FACULTEIT ECONOMIE
EN BEDRIJFSKUNDE

CYCLING IN COPENHAGEN; A COST-BENEFIT ANALYSIS

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Abstract

An increasing number of cities around the world are implementing some sort of sustainable urban mobility policy. Since the 1980s, a more liveable city with cycling as an integral part of the mobility system has been on Copenhagen's political agenda. Several bicycle plans to increase the cycling modal share have been published and implemented. Nowadays, Copenhagen is known for its exquisite bicycle infrastructure and its cyclists-filled streets. On a regular basis, the city publishes the socio-economic gains generated through cycling and how cycling compares to other forms of transport from a socio-economic point of view. Nevertheless, an overall economic policy assessment has not been drafted.

This research investigates to which extent the city's bicycle policy has been effective and whether the policy benefits outweigh the investment costs. Additionally, the research discusses the applicability of a comparable bicycle policy in the Belgian city of Ghent and identifies possible learning points from Copenhagen. The policy has definitely been an effective undertaking, yet it is probable that Copenhagen will have to increase efforts to meet its own ambitious targets. It is estimated that the policy has an economic net present value (ENPV) of 4,5 billion DKK for the period 1996-2017. The benefits have thus certainly outweighed the costs. Although the estimate is quite uncertain due to several assumptions, the bicycle reaps more socio-economic benefits than other forms of transport in the long run. In Ghent, a comparable policy could be implemented if local environmental, societal and cultural particularities are taken into account. Furthermore, a more quantitative planning approach and increased cooperation with academic institutions are identified as key learning points for Ghent.

Samenvatting (Dutch abstract)

Wereldwijd is er een groeiend aantal steden dat werkt aan de uitbouw van een duurzaam stedelijk mobiliteitsbeleid. In de Deense hoofdstad Kopenhagen bekleedt het duurzaamheidsthema een plek op de politieke agenda sinds het begin van de jaren 80. Bovendien wordt fietsen er gezien als een integraal deel van de leefbare stad. Sindsdien zijn verschillende strategieën uitgewerkt om het aandeel van de fiets in de stad te verhogen. Tegenwoordig staat Kopenhagen internationaal bekend voor zijn weelde aan fietsinfrastructuur en zijn expertise als fietsstad. De stad promoot zijn fietsbeleid door te wijzen op de socio-economische voordelen die fietsen biedt ten opzichte van andere vervoersmiddelen. Een volledige socio-economische analyse van het beleid werd echter nog niet uitgevoerd.

Deze masterproef onderzoekt de doeltreffendheid van het fietsbeleid in Kopenhagen en schat in of de aan fietsen gerelateerde economische baten de investeringskosten van de fietsinfrastructuur in de stad overstijgen. Daarnaast beoordeelt de masterproef ook of een dergelijk fietsbeleid in een Belgische stad als Gent mogelijk is en wat precies Gent van Kopenhagen kan leren. Kopenhagen is erin geslaagd om het gebruik van de fiets gestaag te doen stijgen en de perceptie van de inwoners tegenover fietsen positief te beïnvloeden. Het fietsbeleid kan dus als geslaagd worden beschouwd. Toch lijkt het erop dat Kopenhagen in de toekomst een inspanning zal moeten doen om zijn eigen doelstellingen voor te behalen. Een kosten-baten analyse voor de periode tussen 1996 en 2017 geeft aan dat de baten de kosten overstijgen en schat een netto contante waarde van 4,5 miljard Deense kroon. De verwezenlijking van een vergelijkbaar fietsbeleid in Gent wordt ook mogelijk geacht indien rekening wordt gehouden met de lokale noden en de verschillende stedelijke configuratie. Op vlak van professionalisme, het gebruik van kwantitatieve analysemethodes en samenwerking met academische instellingen kan Gent het voorbeeld van Kopenhagen volgen om op termijn zelf een goede fietsstad te worden.

Acknowledgments

This dissertation could not have been written without the persistent support of several people.

My sincerest gratitude goes to my supervisor Prof. dr. Johan Albrecht for giving me the opportunity and providing me with the necessary content to research a highly relevant topic in today's society. Also, many thanks to Wout Behaeghel for giving me incredibly useful advice, tips and addressing my concerns with patience. Besides them, I would like to extend my gratitude to Prof. dr. Rob van der Bijl for letting me participate in the supportive course mobility planning, it has broadened my perspective on mobility's flaws and merits. Finally, my family, friends and school colleagues deserve a lot of gratitude for making this year an enjoyable experience.

Tymen Vererfven

Contents

List of Abbreviations

B/C ratio	Benefit to Cost ratio
CBA	Cost-Benefit Analysis
CPI	Consumer Price Index
CS	Consumer Surplus
DCF	Danish Cyclists' Federation
DKK	Danish Crown
DTU	Danish Technical University
ENVP	Economic Net Present Value
GTC	Generalised Travel Cost
ITS	Intelligent Transport System
OTM	Ørestad Traffic Model
RoH	Rule of Half
SDR	Social Discount Rate
SUMP	Sustainable Urban Mobility Planning
VAT	Value Added Taxes
WHO	World Health Organisation
WTA	Willingness to pay
WTP	Willingness to accept

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1 Introduction

In recent years, the City of Copenhagen has gained international recognition for its remarkable share of bicycle commuters and its numerous bicycle bridges that connect the city. In 2015, Copenhagen-based consulting company Copenhagenize Design Co. declared the city to be the world's best city for cyclist (Copenhagenize Design Co., 2017). Although this statement is based on several arbitrary chosen criteria, the City of Copenhagen has proclaimed it its mission to be the world's best bicycle city (Technical and Environmental Administration Copenhagen, 2017a). Cycling fits in a broader strategy to become a sustainable, liveable city, which is an objective of many European cities at present day. The benefits of cycling are known, yet contemporary mobility systems favouring cars in the city are fairly robust. To that end, the city of Copenhagen attributes much consideration for promoting their system and its benefits. It has published several cost-benefit analyses and frequently mentions the socio-economic gain per km that is generated by cyclists.

This research aims to investigate to which extent the Copenhagen bicycle policy has been effective and whether the benefits of the bicycle policy have outweighed the incurred costs. Subsequently, the applicability of a comparable urban mobility policy in the Belgian city of Ghent will be investigated, as well what can be done specifically to make this policy successful. While most of this research will be literature review, it aims to provide practical information for European urban planners. In section 2, the history of bicycle planning in Copenhagen will be summarised and the effects it has had, will be highlighted. Section 3 gives some practical bicycle infrastructure standards Copenhagen uses to ensure cohesion and safety for bicycles throughout its urban network. In section 4, the use of cost-benefit analysis and its difficulties regarding bicycle policies will be dealt with. Additionally, a CBA will be conducted to provide a rough estimate of the economic costs and gains for the policy. Section 5 will address some stakeholder views for the Copenhagen bicycle policy. In order to make this research useful for other cities, section 6 will cover the applicability of a Copenhagen-like policy in Ghent. Lastly, a conclusion is formulated and suggestions for further research are presented.

2 Strategic bicycle planning: 1905-2025

Urban mobility planning is often perceived as simply providing fitting infrastructure for traffic. Because of the inherent complexity of mobility systems this statement is only partly true. Several authors have argued that there is a relation between mobility, space, economy and social structures (Kaufmann, Bergman, & Joye, 2004; van Oort, van der Bijl, & Verhoof, 2017). Mobility creates value for urban spaces as well as it creates an energy demand or even inequality. A mobility system as most European citizens know it, consists of several forms of transportation and its respective infrastructure that services people to travel from A to B. In several European Cities, historically, the use of cars as the primary form of transportation is dominant. However, because of contemporary issues such as climate change and a demand for healthy cities, governments realize that urban mobility systems require a different approach. The different approach is now universally known as sustainable urban mobility.

The concept of sustainable urban mobility investigates the complexity of a city and establishes better links between the city's complexity and the use of urban space (Banister, 2008). In addition to that, the objective of sustainable urban mobility does also include quality of life, environment, social equity and health in contrast to the more traditional mobility objective that focuses on travel time savings (Wefering, Rupprecht, Bührmann, & Böhler-Baedeker, 2013). From a government point of view, in order to comply with the European commission 2050 objectives, it is in their best interest to adopt some form of sustainable mobility. Thereby external costs created by traditional motorized individual transport can be avoided and greenhouse gasses reduced (European Commission, 2011). However, implementing sustainable mobility is not straightforward and troubles governments all over Europe in 2019, as it often involves radical changes of the urban road infrastructure which comes at an inevitable cost of investment.

Copenhagen, Denmark's capital, has consistently been a pacesetter in terms of sustainable urban mobility. The city, which has a seaport, is characterized by its bicycle and pedestrian bridges that connect different neighbourhoods over its waterways. For decades Copenhagen has been planning urban mobility with cycling as an integrated part of the mobility practises. In recent years the municipality has also invested heavily in bicycle infrastructure and it promises to continue to do so. Today cycling is a part of Copenhagen's ambitious plan to be carbon-neutral by 2025 (Technical and Environmental Administration Copenhagen, 2011). However, throughout time the perception of the bicycle and the relation to its surroundings has shifted in different directions. In the next paragraphs, the bicycle planning policy of the Copenhagen municipality will be briefly discussed.

2.1 Cycling in the 20th century

The beginning of the 20th century is considered to be 'the golden age' for cycling in all of Europe. As a result of the development of the safety bicycle, which is a bicycle without an enormous front wheel, cycling became exceptionally popular (Carstensen & Ebert, 2012).

In Copenhagen the expanding city resulted in a shift from a pedestrian city towards a cycling city. Cycling was regarded a cheap alternative to public transportation and its popularity stretched different levels of society. In 1905, the Danish Cyclists' federation (DCF) was established and managed to persuade the government into constructing the first official bicycle path in Copenhagen (Carstensen, Olafsson, Bech, Poulsen, & Zhao, 2015). The bicycle path network expanded, partly because urban planners believed that separate cycle lanes could improve motorized traffic flow. The network had doubled from 35 to 70 km between 1912 and 1927, and reached 100 km by 1935 (Martin, Oldenziel, & Veraart, 2016). With the emergence of cars in the city, in 1928 DCF advocated the separation of bicycle paths and roadways by kerbs or trees (Carstensen et al., 2015). Nowadays this is considered as the typical 'Copenhagen style' of building bicycle pathways. The popularity of the bicycle was reflected in the traffic counts between 1925 and 1950. The counts show that nearly 90 percent of the traffic on the bridges connecting the city with working class districts consisted of bicycles (Martin et al., 2016).

The bicycle remained a preferred means of transportation until after the second world war. From the 1950s on, the availability of previous rationed resources such as oil and rubber led to cheaper car prices and more car drivers as a consequence. By the 1960s car use had surpassed bicycle use in Copenhagen (Gössling, 2013). Traffic planning was focused towards improving the speed and flow of cars in the city. The city centre was reconstructed during the 1960s primary supporting the vision there would be a considerable increase in car ownership and traffic (Pineda & Vogel, 2014). During the oil crisis of the 1970s car ownership continued at a slower rate. In the city of Copenhagen bicycle use started to increase again. The economic crisis was partly responsible for the increased bicycle use (Pineda & Vogel, 2014). Also, the city centre had become an unpleasant and dangerous place for pedestrians and cyclists. Because of the high fatal accidents rate, lobbying groups such as the DCF caused officials in the municipality of Copenhagen to improve bicycle infrastructure that previously had been taken away (Carstensen et al., 2015). As illustrated in figure 2.1, in the 1970s and 1980s the DCF arranged big demonstrations in favour of bicycles joined by tens of thousands of people. As a result, efforts to alleviate negative consequences of cars in the city were placed on the political agenda(Knudsen & Krag, 2005). From 1979 on the national budget prioritised construction of bicycle infrastructure (Carstensen et al., 2015).

Figure 2.1: Annual bicycle demonstration in the Copenhagen City Centre

From the 1980s onwards the Copenhagen municipality implemented several policies to curb the use of cars in the city centre (Carstensen & Ebert, 2012). In February 1987 Copenhagen joined the WHO's (World Health Organization) healthy cities movement in a bid to put health high on social and political agendas (WHO, 1990). With healthy transportation as one of the focus areas, the intention was mainly to create pleasant, liveable urban space. Later infrastructure designers focussed equally on optimising the cyclist flow (Carstensen et al., 2015). Consequently, in more recent years, the bicycle became a relevant competitor for other forms of urban transportation.

2.2 Bicycle strategies: 1996 – the present

As previously mentioned, the city of Copenhagen had been investing for a long period of time in bicycle infrastructure. However, there was no quantitative basis to support investment plans and likewise forge a distinct cycling strategy. In 1996 Copenhagen introduced a bi-annual bicycle indicator framework that measures relevant key figures such as the share of people that bike to work or an educational institution (Building and Construction Administration City of Copenhagen, 2002). The gathered data allows the monitoring of cycling development and the exposure of issues considering the safety and comfort of the cyclist as well as it provides a basis for setting up targets and investment plans (Nielsen, Skov-Petersen, & Agervig Carstensen, 2013).

In 2000 the City of Copenhagen published the *Subplan for the Improvement in Cycling Conditions*. It was a subsection of the City's *traffic improvement plan* of 2000. For the first time in history, quantitative goals for cycling had to be attained by 2012 (Building and Construction Administration City of Copenhagen, 2002):

- The proportion of people cycling to workplaces shall increase from 34% to 40%
- Cyclist risk of serious injury or death shall decrease by 50%.
- The proportion of Copenhagen cyclists who feel safe cycling in town shall increase from 57% to 80%.
- Cyclist travelling speed on trips of over 5 km shall increase by 10%.

