically, most of the political focus when encouraging shifts in transportation modes has been on just harder measures such as infrastructural improvements, prohibitions or economic tools. This can still be seen when reviewing the national Swedish cycling strategy as well as Jönköpings municipalities bicycle plans in which the majority of focus and funding are on harder measures (Regeringskansliet, 2017; Jönköping kommun 2016/2017). This focus is not wrong per say since, as mentioned, good and safe infrastructure is important when individuals decide on transportation mode and the majority of literature that examine these kinds of harder measures generally indicate cost efficiency. However, these measures may not on their own be effective enough to promote travel mode shifts and some may be problematic to implement due to public opinion or political infeasibility (Bamberg et al, 2011). This has paved the way for an increase in soft transportation measures (mobility management), meaning “techniques of information dissemination and persuasion to influence car users to voluntarily switch to sustainable travel modes” (Bamberg, 2011). Most research indicates that soft measures complement harder ones and they have grown in popularity, especially at municipality level (Dill et al, 2010; Epom, 2018).

3. Literature Review

There is a substantial amount of literature evaluating policies aimed to increase AT, the majority is focused on infrastructural changes but there are those who evaluate other actual or theoretical changes in transportation modes. However there is not much literature that evaluates C2W schemes specifically and only three studies were found. Clarke et al (2014) have written the only CBA of a C2W scheme in which they investigate the C2W scheme implemented in Scotland. They consider an extensive amount of parameters including the forgone tax cost for the government, but they do not include travel time which generally is one of the bigger cost parameters for cyclist. The results are in line with similar research on bicycle investments with a benefit-cost ratio (BCR) of 3.51 and 2.55 (depending on varying definitions of the forgone tax for the government).

The second evaluation of a C2W scheme done by Green et al (2016) is not a CBA but there is comparisons of the health cost and benefits from increased physical activity (PA). They look at the increased amount of PA for 13,000 scheme users in England and Wales and concluded that 65% of these users rapport a 30 min daily increase of PA. They then (conservatively) estimate that if only 5% of the 180,000 total users would increase their PA by 30 min daily the social benefit from reduced absenteeism and increased health levels would be £72 million yearly, and the BCR would be 2.

They then go on and assume if these results are moderately applied to the total amount of users; meaning if only 5% of the 180,000 total users would increase their PA by 30 min daily the social benefit from reduced absence and increased health would be £72 million yearly, and the BCR would be 2. They do not question any possible substitution between AT and other PA. The last evaluation of a C2W scheme is by Caulfield & Leahy (2011) who looked at the users of the Irish tax relief scheme introduced in 2009 which is similar to C2W scheme in Jönköping. They conclude that 95% were satisfied with the scheme (73% very satisfied), that the individuals who did not own a bicycle prior were encouraged to do so because of the scheme and that this could result in a "substantial modal shift toward cycling" (Caulfield & Leachy, 2011).

In addition to these evaluations of C2W schemes there are two other categories of literature that are relevant to this thesis. Firstly there is literature not concerned with C2W schemes specifically but rather evaluations of infrastructural changes or other (sometimes hypothetical) implementations. These studies were still considered relevant due to data/methodological similarities (an overview of all studies included can be seen in appendix A). The inclusion of studies was primary based on similar definitions and inclusion of parameters (the difficulty with this will be discussed later) as well as the presence of a BCR (seen in figure 4) for comparability purposes. Secondly, since the means of transportation many times is a public good and handled at least to some extent by the government there is a vast amount of "grey literature" produced by governmental agencies, that is not published nor peer reviewed. They seldom conduct their own empirical research but rather gather expert opinion and recent evidence within the field to form recommendations and frameworks for national transport evaluation. In this thesis the primary sources of literature in this category is the Swedish Transportation Agency (Trafikverket) which has a framework for evaluating implemented transportation policies within the Swedish context (Trafikverket, 2018; Trafikanalys, 2017). Their recommendations will be loosely followed in section 6.

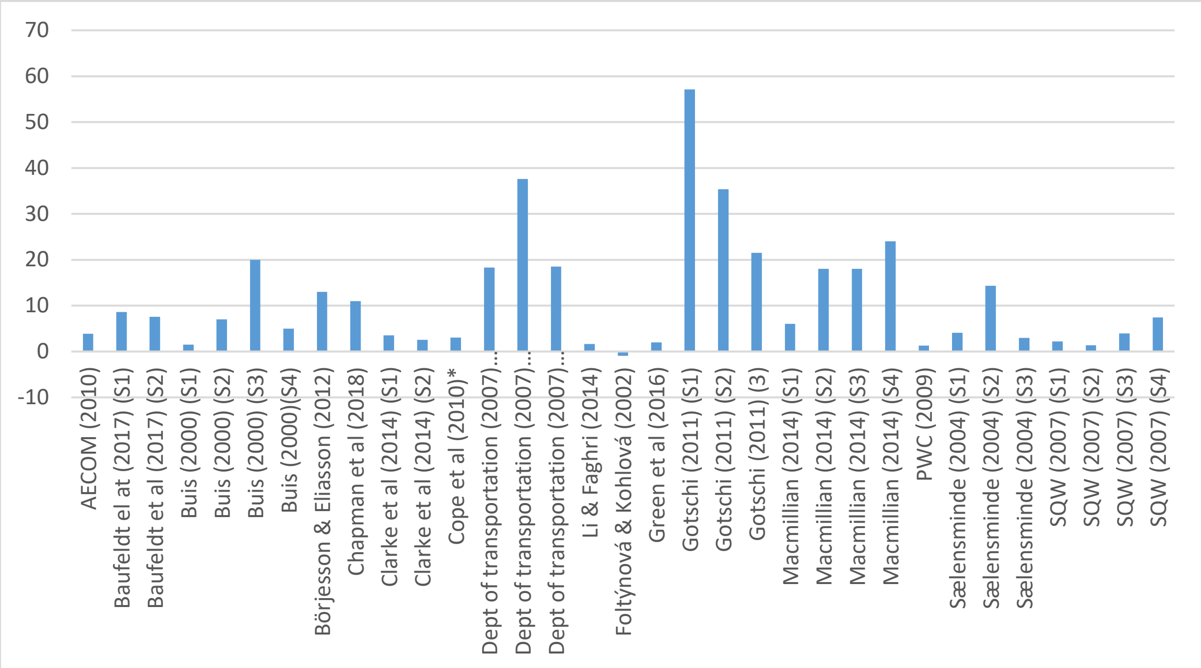

Figure 4: BCR of included studies.

The majority of studies evaluating infrastructural changes use a CBA framework (or similar method) which has become the most common and powerful tool to evaluate planning and policy efforts (Li & Ardeshir, 2014). There is close to a consensus about investments in AT being a cost efficient alternative, meaning that the BCR>1 (see figure 4). The only noticeable exception to this, is the study by Foltýnová & Kohlová (2002) in which the BCR was -0.97. This was one of two studies that considered demand for the bicycle investment (PWC also included a demand forecast), and in which only 0.2% of the city's residents used bicycles which could be the reason for the negative BCR. Even though a clear majority of all studies indicate similar results, there is great variation on how these conclusions are reached. The EU recognized this problem and in 2005 they started a project called HEATCO (developing harmonized European approaches for transport costing and project assessment) which after overseeing existing "national transport infrastructure project assessment" concluded that despite most nations having national guidelines they "differed widely in terms of their methodology, level of detail and indicators" along with "differences in assumptions between countries in terms of the economic valuation of impacts" (IER, 2006). The project, which was finished in 2006, set out to create "harmonized guidelines for project assessment and transport costing at EU level”, but despite this many independent researchers do not apply to the framework, thus the problem with comparability remain.

The problem does not only exist with the definition or estimation, but also, with the somewhat arbitrary decision making- process in the inclusion/exclusion of parameters. This is exemplified in appendix A where there is no identical combination of parameters in any of the included studies. These issues are not helped by the (in many studies) lack of transparency regarding the thought process behind the parameters both included and excluded. Due to these methodological differences comparisons between studies needs to be made with great caution.

4. Method

4.1 CBA: Introduction and Outline

The CBA framework entails assessing, calculation and comparing all benefits and costs of a policy in an attempt to make a well informed decision about whether to implement a policy or not. The aim is to identify the most cost efficient alternative and the framework has become a widely used tool in planning and policy making, especially within transportation planning (Mingxin & Faghri, 2014). Whether a project should be implemented or not is primarily based on the cost-benefit ratio (BCR) meaning, the ratio of the benefits from a policy relative to its costs. The idea is simple: if the BCR is larger than 1 the policy should, on economic grounds at least, be implemented since it would increase the social welfare, and if it is smaller than 1 it should not be implemented since the resources could be used more efficiently elsewhere (Gordon, 2017). The objective with a CBA is to include costs/benefits that affect the entire society rather than just the individual and it is therefore sometimes also referred to as a *social* cost and benefit-analysis. There are different time perspectives that can be adopted within a CBA-framework, the analysis can either be (1) ex-ante; before the implementation of a policy or (2) post-ante after the implementation of a policy. These are the most commonly used time-frames, but there is also a third time frame alternative;(3) medias res, meaning the evaluation takes place at the same time as an ongoing policy (Boardman et al, 1994). The steps in all time variant versions of the CBA are similar, but there can be some variation as too what the steps entail or in which order to perform them. According to (Hanley & Spash, 1993) the essential steps are:

(1) *Defining the project*. What is the project and what is its counterfactual to be compared with? The counterfactual can be some other policy with the same purpose or it can be the most common, status-quo, meaning that no other policy is implemented. Other questions are what reallocation of resources is being proposed and who have standings in either the project or in the counterfactual?

(2) *Identifying impacts which are economically relevant.* Environmental impacts count if 1) they change the wellbeing of one individual and/or 2) change the level or quality of output of some positively valued commodity.

(3) *Physically quantification of relevant impacts*. Determining the physical quantities of the effects of the implementation within the time-frame.

(4) *Calculating a monetary valuation of relevant impacts*. To be able to measure and compare things they must be quantified in the same units; dollars (or some other currency). This is not to say that money is all that matters but for there to be comparison some attributed value has to be concluded and despite its complicated nature, price does carry valuable information (Hanley and Spash, 1993). The CBA analysts must then do three things to address this 1)

predict prices of value flows extending into the future 2) correct market prices where necessary 3) calculate prices (relative values in common units) where none exists. Point 1) entails a necessity of calculating using real values, since nominal values does not give an accurate representation of values in real time. Point 2) and 3) entails adjusting and calculating alternative market prices to estimate what is known as a *shadow price*. This is often done with unconventional pricing methods, which will be discussed in section 4.2.

(5) *Discounting costs and benefit flows*. When values for the costs and benefits have been determined it is necessary to express them in present value (PV). Meaning that since humans have a time preference, ten dollars are worth more for us today when it is spendable than in one year from today, and therefore future costs or benefit need to be discounted to PV. The need for this is either due to human impatience to consume or the possibility to invest today and yield greater economic winnings in the future. To accurately calculate future costs and benefits in present value a present value-formula is used:

$$PV = \frac{C}{(1+i)^n} \tag{1}$$

(C) = future value, i = interest rate, n= time period (most often years)

(6) *Net present value test (NPV)*. The determinant of whether an implementation or a policy is social beneficial is whether the sum of the discounted benefits is greater the sum of the discounted costs.

4.2 CBA: Criticism and Limitations

The straightforwardness and intelligibility of CBA is undoubtedly one of its strengths, in practice however, the situation is more complicated and this strength can become a weakness. The criticism of CBA's can be divided into two major groups: criticism of the framework and theoretical ground on which it is based and criticism of the practical usage of it.

Framework and theoretical ground

The need to monetize parameters, primarily softer parameters, have been ongoing subject of criticism. There are moral dilemmas that stem from giving monetary value to the parameters in a CBA. Firstly some question whether it is at all right to do so with living things such as the environment or even human beings and secondly, how do we value future generations wellbeing or intergenerational fairness (what discount factor should be used?). (Ackerman & Heinzerling 2002, Frank 2007). Gerrard exemplifies the problematic nature of this by stating “if a human life is considered to be worth $8 million, and a ten percent discount rate is chosen, then the present value of saving a life one hundred years from now is only $581. Neither I nor anyone else use this kind of argument” (Gerrard, 1998).

Furthermore the CBA framework rests upon a utilitarian theory (or other similar consequentialist ethical theory) and critics mean that this in itself comes with a ethical dilemma; sometimes the alternative that maximizes the utility is not necessarily the best one for all (Frank, 2007). This criticism entails that the CBA is inherently unjust and that this causes a distributional problem, for example since it gives equal weight to a project for the rich as well as a project for the poor it does not take proper account of the effects of policies, concerning the distribution of burdens and benefits in society (Copp, 1987). Copp also argues that by measuring benefits and costs only in dollars there is implicitly greater significance given to the welfare of the richer members of society. Lastly one other concern with the framework has been raised primarily due to new findings in the field of behavioral economics and addresses that CBA’s are performed assuming an individual application of rational choice theory, but some argue that human decision-making is in itself a social, and not only an individual process (Parks & Gowdy, 2013).

Practical usage

Like mentioned previously, since many frequently used parameters in CBAs lack market value other methods to estimate shadow prices have to be used. These methods primarily consists of surveying methods and drawing inference from market behavior; both methods are associated with some difficulty and uncertainty. The problems with surveys are that they often consists of contingent valuation (CV) which can be problematic for a number of reasons. Firstly the monetary value of the outcome asked to be appraised often exceeds the individual's total wealth, secondly the answers to CV surveys are often very sensitive to how the questions are formulated and thirdly there are problems with loss aversion; meaning that individuals are much more likely to “prevent a harmful effect than to undo a harmful effect that has already occurred” (Frank, 2007). Another way of expressing this is that there are differences between the willingness-to-pay (WTP) and the willingness-to-accept (WTA) that are problematic when interpreting the result of a CV survey.

Making estimates from market behavior using hedonic pricing methods (or indirect economic pricing) is also affiliated with high levels of uncertainty due to incomplete information, immobility and other imperfections (Frank, 2007). Varying hedonic pricing methods are applied in the housing and labor market as well as the market for environmental services. Different parameters are faced with varying estimation problems and the concerns regarding monetary evaluation of parameters (ecological and others) are summarized as follows: (1) does not capture ecological sustainability and distributional fairness (2) possible value incommensurability (impossible to find a monetary value) (3) prices are a result of historical context and reflect historical and existing power structures (4) marginal values should not be confused with total values (5) marginal values should only be used when ecosystems are fairly intact and functioning normally (6) tends to leave policy makers without responsibility (Røpke S, 2005; Howarth & Farber 2002; Parks & Gowdy, 2012; Limburg et at 2002).

One last concern, which has been discussed previously is the human decision making process when including or excluding parameters. As can be seen in appendix A in this thesis and in many other reviews on the topic there is great variation on what parameters are included, which obviously has an effect on the outcome. Some justify the exclusion of some parameters due to the uncertainty mentioned above, while others argue that the same parameters contribute enough information to be worth including. Either way the decision is somewhat arbitrary, possible making the outcome such as well, this will be discussed further in section 9.

5. Case Study Description

5.1 Background

Jönköping municipality has a long history of softer transportation measures such as bicycling courses for newly arrived female immigrant, free courses in bicycle mechanics and variety of information campaigns aimed at informing about the benefits with AT (Jönköping kommun, 2017; Temp, 2008). In 2016 they reformulated the 10 year old bicycle-program and highlighted the importance of safe and efficient bicycle investments as a way to increase AT. It underlines that all more environmentally friendly transportation such as bicycle, walking and public transportation should be prioritised over motorised transportation (an opinion also shared by 58% of the residents) (Jönköping kommun, 2017).

When Trafikanalys reviewed how much resources were assigned to bicycle measures in all counties, Jönköping county was the only county that had not separated the resources assigned for bicycles from the resources assigned to public transportation, the total amount for both is 120 million (Trafikanalys, 2014). The budgeted amount on municipality level is 17 million annually, but in 2016 the spending exceeded this which was taken from the budget planned for 2017. For 2018 the budget was increased to 21 million. This spending are accompanied by ambitious goals; the municipality aims to increase cycling during weekdays by 25% between 2014 and 2019. And since the majority of all trips are made with automobiles, ⅓ of all journeys in the municipality are shorter than 3 km and ½ shorter than 5 km the goal is to replace shorter automobiles journeys with bicycle or e-bikes (Jönköping kommun, 2017).