- Cyclist comfort shall be improved so that cycle track surfaces deemed unsatisfactory shall not exceed 5%.

The traffic improvement plan was the result of a budgetary settlement for the year 2000. The plan passed the bill and funds were allocated to specific projects. Together with *the Proposals for Green Cycle Routes (2000)* and the *Cycle Track Priority Plan (2001)* it formed the basis for creating the 2002-2012 cycling policy (Building and Construction Administration City of Copenhagen, 2002). The plan focusses on different aspects of cycling such as the cycle tracks and their maintenance, bicycle parking or promotional campaigns and information provision.

The overall goal of the plan was to stabilize and if possible, decrease the level of motorized traffic, while increasing public transport and bicycle use. Motorists acknowledged that they could switch to cycling when a number of cycling improvements were made (Building and Construction Administration City of Copenhagen, 2002). Moreover, data analysis and case studies showed that specific infrastructural and promotional policies can encourage people into bicycle use (Pucher & Buehler, 2008).

In 2009 the city council set the goal to be a carbon-neutral city by 2025. The four main areas of action where will be intervened are energy production, energy consumption, City Administration initiatives and Mobility (Technical and Environmental Administration Copenhagen, 2011). Since all traffic movements by bike are carbon-neutral, in the area of mobility cycling can prove to be a valuable asset. Therefore, cycling was welcomed as a crucial part of the 2025 carbon-neutrality goal and a new 2011-2025 cycling strategy was drafted. The new cycling strategy replaced the 2002-2012 strategy and adopted some of its objectives with new more ambitious goals. In order to become the world's best bicycle city, the Copenhagen municipality focusses on travel time, comfort, perceived safety and the city lifestyle (Technical and Environmental Administration Copenhagen, 2011). The cycling strategy also gives an accurate description of measures to be taken in order to achieve the proposed objectives. For instance, in 2025 Copenhagen wants to have established an entire bicycle path network named the bicycle PLUSnet. The network shown in figure 2.2 will be composed of regular bicycle paths, cycle superhighways and bridges with a high level of quality for space. The bicycle tracks forming the PLUSnet should all be at least 3 cycling lanes wide. In this manner it would be possible for 2 cyclists to have a conversation and a third one would still be able to overtake. Most likely, providing 3 bicycle lanes in each direction will demand some compromise for other modes of transport such as the car.

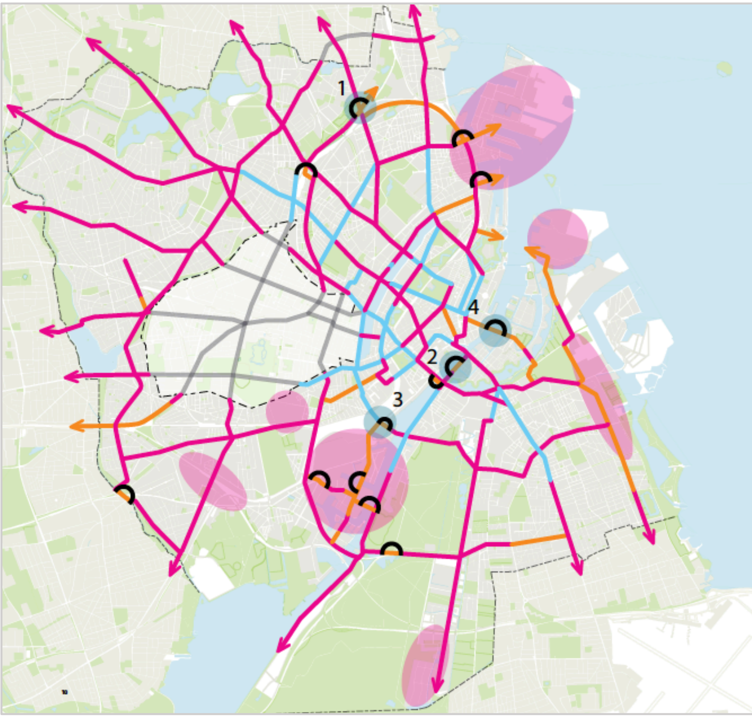


Figure 2.2: The Copenhagen PLUSnet,

In the last decade Copenhagen has invested approximately 1,64 billion DKK in bicycle infrastructure while it is most likely that investment levels will rise even more. The technical and environmental administration estimates that in order to attain the set objectives for the bicycle track priority plan, between 225 and 400 million DKK will be needed on a yearly basis.

2.3 Copenhagen's urban policy effects in numbers

2.3.1 Bicycle policy goals 2025

In their 2025 bicycle strategy, the city administration has set concrete goals within five year periods (Technical and Environmental Administration Copenhagen, 2011). The described ambitions mainly concern increases in modal split for bicycles, and more recently added public transport. In terms of quality the focus is on perception of safety, city atmosphere, maintenance of the tracks and the reduction in travel time for bicycles. All quality indicators seek to improve the edge of the bicycle over other forms of transport. In table 2.1 on page 11, an overview with the intermediate- and end-objectives is given as well as the situation with the most recent numbers dating from 2017.

Besides the quantitative targets Copenhagen has set, it also aims to promote the image of cycling as a real lifestyle and tries to create a sense of project ownership for bicycle projects among Copenhageners. In terms of marketing it appears that Copenhagen has succeeded quite well. It has successfully claimed a spot next to Amsterdam and Utrecht as an authority in the field of cycling.

The targets Copenhagen has set are within reach but not yet accomplished. In terms of modal split there is 8% improvement for trips to work or school relative to 2010, but there is still a 7% gap relative to the 50% target level. The modal splits targets that include public transport and walking are to be reached at earliest in 2020. To attain the objectives regarding safety and bicycle parking, a serious effort is needed. Moreover, the share of the network that has three lanes is nowhere near the target level. Overall Copenhagen does improve on all levels but not always at the desired level. This might be attributable to the ambitious target setting the Copenhagen administration tries to maintain. Thus, the bicycle policy in Copenhagen can be considered effective, in the sense that the realized measures have a visible and substantial effect. In section 4 an indication will be given whether the policy is also effective on a socio-economic level.

Table 2.1: Modal split goals for 2025

MODAL SPLIT GOALS	**2015**	**2020**	**2025**	***2017***
Share of all trips with bicycle or public transportation (2010: 57%)	-	66,7%	66,7%	62%
Share of all trips by foot, bicycle or public transport (2010: 63%)	-	-	75%	69%
Share of all trips by bicycle to work and school in Copenhagen (2010: 35%)	50%	50%	50%	43%
QUALITY				
Share of the network that has three lanes (2010: 25%)	40%	60%	80%	20%
Relative to 2010, cyclists' travel time is reduced by	5%	10%	15%	6%
Percentage of Copenhageners that feel safe cycling in traffic (2010: 67%)	80%	85%	90%	76%
Relative to 2005, the number of seriously injured cyclists will fall by	50%	60%	70%	23%
Percentage of Copenhagen cyclists who find the cycle tracks well maintained (2010: 50%)	70%	75%	80%	71%
Share of Copenhageners who think that bicycle culture positively affects the city's atmosphere (2010: 67%)	70%	75%	80%	71%
Share of Copenhageners who are satisfied with the bicycle parking in the city (2010: 27%)	-	-	70%	37%

3 Copenhagen's cycling infrastructure

As a part of their strategic bicycle plan Copenhagen has an impressive list of efficient, yet logical infrastructure solutions to improve bicycle traffic. In 2013 the City of Copenhagen's Technical and Environmental Administration published design guidelines on how to handle road projects in a Danish context (Technical and Environmental Administration Copenhagen, 2013). Although it is said that the guidelines are not necessarily immediately applicable elsewhere, a lot of bicycle infrastructure can be recognised elsewhere in the world.

A general trend in the design guidelines is that bicycle traffic should be fast, convenient and safe. The Copenhagen-based urban-design company Copenhagenize Design Co. made a distinction between Copenhagen's bicycle infrastructure by categorizing it as macro- or micro-design. Macro-design concerns all infrastructure that is highly visible, affects bicycle flow and is fundamental for cycling. Micro-design concerns small scale adaptations that enhance safety, convenience and foremost the cyclist's perception towards bicycle friendliness.

3.1 Macro design: the fundamentals of cycling

In cycling infrastructure macro design, an essential feature is that infrastructure is not just present, but also connected. People should be able to pursue a path of their choosing when making a trip in the city. Another essential feature is that infrastructure should be uniform so that people recognise different situations and are able to use their knowledge to cycle in a safe manner. In the subsequent sections a few infrastructure design principles frequently used in Copenhagen and outlined in the design guidelines will be highlighted.

3.1.1 Uniform Danish design: the 4 main bicycle pathways

In accordance with the speed and density of cars in the city of Copenhagen a different bicycle pathway is chosen on the street level. In spaces where traffic speed is restricted to 40 km/h the shared space concept is used. Shared space means that bicycles and cars use the same lane. However, in streets with mixed traffic, an extra metre should be added to the width of the street. The illustrated mixed traffic concept in figure 3.2 is a cycle street. In cycle streets cars have duty to give priority to cyclists.

Figure 3.1: Bicycle street in Copenhagen

Another concept are the cycle tracks, which are separated from motorized traffic by a kerb and as a result, make cyclists feel safer. Often there is also a parked car separating the cycle track from the moving cars. In recent years cycle track width has been increased to cope with increasing cycling volumes and more cargo bikes. Also, a superior cycling network has been designated, called the PLUSnet. The aim is so that 80 % of all PLUSnet cycle tracks should be 3m wide in each direction. This is the same as 3 lanes for cyclists in each direction which allows for conversation cycling and a higher capacity.

Although 3 lanes in each direction might seem adequate for all bicycle traffic, Copenhagen had become a victim of its own success in 2011. In rush hours there was cycling congestion, which caused an unpleasant and potentially dangerous cycling environment. Furthermore, Copenhagen was having difficulties in providing enough bicycle parking infrastructure for the growing number of cyclists (Hill, 2011). Multiple measures have since been taken to ease the cycling traffic pressure and the PLUSnet is one of those.

The third concept are painted cycle lanes. Cycle lanes can be physically separated by motorized traffic with parking space but can also be right next to the motorized traffic. Cycle lanes give a limited sense of security compared to cycle tracks but are generally perceived as safer than mixed traffic. The infrastructural adaptation for creating cycle lanes is also much smaller than cycle tracks because bicycles also ride on street level.

The fourth concept are fully separated bi-directional paths. This kind of infrastructure is perceived as the safest and most pleasant. The so-called cycle super highways (figure 6) are often configured in this manner and allow cyclist to travel long distances without having to stop for traffic lights or motorized traffic. Another bi-directional concept are the green cycle routes, which are also fully separated from traffic and have a recreational purpose. Pedestrian areas are included and there is a lot of vegetation along the route.

3.1.2 Cycle Superhighways

The Cycle Superhighways project is a cooperation between 23 of 29 municipalities in the capital region of Denmark (Jens Bjørn Grelck, personal communication, October 18, 2018). The goal of the Cycle Superhighways is to increase the bicycle connectivity across municipal boundaries while decreasing car traffic. As a result of the adoption of the electric bicycle, the impact of the cycle superhighways could become more significant in the years to come. The increased range of electric bicycles could mean an increase in commuters from further outside Copenhagen. In 2018, the total constructed superhighways add up to 167 km of which 24,2 in Copenhagen. So far, the superhighways have secured 174 million DKK of government financing. The total construction cost is estimated to be 386 million DKK.

3.1.3 Missing links: bridges and tunnels

Copenhagen is perhaps most renowned for its bicycle and pedestrian bridges, as illustrated in figure 3.2. The bridges connect large parts of the city over the harbour and make the bicycle trip significantly shorter. As will be seen later, in terms of policy benefits Copenhagen has the advantage that constructing a bridge can cut time costs dramatically. Since 2006 about 13 bicycle bridges have been built. Other bridges such as the Queen Louise's Bridge, the Knippel bridge and the long bridge were retrofitted with wide bicycle tracks for the approximate 40.000 bicycles they accommodate on a weekday (Technical and Environmental Administration Copenhagen, 2017b). Apart from bridges, also tunnels are excellent infrastructure to link cycle tracks under busy roads, railroads or water. In general, providing solutions for missing links increases convenience, speed and safety for cyclists.

Figure 3.2: The Cycle Serpent Bridge

3.1.4 Reducing traffic time: Intelligent Transport System

An intelligent transport system solution or ITS solution practically includes all solutions that make use of data and provide information to traffic participants to control traffic in the city. For cyclists in Copenhagen, nowadays a simple kind of intelligent transport system called the green wave exists. The system illustrated in figure 3.3 consists of green led lights on a cycle pathway that indicate whether or not a cyclist will be able to cross the next intersection. The system encourages the cyclists to ride at a speed of 20 km/h.

Figure 3.3: "The green wave", source: Technical & Environmental administration Copenhagen

In the near future this system will be complemented by dynamic information counters and a mobile app that indicate travel times with real time data and can propose a different route. Cyclists can thus choose for a greener, snow or traffic free route. Instead of the green led lights, the information counter will also show how fast you should ride to be able to cross intersections on a green light. Other ITS initiatives such as intelligent lighting or Wi-Fi-device locating could enhance safety and traffic flow for bicycles.

3.2 Micro design: bicycle convenience

Micro design is about the entirety of bicycle supporting infrastructure that doesn't include cycling tracks, bridges, tunnels or other fundamental infrastructure. Micro means it is usually small, but the impact regarding bicycle use could be rather high. Examples of micro design infrastructure are bicycle parking and traffic signs.

3.2.1 Bicycle parking & repair hubs

In 2016 the city of Copenhagen has installed about 54.000 bicycle parking places in the centre of the municipality, and it is not enough. in 2016 only 37% of Copenhagen's residents were satisfied with the bicycle parking (Technical and Environmental Administration Copenhagen, 2017b). The municipality acted accordingly and drafted a bicycle parking priority plan 2018-2025. The plan has been adopted in 2018 and aims to create about 26.000 to 71.000 new parking spots in the municipality. Currently, the central problem is that bicycles who are parked in random places can reduce accessibility for pedestrians.

Another interesting micro design feature is the availability of bicycle repair stations. The stations are not only provided by the municipality, but also private businesses jump on the wagon. Norwegian oil company Statoil (now Equinor) provides bicycle repair stations at their gas stations as a way to show the people that they aim for an energy transition in the long term and that they encourage cycling. This might be an odd form of marketing, yet a welcome initiative for the cyclists.

3.2.2 Safety-enhancing measures & desire lines

Through simple interventions, the municipality tries to enhance the safety on the road for cyclists. A simple example that may also be observed in Belgian cities, is pulling back the stop line for cars at intersections. As a consequence, the cyclists gain an advantage when the lights turn green as the cyclists are more visible for the car drivers who are turning right.

Furthermore, separate signals for cars and bicycles and blue markings of bicycle paths at intersections are common to enhance safety.

Unsafe situations often originate when traffic participants ignore the predefined path that is available at intersections. Cyclists and pedestrians tend to choose the most convenient path to get as fast as possible to their target destination. The idea behind desire lines is to give cyclists and pedestrians their way, while enhancing safety and convenience. Desire lines are part of project of consulting company Copenhagenize Co., where the behaviour of cyclists is analysed. During a set time, how cyclists cope with different situations and traffic levels on an intersection is observed. In figure 3.4 the desire lines are visually presented to assess the necessary recommendations for intersection redesign. In that way, the redesigned intersection will serve the natural choices of a cyclist better.

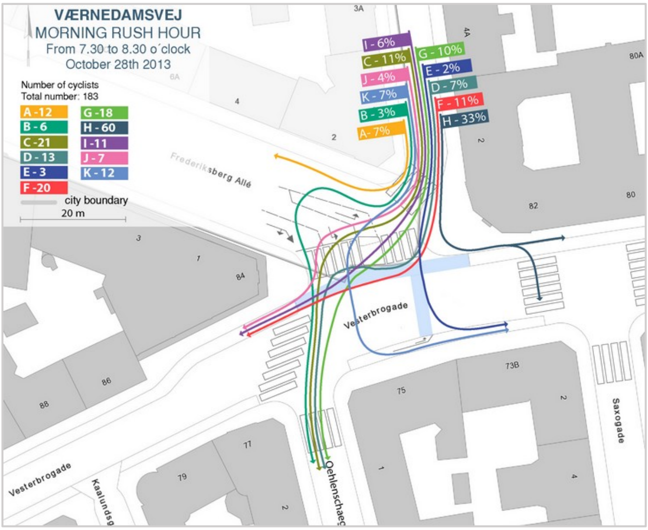


Figure 3.4: Desire lines at the Vesterbrogade intersection

3.2.3 Adding convenience while reducing traffic time

There are still a lot of options left to make bicycle riding more pleasant, convenient and fast. Some examples of those small innovations are the right turn for cyclists at a red light and bicycle footrests at stop lights, as shown in figure 3.5. The ideas are relatively simple and cheap and are a kind of gamification of the daily habits but at the same time they are founded in human psychology and thus really encourage cycling.

Figure 3.5: Bicycle footrest at an intersection

A micro design feature that aims to improve accessibility for cyclists are bicycle ramps. In that way, a cyclist can use stairs for pedestrians to get to elevated city levels. This could be especially useful in places where bicycles traffic is low, because the ramps is a low costs solution to better serve the needs of the bicycles who have to be there.

Perhaps the most important micro design feature that can be spotted along the cycle tracks are the automated bicycle counters. The effect of the counters is twofold. Firstly, the bicycle counters create a sense of ownership and unity among Copenhagen's cyclists. Secondly, the bicycle counters provide excellent information for urban planners who have a better overview over the bicycle traffic flows in the city.

4 Assessing the cost & benefits of the urban policy

4.1 Use of CBA analysis in transportation projects

The planning of thorough new urban sustainable mobility policies is a difficult task for local authorities worldwide. According to the European Commission, the main objectives of sustainable urban mobility are the following (Wefering et al., 2013):

- Ensuring all citizens are offered transport options that enable access to key destinations and service
- Improving safety and security
- Reducing air and noise pollution, greenhouse gas emissions and energy consumption
- Improving the efficiency and cost-effectiveness of the transportation of persons and goods
- Contributing to the enhancement of the attractiveness and quality of the urban environment and urban design for the benefits of citizens, the economy and society as a whole.

For obvious reasons it is essential that a kind of reliable urban mobility system exists in cities. Such a system provides access to services and enables personal mobility. Thus, the system should not only enhance, but is necessary to support a functioning economy (Browne & Ryan, 2011). Considering the main objectives, sustainable mobility can be adopted in multiple ways. One of those ways is public transport, as it serves the main objectives to a great extent. Cycling is another alternative that can help in achieving sustainable urban mobility. To meet all objectives in a city environment a combination of transportation alternatives will probably need to be implemented. In Copenhagen and other cities such as Amsterdam or Utrecht, public transport is ubiquitous. Nevertheless, in those cities, cycling remains a highly prioritised mode of transport to achieve sustainable mobility.

Building a cycling policy requires a wide spectrum of infrastructural and branding measures as previously presented. Also, the attractiveness of cycling appears to be inversely linked to the attractiveness of car driving. Therefore, space designated for car use has to be reconfigured to accommodate growing cycling populations and support cycling identities (Gössling & Choi, 2015; Pucher & Buehler, 2008).

Reconfiguring urban space demands planning and building effort which have inevitable costs. Hence, local authorities have to decide how to spend public funds in the best way possible. "The best way possible" implies a concept called evidence-based decision making. Evidence-base decision making intends to make decisions that reap the most benefits, and are based on ex-ante analysis of a policy's impact (Hüging, Glensor, & Lah, 2014). For this purpose, cost-benefit analysis (CBA) acts as a convenient method to assess projects in an ex-ante manner. If a policy or projects needs evaluation once implemented, a CBA can also be performed in an ex-post manner.

In the majority of European countries CBA is the primary tool to assess transportation investments (OECD & ECMT, 2005). Certain official guidelines exist on how to perform a CBA (OECD, 2018; Sartori et al., 2014). However, CBA techniques can differ significantly because there is a certain degree of freedom in how to perform it. Nevertheless, CBA techniques always refer to one common theoretical framework (Beria, Maltese, & Mariotti, 2012). Essentially, all important impacts of a project are listed and monetized. Monetization is in fact a valuation of a criteria so that they become comparable and people can relate to them. The monetized effects that occur in the future should then be discounted (ex-ante assessment) and added up to achieve the net total benefit or cost of a project.

To ensure this total net benefit or cost is meaningful, indicators such as benefit-cost ratio (BCR) are calculated so that the project can be compared to a best possible alternative. A best possible alternative in practice often means "do nothing" (Van Wee & Börjesson, 2015). For a CBA to be significant, it has to fulfil two hypotheses. The first is the Kaldor-Hicks criterion (Persky, 2001).

According to Kaldor and Hicks allocation of resources is efficient if the surplus obtained by some actors exceeds the surplus losses paid by other actors. Whereas in the scenario of an infrastructural project, surplus is the difference between the willingness to pay for infrastructure and the effort needed to obtain the infrastructure, both expressed in monetary terms. Willingness to pay is actually the perceived benefit an individual designates to a good, in this case infrastructure. The second hypothesis presumes the pricing scheme is marginal, thus not affecting up- and downstream markets. If up- and downstream markets are considered, e.g. the attraction of new businesses along cycling corridor, the analysis would be considered an economic impact analysis. Economic impact analysis takes into account induced and indirect benefits (Weisbrod & Weisbrod, 1997), while CBA only takes into account direct benefits. An example of an indirect benefit is job creation as a consequence of improved accessibility.

Cost-benefit analysis has been a very popular tool for decision-making concerning large infrastructural projects in the past but currently faces several problems. The use of CBA gets increasingly difficult for smaller urban projects. The urban projects nowadays face the challenge of monetizing the environmental impacts of a project. Moreover, it is questioned whether CBA can assess softer policy measures complementing infrastructural sustainable urban mobility policies (SUMP) (Beria et al., 2012). In the subsequent section a more in-depth view on the difficulties of CBA for SUMP and specifically cycling policies will be presented.

4.2 Difficulties for CBA assessing cycling policies

There exists a lot of different criticism regarding the use of CBA for cycling policies. Apart from the obvious criticism that CBA is a method requiring a lot of effort and data, the concerns for its use in bicycle policies originate from environmental and social points of view. The most common criticism states that CBA does not capture all socio-economic impacts of a project (Hüging et al., 2014). This problem is twofold:

The first concern is that some impacts of a policy are practically impossible to quantify or have a scarce economic meaning and are therefore not considered in CBA. CBA thus fails to address all impacts regarding a policy decision and decisions thus have to be made with absence of potentially relevant information. Less tangible impacts such as quality of life, comfort, perceived safety or mental health are frequently neglected. For most of these impacts, a monetary valuation is also nearly impossible.

The second concern is that for several impacts, that can be valued, it remains still difficult to assign a monetary value. Specifically, when no market price is available for a cost or benefit, a monetary value must be assigned using non-market valuation techniques. Those techniques often lack robustness and reliability (Hüging et al., 2014). Furthermore, assigning a monetary value to living organisms raises ethical questions. For example, accident costs can easily be deduced by examining material damage. However, assigning a value to human lives is a lot more difficult and a profound ethical issue.

One could argue that the nature of the impacts presented by a sustainable mobility policy broaden the CBA context and thus complicate its use. For a traditional road project, the impact of not including certain benefits or costs does not affect the decision-making process in a significant manner. If, on the contrary, CBA is used for evaluating an entire cycling policy, all relevant economic, environmental and social impacts should be included in the decision-making process. In this manner, the analysis shows the true economic value of certain projects and could possibly leverage greater public support.

4.3 Cost-benefit analysis for the Copenhagen cycling policy

4.3.1 Identifying relevant impacts

Different impacts have to be considered when assessing cycling policies as there are more stakeholders than just the cyclists alone. In the Copenhagen cycling policy, the stakeholders are the public sector, cyclists (i.e. the users of the infrastructure), new cyclists (i.e. traffic diverted to cycling from other transport modes and society. For each of the stakeholders there are relevant impacts that could be translated into direct costs or benefits as a result of cycling policy measures. In the following paragraphs all impacts that relate to the different stakeholders will be identified and recognised as a cost, benefit or both.

4.3.1.1 The public sector

The public sector comprises of city governments, regional governments and national governments.

Investments Investments are all costs that are made by the public sector and consist of several different investment types. The largest share of investments in a cycling policy are the infrastructural costs though other costs such as promotional costs or maintenance costs are also considered to be investments.

Taxes When a new road opens, a government can choose to raise taxes for the users of this road. Alternatively, it can raise taxes on the possession of a means of transportation. The government can also tax necessary goods or services such as fuel, oil or maintenance under the form of VAT (value added taxes).

Subsidies A government can also choose to subsidize a means of transport in order to facilitate transport access. In most countries, public transport is subsidized. This phenomenon occurs because of government ambitions to provide affordable mobility for its citizens, while operational costs are too high to be covered by ticket prices.

4.3.1.2 Cyclists

Vehicle operating costs Cycling is not free, as it requires a bicycle and maintenance. The operating costs thus comprise the depreciation of a bike, but also the cost of spare parts like tires, cables, oil etc.

Time costs Time is something that is commonly translated into value. Time spend travelling could be used to do something that has more value to someone. Often this is translated into time that has not been used to perform work and thus earn money. Thus, time could be seen as bearing a cost because of the value of the alternative.

Accidents The amount of accidents that occur certainly have an impact on a policy. For a cyclist being involved in an accident could be a cost, depending on insurance policies in a country. The cost comprises medical costs and material damage costs.

Health Several studies show a positive correlation between cycling and health (Oja et al., 2011). Health can be considered as reduced risk for cancer, obesity, cardiovascular diseases and all-cause mortality. It has also been observed that elderly cyclist show reduced deterioration of the immune system (Duggal, Pollock, Lazarus, Harridge, & Lord, 2018). For the cyclist improved overall health is naturally perceived as a positive impact and thus a benefit.

Improved life expectancy Although improved life expectancy is related to better health, the impact for the cyclists does not comprise the same benefits. Better health has an impact over the entire lifespan whereas improved life expectancy allows for extra value at the end of a lifespan. In the sections below improved life expectancy and health will be considered as one entity.