5.2 C2W Scheme

The C2W scheme was implemented in Jönköping municipality in May of 2016 and is planned to continue till spring 2019; with several occasions (at least 2 each year) for municipality employees to lease vehicles. One demand from the municipality was that it should be (or close to) cost neutral and therefore the implementation was carried out via the company Ecochange which has provided both private and governmental/municipal employees with a variation of employee benefits. The scheme gave everyone the almost 10,000 employees at the municipality the opportunity to lease bicycle/e-bikes (maximum 2 vehicles per person) over a 3 year period and when the time period expired they were offered to either buy their vehicle at current market price or return it to Ecochange. During the time frame of this thesis, three leasing opportunities passed, in which a total of 2346 vehicles were leased, by 2012 individuals. Out of which 954 were bicycles and 1392 e-bikes, this means that some individuals leased more than one vehicle, either for themselves or for someone else. According to employees at Ecochange, 90% of all participants purchased their vehicle at the end of the leasing period. There were several different bicycles and e-bikes available, ranging from tricycles and foldable e-bikes to city and race bicycles (an overview of the models can be seen in appendix B). The payment was processed by a gross wage deduction with the total price for the individual leasing was dependent on two things; 1) price of vehicle chosen 2) the individual's marginal tax. In Sweden there is an increase in marginal tax depending on income level, if an individual earns more than $49,880 each year the margin income increases from 33% to 56%

The municipality handled the initial marketing and information about the scheme to the employees. The communication was done via their intranet and through email, meaning that the administrative costs were very low. The local media also covered the initiative in several news outlets which probably contributed to the high participation amongst the employees (around 20%). The municipality did not do any of the practical work, moving or distributing the vehicles, the entire rental service itself was carried out by Ecochange.

Location

The location of the C2W scheme is the city of Jönköping which is located in the middle part of Sweden (see figure 6). The city is the 10th largest city in Sweden and inhabit 137,481 people (Jönköping kommun, 2018). The city is located next to Sweden's second largest lake (Vättern) which cause large differences in altitude, primarily when entering/exiting the central area of the city.

Project time

The time limit of this project is 12 years, this time limit is based on the life expectancy of a bicycle. Obviously the lifespan of a vehicle is dependent on many things, how it is operated, maintenance, original quality etc. Trafikverket use the age estimate 10-16 years depending on the type of bicycle (Trafikverket, 2018). The life expectancy of the battery on e-bikes is shorter, but can be replaced. It should be noted that this thesis does not evaluate the entire implementation made in Jönköping. The time frame for evaluation of this implementation is medias res, meaning that when this evaluation is performed the scheme is still not completed. This means that the monetary outcome of this thesis is smaller than the outcome for the entire scheme. It is likely to assume that given the same municipality employees the effect is decreasing since fewer and fewer lease vehicles. But still, the outcome in this thesis should be noted as only part of the total outcome of the entire implementation.

Standings

The most obvious people who have standing in the scheme are the participants who's wellbeing change through joining the scheme (consumers). The people who supply the scheme also have standing (producers). On a larger scale, other residents in the municipality (or people who are passing through) who are otherwise affected by some of the local externalities from automobiles such as noise pollution and local/regional air pollution also have a standing (third party). And on the largest scale, everyone who is affected by climate change have a standing, since CO_2 emission is a global problem.

5.3 Counterfactual

When considering the counterfactual, the question that needs answering is; what would have happened if no policy was implemented given ceteris paribus? In this case, how would the bicycling amongst the municipality employees changed had the C2W-scheme not been implemented? To answer this, observing the bicycle trend in Jönköping, prior to the scheme, could offer some insight.

There has been transportation data collected in two studies that charted the travel habits of individuals living in Jönköping. Both studies were conducted in the same form with a postal survey being sent to 7000 people, for which they had similar respond rate of 47% and 43% for 2009 and 2014 respectively (Billsjö et al, 2014). As seen in figure 5, the travel habits during the weekdays remain fairly constant between the years with the most notable difference being a 4% increase in driving. The same is true for the weekends, with the exception of a 4% increase in cycling and a 3% increase in public transportation. The difference between weekday and weekend are similar for both years in that there is an increase in driving (10% in 2009 and 2% in 2014) while there is a decrease in all other transportation (with the exception of walking which in 2014 had a 1% increase).

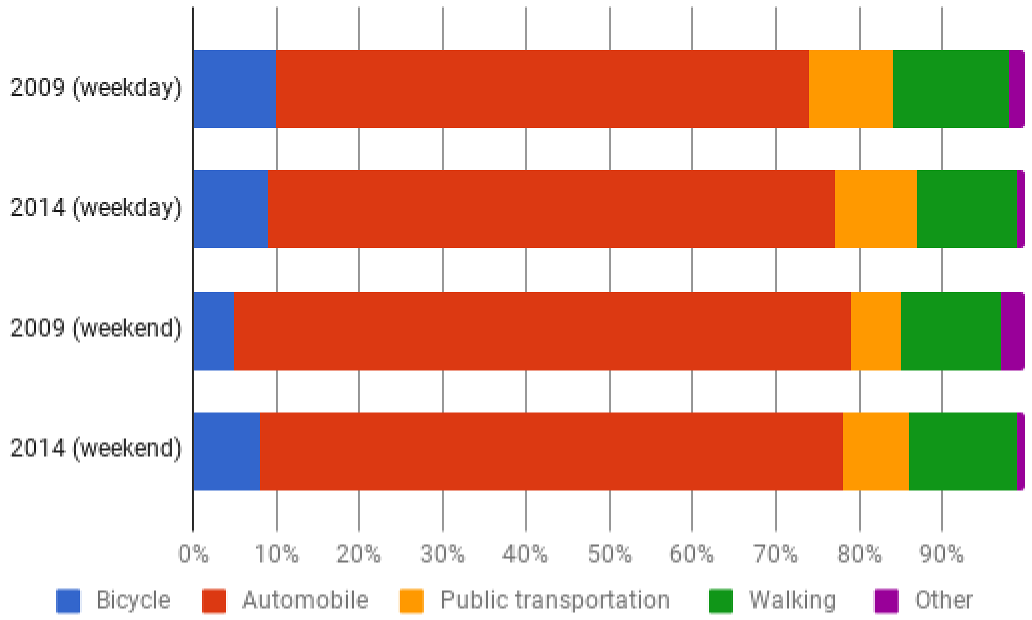

Figure 5: The percentage of users for varying transportation modes during the weekday and weekend in 2009 and 2014 (Billsjö et al, 2014).

Another way to observe the historical levels of cycling is through measuring points positioned around Jönköping city. There are nine measuring points around the city that record how many bicycle pass at all hours of the day. Three of them display the number of people who have passed by that day and the results from the five others can be seen on the municipality home webpage (Infracontrol, 2018). The first measuring point was placed at "högskolan" [university] in 2005, and it was not until 2011 that four more measuring points were added, then one additional one in 2012, two in 2013 and lastly one in 2016. Since research indicates that younger and well educated individuals bicycle to a larger extent, using data between 2005 and 2011 when the observations where only from the local university measuring point might lead to overestimation (Xing et al, 2010; Caufield & Leahy, 2011; Rietveld & Daniel, 2004). To avoid this, assessments from 2012 and forward are displayed in the figure 6 (averages of each year), but it could be noted that during the time period 2005-2012, excluded for reasons mentioned above there was also a continuous increase in bicycles. What can be seen in the graph below is that there was a strong positive trend of bicycles passing the measuring points all the way up until 2016-2017, when there is a small decrease in bicycles. On average there was a 8% increase of passing bicycles/e-bikes every year.

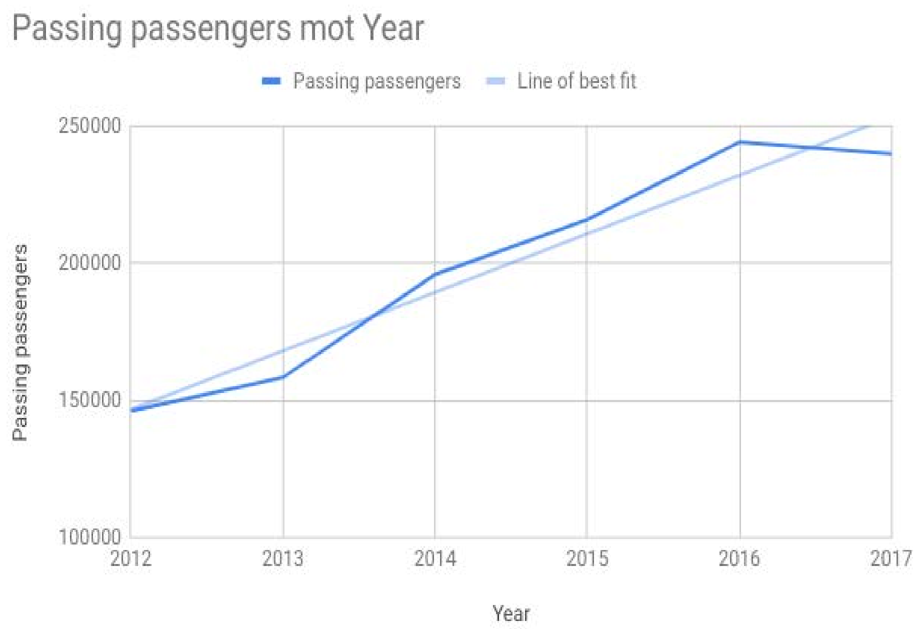

Figure 6: The average amount of passing passengers in nine bicycle measuring points in Jönköping city during the time period 2012-2017 (Infracontrol, 2018)

Another piece of evidence comes from three surveys done by the municipality on the municipality employees which also indicate a positive cycling trend. In 2012 the percentage of employees cycling to work was 16% which increased to 17.5% in 2014 and then to 18% in 2016. The biggest increase was for e-bikes for which there was no question in 2012 but from 2014 to 2016 there was an increase of 165% (from 1.7% to 4.5%). It should be noted that the last survey was done in the end of 2016, therefore it also including some of the C2W- scheme participants which started in May of 2016. Lastly the municipality did their own evaluation of the C2W scheme in January 2017, (meaning that it included two opportunities of bicycle/e-bike leasing from 2016) in which a question whether individuals were planning to purchase a bicycle independently of the C2W scheme was included. The answers indicate that 19% of all participants were planning on buying a bicycle/e-bikes the same year, and another 27% within a couple of years. These results could to some degree also be subject to social desirability bias, since cycling is something most often viewed as a positive (for the individual but also for the environment which is a common resource) especially in comparison with an automobile. This will not be addressed further in this thesis since the effect is most likely not large enough to skew the results but is worth mentioning. Almost all data on the trend of cycling in Jönköping point in the same direction; even without the C2W scheme there would probably have been an increase in bicycle/e-bike activity. The only exception to this is the data presented in figure 3, which indicates a 1% decrease in cycling on weekdays between 2009 and 2014. To what extent the increase is from individuals using their vehicles more often or from individuals buying a new vehicle and using it is impossible to say exactly. As a result of the increasing cycling trend, 20% of the effects calculated in section 7 will be removed from the final outcome.

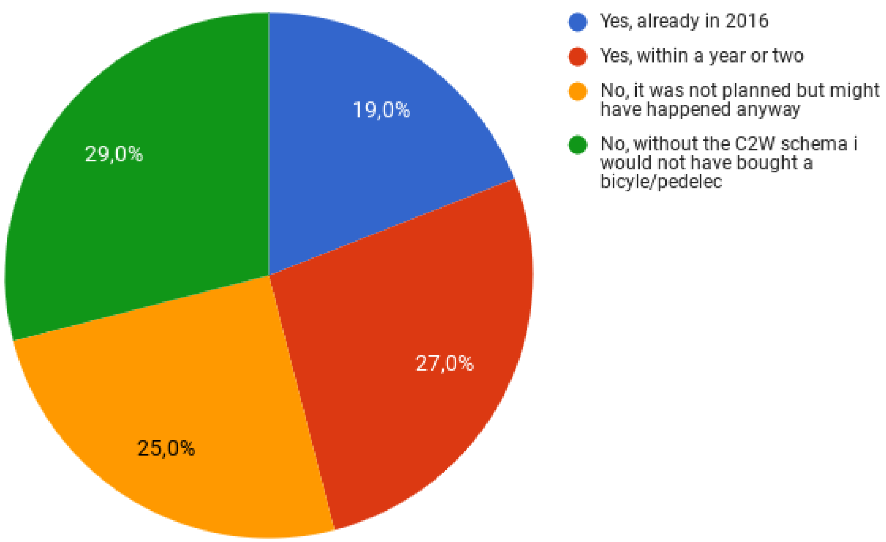

Figure 7: Answers to the question “were you planning on purchasing a bicycle/e-bike independently of the C2W scheme?” asked to the municipality employees.

5.4 Data collection

Apart from literature and contact with the individuals who initiated the scheme at the municipality the main source of data was the participants in the scheme. In the fall of 2017, on two occasions (one week in between) an online-survey was sent out to the work email of all 2012 employees at the municipality who participated in the scheme. The survey consisted of 11 open-end-questions (seen in appendix E). There was a response rate of 21.3% (430/2012), even though some choose not to respond to all questions. The initial questions regarding the age and sex of the participants had similar results as the survey conducted by the municipality itself. The gender dispersion in this survey was 24% male, 74% female and 1% other and the age dispersion can be seen in figure 8 below.

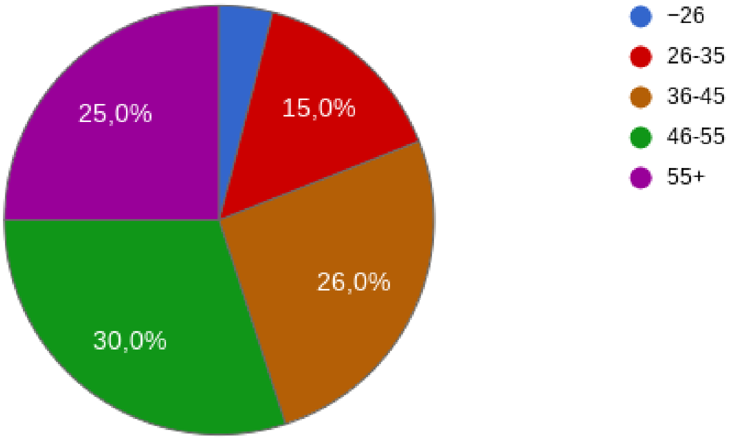

Figure 8: The age dispersion of the participants in the C2W scheme.

5.4.1 Survey mode

Questions	Average answer
How many months out of a year do you use your bicycle/e-bike:	31 weeks/year
How many kilometres motoring (weekly) have you changed to cycling?	30.39 km/person
How many kilometres public transportation (weekly) have you changed to cycling?	10.5 km/person
If you orders 2 bicycles and someone else except yourself is using one of they, please do the same estimation as above for that person. How many kilometres motoring (weekly) have he/she changed to cycling?	18.21 km/person
If you orders 2 bicycles and someone else except yourself is using one of they, please do the same estimation as above for that person. How many kilometres public transportation (per week) do you estimate that he/she replaced with cycling?	31.82 km/person
How has you travel time changed weekly since you received your new bicycle/e-bike?	12 min 36 sec/person/week
How has your amount of physical activity changed (daily) since you received your new bicycle/e-bike?	14 min 30 sec person/day

Table 1: Summary of the survey given to the participants in the C2W scheme, a full version of the survey can be seen in appendix D.

There were also questions regarding walking, but partly because the change in these transportation modes were small (from walking to bicycle/e-bike) and also that they have similar health/environmental effects they were not included in the thesis. The question regarding physical activity was included in an effort to address the possibility of substitution between transportation and other workout. One notable thing is that 24.8% reported no change in PA and many noted that they already had a bicycle since previously so a new vehicle did not change their PA level. The written elaborations do however indicate that there perhaps should have been a clearer distinction between cycling and other sorts of workout. It is unclear whether the respondents equivocated PA due to transportation to other kinds of workouts. Similar results as to change in PA were given for the change in travel time, where 24.6% reported that they had no change in travel time. Some participants noted that they had no change in either because they had a bicycle before the scheme and simply upgraded it. The participants who leased two vehicles were asked to estimate the effect for those who did not, these estimates are for obvious reasons more uncertain since they are second hand estimates. Despite this they were included since they are an effect of the scheme, and including them more likely creates a truer estimation of outcome then excluding them.

6. Costs and Benefits - Effects and Cost Calculations

This chapter overviews and explains the effects of the C2W scheme that are included in the CBA. The effects are divided into direct effects which affect the cyclist and indirect effects which affects society as whole (Krizek, 2007). Many times the effects overlap, meaning what is good for the individual is good for society as a whole and vice versa. The parameters excluded can be found in Appendix C.

CBA Parameter	Expected effect on outcome	Methodology to Quantify Effect	Data Requirement
Direct effects			
Health			
-Physical activity	Positive	Change in vehicle km for all travel modes	Marginal cost estimates for health benefits and change in km travelled
-Noise pollution	Positive	Change in vehicle km for all travel modes	Marginal cost estimates for noise pollution and change in km travelled
-Local and Regional Air Pollution	Positive	Change in vehicle km for all travel modes	Marginal cost estimates for air pollution and change in km travelled
-Accidents	Negative	Change in vehicle km for all travel modes	Marginal cost estimates for accidents and changes in km travelled
Travel time	Negative	Change in time spent travelling different modes	Marginal cost estimated for travel time and changes in km travelled
Parking	Positive	Change in nr of parking occasions	Cost estimations for parking in Jönköping municipality and change in nr of parkings
Vehicle purchase and operation	Positive	Change in vehicle km for all travel modes	Marginal cost estimates for Vehicle operation and change in km travelled for each mode
Indirect effects			
Climate change	Positive	Change in vehicle kilometers	Marginal CO_2 emission cost and change in km travelled
Implementation costs	Positive	Change in public spending by the municipality	Estimates in hours spend on campaign and average hourly wage
Absenteeism	Positive	Change in absenteeism at workplace	Not empirically quantified
Infrastructure	Positive	Change in vehicle km for all travel modes	Marginal cost estimates for infrastructural deterioration

Table 2: All parameters included in the CBA; the methodology to quantify them and what data was used.

6.1 Health

There are many ways in which AT can affect an individual's health. There are firstly possible physical benefits such as decreases in cardiovascular disease, diabetes, cancer, obesity, musculoskeletal conditions, infectious and respiratory diseases. If an increase in AT also entails a decrease of motorised transportation there are other positive health effects such as less noise pollution and regional and local air pollution. However, increased AT also have negative effects such as increased risk of personal injuries due to accidents. Social cost connected to extended life expectancy is outside the scope of this thesis and therefore not included.

6.1.1 Physical activity

The benefits from increased physical activity are well documented within many fields of research. The definition of physical activity and what time interval to stay active (in order to see positive impact) is debated but the recommended amount for an average adult is 30 min of daily moderate physical activity (WHO, 2010). The benefits of this type of activity can be seen in a decrease several diseases: cancer, osteoporosis, coronary heart disease, diabetes as well as in prolonged life and a decrease in all-cause mortality (Warburton et al, 2006; Reiner et al, 2013;).

Most evidence indicate that AT does indeed have positive effects on health, but the robustness of the evidence varies and there is still uncertainty about the dose-response relationship (Saunders et al, 2013; Gordon, 2017; Goodman et al, 2014; Wanner et al, 2012; Kelly et al, 2014). The question is not so much whether AT has positive health outcomes but rather how much it actually contributes to the *total* activity. If the cyclists already take the health benefit into consideration when making their travel choice, meaning if the cyclist substitute their already existing exercise regime with their cycling to work the health benefit has already been internalized and no additional benefit would be made (Börjesson & Eliasson, 2012). There are indications that AT to some degree substitutes other PA and if so, the positive effects of AT could be overestimated. However, no studies focus exclusively on the substitution between AT and other PA, and the substitution degree remain uncertain as a result, most studies assume zero substitution (Mueller et al, 2015; Genter et al, 2008; Kahlmeier et al 2011, Brown et al, 2016)).

Nonetheless, one study indicating the magnitude of a possible incorrect assumption was produced by Börjesson and Eliasson (2012) in which they conclude from surveying cyclist in Stockholm, Sweden that the effect could be up to 60% less than expected. They found that 52% of cyclists stated that exercise was the most important reason to choose bicycle (61% for individuals over years). Björklund and Mortazavi (2013) built on and extended the study by Börjesson and Eliasson (2012) and found that individuals who said that they would exercise more if they did not cycle less (interpreted to mean that they gain additional health benefits from cycling) valued their time slightly higher than those who said that they would not exercise more if they did not cycle (interpreted to mean that they did not get additional health benefits). Even though the difference were small, it could read in favor for some internalisation of health benefits. In one of the only three rapports that estimates a C2W scheme they also found that as much as 50% of the participants did not increase their PA due to the scheme and as much as 6% even decreased the PA because the exchanged walking for cycling which is faster (Clarke et al, 2014). To avoid overestimating possible health effects the assumption of zero substitution will not be made in full in this thesis. This is partly due to the ambiguity within the literature but also due to the results of the survey conducted among the municipality employees where almost 25% indicated no change in their activity levels (for the remaining 75% the average was a 14.5 min/daily increase). Due to lack of data the substitution degree will be somewhat arbitrary based on the indication in the survey and 25% of the effect for both bicycles and e-bikes will be assumed already internalised. Further internalisation will be considered in the sensitivity analysis.

Transportation mode	Marginal cost/benefit from PA ($/km)
Bicycle	0.29
E-bike	0.29
Automobile	-
Public transportation	-

Table 3: Summary of marginal cost/benefit from increased PA for all transportation modes (HEAT, 2018).

Bicycle

There are many studies linking not only increased physical activity in general to health benefits but bicycling specifically. One study by Hu et al (2007) which included 48,000 participants found that "moderate or high levels of occupational or leisure-time physical activity among both men and women, and daily walking or cycling to and from work among women are associated with a reduced 10-year risk of coronary heart disease". In addition, Cavill et al (2008), Andersen et al (2000), Mueller (2015) and other studies discussed in the literature review (see figure 4 and appendix A) all find positive health outcomes from increased bicycle usage.

To calculate the health benefits from increased AT the commonly used health economic assessment tool (HEAT) for cycling and walking will be used (HEAT, 2018). Because of the complexity in assessing health effects WHO developed HEAT as a tool which uses the latest published economic valuations of transport projects and epidemiologic literature (Kahlmeier et al 2011). HEAT only accounts for economic impact of mortality (using value of statistical life; VSL), since the literature is less conclusive about the economics of morbidity, they argue it would lead to greater uncertainty to include it. The authors acknowledge that this is likely to produce conservative estimates since it does not account for disease related benefits (Kahlmeier et al, 2011). The relationship between cycling and mortality is assumed to be linear, despite some evidence that the relationship is not completely linear it was considered “adequate within the foreseen range of activity for HEAT” (HEAT, 2018). The tool takes regional differences into consideration, in this case using the Swedish VSL of $45,457,031 (£3,990,000). No distinction was made between the level of physical ability amongst the participants not between the ages. Age and physical ability have opposite effects on the health benefits, with age the benefit is increasing and with physical ability the benefit is decreasing (NVV, 2005; PWC; 2009; Department for transportation; 2010). The physical ability amongst the participants is unknown but the age is not, nonetheless both were excluded from the calculations in the hopes of the effects somewhat cancelling each other out. For specific inputs in the HEAT calculation see appendix D.

E-bike

There are less studies on the health benefits form e-bikes compared to ordinary bicycles and the demanded level of physical effort, for the same travel distance, is undoubtedly lower. However, given the rising popularity of e-bikes, more and more research which measure the physical effort and thereby determining their health impact is being produced. The measurement most commonly used to measure physical activity is the metabolic equivalent of task (MET), where 1,0 MET represent the metabolic rate associated with being at rest. Haskell et al (2007) suggest that to promote and maintain health the exercise intensity should be at least 3,0 MET. Several studies have indicated that the average MET while riding an e-bike is well above 3 and most likely somewhere between 5-7 (Gojanovic et al, 2011; De Geus et al, 2007; Simons et al, 2009). Since these studies indicate that health impact from an e-bike is sufficiently high to produce desired health effect, the health effect will be assumed identical for bicycles and e-bikes.

Automobile and public transportation

Since motorised transport does not entail any physical activity these will not be considered in the estimation. But it should be noted that in some studies public transportation is denoted as an active transportation mode since it entails more physical movement then automobiles. But in this thesis they are both treated as non-active and no estimate is included.

6.1.2 Noise pollution

Noise pollution (and to some extent vibration which will not be treated separately) is one of the most common pollutants in the western world and a large amount of it is roadway noise (WHO, 2011). How noise affects us is dependent on the noises character (the quality of the noise such as its volume and frequency), surrounding environment, possible vibrations and time of day. The effects of noise pollution are increased risk of cardiovascular disease, sleep disturbance, annoyance, cognitive impairment, metabolic outcomes, hearing impairment, tinnitus and lower quality of life, mental health and well-being (WHO, 2018).

Transportation mode	**Marginal cost due to noise pollution ($/km)**
Bicycle	-
E-bike	-
Automobile	$0.021
Public transportation	$0.105

Table 4: Summary of all marginal costs due to noise pollution (Trafikverket, 2018; Strömmer, 2003)

Bicycle and e-bikes

Bicycles and e-bikes do make some noise while being operated but since the decibel of the noise produced is not high enough to have an effect on human health the damage cost is negligible and not included in the estimation.

Automobile

Noise pollution is especially a problem in bigger cities but is also becoming a problem in smaller cities that have larger roads passing through (Trafikverket, 2016). The exposure to roadway noise is usually over longer periods at lower volumes so it is primarily those circumstances that are considered when constructing cost assessment. With continuous roadway noise pollution (with an average dB of 55) there is an increased risk of cardiovascular disease and myocardial infarction, increased stress levels, difficulty to perceive speech and concentrate as well as worsened sleep and rest quality (Ising & Kruppa, 2004).

The most common way to measure noise exposure is to determine either an equivalent value (an average over a longer time period) or a maximum-value when specific vehicles pass. Trafikverket perform, in accordance with the EU Directive 2002/49/EC, regular noise assessments as well as produce noise maps. They estimate that around 1.4 million individuals in Sweden are during day hours exposed to equivalent levels above 55 dB (Trafikverket, 2018). The effect of roadway noise can be at least partly combated by constructing noise protection, which would reduce the effects on human health but post a cost category on its own. These costs are not considered in the marginal price of noise pollution, instead the assessment has been done using 50/50 outdoor and indoor effects with several different pricing methods. For sleep disturbance and effects on stress, hedonic valuation methods in the form of WTP for reduced noise pollution in the form of property value have been used. These methods do come with a certain degree of uncertainty, for example the interference effects of noise pollution could not be included in the price differences in the housing market, if potential buyers are not able to observe them. Estimates for heart disease come from WHO who have used VSL as a price indication and then the added costs of Swedish health aftercare for individuals suffering from heart disease (Trafikverket, 2016).

When the cost of increased dB levels is determined by the methods mentioned above the marginal cost estimation (for an average automobile in an urban area) is exemplified in the formulas below:

10*Log(1+ 0.5*1/(365*X)) = 0.00000397 dB (2)
0.00000397*Y = Total cost
Total cost/the total length of the road network = marginal cost

(X) = the average yearly traffic flow for 24 hours (between 1100-1800) (Y)= the marginal cost of damage for the increase of 1dB (Strömmer, 2003). Trafikverkets cost estimates of roadway noise have varied with time, the latest estimation will be used here. The marginal cost for urban environment is divided into three: $0.019/km in sparsely populated areas, $0.021/km in middle populated area and $0.023/km in densely populated areas (Trafikverket, 2018). Since there is variation in the population density in Jönköping, the average estimate of $0.021/km will be used (Trafikverket, 2018).

Public transportation

The marginal cost for buses in urban areas is $0.105/km/person, this damage cost was estimates in the same way as for automobiles, with the exception that the damage caused by heavy vehicles was assumed to be seven times higher than for a normal automobile (Strömmer, 2003).

6.1.3 Local and Regional Air Pollution

Local and regional air pollution differ in definition, included substances as well as method of estimation. Local effects of traffic are the direct effects of air pollution close to the source and include health effects due to emissions of NOx, SO_2 and VOC as well as contamination from PMm (Trafikverket, 2018). Regional effects are both direct and indirect effects in a relatively large area around the source. The direct effects are the same as for the local pollution, while the indirect effects are effects that occur because the initially emitted substance react with some other chemical creating a new substance which in turn has damaging effects such as acidification or over-fertilization (a process known as “the cocktail effect”). The substances included in the regional estimates are NOx, SO_2 and VOC for both health and environmental effects.

The local and the regional effect are estimated differently. To calculate the cost of the local effects there are two steps, the first step is estimating the exposure according to the formula below to find the exposure unit per kilo of emission in which (Fv) = ventilation factor, (B) =

population amount, (0.029) = given parameter (Trafikverket, 2018).

Exposure unit per kilo of emissions = 0.029 * F_v * $B^{0.5}$ *(3)*

Depending on the location of the area and its population density, areas are assigned "ventilation factors" which are indicated on the map (figure 6), Jönköping municipality is located in area ventilation zone 3, and is therefore assigned the ventilation factor 1,1.

Figure 9 : Map of Sweden with five ventilation zones, Jönköping is marked with a red circle. (Trafikverket, 2018)

Ventilation zone	Ventilation factor, Fv
1-2	1
3	1.1
4	1.4
5	1.6

Table 5. The ventilation zones and belonging ventilation factor in figure 6 (F_v) (Trafikverket, 2018)

The second step to reach the cost per/kg of emission is to multiply the exposure unit per kilo emission with the specific substance value per exposure unit in table 4.

Substance emitted	Values of local effects of air pollution $/exposure unit
NOx	2
VOC	3.4
SO2	17.2
PMm	585.9

Table 6: The values of the local effects of air pollution, $/exposure unit (Trafikverket, 2018)

The value of the local damage is estimated through a CV-method, namely the WTP for a decrease of the effects the emitted substance has (Trafikverket, 2018). The estimations are obtained using an effect-chain-model, meaning that there is an attempt to establishing the relationship between levels of emission and effects of exposure. The monetized value is gathered from the value of VOLL (Value Of a Lost Life year), that value is in turn taken from a VSL estimate used when estimating the cost of a death in traffic accidents. This could be problematic since the risk analysis and WTP could be dependent on what type of risk the individual is taking, Jones-Lee et al. (1998) has found supporting evidence that the WTP is higher to avoid mortality risk due to air pollution than traffic accidents. Nonetheless there has been no adaptation to this and the valuations are recommended by Trafikverket (2018) and therefore widely used, as in this thesis.

Substance emitted	Values of regional effects of air pollution $/kg emission
NO_x	10.35
VOC	5.38
SO_2	3.36
PM_m	0

Table 7: The values of the regional effect of air pollution emission ($/kg). (Trafikverket, 2018)

The regional damage value of damage due to air pollution is monetized differently than the local damage value. Damage to the environment is difficult to monetize, because of gaps of knowledge about ecosystems. Due to these gaps there is not satisfying knowledge about the exposure/response-relationship. Therefore, amounts are not estimated from damage costs but rather from the cost of action to achieve politically set environmental goal, what could also be described as the "political willingness to pay" which is meant to include damage on the environment as well as damage to human health (SIKA, 2005b). As an example, the cost for NO_X emission is based on the estimated cost to achieve EU's requirements for NO_X-emission for gasoline fueled automobiles in 2005 and the value for SO_X based on the calculated cost to achieve the environmental goals proposed in the MaTs-project (Sika, 2005). There are several uncertainty aspects with these assessments; firstly the effect of air pollution on human health with its many intricate processes is in itself complicated to fully predict, and then to predict the cost of that damage poses additional problems. The emissions can also have negative effects on ecosystems, these effects are difficult to predict due to the nature of ecosystem with characteristics such as accumulation and different levels of resilience. The difficulty to monetize the effects have meant that they often are excluded as a cost parameter.

Transportation mode	Marginal cost from local and regional air pollution ($/km)
Bicycle	-
E-bike	-
Automobile	
Gasoline	0.0005
Diesel	0.003
Ethanol	0.003
Public transportation	0.0005

Table 8: Summary of marginal costs for local and regional air pollution, for all fuel types (Trafikverket, 2018)

Bicycle and e-bike

Neither bicycle or e-bikes produce the emissions during the operating phase and will therefore not be included.

Automobile

Automobiles produces many substances in their exhaust, the once monetized and included in this thesis are: nitrogen oxides (NO_x), volatile organic compounds (VOC), sulfur dioxide (SO_2) and particulate material (PM_m). What emission factor that is used, meaning how much emission a vehicle produces while being operated, depends primarily on what fuel type is being used but also what model the vehicle and its exhaust is. The emission factors in table 6 are estimated using the handbook emission factors for road (HBEFA 3.2) a widely used database for modelling and estimating emission factors from a variety of vehicles. They are averages for the entire Swedish road traffic (apart from the values for VOC), meaning both older and newer automobiles with catalysts and older completely without. They also include driving with a warm engine, starting with a cold engine, evaporation and degradation due to age. (Trafikverket, 2018).