Perceived safety Perceived safety is the feeling of security in traffic, which can have an important impact as it is often mentioned as a factor for using bicycles as a means of transport. The perception of safety is not the same for everyone and factors such as income or gender influence perceptions (Heinen, van Wee, & Maat, 2010).

Comfort A good road surface, coverage from the wind, not having to stop at a red light and availability of bicycle repair points are all factors that influence how comfortable a cyclist feels when riding his bicycle. Although comfort is mainly a personal opinion, policy measures can create favourable conditions for comfort.

Urban open space Urban open space provides room for social interactions, relaxation and aesthetic, environmental or economic functions. It is clear that people tend to attribute value to spaces. Value can either be economic, social, symbolic and differs for different users of space. A cycling policy providing infrastructure for conversation cycling sets a basis for social value creation. People also attribute aesthetic value to places, for instance cycle routes along historical buildings or trough city parks. Open spaces such as parks also have social as well as recreational value.

4.3.1.3 Society, external impacts of policy measures

Not only transportation users benefit or suffer from the effects of policy measures, society does as well. An impact of a policy can be entirely accounted for by society, which means the external costs are fully at the expense of others. For instance, an impact like traffic noise comes at a cost of causing stress or sleeping disorders for multiple people, yet car or public transport users creating a noisy environment don't pay for the negative effects it causes. Because of traffic externalities, the government raises taxes that internalise these costs. In some cases, the cost of an impact is not entirely internalised. For a transportation policy, this means the users of a means of transport does not account for all costs incurred by an impact. For instance, in Belgium medical costs are usually paid for by a health insurance fund, hence if accidents occur not only the victim has to bear the costs. Conversely, society can also gain because of the external impacts from transport, e.g. the reduced medical costs because of healthy cyclist. The impacts below will include impacts that are attributable to cyclist, cars or both.

Health	Society can benefit from the health increase of cyclists because of reduced medical treatment costs and less short & long term absence (Sælensminde, 2004). Because the amount of working days increases also productivity and tax returns for the government increases.
Improved life expectancy	The costs of premature deaths as a result of physical inactivity can be avoided (Gössling & Choi, 2015). Without premature deaths the workforce is higher and therefore there is no productivity loss. Improved life expectancy can also be negative for society due to prolonged pension payments (Gössling & Choi, 2015).
Accidents	Society often bears medical costs or material damage created by an accident depending on the policy of the country. When accidents occur, also public services such as police and emergency services incur costs. The impact of accidents is treated as a cost to society for accidents involving cyclists or cars.

Air pollution Air pollution is a result of pollutant emissions by motorized vehicles, industry and household fuel combustion. Gases containing nitrogen, sulphur and carbon affect human health, agriculture and other ecosystems (Gössling & Choi, 2015). The air pollution also affects buildings containing calcareous stones or ferrous metals (Butlin, 1990). Respiratory diseases are the most visual effects of air pollution. Because of these negative effects air pollution is treated as an external cost for cars.

Climate change Although the impact of the emissions of greenhouse gases (GHG's) cannot directly be noticed by individual citizens, GHG's contribute to climate change and the extreme weather events or rising sea levels it provokes. Being a port city, Copenhagen is very aware of flooding risks by storms and increased precipitation. Copenhagen is already implementing their climate change adaptation plan, that incorporates everything from weather measurement and building prescriptions to waste water management and drainage (City of Copenhagen, 2011).

Noise Noise is often overlooked as an important environmental impact, actually this not so silent killer accounts for an estimated 45.000 years lost in terms of morbidity and mortality in western Europe (WHO, 2011). Epidemiologic studies found that noise annoyance, sleep disturbance and cognitive impairment are a direct consequence of noise exposure (Münzel, Gori, Babisch, & Basner, 2014). It has also been observed that chronic exposure to noise can increase the risk for cardiovascular diseases such as hypertension or arteriosclerosis due to an imbalance in the human cardiovascular system (Basner et al., 2014).

Congestion Congestion is the phenomenon that takes place when the demand for transportation is bigger than the supply, i.e. the capacity utilisation of a road network has surpassed its maximal capacity. Congestion is typically a problem for cars because it involves single economic agents making use of a scarce public resource, the road infrastructure. It can be defined as the deadweight-loss in economic welfare theory (COWI, 2004). In a city with high bicycle use and a low capacity, congestion for bicycles is possible. However, as far as one can tell from literature review, the congestion costs for bicycles have not yet been valued.

4.3.1.4 Migrated cyclists

Migrated cyclists are those cyclists that started using a different means of transport because of the policy or infrastructural change. For a bicycle policy this means of transport would naturally be a bicycle. To understand why a car driver or a public transport user would switch to cycling, a linear transport demand and supply graph should be examined. In figure 4.1 the demand graph is portraited as Qd. The demand graph represents the willingness to pay for a trip on a bicycle. The supply graph in a reference scenario is shown as Qs0. The supply and demand graph intersect at equilibrium price which is the generalised travel cost (GTC) at a certain number of trips Q_0. In this case, the GTC represents time value, operational costs and possible taxes or tariffs. If the willingness to pay for transport of a consumer is higher than the GTC, the consumer will decide to use a form of transport. The difference between the willingness to pay (i.e. demand curve) and the GTC is the consumer surplus and represents welfare in economic theory. The consumer surplus is represented by the enclosed area under the demand graph Q_d and above GTC_0.

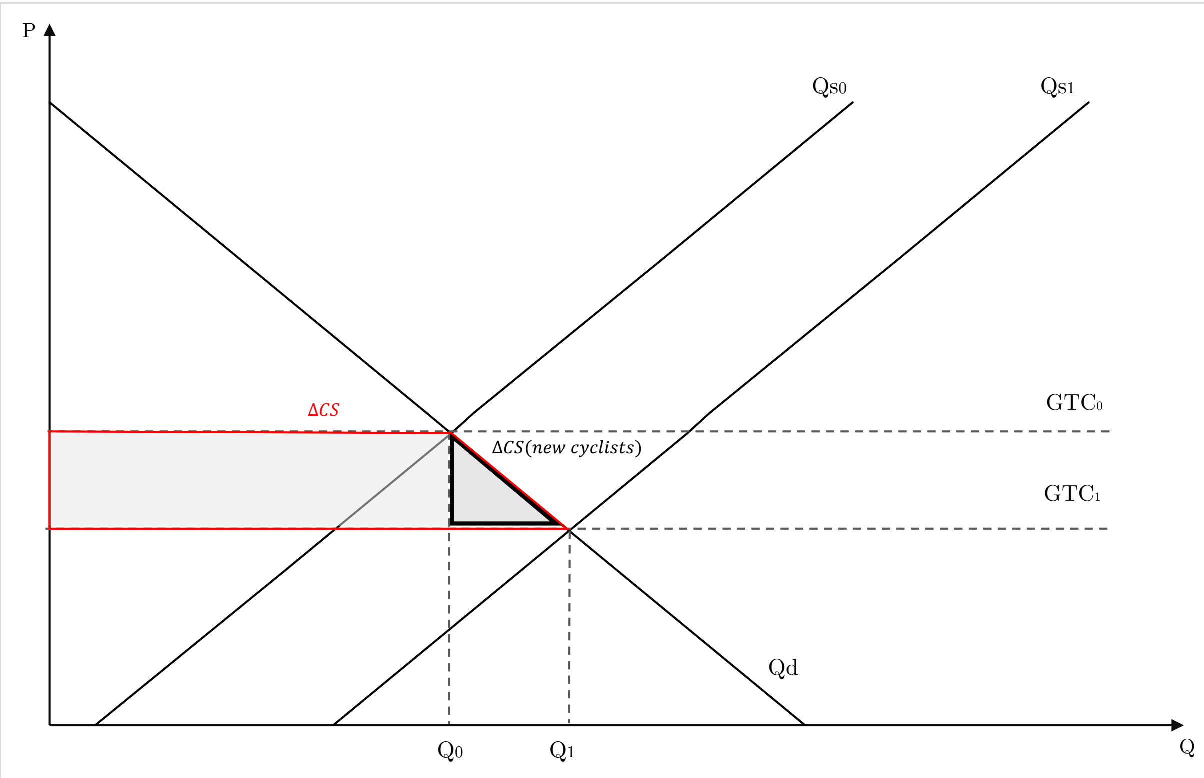


Figure 4.1: Demand and supply-curve for bicycle trips

Because of policy improvements, it is possible that trip time improves, or operational costs go down. As a result, the supply graph will shift and form a new equilibrium at the intersection of Q_d and Q_{s1}. The GTC is now lower. The consumer surplus has thus increased and is represented by the difference between the willingness to pay and the new GTC. The consumer surplus has increased for cyclists who were already cycling while new users started cycling because their willingness to pay for a trip by bicycle is now higher than the GTC. The total extra consumer surplus ΔCS because of the policy is calculated with equation 4.1 below (Sartori et al., 2014) and is visually presented by the trapezoid area under the Q_d graph in figure 4.1.

$$\Delta CS = \int_{GTC_1}^{GTC_0} Q_d(GTC)dGTC = \frac{1}{2}(GTC_0 - GTC_1) * (Q_1 + Q_0) \tag{4.1}$$

The consumer surplus generated by the new or migrated cyclists can be approximated by equation 4.2:

$$\Delta CS(new\ cyclists) = \frac{1}{2}(GTC_0 - GTC_1) * (Q_1 - Q_0) \tag{4.2}$$

Because of this, the consumer surplus for an infrastructural improvement that transfers users from another mode of transport to cycling is equal to approximately half the benefit of an existing cyclist. In cost-benefit analysis this is known as the rule of half (RoH). It can be used of supply conditions improve. However, in case of totally new infrastructure, the supply conditions are totally new, thus the rule of half is not applicable.

In addition to this, transferred cyclists coincide with a decrease in other means of transport. As a consequence, every transferred cycle-km implies avoided external costs of other modes of transport. The reduction of congestion, air pollution, climate change, noise pollution and accidents will count as a benefit for the policy change. In further sections, the consumer surplus of new cyclists will not be calculated as a result of several assumptions that will be explained later.

4.3.2 Valuating relevant impacts

In order to make an economic analysis of the impacts of a bicycle policy, the impacts will be translated into costs and benefits. Valuating impacts with a monetary unit of measurement allows users to compare certain impacts in a complete analysis. For the purpose of conformity, the 2019 DKK will be used as unit of measurement unless otherwise stated. The Danish krone uses a fixed exchange rate system with the Euro, which ensures comparability between the Danish values and other values in European Union countries. Apart from the monetary units, it is impossible to compare the benefits of a 2-hour train drive with a 10-minute bicycle ride. The impacts of both transportation methods can only be compared if they have a shared basis. In its CBA's Copenhagen uses travel kilometres as a basis of comparison, thus costs or benefits are always denounced as per km costs. For the sake of simplicity and because kilometres are an excellent basis of comparison for projects involving transport, the costs and benefits will be stated as per km. This is called a unit cost. Naturally, negative unit costs represent real life benefits.

If costs or benefits relate to a tradable product or service, market prices are usually available for calculations. A good example is the operating cost of a car, which depends on market prices for goods such as fuel, oil, rubber and maintenance working hours. However, because of market distortions such as imperfect markets, fiscal requirements and administered tariffs the prices fail to reflect the true social opportunity costs, i.e. the opportunity costs taking into account private costs as well as externalities for society. Moreover, for some consequences of a policy or project no market prices are available (e.g. Noise pollution, time savings, air pollution) (Sartori et al., 2014). Another example are accident costs, which lack market prices for obvious ethical reasons, i.e. human lives tend to be not tradable. In order to attribute a certain value to those consequences that are not market tradable, methods estimating a person's willingness to pay (WTP) or a willingness to accept (WTA) exist.

To estimate WTP or WTA three main methodologic categories exist (Sartori et al., 2014). The revealed preference method, the stated preference method and benefit transfers. Each methodological category contains a few frequently-used methodologies for valuating impacts.

4.3.2.1 Revealed preference methodologies

Revealed preference methods measure is based on the measurement of actual behaviour and purchases in actual markets. The most common methods are hedonic pricing and travel cost method.

The concept of hedonic pricing was introduced in 1974 by Sherwin Rosen. The principle is based upon the assumption that each price of a good can be decomposed in accordance with its characteristics and that a price for the characteristics can be found as the marginal cost (Rosen, 1974). The best-known example for hedonic pricing is the use of housing market prices in order to determine noise or air pollution. Noise and air-pollution are assumed to be one of the characteristics determining housing prices.

The travel cost method values particular locations by deriving a consumer willingness to pay to access the particular location (Sartori et al., 2014). If someone regularly visits a nature reserve this willingness to pay can be calculated by considering the costs of the trips that are incurred because of the visits.

4.3.2.2 Stated preference methodologies

Stated preference methodologies depend on people's opinions. The methodologies are always survey-based and can therefore be applied on almost every impact that needs a valuation. Nevertheless, there tends to be a lot more ambiguity because the results of a survey are often dependent on the study design (Sartori et al., 2014). There is also a possibility that people do not fully understand the survey or do not want to value certain goods or impacts (for instance human life value).

The two most common methods are contingent valuation and discrete choice modelling (Johnston, Rolfe, Rosenberger, & Brouwer, 2015).

For contingent valuation respondents are asked to assign a monetary value to a good directly. However, the survey is structured in such a way that the respondent's behavioural profile is known, and that the respondent has a profound understanding of the contingent scenario he is asked to evaluate (Sartori et al., 2014).

Choice modelling allows a respondent to rank certain goods with their attributes according to their preference. The respondents have several descriptions of a good and are asked to assign a preferred ranking. One of the attributes of a good is its price, whereby the willingness to pay can be modelled directly from the respondents ranking (Sartori et al., 2014).

4.3.2.3 Benefit transfer method

The benefit transfer method relies on previous studies to predict welfare estimates for unstudied policy sites (Johnston et al., 2015). There are several approaches to this benefit transfer method and estimates should be scaled and their accuracy should be verified. Because of the different policy environment, it is advisable that values are adapted to geography, population etc. Benefit transfer methods include benefit unit transfer and benefit function transfer. Unit transfer assumes a value i.e. WTP per unit (for instance km) and that is transferred to a new context. Values can be used as they are or adjusted to different factors such as culture, income or currency. Either way the values should be adjusted to the population size or the scope of a policy or project. Benefit function transfer makes use of a benefit function based on parameters in a previous study. When those parameters are available for the desired policy, the benefit function can be used to calculate the benefit in the new situation.

4.3.3 Unit values for Copenhagen

The previously mentioned relevant impacts can be valued for the Copenhagen region for the purpose of a cost-benefit analysis. The Danish ministry of Transport has developed a spreadsheet-model called TERESA for calculating costs and benefits of traffic infrastructure in 2004. The spreadsheet contains unit values for travel time, operating costs for vehicles and external costs of traffic. It has been adapted continuously to comply with more accurate parameters for the valuation of the unit values.

In 2013, unit values for bicycles were added. However, the spreadsheet mentions that the unit values for bicycles should only be used for rough socio-economic estimations of the effect of bicycle interventions. The spreadsheet also shows projection for unit costs till 2090, that way projects can be evaluated ex-ante when traffic levels are estimated. The unit values are relatively uncertain and possibly underestimated because the lack of knowledge of several costs and benefits concerning cycling. table 4.1 gives an overview of the unit values, their cost elements and their method of valuation. The methodologies will be mentioned but not discussed further. Readers with interest in the exact valuation methods used by the Danish can find information in "External Costs of Transport - 1st Report - Review of European Studies" by the Danish Ministry of Transport (COWI, 2004). Note the dose response method and human capital cost approach have not been explained earlier but can also be found in the report from the Danish Ministry of Transport.

Table 4.1: Danish unit values used for transport CBA with their cost elements and valuation method, Source: TERESA v1.8

Cost component	**Cost elements**	**Valuation method**
Time	Alternative travel modes	Willingness to pay
Vehicle Operation	Depreciation Maintenance	Market values
Accidents	Material damage Loss of productivity Deaths & injuries Public expenditure (police, rescue)	Willingness to pay Human capital cost approach
Congestion	Delays (weighted time cost)	Willingness to pay
Air pollution	Health Agricultural damage, building damage (not included)	Impact pathway method Dose-response method
Noise	Health, annoyance	Willingness to pay
Climate Change	Greenhouse gases	Market value*
Road deterioration	Road maintenance costs	Market values
Health	Sick leave days Medical treatments Life expectancy	Avoided costs

* Market values of greenhouse gases (GHG's) are determined by the European emission trading system and depend on the willingness to pay to emit GHG's. Greenhouse gases comprise different substances which are all expressed in CO_2 equivalents.

The values for costs and benefits are not always readily available in DKK per km and thus have to be deducted from several parameters. Therefore, there are considerations to be made. Considering the values for time, the purpose of the trip has to be taken into account (i.e. commuting, business or other), as the valuation of time in a working environment can be significantly higher. Thus, the cost for time has to be multiplied with the distribution for trip purposes. The calculation of the unit value for time in person hours is illustrated in table 4.2. To convert that cost into DKK/km an average speed of travel has to be assumed. In Copenhagen a speed of 16 km/h is used for bicycles and a speed of 50 km/h is used for cars.

Table 4.2: Calculation of the unit values for time in DKK/person hour

DKK/person hour	**Bicycles**		**Cars**	
	Time Value	Trip distribution	Time Value	Trip distribution
Commuting	93	44,2%	93	25,4%
Business	396	2,2%	396	11,1%
Other	93	53,6%	93	63,5%
Total	100	100%	127	100%

Another consideration that has to be made considers the capacity and occupancy rate of the different means of transport. For bicycles this is fairly straightforward 100% but for cars and busses, the situation is different. While cars have a capacity of 4 persons per vehicle, most of the time they don't carry as much passengers. According to a road directorate transport habit survey, the weighted average occupancy for cars is 1,42 passengers per vehicle. For the purpose of simplicity, a 25% occupancy rate for cars will be assumed. That way, all costs are entirely attributable to the car driver.

The last considerations to be made, deal with the vehicle operation costs. Similar to trip purposes for time costs, vehicle operating costs for cars depend on the type of vehicle (i.e. personal or business). For cars, vehicle operation costs also depend on taxes, such as import tax, vehicle registration tax, fuel taxes, etc. Since the unit values represent marginal costs, some taxes such as registration tax are not relevant in CBA. In table 4.3 a breakdown of the vehicle operation costs and the taxes are given.

Table 4.3: Breakdown of unit costs for vehicle operation

DKK/km	Excl. VAT	Incl. VAT
Fuel	0,345	0,792
Battery (hybrid & EV's)	0,001	0,001
Tires	0,076	0,094
Repair & maintenance	0,375	0,551
Other Taxes	-	-
Depreciation	0,099	0,236
Total	**0,895**	**1,675**

Because the unit costs are marginal and other taxes such as import tax or registration tax should not be taken into account, the taxes are represented by the ubiquitous value added taxes or VAT.

For the external costs, i.e. costs for accidents, air pollution, climate change, noise, congestion, road deterioration and health, no extra considerations are required. The external costs are readily presented in DKK/km in the TERESA catalog. However, up until now, it has not been mentioned that the external costs for bicycles are in fact average instead of marginal. The unit values are average because, up until now, marginal values for bicycles have not been calculated. Despite this, for calculations and in summaries below, the unit costs for bicycles will assumed to be marginal. Since bicycles have considerably less fixed costs than cars, the effect of the assumption is nearly negligible.

In table 4.4 the unit values for the bicycle and car are summarised. The tax is mentioned separately as it is a government attempt to internalize external cost of cars. The taxes per km are illustrated as a negative unit cost. This indicates that taxes are actually a benefit to society. This is only valid if we consider the government as a part of society and assume that the received funds are used to counter the external costs of cars, for example by planting trees or making traffic safer.

Table 4.4: Danish unit values in DKK/km per person for bicycles and cars

DKK/km	Bicycles (16km/h)		Cars (50km/h)		
	Internal	External	Internal	External	Taxes
Time	6,25		2,54		
Vehicle Operation	0,39		1,68		-0,78
Externalities					
Accidents		1,16		0,33	
Congestion				0,41	
Air pollution				0,05	
Noise				0,08	
Climate Change				0,01	
Road deterioration				0,01	
Health	-7,41	-3,64			

Note: Health is considered a positive externality for cycling, yet it also has an internalised component

An informed reader might notice that the unit costs for health seem quite high compared to some years ago. The main cause for the high values is that the value of statistical life was raised by 70% in 2017 by the Danish ministry of finance. Currently the value is set at approximately 35,5 million DKK. The greater part (71%) of the internalised health benefits are calculated with the value of statistical life and the increased life expectancy due to physical activity, as a result the unit value rose accordingly.

Some of the above unit values are susceptible for debate in different ways but give some important insights as well. First of all, it should be noted that the unit values are calculated for average conditions. This implies external costs for accidents, congestion, air pollution, noise, climate change and road deterioration are significantly lower than during rush hour. As a consequence, it seems the externalities caused by cars are almost fully internalized because of taxes. However, the truth is more complex. In peak hour congestion costs amount up to 1,64 DKK/km which absorbs the entire tax share for cars. Other external costs also tend to rise in peak hours and in addition to that, the external costs for air pollution and climate change do not represent the real social cost. For air pollution, agricultural damage such as crop losses and building deterioration because of sulfur gases are not included in the costs. For climate change, it is well known that the real social costs of carbon dioxide are much higher than the market value for which CO_2 is traded in the European emission trading system.

Another concern are time costs for cars, which are questionable because an average speed of 50 km/h for cars is assumed. It is quite probable that average speeds during peak times or because of speed restrictions in city centers are significantly lower. From a policy-maker perspective the importance of travel times in economic evaluations opens up opportunities. By enabling bicycles to move faster trough a city, time costs are reduced, and bicycles become more competitive relative to cars. The time savings probably also don't go unnoticed by the car drivers and give several doubters an incentive to switch to a bicycle for their daily commute. This phenomenon can be linked to section 4.3.1.4 where the GTC decreases as a result of improved travel conditions.

In addition to unit values for cars, the unit values for bicycles can also be compared with those for busses. In table 4.5 the unit values for busses are presented next to the unit values for bicycles. In the TERESA catalogue, busses are assumed to have a capacity of 40 persons. A capacity utilisation of 100% can never be attained, thus in table 4.5 an occupancy rate of 75% will be assumed. The operating costs of busses depend highly on the trajectory and bus operator. For Copenhagen, 2017 values from the Danish transport, construction and housing authority were used describing key figures of bus operator Movia. The average speed for Movia busses was 25,8 km/h. Operating in the busy capital, the Movia busses are slower than those of other operators. Still the maximum average speed among operators is only 38 km/h. For vehicle operation costs of buses, the total operational expenses are divided by the total bus-km's times 30 passengers per bus. The division between internal costs and subsidies are determined by a 48% passenger finance ratio (Danish Technical University & COWI, 2018).

Table 4.5: Unit values in DKK/km per person for bicycles and busses

DKK/km	Bicycles (16km/h)		Bus (25,8km/h)		
	Internal	External	Internal	External	Subsidies
Time	6,25		4,40		
Vehicle Operation	0,39		0,46		0,49
<u>Externalities</u>					
Accidents		1,16		0,02	
Congestion				0,03	
Air pollution				0,06	
Noise				0,01	
Climate Change				0,00	
Road deterioration				0,02	
Health	-7,41	-3,64			

*Based on received regional grants and municipal subsidies by Movia for their bus operations in 2017

For public transport the capacity utilization is certainly not unambiguous, as there are probably busses that are less frequently used or busses that are full continuously. As a consequence of inefficient use of capacity, the unit costs for busses would rise and therefore busses would be less competitive compared to other means of transport. However, the Danish public transportation actors Movia, DSB, Rail net Denmark and Metroselskabet's efforts for fares and timetable planning are coordinated through the mechanisms of ownership, contracts and partnership and are often successful (Sørensen, 2018). Nevertheless, efficiency is of vital importance for public transport companies, because external costs who are otherwise relatively modest would rise dramatically and revenue from tickets would fall.

4.3.4 Non-Monetary variables

Besides policy impacts that have no direct market value, there are also impacts that are nearly impossible to assign a monetary value to. Such impacts are called non-monetary variables. They should however not be excluded from the decision-making process. People can attribute value to a number of things, sometimes without it being the welfare maximizing decision. The bottom line is that preferences differ but there is a general trend in how people can appreciate an impact of a project. In 2009 consulting company COWI advised to include impacts such as discomfort, perceived safety, recreational value, branding and value for urban open space in CBA's for cycling projects (COWI, 2009). Other important but frequently overlooked impacts of transport policies are social inclusion and quality of life (Beria et al., 2012). For cycling projects, social inclusion is debatable as cycling requires a considerable investment in a good bicycle for daily transportation. Quality of life in fact encompasses most of the other impacts mentioned by COWI.

While some of the impacts seemingly have nearly no economic value, the truth is different. There might be some indirect effects. If the perceived safety and recreational value of a cycling commuter would be high while the experienced discomfort would be low, this could reduce stress and increase the productivity of the city's population. Another impact where economic value is arguable is the impact of urban open space or green space. It is considered to be natural asset (Chiesura, 2004), as it provides services such as air- and water purification and a possibility for leisure activities and social interaction. Also, the psychological impact in terms of well-being and stress relief of urban open space should not be underestimated. The question remains however, whether those impacts are significant enough to impact the results of cost-benefit analyses.

If one thing should be said about non-monetary variables, it is that the desirability of a transport project should not be based on the outcome of a CBA alone. Along with the economic performance other factors that ensure a livable city are also important. Several authors recognize this importance and have created models such as the 5E-model for public transport (van Oort et al., 2017) to capture the full value of transportation. "5E" stands for environment, economy, equity, efficient mobility and effective use of space, which have all become incredibly relevant in 2019.

4.3.5 How Copenhagen uses CBA

Because of the intrinsic data needs a cost-benefit analysis requires, it is nearly impossible to do an analysis of all the projects in a city. Another barrier for performing CBA's is the uncertainty concerning the actual use of infrastructure before it has been built. Traffic levels on new bicycle bridges are always predictions and therefore partly uncertain. Also, the amount of people replacing their car as their main means of transportation is uncertain but could be estimated if the demand cross elasticity for the car and bicycle is known.