Fuel	NOx	NMVOC*	SO_2	PM_m
Gasoline	0.22	0.048	0.06	0.0014
Diesel	0.43	0.008	0.02	0.0072
Ethanol	0.05	0.062	0.0008	0.08

Table 9: Emission factors for nitrogen oxide (NO_x), non-methane volatile organic compounds (NMVOC), sulfur dioxide (SO_2) and particles from road/tire friction (PM_m) in g/km travelled using three different fuels types for automobiles (Trafikverket, 2017; EMEP/EEA report, 2016). *This value is taken from the European emission standard and the value is an average of the emission from all vehicles types. The emission values are Tier 2 emission factors which are recommended when the distance travelled is known but the speed is not. It should also be noted that for biofuels, which ethanol is, no internationally accepted emission factors exists, thus some uncertainty remain. (EMEP/EEA report, 2016; Åström et al, 2011)

Public Transportation

The large majority buses in Jönköping run on biofuel (or compressed natural gas, CNG) which is a renewable fuel. The same cost assumptions used on automobiles will be used on buses. Since there is no fuel taxation of buses that run on biofuels, meaning that the internalisation degree will be 0.

Substance emitted	Emission (g/km)
NOx	0.056
NMVOC	0.045
SO2	-
PMm	0.005

Table 10: Emission factors for nitrogen oxide (NO_x), volatile organic compounds (NMVOC), non-methane sulfur dioxide (SO_2) particles from road/tire friction (PM_m) for a bus which runs on biofuel (EEA, 2010)

6.1.4 Accidents

There are two primary aspects to road accidents; damage evaluation and material costs. Damage evaluation entails assessing damage to or loss of human life, while material costs covers not only vehicle and surrounding damage but production loss as well as medical and administrative costs (Trafikverket, 2018). The terminology can differ and sometimes they are instead referred to as direct and indirect costs. The direct cost being medical care, rehabilitation and property damage whilst indirect costs is the loss of production due to human injury or death (Nilsson & Johansson, 2014).

Transportation mode	Marginal costs for accidents ($/km)
Bicycle	0.17
E-bike	0.17
Automobile	0.02
Public transportation	0.03

Table 11: Summary of marginal cost for accidents for all transportation modes (Trafikverket, 2018; Trafikanalys, 2017)

Bicycle

There is a 35-40 times greater risk of being injured (enough to need hospital care) whilst travelling by bicycle or foot then when travelling in an automobile (Öberg, 2011). Even though automobile accidents usually have a higher material damage costs, bicycle accidents are more costly since the cycling individual is more physically exposed (Gössling & Choi, 2016). There are no estimates (found by the author) for the marginal cost of bicycle accidents within a Swedish context. However, Trafikanalys estimates that everyday people in Sweden bicycle 5.6 million kilometers; 2,04 billion kilometers each year (Trafikanalys, 2015). Furthermore Trafikverket estimates that there is 2.5 accidents per million bicycled meters and that the cost per accident is $66,315 using these numbers the marginal cost is $0.17/km (Trafikverket, 2018). The estimated cost per accident is put into relation with the cost for falling accidents when walking which is $44,210. This estimation only includes those injured badly enough to have to seek medical attention and is based on QALY. Trafikverket admits that there is newer data indicating instead that the cost for falling whilst walking is instead $331,575 but revising this whilst not revising the cost for bicycle accidents would cause great unbalance thus this recommends the lower of the estimations. The estimate calculated here is in line with an estimate produced by the Danish Transportation minister (€0.106 or $0.12) and since the two countries are fairly similar it is an indication that the estimate is reasonable and will therefore be used.

E-bike

There is no estimate for the marginal cost of accidents for e-bikes, so the same cost as for bicycles will be used. It is reasonable to assume that the cost are similar since the vehicles are similar, perhaps the cost would be somewhat higher since the average traveling speed it higher so using the same estimate would leastwise not cause an overestimation.

Automobile

Trafikverket (2018) classifies injuries to individuals in traffic using STRADA (Swedish Traffic Data Acquisition), which is an information system on all accidents based on data from police and healthcare system. The valuation of the social economic cost due to road accidents is based on the damage rating done by the healthcare system (which is new from 2018, prior the damage rating was from police rapports). There are five classifications ranging from death (DF) to no serious injury (EAS). The estimate are expressed in terms of “value of statistical injury” (VSI) and value of statistical life (VSL). The data is taken from a report produced by Olofsson et al (2016a+b) which was done in two parts, the first (2016a) investigates the general public's WTP to avoid injury or death and the second (2016b) estimated the cost of injured and death due to traffic accidents by looking at patient surveys, National Board of Patients' and Drugs Register, and the transport agency's STRADA register. The accident evaluation was done in terms of QALY which was then translated into VIS/VSL by using death equivalents (e.g. death =1.0, very serious injury=0.302, serious injury= 0.294) (Trafikverket, 2018). The marginal cost estimate for mixed environment (both urban and rural, urban being the generally highest estimate due to more traffic) is $0.02/km (Trafikverket, 2018). This estimate is in line with the estimate by other governmental agencies such as Banverket and Trafikanalys, but it is the most moderate estimation and will therefore be the one used in this thesis (Banverket, 2005, Trafikanalys, 2017). Trafikverket also recommends to set the internalisation of accidents to zero, meaning that the cost burden is fully external and the individual does not take any direct economic responsibility, a recommendation which is verified in HEATCO (Trafikverket, 2017; IER, 2006).

Public transportation

Trafikanalys (2017) makes estimates about the social marginal cost of accidents for buses. They base their estimates on a study by Nilsson and Haraldsson (2016) which in turn use the information gathered by Trafikverket discussed above. The cost evaluations are however collected before 2018 after which Trafikverket firstly reformed their classification of injuries but also made new estimates of WTP and materialistic costs, which increased the cost estimates. For example the VSL increased from $2,652,607 to $4,476,275. Since there are no newer estimates of the marginal damage due to accidents by buses the older, lower estimates will be used. Nilsson and Haraldsson (2016) connected STRADA to NVDB (nationella vägdatabas), the latter being a database of all public roads in Sweden (therefore non-public roads are excluded from the estimate) to estimate the different costs on different types of roads (and many other things such as speed limits, traffic flows, road conditions etc.). Based on this Trafikanalys (2017) concludes that the external marginal damage cost for accidents involving buses is $0.03/km in both urban and rural environment. What is important to note with this value that it is per *vehicle* kilometer, not per *person* kilometer. This is adjusted by considering the occupancy of the vehicle. For automobiles it is assume that the individuals travel alone so that the occupancy is one (even though it is possible that some carpooling happens it is outside the scope of this thesis) but for buses the occupancy for a 40 seat bus is 11, meaning that the estimate later reached will be divided by 11 (Trafikanalys, 2017).

6.2 Travel time

Shorter travel time compose a significant part of the benefits gained from infrastructural investments, for example 90% of the benefits from the Swedish Transport Investment Plan 2010-2021 consist of reduced transportation time and costs. Since this is a large part of the benefit from investment in infrastructure there is an extensive amount of literature on how drivers as well as cyclist and individuals who travel by public transportation value their travel time. The variable measured is "saved travel time" (or value of travel time saved, VTTS), meaning how an individual values spending marginally less time travelling. There are two primary things of importance when conducting time value estimates, firstly the time spent has an alternative cost and the individual could instead have more free time or spend more time working. Secondly, the comfort-level the travelling entails, the same time period in a less comfort transportation mode is valued higher than in a more comfortable mode, this also why connecting journeys, delays and transfers are usually valued higher. Both aspects are affected by income, since the marginal utility of income decrease with the income increase.

Transportation mode	Marginal cost of travel time ($/h)
Bicycle	18.65
E-bike	18.65
Automobile	-
Public transportation	-

Table 12: Summary of marginal travel time costs (Trafikverket, 2018)

Bicycle and E-bike

There are no separate estimate for e-bikes so the same estimate will be used for both vehicles. It is not completely unreasonable to assume that the valuations are similar due to the similarities in the vehicles. Even though e-bikes might have a lower estimate since the physical effort required is lower. Trafikverket base their estimates of VTTS on two studies, one by Börjesson and Eliasson (B&E) (2012) and one by Björklund and Mortazavi (B&M) (2013) both which have been discussed in section 6.1.2. Both studies used a stated preference-methodology (SP-methodology) with which B&M (2013) build on the questionnaire used by B&E (2012) and extended it with several questions about the attitude toward cycling, health and exercise. It was also given to a larger number of people in smaller cities (Karlstad (86,409 inhabit.), Luleå (74,426 inhabit.), Norrköping (130,623 inhabit.), and Västerås (138,709 inhabit), unlike B&E survey which was only conducted in Sweden's biggest city, Stockholm. Both surveys were given to individuals while they were travelling (where there were natural stops in traffic). B&M also emailed a number of participants after the meeting on the street, asking them to value their regular journeys (preferably to work or school), arguing that it is at these more common journeys individuals "do some conscious considerations regarding travel times and travel costs and choice of travel mode". Both studies included a number of socio-economic factors such as education level, income, employment, home ownership etc. (Börjesson & Eliasson, 2012; Björklund & Mortazavi, 2013). In their recommendations Trafikverket does not specify how they use the data from the two studies it is impossible to know how they weighted them.

Automobile and public transportation

Since it is only the increase in travel time, which is assumed to be time spent cycling, that is used to calculate, there is no estimation for the valuation of travelling with automobile or public transportation needed**.**

6.3 Parking

Parking costs can be divided into the more occasional private cost which effects the individual directly and then the social costs for parking facility land, construction and operating costs, as well as storm water management and cleaning costs (Litman, & Doherty 2009). In Sweden there is such a thing as the "parking norm", which is a acquits by which municipalities base their planning and construction of parking lots on have varied throughout time and between municipalities.

There are several suppliers of parking spaces, in some instances the employer pay for spaces, in others the private individual pays and the third option is when the spaces are public and paid for with governmental funds. There is often debate about firstly the definition of what constitutes a parking space and secondly who the main supplier should be (Stockholm stad, 2013). Svensson & Hedström concludes that the market for parking functions poorly and due the "parkingnorm" those who do not use their parking more or less are subsidize those who do (Svensson & Hedström, 2010; Wetterstrand & Svensson, 2011). Nonetheless the "parkeringsnorm" in Jönköping municipality dictates that a certain number of parking places must be built depending on location of the building, what kind of property the resident is and if there is an active ambition to decrease parking supply (in which case a 15% reduction is allowed) (Jönköping kommun, 2016). The number of spaces per 1000m^2 BTA that is required depending on the factors mentioned above; for bicycles the amount varies between 18-22 spaces and for automobiles it varies between 8-10 (Jönköping kommun, 2016).

Transportation mode	Marginal parking cost ($/km)
Bicycle	-
E-bike	-
Automobile	0.12
Public transportation	-

Table 13: Summary of marginal parking cost.

Bicycle, E-bike and Public Transportation

The cost for parking spaces for bicycles/e-bikes are not included in this thesis, neither is the cost for public transportation parking. There is undoubtedly a cost attributed to the provision of these parkings spaces but due to the lack of cost estimations and given the low estimate for automobiles below (it is reasonable to assume that provision of automobile parking spaces is much more expensive due to size) it would be misleading to include an estimation.

Automobile

As already mentioned there is not much literature on parking costs within a Swedish context. However, Jernberg & Örnfeldt (2009) did estimation for three parking spaces in Linköping (which is a Swedish municipality of similar size to Jönköping) and found that including construction costs, a 30 year economic lifetime and 4% discount rate the cost per parking space ranged from $2,911-$6,050. This excluded the price paid by homeowners and employers and because of the difficulty turning it into a marginal cost this estimate will not be applied in this thesis but does however point to the high cost associated with automobile parking. Another possible estimate is produced by NVV which only estimates the parking cost reduction put on the employer not on the individual since, that cost reduction has already been taking into consideration when the decision to change transportation mode was originally made (NVV, 2005). They calculate this firstly by assuming 17% of all bicycling journeys are back and forth to work and a parking cost of $2.2 per parking. The marginal parking cost was then $2.2 multiplied with the decrease in automobile traffic (17%), which when using their numbers produced a parking cost reduction by $0.27 per journey (NVV, 2005). The numbers used are arbitrary and are, according to themselves, a very rough estimate. And since they assume that individuals can freely factor in and also change their parking costs, an assumption that is not in line with the "parkingnorm" it makes the estimate more uncertain. Perhaps it is a somewhat reasonable assumption in the very long run but in reality the adaptation lacks flexibility. The paucity of research makes determining the marginal cost per parking difficult, but it is reasonable to assume that each individual who participated avoid one parking every weekday (this is a very conservative assessment since it excludes all house parking) in addition to this the most conservative hourly rate in Jönköping $0.95 will be used (Jönköping Kommun, 2018). Given that an individual in the C2W scheme on average bicycles 6.5 km daily, the marginal cost is then $0.12/km. This only includes the direct cost paid by the motorist, but in lack of better estimated this will still be used, and if nothing else the likelihood of it being an overestimate is very small.

6.4 Vehicle Purchase and Operation

The price of vehicle purchase and operation includes many things that can be divided into direct and indirect costs. Direct costs include driving expenses, fuel, personal, maintenance, reparation and capital costs associated with traffic work. Indirect costs are capital costs that are independent on amount of traffic such as depreciation and interest costs as well as costs associated with ticket sales and traffic information.

Transportation mode	Marginal purchase and operating costs $/km/person
Bicycle	0.03*
E-bike	0.03*
Automobile	0.6
Public transportation	0.02

Table 14: Purchase and operating costs for all transportation modes. *This is only the marginal cost which is used after the leasing period is over, prior to that a fixed cost is used for calculation.

Bicycle and e-bike

The general cost for bicycles and e-bikes can range from hundred dollars to several thousands of dollars, e-bikes tend to be more expensive due to the mechanics of the vehicle. According to the C2W scheme, as mentioned previously, individuals lease their vehicles for a three year period, with the possibility of then buying them at market value or return it. The total costs of the bicycles/e-bikes leased for this population is unknown, but the approximated average cost per person (estimated by employee at Ecochange) is $30-$33.7/monthly. As mentioned previously, 90% of the participants purchase their vehicle when the leasing period is over. The company did however not reply to how much the average participants were allowed to purchase their vehicle for, so the assumed average price for this will be $400. After the leasing period is over, the marginal maintenance cost of $0.03km will be used for remaining participants. The maintenance is calculated using information about purchase cost, life expectancy for the bicycles, and yearly usage in kilometer. The assumptions about the usage and life expectancy of a bicycle are free interpretations of calculations done by Persson (1986) which were based on surveys conducted in the neighboring country Finland (NVV, 2005). No distinction of the operating/maintenance cost between bicycle and e-bikes were made, although it could be argued that it is more expensive to operate e-bikes than ordinary bicycles especially since e-bikes demand electricity, but due to the lack of estimations of this additional cost it was disregarded.

Automobile

There is a large number of varying automobile models in Sweden and it is not possible to know exactly which are affected by the C2W-scheme in Jönköping. The estimate will therefore be concluded by averaging the cost per mile for the ten most common automobiles registered in 2016 in Sweden. This was done by using a online automobile cost-calculator for all ten models. The assumptions made for each model were 12,260 km driven each year, 5 years of ownership, average car prices of 2017 for the ten most popular cars, fuel consumption: 0.85L/10km, taxes: $221/year, inspection $31.16/year, tire consumption $221/10,000km, service $386.84/ 10,000km, washing and care $110.53/year, insurance $442.10/year and a depreciation rate of 15% yearly (Trafikanalys, 2016; Bilkalkyl, 2018). The average marginal cost was then estimated to be $0.6/km. The estimate is a bit more conservative than that marginal estimate used by Trafikverket (2018), which is $0.66/km. However, there are no specifications on many of the inputs which were used to calculate this estimate so therefore the automobile cost-calculator was used instead (Trafikverket, 2018).

Public Transportation

The private cost is primarily affected by the distance driven whilst for public transport both the distance and time dependent cost are relevant, due to the volume of business (Trafikverket, 2018). Public transportation with buses is defined as urban, regional and long distance traffic and due to the differences in driving (length and speed) their marginal costs vary. The population in Jönköping municipality is dense enough to be considered urban environment so the Trafikverkets (2018) estimate for urban bus driving will be used. There are also a variety of bus models; articulated bus, normal bus and "boggi"-buses (a bus with a special underframe that is rotatable against the vehicle body), the cost used here is for a normal inner city bus since they the majority of buses in Jönköping are normal buses.