Partly because of the substantial need for data, it makes sense that the city of Copenhagen mainly uses CBA to evaluate a project after it has been completed. In a way, the cost-benefit analysis is a manner to gain public support for cycling and other projects. Cost-benefit analysis was implemented in Copenhagen to professionalize the cycling policy administration. Moreover, the manager who implemented CBA deemed a socio-economic approach necessary to be able to communicate with the transport planning community (Jensen, Cashmore, & Elle, 2017). In 2009 the city of Copenhagen appealed to consulting company COWI to develop a methodology for cost-benefit analysis for cycling projects. The previously mentioned unit values where calculated by COWI and are now, albeit updated, still adopted for cycling-CBA. In its yearly publication of the bicycle account the city of Copenhagen also frequently mentions the economic gains that can be harvested by one extra km of cycling. Another thing that is frequently published to gain support is the health component of the cycling gains. This is arguably a way to leverage public support for cycling but mentioning health benefits in an economic manner is actually branding for a cycling policy in its entirety.

That being said, recently the Danish road directorate and the city of Copenhagen have asked Danish researchers to improve the capabilities of modelling bicycle traffic in their Ørestad Traffic Model (OTM) relative to car traffic and public transport. The updated model will be based on a route choice model and a bicycle demand model. The model has been tested against a newly opened bicycle bridge and the idea is to use the OTM as a decision-making tool to assess the costs and benefits of a bicycle project (Anders Tønning, personal communication, March 13th, 2019). If this model would actually be used in practice, it would allow bicycle planners to perform more accurate ex-ante CBA's of bicycle projects and professionalise bicycle planning.

4.3.6 Costs per km for the different transportation modes

The unit values in section 4.3.3 can now serve as a basis of the total benefit or cost per km as a result from an increase in bicycle traffic. By calculating the total benefit per extra km of cycling, car driving or bus riding it is easy to compare several modes of transport. In the yearly bicycle account Copenhagen frequently publishes these numbers, which indicate a clear economic potential for the bicycle. Hereby, the city of Copenhagen can justify its investments and its 50% modal share goal for cycling commuters. To illustrate its relevance there are five distinct scenarios. Firstly, the benefit of 1 km of extra cycling. Secondly, the cost of 1 km extra driven by car. Thirdly, the cost of 1 km extra bus driving. And lastly the benefit if one km by car or bus would be replaced by one km of cycling. With the unit values, those 5 scenarios can now easily be deducted.

4.3.6.1 1 extra bicycle-km

The costs for the cyclists are mainly time costs and operating expenses. The health benefits for the cyclists surpasses the costs. Thus, in total, the cyclist gains 0,77 DKK for every cycled km. Only a few costs of cycling are considered external. Accident costs are attributable to society as there are medical costs that have to be paid by social security or costs for intervention of public services (fire brigade, police, ambulance, etc.). Thus, the entire society loses money. It is assumed that society pays all accident related costs, while in reality, these costs are partly internal. The benefits for society are caused by the increased health of the cyclist. The benefits are in fact reduced costs because of increased productivity of employees, less sick days which implies more tax income and eventually reduced medical costs paid by social security. The societal benefit adds up to 2,48 DKK/km. Given the speed input parameters, the total socio-economic gain for a km of cycling is equal to 3,25 DKK. In table 4.6 the socio-economic costs for 1 new cycling km are summarised.

Table 4.6: Socio-economic costs for an extra km of cycling

	Cost per new bicycle km
Personal	-0,77 DKK
Societal	-2,48 DKK
Total	-3,25 DKK

4.3.6.2 1 extra car-km

As for cyclists, one km of extra car driving implies also time and operating costs, but the health benefits incurred by cycling are no longer present. Also, from a personal point of view, the operating expenses are understandably higher, which makes car driving more expensive than cycling. The personal costs per new km add up to 4,22 DKK.

As opposed to cycling, society also bears significantly more external costs. The externalities associated with car driving are costs for accidents, air pollution, noise pollution, climate change, road deterioration and most importantly, congestion. It should be noted that accident costs related to car driving are far less than those related to cycling. Naturally, this is a consequence of the cage protection a car provides for its driver. In a bid to internalise the external costs, the government raises VAT on the vehicle operation costs. The exact values were previously shown in table 4.3. After tax deduction, the societal costs equal 0,11 DKK/km. But as said before, during rush hour this cost rises rather fast. Because of congestion the societal cost per new km would be equal to 1,34 DKK. For averages conditions the total social economic cost equals 4,33 DKK/km. In table 4.7 the socio-economic costs for an extra km of car driving are summarised. In addition to the average conditions, also a peak hour scenario is added. For this, a car speed of 30 km/h is assumed, which increases the time costs.

Table 4.7: Socio-economic costs for an extra km of car driving

	Cost per new car km
Average Conditions	
Personal	4,22 DKK
Societal	0,11 DKK
Total	4,33 DKK
Rush hour	
Personal	5,91 DKK
Societal	1,34 DKK
Total	7,25 DKK

This simple table gives an excellent idea why congestion is such a big loss for society. At the same time, it also clarifies why politicians are often in favour of better traffic flow and expansion of the existing road network. This estimate implies an extra car km costs up to 67% more in rush hour than in average conditions.

The main reason why cost-benefit analysis for projects favouring cars, give a high socio-economic return are the time benefits. This common knowledge might not be as interesting anymore as it once was. While a road network in a city such as Copenhagen bounces upon its capacity limitations, infrastructural adaptations provide individual time savings for motorists in the short term. However, empirical evidence shows that in the long term those savings tend to disappear because the increased access provided by the infrastructure is used to travel further distances (Metz, 2008). That, in turn, should increase the external costs caused by cars even further.

4.3.6.3 1 extra bus-km

From a personal point of view public transport is not as cheap as it may appear in table 4.5. The unit costs give an average perspective as they take into account ticket revenue per km for all driven bus km's. However, for a passenger, in most cases ticket prices will be higher than the per km internalised unit cost because capacity utilisation is not optimal and different tariff formulas exist. If calculated with the unit values, the personal cost of taking the bus equals 4,84 DKK/km. The societal costs on the other hand can be calculated accurately as a per km cost. Per km, the regional and municipal government subsidize 0,49 DKK for bus operator Movia. As opposed to car driving the external costs of public transport are relatively modest because the costs are spread out over multiple public transport users. The societal cost of an extra km driving by bus is 0,63 DKK. A large part of this costs is attributable to government subsidies. A more efficient public transport system could partly reduce this cost. The total socio-economic cost of taking the bus equals 5,47 DKK/km. The socio-economic costs are summarised in table 4.8 below.

Table 4.8: Socio-economic costs for an extra km of bus driving

	Cost per new bus km
Personal	4,84 DKK
Societal	0,63 DKK
Total	5,47 DKK

Using public transportation remains interesting from a spatial efficiency point of view. The benefits of public transport also stretch beyond the merely economic ones. Non-monetary benefits such as comfort or value for urban open space, which is inherently coupled to public transport because of its spatial efficiency, should be taken into account.

4.3.6.4 1 car-km replaced by 1 bicycle-km

If one km of car driving would be replaced by one km of cycling, the internal costs and benefits for cyclists would be preserved, while the internal costs for cars is considered to be an avoided cost. This means that the personal benefit for a cyclist transferred from a car equals 4,99 DKK/km. The benefit for society can be obtained by adding the avoided external costs of 1 km from car driving to the external costs of cycling (which are already negative, because of health benefits) and correcting for tax losses. The benefit for society adds up to 2,59 DKK for a km transferred from car driving to cycling in average traffic conditions. In total, the socio-economic gain is thus equal to 7,58 DKK per transferred car km. The socio-economic costs are summarised in table 4.9 below. An additional scenario for peak hours is added, whereas the speed for cars is assumed to be 30 km/h.

Table 4.9: Socio-economic costs for a transferred km of car driving

	Cost per transferred car km
Average Conditions	
Personal	-4,99 DKK
Societal	-2,59 DKK
Total	-7,58 DKK
Rush hour	
Personal	-6,68 DKK
Societal	-3,82 DKK
Total	-10,5 DKK

4.3.6.5 1 bus-km replaced by 1-bicycle km

Coinciding with a km of car driving replaced by cycling, the societal costs consist of the costs of cycling minus the avoided external costs caused by the bus. The difference between the bus and the car is that instead of having a tax distortion loss by transferring a km from car to bicycle, society gains because of reduced government spending. Presuming the subsidies granted by the government are variable in accordance with the amount of km's driven by the bus operator, the societal benefit is equal to 3,11 DKK.

The personal benefit for the cyclist is calculated in the same way as for a migrated car km's. The personal benefit of transferring from bus to bicycle is 5,63 DKK/km. The total socio-economic benefit equals 8,47 DKK/km transferred from bus to bicycle. The socio-economic costs are summarised in table 4.10 below.

Table 4.10: Socio-economic costs for a transferred km of bus riding

	Cost per transferred bus km
Personal	-5,63 DKK
Societal	-3,11 DKK
Total	-8,47 DKK

4.3.7 Costs per km breakdown by cost components

The personal costs and benefits for the first three scenarios are portraited in figure 4.2. The costs are shown as broken down by their components and as the resultant cost or benefit. In accordance with the above values, the benefits are shown as negative costs. Note the health impact of cycling is proportionally high in comparison with other impacts. If the transport modes are considered from a personal point of view, thus only taking into account internalized costs, the bicycle is the only mode with a net benefit. Time costs are higher for bicycles, but the health benefits and low operational costs counteract this.

As previously seen in table 4.4, the health benefit of 7,41 DKK/km is impressive. In euros this would approximately be € 1 per km. Although not directly noticeable for the cyclist, on a yearly basis this adds up to a reasonable amount.

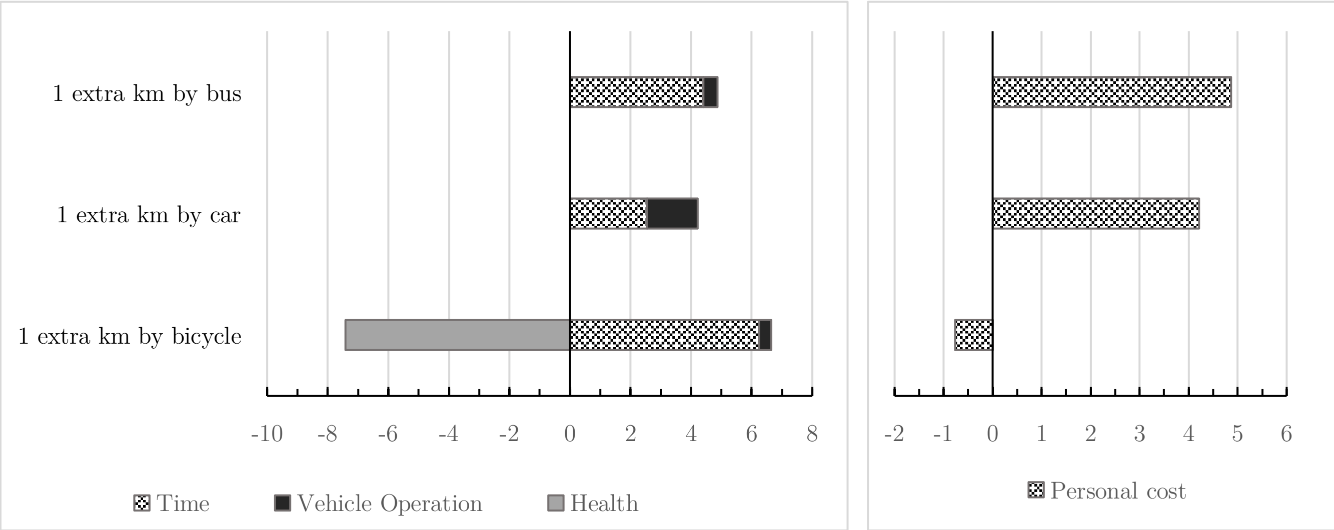


Figure 4.2: Internalised costs in DKK/km for the three transport modes

In the same manner, the societal costs for the three transport modes, and the transfer scenarios are shown in figure 4.3. The external costs for accidents, congestion, air pollution, climate change and noise are aggerated as external costs.