The cost for public transportation are divided into three categories. Firstly there are distance-dependent costs such as fuel, tires, oil, reserve parts, insurance and part of the administrative expenditures (10% of the total cost). Secondly, there are time-dependent costs such as salaries, service and administrative expenditure (70% of the total cost) and lastly there are vehicles-based costs such as insurance, taxes, addition for wagon reserves, cleaning, warehouse costs (not personal), appreciation (10 years appreciation time), interest (5%) and administrative costs (20% of total costs). These costs are estimated without value-added tax (VAT) (unlike the private cost for automobiles), because the only things included in the cost calculations that have VAT are fuel and tickets, which in comparison to the labor costs is much smaller and therefore not included. Adding these three costs groups together the marginal cost for buses are $0.02/km/person (Trafikverket 2016).

However, since public transportation is, in varying degree, subsidized with taxation the estimate needs to be adjusted accordingly. Tax subsidization of services such as these generates a cost for the actual tax-financing, known as "the marginal cost of public funds" (MCF or MCPF). The tax factor used to enumerate have varied with time but the latest recommendation in cases with investment and infrastructure cost within a traffic context is 1.3 (Trafikverket, 2018). If the assumption that the public sectors budget is none-constant but instead if spending increases the taxes will also, the tax factor should according to Trafikverket be set by "the modified Samuelson rule":

$$SUM\ b_h - c * (1 + MEB) > 0 \quad (4)$$

In which b_h = the value for household "h" from the collective utility, c = tax subsidized production cost for the collective utility, MEB = the marginal excess burden of taxes, (1 + MEB) = MCF (Trafikverket, 2018). MEB was estimated through the marginal deadweight loss (which is under some circumstances equal to MEB) from a proportional increase of the income tax. The increase was a municipality tax to 24.2%, which means that MEB=24.2/75.8= 0.32 and MCF becomes 1.3 (Trafikverket, 2018).

6.5 Climate change

Generally, CBAs account for the avoidance cost of increased cycling, meaning that the direct emission from automobiles that is defaulted due to replacement with bicycles are accounted but nothing else. This approach implicate that non-motorised vehicles have zero emissions, which is not true. This becomes apparent when instead using a more complex life -cycle assessment (LCA) in which not only the operating phase of the vehicle is included but also the production and maintenance. During their entire lifecycle, automobiles, e-bikes and bicycles all emit GHGs that have damaging effects on the environment. Two sources of estimates will be used, firstly a LCA including estimates of emission during production and maintenance and secondly Trafikverkets estimates of the marginal cost due to emission during the operating phase and during the production of fuel for motorised vehicles. The LCA was conducted by Hendriksen & van Gijlswijk (2010) in the Netherlands, this is because no other source, ideally within a Swedish context, could be found that performed a LCA on all vehicles needed. Adaptation to Swedish energy and emission values was done when possible.

The GHG gases that are included are the three most common; carbon dioxide (CO_2) in all phases in the vehicles life cycle as well as methane (CH_4) and nitrous oxide (N_2O) in the operation phase. The latter are emitted in much smaller quantities than CO_2 but have greater global warming potential (GWP) per unit and may therefore still be significant. The GWP, given a 100 year time horizon, for CO_2, CH_4 and N_2O are 1, 21 and 310 (IPCC, 2007). There are emission of other GHGs during all phases for all vehicles but these will not be included primarily because the small impact of the emissions as well as the lack of or high uncertainty in the cost evaluation for these substances. The assumed price for CO_2 emission is $0.132/kg, a separate discussion on this pricing can be found in section 6.4.1.

Transportation mode	Marginal climate cost ($/km)
Bicycle	0.0061
E-bike	0.0036
Automobile	0.015
Public transportation	0.008

Table 15: The marginal cost for climate change for all transportation modes.

Bicycle

Production and maintenance

The calculations of the GHG emissions from producing and maintaining a bicycling were gathered from the international LCA-database *Ecoinvent* (Hendriksen & van Gijlswijk, 2010). The assumed total yearly cost for the bicycle is $199, given purchase price of $1025, maintenance cost of $74. Its assumed travel length is 1000 km yearly and life-length 8 years. The final estimates where that in the production and maintenance of a bicycle there is an emission of 5 grams CO_2 /km (Hendriksen & van Gijlswijk, 2010).

Operation

Operation inputs for bicycles are not as singular as they are for motor driven vehicles where it is primarily a case of varying fuel usages. With a bicycle, the source of energy is the food consumed by the person riding the bicycle; if the effort increases, so must the the input of kilocalories (kcal). The majority of theses performing CBAs on bicycles do not include food consumption as a emission factor arguing that bicyclists generally are thinner which indicate that they burn more calories bicycling than they consume specifically for bicycling (Cherry, 2007). Disregarding calorie consumption Coley (2002) argues leads to an overestimation of the energy efficiency of bicycles as well as e-bikes. Others go even further arguing that given the additional health benefits inducing longer lives and therefore additional emissions, AT is not as environmentally friendly as most argue (Ulrich, 2006). The second argument will not be considered here, neither will additional emission of CO_2 due to increased breathing during cycling. But given continued AT usage there is at some point a need for a larger amount of calories due to this the additional calorie consumption will be considered in the LCA framework. However, as mentioned previously in section 6.1.2 there is possible substitution between cycling and exercise. In this case it would mean that if there is internalisation of PA there would be a smaller need for calories. The same internalisation degree (0.25) will be used with the calorie consumption for both bicycles and e-bikes.

The calorie usage during physical activity varies greatly between individuals depending on their basal metabolic rate (BMR), current weight and effort put into the activity. As mentioned previously, the physical effort demanded in a task is measured in MET’s, where 1.0 MET represents the metabolic rate associated with being at rest. The MET value for cycling according to the compendium of physical activity ranges between 4-15.8, depending on speed, inclination and type of bicycle (Ainsworth, 2011). Empirical experiments carried out by de Geus et al (2007) indicated that bicycling to work (for those who are not regular cyclists) was associated with a MET value of 6.8 (SD: 1.9) (and a calorie expenditure of 540 kcal/h.) The equation to calculate the calorie expenditure from MET is:

Kcal= MET * weight in kilograms * duration in hours. (5)

Given a MET value of 6.8, an average weight of a Swedish citizen (both male and female) of 75kg and the duration of one hour the average calorie expenditure is 510/h (SCB, 2018). Which is to be compared with 75 kcal/h from driving an automobile. At the average speeds of 14 km/h on bicycle and 50 km/h in automobile the difference between the two per travelled kilometer is 41 kcal/km. However the increase in CO_2 emission due to the difference in kcal demand is not easily calculated without some rather drastic assumptions.

Since different diets have very varying emission levels, beef has a higher CO_2 emission per kcal content than root crops, this makes it nearly impossible to calculate the exact environmental impact from every individual diet so an average diet must be used. In Sweden the daily average intake of kcal is 3100 and the yearly Swedish emission per person due to food consumption is 1.8 ton CO_2 equivalents (NVV, 2015). Given this, the emission is 1.59g CO_2 per calorie, meaning that for every cycled kilometer an average Swedish person emits 67.57g CO_2. Subtracting the internalised part due to substitution from the operating phase, and adding the production and maintenance the total emission for every bicycled kilometer by an average Swedish person 55.65g CO_2 is emitted.

E-bike

Production and maintenance

E-bike are expected to have the same life length as a regular bicycle: 8 years. It is assumed to weigh 19.9kg (14.6 kg aluminum, 3.7 kg steel, 1.6 kg rubber) and travel 2400 km yearly (Hendriksen & van Gijlswijk, 2010). The assumed average yearly price is $330, that is including the average purchase price of a Sparta ion (a specific model of an e-bike which used an ion-battery which is the most common, most lightweight battery used on e-bikes) and a maintenance cost of $85 (including tires). Another $17 are added yearly from electricity costs. The emission are just like with the bicycle estimated using Ecoinvent for a standard e-bike with a ion battery and are concluded to be 7g of CO_2/km.

Operation

The difference between a bicycle and an e-bike lies in the energy source required to operate the vehicle. Since, to some extent, the e-bike runs on electricity there is a difference in CO_2 emissions depending on how the electricity is produced. When Hendriksen and van Gijlswijk (2010) calculated using an average energy consumption of a standard e-bike, they used the CO_2-intensity in the Netherland and found that 10g $CO_2$was emitted when producing the electricity demanded to assist the e-bike for one kilometer. However, Swedish electricity has a CO_2 intensity that is 19 times lower than that of the Netherlands, meaning that the emissions are instead 0.52g CO_2/km (Messagie, 2014). E-bikes also have very low levels of NO_2 emission during the operating phase but this is primarily when the power is produced using coal, as is the case in many instances in for example China (Asian Development Bank, 2009). In the context of Swedish energy production, the emission is negligible.

In addition there are also, just like with a bicycle, the energy needed to fuel the cyclist operating the e-bike. The MET for e-bikes is lower than for normal bicycles and range between 4.1-6.1 (Berntsen et al, 2017). An average of this will be used, meaning a MET value of 5.1. Given equation (5) and the same average weight and duration time, the calorie expenditure on an e-bike will then be 382.5/h. Given an average speed of 17.4 km/h emission of 1.59g CO_2 per calorie the average emission of CO_2 due to food consumption is 34,95g CO_2/km (Schleinitz et al, 2017). Subtracting the internalised part due to substitution from the operating phase, and adding the production and maintenance the total amount of emission is 26.73g CO_2/km.

Automobile

Production and maintenance

The data used in Hendriksen & van Gijlswijks (2010) LCA was produced by Ce Delft (2008) using Simapro (a LCA software program) and data from Ecoinvent. From which they estimate that the emission per automobile is 5.5 tons CO_2 per ton vehicle Given that an average automobile weighs 1.19 tons this gives an emission of 6.6 tons CO_2 per automobile, including; production of raw material, automobile manufacturing's'energy consumption and subcontractors energy consumption (maintenance not included) (Ce Delft, 2008). Given a lifespan of 160.000 km and that a 1.19 ton car is composed of 119 kg plastic, 83 kg aluminum, 48kg glass, 595 kg steel, 59 kg rubber, 83 kg liquids, and 202 kg of other components the emission his brings the CO_2 emissions for a cars' production to 42 g/km (ECF, 2011).

Operation

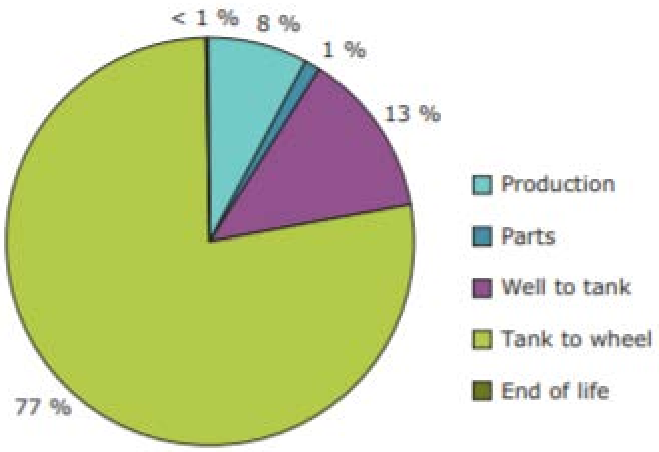

Figure 10: Emission from automobiles during their entire lifecycle (EEA, 2010).

EEA estimates that 77% of the emissions from automobiles are produced in the “usage-phase” which they call “tank to wheel” (EEA, 2010). The emissions are greatly affected by which fuel is used to operate the vehicle, the most common fuels are gasoline, diesel and ethanol (or some mixture of ethanol usually named flexi fuels). There is no data on the exact composition of automobiles in Jönköping so the national average ratio will be used. According to Trafikanalys, in 2017 there were 4,845,609 automobiles in Sweden, and of these 58.2% were fueled with gasoline, 33.9% diesel, 4.5% ethanol/flexi fuels (Trafikanalys, 2018).

Trafikverket estimates that there is emission of 2.77kg, 2.55kg, 1.12kg of CO_2-equivalents per liter of fuel, for gasoline, diesel and ethanol respectively. The unit of CO_2-equivalents means that other emission such as CH_4 and N_2O are already included in the calculations but are expressed in CO_2-equivalents, based on the discussion in section 6.1.3 on the different emissions GWP. The assumed fuel consumptions for gasoline, diesel and ethanol are 8.2L/100km, 6.1L/100km, 6.5L/100km. The emission are calculated using the HBEFA 3.2 model, the same way as in section 6.1.3.

Public transportation

Production and maintenance

The assumption above for automobiles carries onto buses, namely that the emission due to production is 5.5 tons of CO_2 per 1 ton vehicle. Given that an average bus weighs 18 tons the lifespan is 1,000,000 km and with an average of 10 passengers the emissions for a bus to be produced is 6g CO_2/km (Ce Delft, 2008; Transportstyrelsen, 2018).

Operation

The buses in Jönköping municipality run on biofuel, and the majority is of the brand MAN and the model Lion's City G. Trafikverket only rapports CO_2 in their emission so in an effort to include the other GHGs which has been included for the other transportation modes, another LCA analysis will be used. In the study a conventional biogas fuel and the division of origin sources for the fuel was 35% industrial waste, 26% sludge, 17% sorted food waste, 9% crops, 9% manure, 2% fat from restaurants and 1% other (Hjort, 2017). The estimates included production and transportation of the biogas as well as emissions of all GHG when operating, the estimated emission of CO_2-eq is 0.21g/km. There is no distinction between different GHGs, so no way of knowing how much of each gas is emitted since they are expressed in CO_2-eq. Adding production, maintenance and operation together the emission of 6.21g CO_2eq/km.

6.4.1 Pricing CO_2 emission

The pricing of CO_2 emissions is an area in which there is great dispute and there is a lot of variation in methods used to calculate, as well as the results with estimates ranging from \$0.011/kg to \$0.99/kg (Trafikanalys, 2017). Nonetheless it is important to determine an economic value for emissions so that informed and reasonable goals can be set for emission reduction and the evaluation can be incorporated social economic calculations (Trafikanalys, 2017). In the case of traffic it is needed in an effort to establish how much economic damage is done as well as how much of the damage is already internalized in the price paid by the consumers. There are two primary ways to reach a cost estimation of this sort; one based on the actual damage done by the emissions and one based on the measured cost to correct the damage done. In the prior, estimates are based on the long term marginal damage cause by emission, this is also associated with great uncertainty because of the environmental aspect and the longer time frame (Trafikanalys, 2017). Instead Trafikanalys and VTI (Swedish governmental road and transport research institution) recommend that the CO_2 price should be based on the cost to correct the damage done, which could either be through the hypothetical tax rate that is needed to reach the goal or by including different measures constructing a marginal cost curve and using this to estimate a shadow price (Nilsson & Haraldsson, 2016; Trafikanalys 2017). The recommendations from the governmental agency have varied with time, ranging from the lowest \$0.053/kg to the highest \$0.19/kg. Today the recommendation is draw from a political shadow price (an alternative interpretation would be to view it as a political WTP) derived from the current CO_2 tax and the recommendation is \$0.132/kg (Trafikverket, 2018). It is obviously difficult making these kinds of assessments and Kahn (2017) who evaluated three governmental investigations concludes that the political evaluation is not an accurate assessment of what the carbon dioxide taxation should be. This will not be addressed further here, but it is worth mentioning that this topic is problematic and that the debate on how to accurately price environmental damage continues. This estimate is used since it is the official recommendation from governmental agencies but also for comparative purposes. The same cost estimate will be used for CH_4 and N_2O, in CO_2 equivalents.

6.6 Implementation Costs

For every political incentive there is a cost involved for marketing, implementation and operation. There are a variety of campaigns/programs concerned with active mode transport encouragement such as; general travel programs, trip reduction programs, travel awareness programs, individualized marketing etc. (Dill et al, 2009). The estimates of the implementation costs of the C2W scheme in Jönköping will be done with estimations of time spent by municipality employee (estimated by the employee) multiplied by the average wage of a municipality employee. Since the employee implementing and working with administrative tasks such as this is likely to have a higher wage then the average municipality employee the estimate will be an underestimation.

6.7 Absenteeism

Like mentioned previously there are many studies linking increased physical activity such as cycling and walking to better health, and it is reasonable to assume that better health should cause less absenteeism. There is a fair amount of literature connecting physical activity in general with lower levels of absenteeism, there is however less literature on the more specific topic of absenteeism and AT or cycling (Van den Heuvel et al, 2005; Jacobson & Aldana, 2001). Davis and Jones (2007) in an effort to lessen the gap of knowledge on the effects of AT on absenteeism (and productivity which was also included) conducted a review, in which they, due to paucity of research, included a "wider range of physical activity interventions in the workplace". The interventions were divided into four categories: (1) Workplace health promotion programs, (2) fitness and physical activity focused interventions, (3) physical activity counselling and (4) physical activity and health care costs (and implicit absenteeism rates). They found evidence that in particular (1), (2) and (4) caused reductions in absenteeism as well as limited evidence that (3) was associated with "self-reported increases in physical activity" (which however was associated with fairly high costs).

The estimated effect of AT that will be used in this thesis was produced by Hendriksen et al (2010) did a study in which 1236 participants of three categories (Cyclists, non-cyclists and irregular cyclists) and were asked to self-rapport according to a web-based questionnaire. Self-reporting is associated with obvious problems such as social desirability bias which was discussed previously. The non-randomness of the participants was dealt with using propensity score matching and "dividing the original group into quintiles to achieve a balance between treatment groups within each quintile" (Hendriksen et al, 2010). Their results indicate that over a full year the absence was on average one day shorter for those who cycled either more than 3 km 3 times per week or more than 2 km 4 times a week. They found that there was a positive dose-response relationship between the speed and distance of cycling and absenteeism: concluding that "cycling to work is associated with less sickness absence" (Hendriksen et al, 2010)

6.8 Infrastructure

Infrastructure consists of the network of roads and railroad that are necessary for the society to function. When infrastructure is used by vehicles there is wear and breakage which is imply a cost to continuously repair and to, when necessary, do major reinvestments in larger areas. The outer circumstances have great impact on the deterioration of infrastructure, partly how many vehicles that travel on the road but also the environmental circumstances such as wind and temperature. In countries such as Sweden that has cycles of freezing and thawing there is more deterioration then in countries that have a higher more stable temperature. Infrastructure differs from buildings in that it has no alternative value which need to be considered.

Transportation mode	Marginal infrastructure costs ($/km)
Bicycle	NA
E-bike	NA
Automobile	0.005/0.007
Public transportation	0.084/0.088

Table 16: Summary of marginal infrastructural costs for all transportation modes. For automobiles and buses the price during warmer conditions is first followed by the price in winter conditions (Nilsson & Johansson, 2014)

Bicycle and e-bikes

Neither Trafikverket or Trafikanalys have any infrastructural marginal cost estimates for bicycles or e-bikes and most of the literature excludes this cost all together (Gössling & Choi, 2015; Chester, 2008, Trafikverket, 2018; Trafikanalys, 2017; Shreya, 2010). There is most likely some cost associated with building and maintaining bicycle roads. However, the marginal cost is likely to be insignificantly low and is assumed to be zero.

Automobile

The marginal cost of infrastructural investments is dependent on the type of motorised vehicle. Normally the road tear is proportional to the vehicles number of axis, and the larger the vehicle the higher is the marginal cost. The cost is also higher in the winter due to the extra need for clearing snow of, and gritting, the roads. However, Trafikverket only demand their entrepreneurs to be fully “winter-organized”, meaning they should be fully prepared to deal with winter road conditions, from 1st October- 30th of April (Trafikverket, 2017). And since the participants on the C2W-scheme on average only bicycles for 7 months and 3 weeks this only leaves 7 weeks months in which there is the winter cost, so there for 22% of the distances travelled by the participants will be calculated with the winter marginal cost. Since Trafikverket does not differentiate between different types of vehicles in their marginal cost estimates their estimate is likely to be an overestimation of the cost of passenger automobiles. Instead an estimate produced by Nilsson and Johansson (2014) will be used in which data was gathered from 109 maintenance contracts (contracts are implemented for infrastructural operation areas of the total governmental road network) during the time period 2004-2012. These contracts contain information about costs, the roads technical attributes and amount of traffic. The material used is road and traffic data from the national road database (NVDB) and cost data from Trafikverkets accounting. The cost for maintenance and general operation (e.g. rest stops and lightning) estimated in separate econometrics cost functions, static logarithmic models were also estimated. These models also produced cost elasticity that was used in combination with the average cost to produce the marginal cost (Nilsson & Johansson, 2014). The way to calculate the average cost can be seen in the formula below in which (e) = elasticity, (AC)= average cost, (i)= interest, (u)= uncertainty component.

$$\text{Marginal cost (MC)} = e * AC * i * u \qquad (6)$$

The elasticity in this context is the breakdown elasticity of the road, meaning how a change in traffic effects the roads lifespan. The lifespan of a road is 17 years, and is determined by reviewing the Pavement Management System (PMS), which is an information system used by Trafikverket to register and analyse the condition of the roads as well as collecting data on the weight of passing vehicles. The average cost is the average cost to pave 1m^2 of road which is \$9.6/m^2, this was estimated by overviewing pavement contracts with varying pavements in different areas in Sweden. The interest is connected to the discount rate as well as the expected life-span of the road. The recommended discount rate within Swedish infrastructural planning is 3.5% (Trafikverket, 2018). Lastly the uncertainty component is the uncertainty about when the change (breakage/wear) happens between the completion of the road and the time that it would (anyway) be reconstructed, the value of this parameter is 0,976 which also means that it does not have a great impact on the marginal cost. The end result is that the average marginal cost for an automobile is \$0.005/km under warmer conditions and \$0.007/km in winter conditions (Nilsson and Johansson, 2014). And similarly to section 6.4 with public transportation infrastructure is provided public taxation funds, the same tax factor of 1.3 will be used in these calculations as well.

Public transportation

Buses are considered a heavy vehicle and their ESAL (equivalent standard axle load) is on average 0,93. The marginal cost is calculated using the same method as with automobiles with the exception that the elasticity is higher and therefore the marginal cost is higher as well. The marginal cost per kilometer driven is \$0.084/km during the warmer conditions and \$0.088/km during winter conditions (Nilsson and Johansson, 2014).

6.9 Discount rate

When estimating the social cost of various implementations it is important to decide what social discount rate (SDR) should be used (which was previously introduced in section 4.1). This is a topic of continued discussion and the SDR used in the literature vary, which also means that there is great variation in results. Discounting is a vital step of any socioeconomic analyze to estimate present value of future costs and benefits. It is expression of concerns about equity between the present and future generations and among future generations (Arrow, 1999). There are several formulas to use, but one of the most frequently used on is the “Ramsay formula” by British mathematician and economist Frank Ramsey expressed as seen below:

$$SDR = \gamma + \eta g \tag{7}$$

The formula expresses that the social discount rate is equal to the sum of (γ) the pure rate of time preference (PTP-rate,) and η, the marginal elasticity of utility multiplied with g, the rate of growth per-capita consumption. The pure rate of time preference is a parameters that captures an individual's tradeoff between consuming now or on the future, it can also be defined as the marginal rate of substitution between present and future consumption (Anthoff & Tol, 2008). The PTP-rate is itself also a matter of discussion and variation, the most well-known example being the “Stern Review on the Economics of Climate Change” in which Nicholas Stern used a low PTP-rate and some have argued that this is the primary reason for his high estimated of the social cost of carbon (Anthoff & Tol, 2008).

The recommended discount rate is also dependent on what time period the project is expected to have. The longer the time period for assessment is, the lower the discount rate usually is, since we value consumption that is closer to us higher than that further away. The estimated time period for this project is 12 years, and for this the SDR of 3.5% will be used. 3.5% is the recommended rate by HM treasury, as well as the rate used by NVV and Trafikverket for both environmental as well as traffic projects during this time period (HM Treasury, 2003; NVV, 2005; Trafikverket, 2018). 3.5% is usually the recommended discount rate for projects with a time period of 0-30 years, if the time period exceeds 30 years the discount rate us usually lowered.

6.10 Internalisation

Prior to the cost calculations from previous section being applied to the C2W scheme in Jönköping there needs to be a discussion regarding the already existing internalisation of externalities to the price paid by the consumer. Meaning that the damage cost for an external negative effect, such as for example emission of GHGs, have already been included in the price paid by the consumer through for example fuel taxes. The internalisation of the external costs varies depending on governmental approach but is usually done by taxation, by a command-and-control approach, or through a combination of the two (Santos, 2017). To what extent an externality is internalized is captured in the “degree of internalisation”, which is the ratio between the withdrawal of variable taxes/fees and calculated external marginal costs.

The externalities internalized to some degree are; noise pollution, air pollution (health and environmental effects), accidents, carbon dioxide emission and infrastructure. Congestion and traffic disturbance was not considered properly economically evaluated to be included, this also means that congestion charges are not included (Trafikanalys, 2017:2). The estimates for the Swedish degree of internalisation of traffic externalities are differentiated dependent on fuel; gasoline: 81%/177% and diesel 51%/120% (urban/countryside) (Trafikanalys 2017:2). Since Linköping is enough densely populated to be considered urban and cycling is primarily a transport mode used for shorter distances the estimates for an urban environment will be considered. For ethanol there is no already existing internalisation degree so an estimation of this was calculated by the author after recommendations by employee at Trafikverket. It should be noted that this is only a rough estimate, but was considered favorably over either excluding those vehicles completely or assuming zero internalisation. However, this estimation only applies to the years 2016 and 2017 since in 2018 the taxation was removed meaning that there is zero internalisation (Skatteverket, 2018). The biogas that fuels the cities buses public are not subjected to any taxation and therefore no internalisation takes place (Trafikverket, 2018). The same percentage of fuel distribution used to estimate other effects will be used when considering internalisation.

7. Result

Direct effects	(1)	(2)	(3)	(4)	(5)
Health					
Physical activity	$2,470,000	$1,852,500	$1,444,904	$861,385	$8,003,439
Noise pollution	$53,958	$25,513	$20,410	$12,167	$113,045
Local and Regional Air Pollution	$16,883	$6,754	$5,403	$3,221	$29,928
Accidents	-$456,243	-$481,018	-$384,814	-$229,408	-$2,131,512
Travel time	-$244,279	-$244,279	-$195,432	-$116,507	-$1,082,507
Parking	$248,448	$248,448	$198,758	$118,490	$1,100,934
Vehicle purchase and operation	$486,607	$486,607	$389,286	$232,074*	$9,130,513
Indirect effect					
Climate change	$50,371	$6,010	$4,808	$2,866	$20,526
Campaign Cost	-$6,631	-$6,631	-$6,631	-$6,631	-$6,631
Absenteeism	$351,094	$351,094	$280,868	$167,440	$1,555,746
Infrastructure	$17,645	-$10,164	$8,131	$4,847	$45,033
NV/NPV	$2,987,853*	$2,244,998*	$1,765,691*	$1,049,944*	$16,778,514
Total Cost	-$707,153	-$731,928	-$586,877	-$352,546	$3,220,650
Total Benefit	$3,695,006	$2,976,926	$2,352,568	1,402,490	$19,999,164
BCR	5,22	4,06	4	3,98	6,21

Table 17: Summary of all cost and benefits estimated in this study. (1) the yearly cost/benefits without any alteration, (2) Subtraction of the costs already internalised through taxation/fees for parameters: noise pollution, local and regional air pollution, accidents, climate change and infrastructure, as well as subtraction of 25% of the effect of physical activity due to substitution, (3) reduction of 20% due to the prediction in the counterfactual, (4) adaptation to the yearly bicycle season (31 weeks), (5) the accumulated costs/benefits over the entire evaluation time period (12 years). All calculated with 3.5% discount rate. *For column (1)-(4) it is not the NPV but rather just the net-value that is reported, since it is only the benefits/costs for 1 year and no discounting

7.1 Cost and Benefits - Applied to the Case Study

All final estimates in this section are those in column (4) in table 17, meaning that relevant internalisation of the effects mentioned in section 6.10 as well as 25% of health effect due to increased PA has been made. A 20% reduction due to the prediction in the counterfactual section and a subtraction of the winter weeks in which the participants did not use their vehicles (the average cycling season was 31 weeks). Also, since 10% of all participants are expected to not purchase their vehicle, 10% of the effect was subtracted after the third year. All estimates are counted with a 3.5% discount rate if nothing else is stated. The avoided cost for public transportation has been divided by 11 due to the occupancy level for buses (except for vehicle purchase/operation and accidents) and well as multiplied with the tax factor 1.3 discussed in section 6.5.

7.1.2 Health

7.1.1.1 Physical activity

When doing estimations with HEAT the distance travelled as well as the geographical location are used as inputs. The geographical specification is needed since the program uses VSL in the given country, which in Sweden is 3 990 000 EUR/death. Using an average speed of 14 km/h the final assessment is that the health benefit is $861,385/yearly.

Since HEAT only includes the cost of mortality similar calculations were also done using estimate produced by NVV (2005) in which the Swedish medical cost for diabetes, blood pressure and stroke where considered. The benefit from the two methods were very similar, NVVs estimate was initially $839,270 (with a pre-assumed internalisation of 10%). Due primarily to the similar outcome but also the possible change in the cost assessments because of the age of the data on medical costs used by NVV, this cost estimate was not included.

7.1.1.2 Noise Pollution

Transportation mode	Cost for noise pollution	Cost for noise pollution after internalisation	−20%	31 weeks
Bicycle	-	-	-	-
E-bike	-	-	-	-
Automobile				
Gasoline	-25,304	-4,807	-3,845	-2,292
Diesel	-14,739	-7,222	-5,777	-3,444
Ethanol	-1,956	-1,525	-1,220	-727
Public transportation	-11,959	-11,959	-9,567	-5,703
Total	-53,958	-25,513	-20,410	-12,167

Table 18: Summary of all yearly costs for noise pollution, all transportation modes. ($)

Noise pollution is one of the parameters which cost is already partially internalised through taxation therefore the so the cost will be separated per specific fuel. Given the cost of $0.021/km and the change in travelled kilometer by all transportation modes the avoided damage cost for gasoline, diesel and ethanol is $2,292, $3,444, $727 respectively. The avoided cost for public transportation is $5,703 and combined the total yearly avoidance cost is $12,167.

7.1.1.3 Local and Regional Air Pollution

Transportation mode	Cost of local and regional air pollution	Cost of local and regional air pollution after internalisation	−20%	31 weeks
Bicycle	-	-	-	-
E-bike	-	-	-	-
Automobile				
Gasoline	-7,296	-1,386	-1,108	-660
Diesel	-7,951	-3,895	-3,117	-1857
Ethanol	-739	-576	-460	-274
Public transportation	-897	-897	-717	-427
Total	-16,883	-6,754	-5,402	-3,218

Table 19: Summary of all yearly costs for local and regional air pollution, all transportation modes. ($)

Local and regional air pollution is one of the parameters for which the cost is already partly internalised through taxation and therefore the cost will be separated per specific fuel Considering that the internalisation varies for different fuels the avoided cost estimate for gasoline, diesel and ethanol automobiles are; $660, $1857 and $274. And the avoided cost from the change from public transportation to bicycles/e-bikes is $427 and the total yearly avoidance cost is $3,218.

7.1.1.4 Accidents

Transportation mode	Cost of accidents	Cost of accidents after internalisation	−20%	31 weeks
Bicycle*	248,121	248,121	198,496	118,334
E-bike*	248,121	248,121	198,496	118,334
Automobile				
Gasoline	-24,099	-4579	-3,663	-2,183
Diesel	-14,037	-6,878	-5,502	-3,280
Ethanol	-1,863	-1,453	-1,162	-693
Public transportation	-2,314	-2,314	-1,851	-1,103
Total	456,243	481,018	384,814	229,408

Table 20: Summary of yearly cost and benefits due to change in accidents. ($) *Since bicycles and e-bikes were not separated in this calculation the total amount was divided in 2 for presentation purposes.

Accidents is the one of the parameters for which the cost is already partly internalised through taxation and therefore the cost will be separated per specific fuel. Given the change in travelled kilometers the avoided costs for automobiles fueled by gasoline, diesel and ethanol are $2,183, $3,280, $693, and for public transportation it is $1,103. Given the increase in cycling ($236,668) the total cost increase for accidents is $229,408. This is, as mentioned previously, because even though accidents with automobiles have greater material damage, bicycles leave the individual more exposed to personal injury which has a higher cost.

7.1.3 Travel Time

Transportation mode	Cost due to change in travel time	−20%	31 weeks
Bicycle*	-122,139	-97,432	-58,253
E-bike*	-122,140	-97,433	-58,254
Automobile	-	-	-
Public transportation	-	-	-
Total	-244,279	-195,432	-116,507

Table 21: Summary of all yearly costs due to change in travel time. ($) *Since no distinction is made between the cost for bicycle and e-bikes the number is divided in 2 for presentation purposes.

The average change in travel time by the respondents was an increase of 12.6 min/week, which is surprisingly low but could in part be explained by the high number of respondents who reported no change at all (24.6%) of which the majority noted that they had a bicycle/e-bike from previously. Some individuals who switched from walking to bicycle/e-bike might also have experienced a decrease in travel time. The reported increase in travel time by all users in one year is 13,098h and with a cost of $18.65 the total cost for increased travel time is $244,277, after adaptation the increased cost is $116,507.