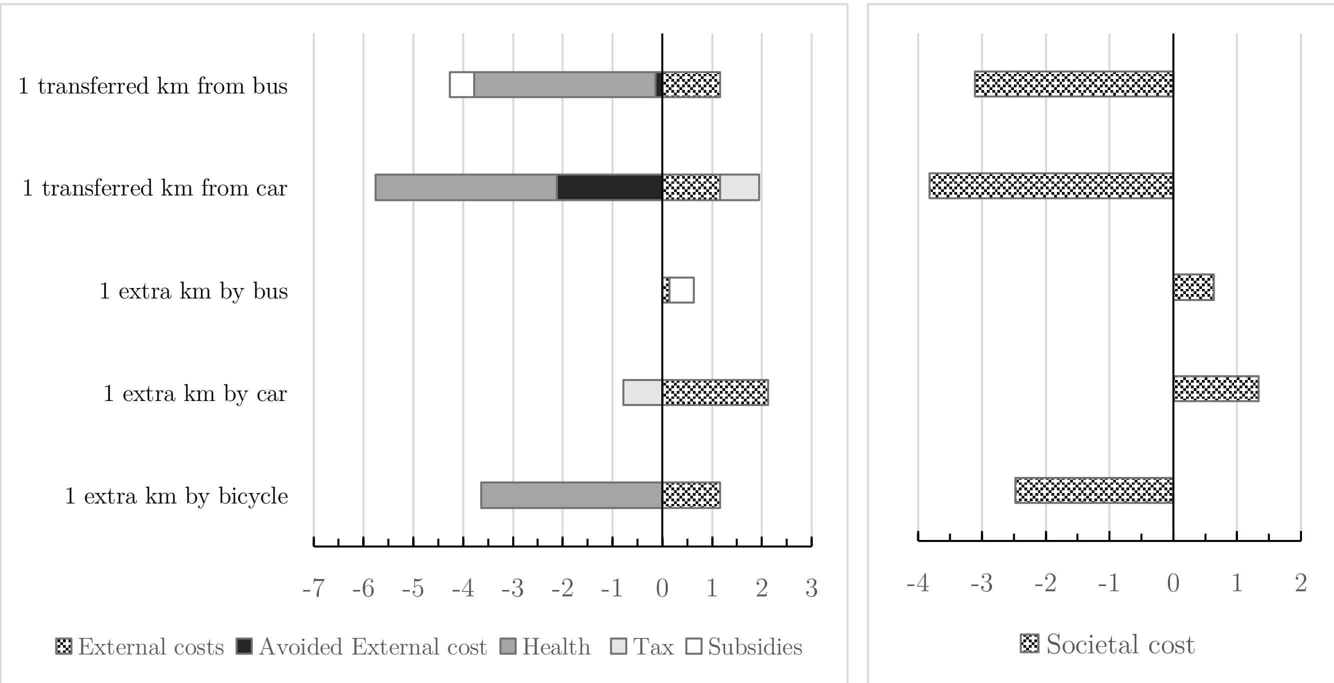


Figure 4.3: Societal costs in DKK/km for the 5 distinct scenarios

Overall, cycling appears to be the best alternative as a mode of transport from an economic point of view. The extra health generated by cycling is the main driver for economic gains and Copenhagen has taken full advantage of this. However, the above considerations are far from a full-scale socio-economic cost-benefit analysis. In a full-scale cost-benefit analysis, the effects are usually attributable to a distinct scenario, such as time savings. As a result, the fiscal consequences for the public sector and the productivity gain because of time savings have to be considered. For example, a gain for the public sector because of increased public health can result in lower taxes which in turn increases labour supply. Also, a full-scale cost-benefit analysis takes into account time preference, which represents the opportunity cost of capital. The unit values for cycling can be used in CBA's if more accurate numbers are not available. In next section, an estimate of the bicycle policy related socio-economic gain will be made using the above per km costs and benefits calculated in previous sections.

4.3.8 Cost-benefit analysis for the Copenhagen policy

An ex-post CBA for the entire bicycle policy of Copenhagen might be near to impossible, as all individual traffic effects of different infrastructural adaptations would have to be taken into account. This requires a great amount of data that is not available. However, the unit values of cycling provide an excellent basis to estimate the total socio-economic gain. Prior to the actual CBA, several assumptions are made. Firstly, the calculation period for the cost-benefit analysis stretches between 1996 and 2017, as for these years traffic data was available. Secondly, in accordance with the Danish Ministry of Transports' recommended discount rates for large projects, a discount rate of 4% is adopted. All costs and benefits will be actualised to 2019 price level. Finally, the costs of investments prior to 2004 are not known. Consequently, the lowest investment level of 2005 will be assumed for the years 1996 until 2003 and adapted for inflation. The used assumptions are summarised in table 4.11 below.

Table 4.11: Economic assumptions for the CBA

Calculation period	**1996-2017**
Discount rate	4%
Price level	2019
Lowest investment level (2005)	20 mln. DKK

For readers who are not familiar with the concept of a discount rate, in brief, a discount rate represents the opportunity cost of capital. For example, the return on a risk-free government bond. For social projects, the social discount rate (SDR) is used. The SDR represents the opportunity cost of capital for society as a whole (Sartori et al., 2014). This discount rate is usually higher than a traditional discount rate, used for investment analysis. One could argue that for social projects the time preference is higher, because possible positive impacts that are related to a project have not yet been discovered. For example, in the future researchers might find that cycling had more health benefits than originally assumed or that the cost of climate change is higher than previously estimated.

A difficulty for performing CBA is that the exact benefits and costs because of the policy investments are not known. When the per km values are used to estimate the total socio-economic benefit, the km's that arose because of the policy can be estimated. For this, the amount of km's cycled in 1996 is taken as a reference level. Thus, every year with more km's than 1996 has additional km's which will later be translated into costs and benefits with the unit values. The yearly cycling level is calculated by extrapolating the amount of km's Copenhageners cycle on a weekday for a whole year. Because there is no commuting, weekends and public holidays are considered to have half the bicycle traffic of a weekday. Thus, the total yearly km's equal the total amount of "cycling days" multiplied with the amount of km's ridden on a weekday. A breakdown of the "cycling days" is illustrated in table 4.5 below. Note, that data was only available for every two years, traffic levels in un-even years have been interpolated.

Table 4.12: Calculation of the amount of "cycling days"

	Days	**Cycling days**
Work	252	252
Weekend	104	52
Public Holiday	11	5,5
Total	365	309,5

Because specific time gains are unknown, the effect of this gains can also not be calculated. Also, the time gains for car users who transferred from cars to bicycles are not known. This implies that the change of GTC is unknown, so the consumer surplus is not known. Therefore, time gains and consumer surplus will not be discussed in the CBA. However, it is known that while bicycle traffic has risen, the cycling travel time has improved (Technical and Environmental Administration Copenhagen, 2017b). Thus, the exact economic gain is expected to be higher than the estimation because of these time gains.

The benefit of 3,25 DKK per new cycling km and 4,22 DKK per new km car has been calculated in table 4.6 and table 4.7. These values have been calculated in 2019 prices, according to the newest value of statistical life and based on several other assumptions. To be able to attribute the benefit per km for a different year than the 2019 prices, the benefit has to be adapted for inflation. The price level for a certain year (P_i) can be calculated with the consumer price index (CPI) as shown in equation 4.3 below. The CPI measures the change in prices for a package of goods and services in relation to a base year. In the package, prices for food but also transportation and education can be present.

$$P_i = \frac{CPI_i}{CPI_{2019}} P_{2019} \tag{4.3}$$

Notations:

P_i is the price level for a corresponding year i.

CPI_i is the consumer price index for a corresponding year i.

The yearly benefit can thus be calculated by multiplying the total benefit per new cycling km for the respective year, with the cycling km's of the corresponding year. However, if the marginal cycling km's increase or decrease on a year by year basis, the gain or loss because of avoided or renewed costs from migrated car traffic should be added. The marginal cycling km's do not increase or decrease solely because of migrated car traffic. Cyclists cycle more as a result of the improved infrastructure and also population grows. While the cycling modal share for commuters saw a 6% increase between 2010 and 2016, the car traffic only saw a 2% decrease. Although this is an oversimplification, it will be assumed that the increase in 33% of the increase in cycling traffic is a result of migrated car traffic. Possible transfers from public transport will not be included in the analysis.

Finally, the benefit for each year has to be actualised to become the total yearly benefit in 2019 prices. All yearly benefits form the net total benefit. The benefits are actualised and added up using equation 4.2 below.

$$B_{total,2019} = \sum_{i=0}^{n} B_i * SDR^{n-i} \tag{4.4}$$

Notations:

$B_{total,2019}$ is the net total benefit in 2019 prices.

B_i is the yearly benefit in prices for the corresponding year.

In table 4.13 on page 58 an extract from the CBA is shown, all values used in the worksheet can be found in appendix A.

Table 4.13: Extract from Copenhagen policy CBA, benefit calculation

Year	**1996**	**1997**	**1998**	**1999**	....	**2015**	**2016**	**2017**
CPI	69,46	70,98	72,29	74,09	....	100,00	100,25	101,40
Benefit/new cycle-km [DKK]	2,19	2,24	2,28	2,34	....	3,16	3,17	3,20
Cost/new car-km [DKK]	2,92	2,98	3,04	3,11	....	4,20	4,21	4,26
Cycling distance/weekday [million km]	0,93	0,925	0,92	0,985	....	1,37	1,40	1,39
Cycling distance / year [million km]	288	286	285	305	....	424	433	430
Additional cycling distance/year [million km]	0,000	-1,548	-3,095	17,02	....	136,18	145,46	142,37
Migrated from cars (33%) [million km]	0,000	-0,511	-0,511	6,639	....	44,939	3,064	-1,021
Total benefit [million DKK]	0,00	-4,99	-8,62	60,51	....	619,00	473,50	451,60
Actualised benefit [million DKK]	0,00	-11,83	-19,64	132,58	....	724,14	532,62	488,46

Up until now, investment costs have not been mentioned. The yearly investment has been extracted from the 2018 bicycle account. The investments where given between 2004 and 2018 and a rising trend is visible. The investment costs are also actualized using the SDR to 2019 levels and added up to form the net total investment cost. Similar to equation 4.4, equation 4.5 actualises and adds up the investment costs. Note the investment costs also include costs for maintenance and renewal.

$$C_{total,2019} = \sum_{i=0}^{n} C_i * SDR^{n-i} \tag{4.5}$$

Notations:

$C_{total,2019}$	is the net total investment cost in 2019 prices
C_i	is the yearly investment cost in prices for the corresponding year

Similar to the benefit calculation, an extract from the CBA is presented in table 4.14 showing the investments the actualised investment costs.

Table 4.14: Extract from Copenhagen policy CBA, investment costs

Year	**1996**	**1997**	**1998**	**1999**	**..........**	**2015**	**2016**	**2017**
Investment cost/year [million DKK]	16,53	16,90	17,21	17,64	....	150,00	82,50	65,00
Actualised investment cost/year [million DKK]	40,75	40,04	39,21	38,65	....	175,48	92,80	70,30

The total actualised benefit equals DKK 6.847.693.964 or approximately 900 million euros. The total actualised investment cost equals DKK 2.313.175.555 or approximately 300 million euros. Since both the benefit and cost are already actualised, the economic net present value of the project (ENVP) is calculated by subtracting the investment costs from the benefit. To be able to compare the profitability of the policy with other policies, also the benefit to cost ratio (B/C ratio) should be calculated. A summary with relevant economic values for the project is depicted in table 4.15 below.

Table 4.15: CBA results for the Copenhagen bicycle policy

	DKK (2019 prices)
Total benefit because of policy	6.847.693.964
Total investment cost	2.313.175.555
ENVP	4.534.518.409
B/C Ratio	2,96

According to the positive ENPV and a B/C ratio greater than 1, the Copenhagen bicycle policy has proven to be efficient from an economic point of view. The exact numbers should not be taken too seriously, because they are a rough estimate. Also, the exact effect of the investments is rather unknown, because the benefits cannot be attributed to one specific investment. Nevertheless, it should be noted that in relation to other modes of transport, especially motorized, cycling clearly opens possibilities for considerable economic gains. To have a better idea of the profitability of cycling, several separate projects should be considered.

4.3.8.1 CBA discussion

A positive economic net present value and a B/C ratio greater than 1 are always a desired outcome of a cost-benefit analysis. Nevertheless, the previous calculations were made with several assumptions that influence the outcome of the CBA significantly. To illustrate the importance of input parameter and assumptions, the ENVP was calculated for a different average bicycle speed. Examining the change of a CBA's outcome as a result of an input parameter is commonly known as a sensitivity analysis. Table 4.16 below summarises the effects of a 12,5% and 25% increase and decrease in bicycle speed on the ENPV.

Table 4.16: Sensitivity analysis of the ENPV

Bicycle speed	Speed difference [%]	ENPV [DKK]	ENPV difference [%]
12	-25%	323.863.093	-93%
14	-12,5%	2.729.951.845	-40%
16	-	4.534.518.409	-
18	+12,5%	5.938.070.181	+31%
20	+25%	7.060.911.598	+56%

Because the ENPV is estimated for the entire policy, a small change in input parameters might result in a large change in ENPV. Not only does table 4.16 indicate that the ENVP is sensitive to changes, it also implies an economic opportunity. If the city of Copenhagen can manage to decrease bicycle trip time or increase bicycle speed, the ENVP will rise accordingly. If at the same time the speed for cars decreases, the ENVP will rise even more due to increased avoided congestion costs of transferred car users.

In brief, the CBA for the Copenhagen bicycle policy has a desirable outcome. On the other hand, there is no comparable basis of other transport policies, because a CBA for an entire car centred or public transport-oriented policy might not exist. Also, the exact impact of the bicycle investments is rather difficult to attribute to a specific period as the investments are still ongoing. At the same time, it is questionable whether a car centred CBA performed in the same manner would generate a positive economic outcome at all. Most car centred policies are based on time savings which tend to disappear in the long run as roads become more congested. Other strategies to ensure a more liveable city, such as high-quality public transport or an electronic road pricing system could reap economic benefits from avoided car km's or internalise external costs through taxes. However, the infrastructural costs to provide such systems are likely to be higher than those for cycling infrastructure and fluctuate depending on the available space in the city. Also, public transport systems are more complex to operate and maintain, as it involves multiple information systems, an entire vehicle fleet, and a lot of employees. All things considered, cycling infrastructure is relatively easy to build, maintain and fits the local culture in Copenhagen. Moreover, in relation to the car it is certainly economically and ecologically beneficial to opt for the bicycle.