In addition to time evaluation and reported change in time by the participants, there was also calculations made based on time evaluation and reported change in kilometers travelled. However, these two estimates were significantly different in size, the latter being 9.7 times larger. This was considered an overestimation, although the response rate to the survey was fairly low (21.3%) even if only these 428 people had an average weekly travel time increase of 12 min and 36 sec, to reach the cost of $2,120,700 all the other participants would have had to have an increased travel time by 2.3h weekly which seems unlikely. It seems even more unlikely in the light of the fact that 24.6% reported no increase in travel time. Many noted that their PA did not increase because they had a bicycle since previously, meaning that for those individual the travel time would be the same, or shorter if they replaced a bicycle with an e-bike.

7.1.4 Parking

Transportation mode	Cost of parking	−20%	31 weeks
Bicycle	-	-	-
E-bike	-	-	-
Automobile	248,448	198,758	118,490
Public transportation	-	-	-
Total	248,448	198,758	118,490

Table 22: Summary of yearly parking costs for all transportation modes. ($)

Given the marginal cost is $0.12/km the total avoided cost for parking is $118,490/year.

7.1.5 Vehicle Purchase and Operation

Transportation mode	Cost of vehicle purchase and operation Benefits	−20%	31 weeks
Bicycle*	-386,304 -405,946 -43,786	-309,043 -324,757 -35,029	-190,180 -193,605 -20,882
E-bike*	-386,304 -405,946 -43,786	-309,043 -324,757 -35,029	-190,180 -193,605 -20,882
Automobile	-1,242,242	-993,794	-592,454
Public transportation	-16,973	-13,578	-8,095
Total	-486,607 -447,323 -1,171,643	-389,286 -357,858 -937,314	-232,074 -223,339 -568,789

Table 23: Summary of all the costs and benefits from change in vehicle purchase and operation. ($) *Since there is no separation between bicycles and e-bikes the number is divided in 2 for presentation purposes. In those fields where there are three values the values are divided into year 1-3/4/5-12 (without discounting).

The initial cost for all individuals is assumed to be $32/monthly, this payment is calculated for all individuals over a three year period. After the leasing period is over (year 4) Ecochange estimates that 90% of all participants (1810) purchase their vehicles at the market value, this was calculated as $500. In addition the maintenance cost of $0.03/km was added in year 4-12. The marginal cost for automobiles and public transportation is $0.6/km and $0.02/km respectively for the entire time period. Then, given the change in travelled kilometers by all transportation modes the avoided cost is $253,315/year.

7.1.6 Climate Change

Transportation mode	Cost of climate change	Cost after internalisation	−20%	31 weeks
Bicycle	$5,745	$5,745	$4,596	$2,739
E-bike	$7,155	$7,155	$5,724	$3,412
Automobile				
Gasoline	-$42,807	-$8,133	-$6,506	-$3,878
Diesel	-$18,302	-$8,968	-$7,174	-$4,277
Ethanol	-$1,467	-$1,114	-$891	-$531
Public transport	-$695	-$695	-$558	-$333
Total	-$50,371	-$6,010	-$4,809	-$2,868

Table 24: Summary of cost for climate change (emission of CO_2-eq) for all transportation modes.

Given the change in kilometers by each travel mode and fuel consumptions for gasoline, diesel and ethanol being 8.2L/100km, 6.1L/100km, 6.5L/100km respectively the total avoided cost for automobiles is $8,686 (Trafikverket, 2017) and for public transportation it is $333. In total the avoided cost from reduces climate impact is $2,868 each year.

7.1.7 Implementation Costs

One of the demands from Jönköping municipality was that the initiative should be entirely or very close to cost neutral. When working through the company Ecochange who did part of the advertisement (producing brochures and likewise) and the administration of vehicles, this was almost achieved. The only time spent on the implementation was spent evaluating the possibility for the scheme and acting as a mediator between Ecochange and the employees. The employee at the municipality that instigated the initiative and remained the coordinator estimate that he spend 304h in total on the implementation. With the average monthly salary of $3490 (calculated by an municipality employee at salary office) this makes the total cost $6,631.

7.1.8 Absenteeism

The average monthly income for a municipality employees (n= 10,998) is $3490 (calculated by employee at salary department in Jönköping municipality). Trafikverket recommend that the gross salary and social fees, pension and other costs that varies with the employees work hours should be included in the calculation (Trafikverket, 2018). However, since the empirical evidence was compiled assuming a full year cycling and the participants in this scheme only cycled on average 31 weeks, the cost for social fees, pension and other costs will be disregarded. Using these assumptions the estimated avoided cost is $167,440, which is a more conservative estimate then that using an average Swedish wage produced and recommended by Trafikverket (2018).

7.1.9 Infrastructure

Transportation mode	Infrastructure cost	Infrastructure costs after internalisation	−20%	31 weeks
Bicycle	-	-	-	-
E-bike	-	-	-	-
Automobile				
Gasoline	-6,555	-1,245	-996	-594
Diesel	-3,659	-1,977	-1,581	-942
Ethanol	-883	-394	-315	-187
Public transport	-6,548	-6,548	-5,238	-3,123
Total	-17,645	-10,164	-8,130	-4,846

Table 25: Summary of infrastructural cost for all transportation modes. ($)

Infrastructure is one of the parameters for which part of the external cost is internalized through taxation so the cost is separated per specific fuel. Given the change in travelled kilometers and varying colder and warmer conditions (the cost for winter road conditions is only implemented for 3 weeks out of total 31 for cyclists) the avoided costs for automobiles fueled by gasoline, diesel and ethanol are $594, $942 and $187 and for public transportation the cost is $3,123. The total yearly avoided cost is $4,846.

8. Sensitivity Analysis

Given that there are uncertainties in the assumptions and estimates used, much can be learned about the robustness of the result by seeing how it is affected when some of the parts driving it are manipulated. In this thesis the manipulation will firstly be of the discount rate and price of CO_2 emission; these are chosen to see how the result is affected by a varied outlook on the importance of future generations (discount rate) and because this is a frequently used manipulation also recommended by Trafikverket (2018). Due to the ambiguity in prior research discussed in section 6.1.2 the substitute rate for AT with other PA will be manipulated. And lastly the effect of the seldom included effects of internalisation through taxation/fees and inclusion of seasonal usage will be examined.

Discount rate

The recommended discount rate to use in traffic evaluation is 3.5%, to see how the results change both a higher and a lower discount rate will be used (Trafikverket, 2018). As seen in table 26 the BCR stays positive and very consistent with all discount rates. The NPV also remain positive and even with 6% discount rate the NPV is $15,125,357.

Direct effects	1%	3.5%	6%
Physical activity	9,068,575	8,003,439	7,133,580
Noise pollution	128,090	113,045	100,759
Local and Regional Air Pollution	33,911	29,928	26,675
Accidents	-2,415,184	-2,131,512	-1,899,847
Travel time	-1,226,572	-1,082,507	-964,854
Parking	1,247,451	1,100,934	981,278
Vehicle purchase and operation	10,088,863	9,130,513	8,309,067
Indirect effect			
Climate change	22,956	20,526	18,532
Campaign Cost	-6,631	-6,631	-6,631
Absenteeism	1,765,792	1,555,746	1,386,659
Infrastructure	51,026	45,033	40,139
Cost	3,648,387	3,220,650	2,871,332
Benefit	22,406,664	19,999,164	17,996,689
NPV	18,758,277	16,778,514	15,125,357
BCR	6,14	6,21	6,27

Table 26: All cost and benefit estimates for one bicycle season (31 weeks) using three different discount rates: 1%, 3.5% and 6%. ($)

Figure 11: NPV for each year within the time frame, using varying discount rates. The difference from year 3-4 is explained by the 10% who return their leased vehicle and were no longer part of the scheme.

CO_2 pricing

In CBAs with an environmental aspect, changing the shadow price of CO_2 emission is a common way to check the sensitivity of the result. Trafikverket (2018) recommend that the usual price for CO_2 emissions $0.132/kg is replaced with $0.39/kg. In this thesis the benefit from decreased CO_2 emission over the full time period of 12 years is $26,627, which is only 0.16% of the total benefit. Changing the price of emission increases the benefit from $26,627 to $286,391 which is 1.7% of the total benefit. There are two factors that lower the environmental benefits in this thesis, firstly the inclusion of the internalisation through taxation/fees and secondly the inclusion of the emission caused by the increased need for calories when bicycling. When excluding both, the total damage cost avoidance due to change in transportation mode is $465,128 which is 2.8% of the total benefit, increases the BCR to 5.27 from 5.1.

Substitution of physical activity

The largest effect from the implemented scheme is the health benefits, however as indicated by Börjesson & Eliasson (2012) and Clarke et al (2014) if there is substitution between AT and other forms of previous exercise the benefit could be significantly less. Survey responses in the study by Börjesson & Eliasson (2012) suggest that substitution could lead to as much as 60% less benefit. Clarke et al (2014) being one of the few studies evaluating a C2W scheme similarly found that 50% of the participants did not increase their PA (6% even decreased their PA since switching from walking to cycling due to travelling speed). When comparing the result with varying percentage of substitution the effects on both BCR and NPV are fairly large. With the assumption of zero substitution and 3.5% discount rate the NPV is $19,720,302 whilst with 50% substitution the NPV is $14,247,686. This study only included 2012 individuals if a similar scheme was to be implemented on a greater scale the possible miscalculation if neglecting to consider the possibility of substitution could be very large. The NPV remain positive with all levels of substitution. The BCR is lowest at 5,23, with 6% discount rate and 50% substitution and highest at 7,57 with 1% discount rate and 0% substitution.

	1%	3.50%	6%
PA benefits with 0% substitution	12,401,869	10,945,227	9,755,638
PA benefits with 25% substitution	9,068,575	8,003,439	7,133,580
PA benefits with 50% substitution	6,200,933	5,472,611	4,877,815
BCR (0%/25%/50%)	7.57/6.54/5.64	7.12/6.21/5.42	6.75/5.93/5.23

Table 27: Benefit from PA with different discount rates and with different internalisations degrees due to substitution (0, 0.25 and 0.5). ($)

	NPV (1%)	NVP (3.5%)	NPV (6%)
PA benefits with 0% substitution	21,176,944	19,720,302	18,530,713
PA benefits with 25% substitution	17,843,650	16,778,514	15,908,655
PA benefits with 50% substitution	14,976,008	14,247,686	13,652,890

Table 28: NPV with varying discount rates and different internalisation degrees due to substitution (0, 0.25, 0.5). ($)

Internalisation and inclusion of seasonal usage

The internalisation rates in Sweden has been discussed in section 6.10 and the average seasonal usage was given by the respondents to be on average 31 weeks each year. Inclusion of both these limitations lower the outcome, disregarding them entirely results in a NPV of $24,270,507 when including them both the NPV is $16,778,514, which is a large difference (41%). The difference between NPV when excluding/including the seasonality is surprisingly similar, $16,821,434 and $16,778,514, this is because the internalisation almost only affects the benefits (apart from the accidents) whilst all effects are affected by the seasonal usage, this can also be seen on the BCR.

	No internalisation	No internalisation but seasonality	Internalisation	Internalisation and seasonality
Cost	-5,223,653	-3,110,866	-5,397,850	-3,220,650
Benefit	29,494,160	16,373,496	22,219,284	19,999,164
NPV	24,270,507	13,262,630	16,821,434	16,778,514
BCR	5,64	5,26	4,11	6,21

Table 29: The costs, benefits and NVP for only with internalisation and seasonal usage (31 weeks). ($)

9. Discussion

This study has evaluated part of a C2W scheme involving 2012 individuals, all employed at Jönköping municipality. In total, 11 cost and benefit parameters have been included, those parameters that were excluded were primarily excluded due to the small sample size or insufficient data (see appendix C). Softer transportation measure such as this scheme have gained popularity on all political levels and are often used in combination with harder measures such as infrastructure and other monetary tools. This is the first study to date evaluating a C2W scheme within a Swedish context. The main goal to increase AT among the participants in the scheme was met, which in turn generated other benefits (and costs) that were evaluated. The outcome indicate that the implementation was clearly economically justified, lending support to prior research which overwhelmingly has evaluated AT investments as cost efficient. As can be seen in the sensitivity analysis, the main drivers of the result were the larger parameters such as health and vehicle purchase and operation but also the internalisation of externalities through taxation and consideration of seasonal usage. However, regardless of manipulation of the main drivers of the result the BCR remained between 4.11 and 7.15. Meaning that an investment of $1 would generate benefits of $4.11-$7.15.

The results in this study are in line with prior research, despite including some limitations most studies do not. These limitations are primarily the internalisation through taxation/fees and the seasonal usage of the vehicles. However, it should be noted that it is not always clear what exactly is included or excluded in studies, which Brown et al (2016) note in their review writing that limited detail on methods make "it difficult to comment on the overall quality of the data and factors such as bias or seasonality". Despite this, since these limitations cause large differences in outcome, it seems unlikely that if they were taken into consideration there would be no mentioning of it. The shorter usage due to seasonal winter conditions is not an issue relevant in many countries in the southern hemisphere. However, as exemplified by Foltýnová & Kohlová (2002) which produce the only BCR<1, considering the demand is vital to the outcome of an implementation and despite insignificant weather fluctuations there can still be fluctuations in demand. Aecom (2010) conducted a study in Australia, a continent with a significantly higher mean temperature then Sweden and still found significant differences in demand depending on season. If these differences are not taken into consideration, there can be either an underestimate or an overestimate of the outcome from any AT implementation.

The second major limitation, inclusion of externalities through taxation/fees was only found in two other theses (Börjesson/Eliasson, 2012; Aecom, 2010). This was a little bit surprising, especially in those that calculate other taxation losses such as forgone taxes when implementing a scheme paid for by gross wage deduction or fuel tax revenue (Clarke et al, 2014; Department of Transportation, 2010; Baufeltd, et al, 2017). Granted, some studies only include effects that are not internalised through taxation but the majority do not (Gotschi, 2011; Green et al, 2016; Donovan et al, 2008). The internalisation varies in nations depending in the national tax policy, but most nations do have some degree of internalisation and not including it leads to double counting of the costs, causing overestimation of the benefits from shifts in transportation. Börjesson and Eliasson (2012) argue that the effects on health and environment from motorised transportation are dependent on the cross-elasticity of bicycle/automobile (which is not relevant in this study since the change in km is known) and “the fraction of external costs that are internalized”. Saying that if these are taken into consideration, within the context of their study, the benefits from reduced car traffic are very small (Börjesson & Eliasson, 2012). In this study, the benefits are not very small despite considering internalisation (this study also included many more variables) but nonetheless, it does have a significant impact on the result. When including both internalisation and seasonal usage the NPV is 31% lower than when excluding them.

One perhaps rather unconventional conclusion reached in this thesis is that e-bikes are more environmentally friendly than conventional bicycles. This finding is based on the low carbon intensity of Swedish electricity, due to the high degree of electricity produced by hydropower, and the rather high CO_2 emission per calorie due to long periods of unusable soil due to winter conditions. Consequently, this can almost certainly not be generalised to studies outside of Sweden. The inclusion of calorie consumption was a result of the attempt to use the outcome from a LCA-framework within the CBA framework. The LCA framework applied in this thesis was not originally performed by the author (due primarily to time restraints) and since they are almost always performed with software, using them as a second hand source the inputs are not always fully known. Also, the study used was produced in the Netherlands (although adaptation to Swedish data was made when possible) which was a necessity since there is a lack of knowledge of the complete environmental effect by e-bikes within a Swedish context, which perhaps is due to their more recent success on the Swedish market. Despite the somewhat suboptimal application of the LCA this was an attempt to narrow in on the actual environmental impact when including production of the vehicles as well as production and consumption of fuel. The argument that most studies use for not including food consumption is based on a discussion carried out by Cherry (2007). Cherry states, based on a study by Bell et al (2002) which indicates that cyclists generally are thinner than motorists, that cyclists “burn more calories cycling than they consume specifically for cycling”. This might be true to some extent, but during a longer time period, all things equal, if a cyclist does not have a higher calorie consumption then the non-cyclist he/she would sooner or later perish. Exactly what the relationship between the AT and increased demand of calories is remains unclear. But assuming that cycling is a transportation mode without any environmental impact seems (especially when including the production of the vehicles and e-bikes that run on electricity) like a somewhat unduly assumption. Nonetheless, this was an attempt to close in on the actual environmental impact, and undoubtedly LCAs offer a more in depth method of doing this. A method that should perhaps be used in combination with the CBA framework to a greater extent.

In their study, Gössling & Choi (2017) highlights the importance of the highly developed CBA framework produced by the Danish government in guiding and implementing transportation policy (many nations, Sweden included have similar frameworks) but also point to the absence of a European CBA framework for bicycles. There is an existing framework for automobiles, and it can be argued that extending this to include non-motorised transportation would be beneficial. Not only because it would perhaps bring some clarity to the framework itself, meaning that it would gather the most updated data and making accessibility easier, but also that it would make comparison between studies more realistic and lend support and extend legitimacy to results of CBAs. A framework like this would perhaps also, to some extent, address the lack of transparency in the decision making process when including or excluding parameters. In most studies it is not apparent which parameters were chosen over others or what the decision making was regarding their monetization. And it seems likely that with time, motorised transportation is going to become more expensive and non-motorised transportation will comparatively become more affordable. This will most likely mean an increased demand for good non-motorised infrastructure and other facility/programs, general framework would perhaps also be beneficial in determining the most cost efficient ways to meet this demand.

The difficulties and limitations with the CBA framework have been mentioned many times before, undoubtedly CBA is not an exact science and there are still gaps of knowledge about shifts in transportation modes. The issue of substitution between PA and other exercise is one example of this. Like mentioned, most studies assume that there is zero substitution, which leaves the possibility for overestimation of health effects. Chapman et al (2018) argues that this might be less of a problem since despite individuals being aware of the positive health benefits these are "unlikely to be fully appreciated by cyclists and may well be significantly underestimated". It is true that it is likely that the health benefits from both PA and AT are underestimated firstly by the cyclists themselves since they as are not fully aware of the social health benefits (Chapman et al 2018). Secondly, health benefits could also be underestimated within the framework simply due to the crude monetization method and difficulty to include all aspects. This can be exemplified when comparing NVVs estimate which included Swedish health care costs to the estimate produced with HEAT which only included VSL. Given that the estimates were similar to each other, the actual total health benefit could perhaps be double what is estimated here. Until further research is conducted the degree of substitution remains unknown, which is why thesis adopted a precautionary approach and excluded 25% of the health benefit.

There are many different ways of influencing transportation demand, as mentioned the most common ways are through harder economic measures. However, the strength with the C2W scheme is that the initiative in a way comes from the participants themselves, and it seems like the offering of a scheme (which also eliminated the initial entrance cost with making a full purchase) acts like a catalysts for change. It is difficult to change travel behavior on a long-term basis, perhaps this change will remain long-term since it allowed for the participants themselves to be the driving force in the decision making process. It is of course impossible to know whether the change in travel behavior will be maintained. This is a possible field for further research, to determine what the full long-term benefits from schemes such as this are and how efficient the method is at altering individual travel behavior.

10. Conclusion

The C2W scheme set out to increase bicycling amongst the employees in the municipality; a goal that was successfully meet. The outcome of this study lends further support to previous literature which overwhelmingly concludes that investments in AT are cost efficient. The final BCR of this implementation was estimated to be 6.21:1. Granted, there are insufficiencies with the CBA framework and uncertainties with the price evaluation of the effects, but the BCR in this thesis remained larger than 4:1 regardless of manipulation in the sensitivity analysis. In light of this, C2W schemes are a cost efficient way to promote increased usage of AT.

Appendix A: Summary of Studies Included

	Author(s)	Study Design	Description	Parameters included	BCR	Other result	Peer reviewed
C2W	Caufield & Leahy (2011)	CB	Evaluates a tax relief scheme for bicycles in Irland. Does not do any monetary evaluation of parameters but rather examines the schemes success in increasing bicycling, the particpants and their incentives.	Health, accidents, absenteeism, congestion, infrastructure, noise, local air quality, GHG-emissions, fuel duty loss,	NA	Tax relief for bicycles encurage cycling, especially with those that did not previously own a bicycle.	Yes
	Clarke et al (2014)	CBA	Evaluates C2W scheme in Scotland, taking individuals vehicle ownership status into consideration on health effects.	Health, accidents, air pollution, noise, congestion, infrastructure, absenteeism, fare revenue losses, NI savings for employers, VED, income tax and NI, indirect Taxation	3.51 / 2.55		No
	Green et al (2016)	CB	Evaluates C2W scheme in England and Wales	Health, absenteeism	2		No
CBA of other policy aimed to increase AT	AECOM (2010)	CBA	Evaluates the costs and benefits of a possible implementation of "The Inner Sydney Regional Bicycle Network" - a bicycling network in Sydney.	Health (mortality + abseentism), accidents, travel time, parking, GHG-emissions Journey ambiance (joyment, improved wayfinding and perceived safety), congestion, air/water pollution, noise pollution, urban seperation, vehicle operations and purchase	3,88		No
	Baufeldt et al (2017)	CBA	Evaluatse a Mon-Motorised Transport Project Appraisal Tool (NMT-PAT) in Cape Town. Two case studies were developed, one inclduing only the buisness center and the other the whole meteropolitan area.	Health, travel time, injuries (other parameters are considered but not monetarized)	8.63 / 7.58		Yes
	Buis & Wittink (2000)	CBA	Summerizes research and exemplifies how pro-bicycle investments can have different impacts depending on several factors using four different geographic locations; Amsterdam, Bogota, Dehli, Marogoro,	Health, traffic saftey, vehicle costs, infrastructure, accessibility, urban economy, air and noise pollution, economic activity	1.5 / 7 / 20 / 5		No

	Author(s)	Study Design	Description	Parameters included	BCR	Other result	Peer reviewed
CBA of other policy aimed to increase AT	Börjesson & Eliasson (2012)	CBA	Investigate cyclists time valuation in Stockholm, Sweden. Also included health and environmental aspects.	Health, GHG- emission, travel time,	13		Yes
	Chapman et al (2018)	CBA	Zealand's Model Communities Programme using an empirical analysis comparing two intervention cities with two control cities	Health (including injury), GHG emissions.	11		Yes
	Choi & Gössling (2015)	CBA	Compares the cost of cars vs bicycles in Copenhagen	Vehicle operation costs, health, travel time, accident costs, climate change, air pollution, noise, congestion, road deterioration, safety and discomfort, branding tourism.	NA	0.081€/km with bicycle 0.503 €/km with automobile	Yes
	Cope et al (2010)	CBA	Economic evaluation of the English Cycling Demonstration Town investment programme	Health, accidents, abseentism, congestion, journey ambience	2.6-3.5:1		No
	Dept for transport (2007)	CBA	Guide on appraisal walking and cycling schemes. Inclused case studies.	Health, GHG emissions, Absenteeism, safety, accidents, travel time, fuel tax revenues,	18.4/37.6/18.5		No
	Faghri & Li (2014)	CBA	Attempts to form basis for proposing a comprehensive methodology to estimate the most important benefit components and expenses associated with the installation of bicycle facilities as well as implement these on a case study in which an old railroad is transformed to a pedestrian/bicycle path.	Vehicle costs, health + mortality benefits, congestion, air pollution, noise, parking costs, accidents,	2,07		Yes
	Foltýnová & Kohlová (2002)	CBA	Estimates the effects of improved cycling infrastructure in the Czech Republic	Health, accidents, air pollution, travel time, security	−0,97		Yes
	Gotschi (2011)	CBA	Compares bicycling investments plans in Portland with with two types of monetized health benefits, health care cost savings and value of statistical life savings.	Health, fuel costs	1.3-53.3		Yes

	Author(s)	Study Design	Description	Parameters included	BCR	Other result	Peer reviewed
CBA of other policy aimed to increase AT	Grabow et al (2010)	CRA	Estimating the value of bicycling to tourism and health in Wisconsin and reviewing the potential to increase that value in the face of changing demographics, lifestyles, and economy.	Health (PA and air quality), GHG emissions	NA	Estimated that the economic value of recreational bicycling in wisconsin as well as the possible health benefits to be almost $2 billion.	Yes
	Macmillian et al (2014)	CBA	Uses system dynamic modelling to compare realistic policies, incorporating feedback effects, nonlinear relationships, and time delays between variables. Then simulate five different scenarios over a 40 year period in the Auckland, NZ area.	Operation costs, health, air pollution, CO2 emissions, injuries.	6 / 18 / 18 / 24		Yes
	PWC (2009)	CBA	Assesses the net benefits of investing in 9 of the 12 major missing links of the Sydney Metropolitan Strategic Cycle Network for which demand forecasts are available.	Health, accidents, travel time, parking, congestion, noise, infrastructure, parking, GHG gases, air pollution, infrastructure, user costs, capital costs,	1.3		No
	Sælensminde (2004)	CBA	CBAs of replacing 15% of automobiles <5km with bicycling networks in two norwegian towns (Hokksund and Hamar) and new bicycle and walking infrastructure in Trondheim.	Health, security, parking costs, external costs (CO2 emissions, local air emissions, noise, congestion and infrastructure costs).	4.09 / 14.34 / 2.94.		No
	SQW (2007)	CBA	Examine the economic benefit of cycling from four interventions 1) provide safe cycling/walking for children to school 2) "Bike it" encuraging young people to increase AT primarily by means of education 3) LCN+ wants to increase the level of cycling by delivering is fast, safe, convenient and easy cycle networks 4) training- increasing cyclists saftey levels.	Health (loss of life + medical costs), accidents, air pollution, congestion, productivity,	2.17 / 1.36 / 3.94 / 7.44		No
	Cope & Wilson (2011)	CBA	Provides a overview of the methodology aviable for evaluating investments in AT in a Scottish context. Also includes case studies.	Health, accidents, abseentism, congestion,	1.3 / 13.4		No

Appendix B: Bicycles

The vehicles available to participants in the C2W scheme

Monark - City bike "Original" Open frame, 3 gears, v brake and hub break.
Monark- City Bike "Original" Closed frame, 3 gears, v brake and hub break.
Monark - City bike "Emma" Open frame, 3 gears, foot brake.
Monark - City bike "Sigvard" Closed frame, 3 gears, foot break.
Monark - City bike "Karin" Open frame, 3 gears, foot brake.
Monark - Tricycle "3313" Open frame, 3 gears, V brake and hub break
Crescent - City bike "Tove" Open frame, 7 gears, foot brake.
Crescent - Hybrid "Tarfek" Closed frame,7 gears, foot break.
Crescent - Hybrid "Starren +" Closed frame, 24 gears, hydraulic disc brakes.
Crescent - Hybrid "Åkulla+"Open frame, 24 gears, hydraulic disc brakes.
Crescent - Hybrid "Centi" Open frame, 18 gears, hydraulic disc brakes.
Crescent - Hybrid "Zetta" Closed frame, 18 gears, hydraulic disc brakes
Crescent - Hybrid "Yotta" Closed frame, 20 gears, hydraulic disc brakes
Specialized - MTB "Chisel Comp" Closed frame, 20 gears, disc brakes (2 colors)
Scott - MTB "Scale 930" Closed frame, 20 gears, disc brakes
Bianchi - Race bike "Via Nirone 7 AL 105" Closed frame, 22 gears, caliper brakes
Bianchi - Race bike "Intrepedia Ultegra" Closed frame, 22 gears, caliper brakes
Monark e-bike Tricycle "3313 EL" Open frame, 3 gears, V brake and hub break
Crescent e-bike "Elin" Open frame, 7 gears, roller brake + foot brake
Crescent e-bike "Edvin" Closed frame, 7 gears, roller brake + foot brake
Crescent e-bike "Elora" Open frame, 7 gears, hub break + foot brake
Crescent e-bike "Elda" Open frame, 10 gears, hydraulic disc brakes
Crescent e-bike "Elder" Closed frame, 10 gears, hydraulic disc brakes
Ecoride e-bike "Urban8" Closed frame, 8 gears, hand and foot break
Ecoride e-bike "Ambassador" Open frame, 8 gears, hub brakes
Ecoride e-bike foldable "Flexible" Open frame, 3 gears, hand and foot brake

All vehicles came equipped with: safety approved lock, lock wire, safety approved helmet, lighting, vehicle-support, mud flaps and package holder. They were also delivered to the participants home and came with three years warranty and insurance.

Appendix C: Parameters excluded

Effects that are excluded in this thesis are primarily excluded because of two reasons 1) the effect is not large enough within the context of the specific implementation 2) there are no cost estimates within a relevant context. Some are not relevant for a C2W scheme, but rather to infrastructural implementations or other restrictions.

Parameters excluded

Cost of health deterioration due to inhalation of exhaust
Intrusion in the environment and barrier effects
Time reliability
Business activity
Alternative price
Spill-over effects
Amenity
Decreased fuel tax revenue
revenue loss of public transportation
Congestion
Productivity
Journey ambience
Social inclusion (of those that do/cannot own automobiles)
Increased emission of CO_2 due to increased breathing rate while cycling

Appendix D: HEAT

Inputs:

Travel mode: cycling
geographic scale: City: Sweden: Jonkoping (Jönköping)
Comparison and time scale: Single case: 2016: 12 years.
Impacts: physical activity
Unit: Km
Amount: 49.89km/weekly/7= 5.8km/ daily
Population type: general population (adult; 20-64 year)
Population size: 2012
Temporal adjustment: 0% (will be adjusted later)
Substitution 0% (will be adjusted later)
Average speed 14 km/h
Discount rate 3.5%

Appendix E: Survey sheet

This survey has been translated and was originally conducted in Swedish.

This is a short questionnaire about the benefit bicycle(s)/e-bikes(s) you have chosen to rent. Please answer as accurately as you can, if you are not sure, answer the question to the best of your abilities.

Q 1. What is your age?

Q 2. What is you sex? Male/Female/Undefined/Other

Q 3. How many months yearly do you use the bicycle you obtain through the C2W scheme?

Q 4. How many kilometers motoring (per week) do you estimate that you replaced with bicycling?

Q 5. How many kilometers public transportation (per week) do you estimate that you replaced with bicycling?

Q 6. How many kilometers walking (per week(do you estimate that you replaced with bicycling?

Q 7. If you orders 2 bicycles and someone else except yourself is using one of they, please do the same estimation as above for that person. If you did not order 2 bicycles you can skip the next 3 questions.

How many kilometers motoring (per week) do you estimate that he/she replaced with bicycling?

Q 8. If you orders 2 bicycles and someone else except yourself is using one of they, please do the same estimation as above for that person.

How many kilometers public transportation (per week) do you estimate that he/she replaced with bicycling?

Q 9. If you orders 2 bicycles and someone else except yourself is using one of they, please do the same estimation as above for that person.

How many kilometers walking (per week) do you estimate that he/she replaced with bicycling?

Q 10. How has your travel time changed (daily) since you received your new bicycle/e-bike?

Ex. + X minute(s) (if you had increased travel time)
- X minute(s) (if you had decreased travel time)

Q 11. How has your amount of physical activity changes (daily)) since you received your new bicycle/e-bikes?

Ex, + X minutes (if there was an increase)
- X minutes (if there was a decrease)

Q 12. Do you have anything you want to add about your experience with the C2W scheme or with this questionnaire?

Appendix F: Internalisation of cost from vehicles that run on ethanol fuel

Since there was no existing estimation of the internalisation degree for vehicles that run on ethanol an estimation was made by the author after recommendations on a simpler method from experts at Trafikanalys. The recommendation was to add up the total energy tax collected from the usage of ethanol vehicles and then divide this by the sum of accident, infrastructural and noise pollution marginal cost as well as 20% of the cost of pollution and CO2 emissions caused by gasoline fueled automobiles. 20% because in the summer ethanol is usually comprised of 15% gasoline and 85% ethanol and whilst in the winter it is 25% gasoline and 75% ethanol. However, this is only prior to July 2018 when the government removed taxation on ethanol and after this there is zero internalisation (Skatteverket, 2018).

Calculations:

<u>Before 2018:</u>
∑Marginal cost of noise, accidents, infrastructure = $0.013/km
20% of marginal cost of pollution and CO_2 emission = $0.003/km
Total marginal cost= $0.016/km (Trafikanalys, 2018)

The total usage of ethanol within the transport industry in 2017 was 3,199,000,000L (Trafikanalys, 2018).
The energy tax on ethanol driven vehicles was $0.034/L (Skatteverket, 2018)
This generates a tax revenue of $109,725,601

The total distance driven with automobiles in Sweden in 2017 was 680,819,554,600km, out of which 4.4% was fueled with ethanol; 29,956,060,400km. (Trafikanalys, 2017)
Given a marginal cost of $0.016/km, this generates a cost of $479,296,966

Finally the internalised tax (tax revenue) is divided with the cost of external damage:
109,725,601/$479,296,966= 0.2289303= 22% internalisation degree.

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