5 How do stakeholders evaluate the policy?

An interesting thing to consider about the policy is how Copenhagen locals adapt to the policy and take advantage of it by setting up new enterprises that make use of the open bicycle culture. Anyone who wants to ride a bicycle needs a bike, thus there is a demand for bicycle retailers and repair shops. Existing businesses and transport companies seek new ways to deliver their products efficiently and with minimal carbon footprint. Big companies such as DHL and TNT have already found their way towards the cargo bike, which has become a fast way to deliver goods in the Copenhagen city centre, where bicycles can get around easier than cars. Companies such as Wolt or Just Eat have made food delivery by bike a more common street image.

Although a lot of companies appear to have taken advantage of the bicycle policy, very little is known on how several businesses, public service providers and households assess the bicycle policy. How do shopkeepers react to disappearing parking spaces for cars? Do multinationals tend to establish offices in Copenhagen due to the increased productivity of cycling employees? Have households increased their personal wealth because of cycling? Do public services integrate bicycle use into their activities and is it beneficial? At the moment it is still guessing how these questions would be answered and it would be interesting to investigate some actual data to have an accurate image on what stakeholders think about the policy. Below are some initiatives in which stakeholders where surveyed for several aspects regarding a bicycle policy.

5.1 Cargo Bikes

What originally started as CycleLogistics, now called CityChanger CargoBike, is a cooperation between municipalities, non-profit organisations and companies. As Copenhagen representatives, consulting company Copenhagenize Design Co. also participates. CityChanger CargoBike's mission is to promote the usage of cargo bikes among private, public and commercial users. The organisation is funded by the CIVITAS initiative, which consists of several cities around the world, among which Copenhagen, who are committing themselves to implement sustainable urban transport policies. The CIVITAS initiative is co-funded by the European Union.

In a document of CycleLogistics (Wrighton, Rzewnicki, & Reiter, 2012), several stakeholder thoughts on cargo bikes and the possible barriers to implement them were described. The partners of CycleLogistics where instructed to set up seminars in which focus groups took part. The stakeholder focus groups for the project where:

1. Logistics sector
2. Municipalities
3. Service providers
4. Private individuals
5. Retailers
6. Cyclists associations
7. Marketing sector
8. Industry
9. European Union

One of the partners, Copenhagenize Co., held a seminar with several important stakeholders in Copenhagen. Among the stakeholders where supermarket managers, shop owners, city officials, bike rental partners, consultants and other companies that promote bicycle use. Besides stakeholders who were present, there are more possibilities to include in the focus group. Apart from the logical stakeholders also carpenters and electricians on cargo bikes as shown in figure 5.1, have become visible in Copenhagen's streets. Because at the time Copenhagen already counted 25.000 cargo bikes, the seminar took a slightly different approach from the other seminars.

Figure 5.1: Electrician using a cargo bike

The general findings for Copenhagen where the following:

1. It's important to continue promotion of cargo bikes and deliver information to shop owners on what the advantages are in contrast to motorized vehicles.
2. There is a need for designated parking spaces for cargo bikes.
3. Insurance policies and liabilities are often a barrier for the professional use of cargo bikes.
4. The manager of a project called City Logistics, said there would be an opportunity for cargo bikes to transport goods who are delivered by trucks from depots out of the city centre towards the inner city.

Among findings of other focus groups where the lack of suitable cycling infrastructure and the legal position for electrically assisted cargo bikes, which are for example in the UK not considered as a bicycle.

With the positions taken by different stakeholders it is quite clear that people are willing to participate in a system where cargo bikes are used for transportation of people or goods. In return they expect authorities to facilitate the use of cargo bikes through legislation and infrastructural measures such as cycle paths and parking for cargo bikes. Additionally, a lot of stakeholders perceive the use of a cargo bike as a commercially interesting initiative.

5.2 Employers

From an employer point of view, it is desirable that employees use a bicycle for their daily commute. Not only does the company hereby gain a positive image regarding physical activity and health, the health benefits are also translated into less absence and ease congestion which results in productivity gains.

Nowadays in Denmark, people living more than 12 km from their work can claim a tax deduction for their daily commute. The tax is mode-neutral thus in fact encourages all forms of commuting. In 2017 the Danish cycling federation asked the federal government for a new tax deduction scheme. The scheme would give an extra tax deduction for people choosing to commute by bicycle if they live more than 3 km from work (Danish Cyclists' Federation, 2019). A comparable tax regime is already being used in European countries such as Belgium, Germany, the UK, Austria and Ireland (Bike2Work, 2016).

Although the cyclists' federation regularly proposes several measures to promote cycling, it has become clear that employers also see the benefits of a tax reduction for people who choose to cycle for their daily commute. A major indication for the support of employers is the fact that after the announcement from the Danish cyclists' federation, the national confederation of industry, Dansk Industry, backed the proposal of the cyclists' federation saying there was a potential to save 267.000 sick days on a yearly basis (Wenande, 2019).

6 The Copenhagen system in a Belgian context

Urban planners around the world recognise that a city's planning system cannot be copied in a different environment in other parts of the world. It is important to acknowledge the fact that infrastructure such as bicycle infrastructure has to fit the city it is situated in. Although a lot of urban planners get their inspiration from cities with extensive cycling experience such as Copenhagen, Amsterdam or Utrecht, those cities stress their design solutions might not fit local planning culture of other cities. Instead, researchers claim it is preferred to design bicycle infrastructure according to the Dutch CROW principles (Zhao, Carstensen, Nielsen, & Olafsson, 2018). CROW is a non-profit organisation founded in 1987, aiming to transfer knowledge about transport infrastructure. In 2007 CROW published a document with guidelines for planning bicycle infrastructure, in which five principles were formulated (de Groot, 2007): cohesion, safety, directness, attractiveness and comfort. Hull & O'Holleran (2014) also mentioned experience, spatial integration and socio-economic value in order to be able to evaluate the infrastructure quality.

In an interview Zhao et. al (2018) conducted with Danish urban planners it became clear how the CROW principles where applied in Copenhagen. Cohesion meant primarily that separate bicycle tracks form a real network because of ruling out the missing links. Safety is about the separation of different forms of traffic and about actual and perceived safety, which in Copenhagen becomes visible under the form of painted bicycle crossings or high kerbs. Directness determines the competitiveness of the bicycle relative to the car. For the directness principle speed and also missing links are important.

For Copenhagen's bicycle planners, attractiveness is about showing the people how nice it is to ride a bicycle and being welcoming to cyclists. Infrastructure to support this principle is small and functional, for example a right turn at red lights for cyclists or footrests at traffic intersections. Lastly comfort is about anything that reduces physical activity to ride a bicycle. In Copenhagen this is about providing a smooth road surface for cyclists, but also the possibility to combine cycling with public transport.

If a bicycle policy with resemblance to the Copenhagen bicycle policy would be implemented in Belgium, it would be important not to copy all design features but use planning guidelines instead and look for inspiration in Copenhagen. Whether or not a city is suitable for a Copenhagen-like bicycle policy will be discussed in the sections below.

6.1 Applicability of the Copenhagen policy in Belgium

Whether a comparable cycling policy can be used efficiently in a Belgian city depends on a number of factors. A common misperception is that a city's well-functioning bicycle policy serves as a manual for other cities elsewhere (Walta, 2018). In fact the transferability of a cycling policy even within the same country or region is highly dependent on spatial and social variations (Harms, Bertolini, & te Brömmelstroet, 2014). Transferability is in fact dependent on how frequent bicycles are used with respect to a policy. In Belgium, Vandenbulcke et. al (2011) studied the inter-municipality variation in bicycle use. They found the key determinants where environmental, demographic & socio-economic, cultural & societal and policy related determinants. In accordance with the findings of Harms, Bertolini and te Brömmelstroet, spatial variations coincide with environmental determinants, while social variations coincide with the other determinants. The policy related determinants correspond with either social or spatial variations.

6.1.1 Environmental determinants

Among environmental determinants are the built environment and the natural environment. The built environment is about the urban spatial structure and the infrastructure of a city. Because of the urban spatial structure, a city can harbour potential points of interest for human activity. Rietveld (2004) described the density of human activity as one of the aspects that impact modal choice set of the population. Human activity stretches multiple aspects of life such as, living, working and recreation. The transport mode decision is also dependent on the connectivity (i.e. the directness of a trip) and the proximity (i.e. straight-line distance) in a city (Saelens, Sallis, & Frank, 2003). A very common claim is that denser cities have a higher probability of being "cycling cities"(Harms et al., 2014).

In 1989 Newman & Kenworthy plotted the relationship between the urban density and the transport related energy consumption per capita. The graph presented in figure 6.1 shows a general trend: less dense, more decentralized cities have higher transport related energy consumption. This can be explained by a larger energy requirement for further transportation distances, as people rely on motorized transport to make their trips rather than their own physical strength. Shorter distances require less energy as people rely on public transport, or bicycles to make their trips. Noteworthy is that cities with a low urban density see a dramatic rise in energy consumption relative to cities with a high or very high urban density, hence the hyperbolic shape of the graph. Another remarkable fact is that cities like Amsterdam and Copenhagen perform better in terms of energy consumption than other cities with a comparable density. At the same time, Amsterdam and Copenhagen are both cities renowned for their bicycle use. This indicates that density alone certainly is not the key to high bicycle use.

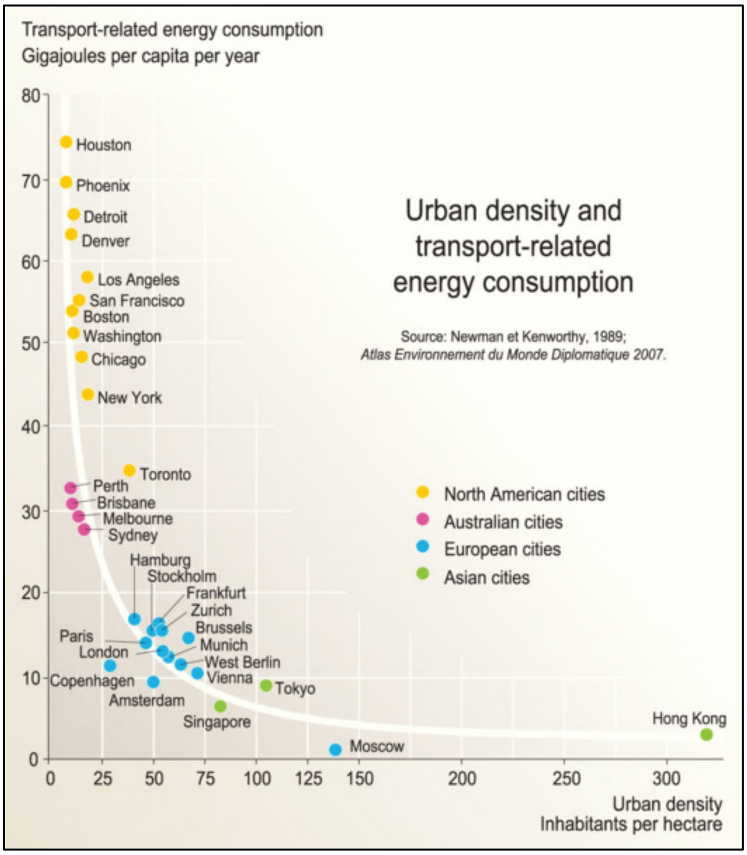


Figure 6.1: The Newman & Kenworthy hyperbola

Other environmental determinants are related to the natural environment. The natural environment concerns the climate, weather conditions and the city's topography (Heinen et al., 2010). A city with hilly terrain will be less suitable for cycling as the necessary effort for cycling increases. Like topography, harsh weather or climate also increases the physical effort while decreasing the comfort of cycling. Unsurprisingly, physical effort is found to have a large influence on bicycle use (Rietveld & Daniel, 2004). However, with electric assisted bicycles gaining popularity, the physical aspect might become less important over time.

6.1.2 Demographic and socio-economic determinants

Demographic and socio-economic factors include age, gender, political preference, education etc. In different professional fields, the bicycle is also used differently. A messenger courier might prefer to ride a bike in a busy city irrespective of the possible hilliness or weather.

On the other hand, a top manager might prefer a car with a driver for the ability to communicate and work while travelling. The educational level of the citizens can also impact the bicycle use but is highly dependent on the region or country (Vandenbulcke et al., 2011). Looking at the impact of gender, women tend to find personal security a larger barrier for cycling than men. Up to some level, all of these factors seem to be related to personal perceptions and can differ significantly depending on the group of people that are targeted.

6.1.3 Cultural, societal and policy related determinants

Cultural and societal factors are often linked to bicycle use. In European countries such as Denmark and the Netherlands, a strong bicycle culture is present (Carstensen & Ebert, 2012). In Belgium, every weekend large troops of cyclists are tackling small hills and cobblestones for the sake of the sport, while cycle commuting is nowhere near the Danish or Dutch level. Other countries such as the USA attribute a low societal status to cycling, if not for recreation (Pucher & Buehler, 2008). It is clear that culture related issues change the perception of bicycle use.

Besides the culture, the policy a country or city adopts can also influence the bicycle use. In different cultures legislation around bicycles can be different. In countries such as Australia, New-Zealand and Argentina, wearing a helmet when cycling is mandatory. In the USA helmet laws differ depending on the municipality or state. In Saudi Arabia and Iran, legislation does not allow women to ride a bicycle. All those legal barriers decrease the possibility of a successful bicycle policy.

On the other hand, traffic laws in Denmark and the Netherlands favour bicycles which leads to safer driving behaviour from motorists (Pucher & Buehler, 2008). Promotional events are an effective way to change attitudes towards the use of bicycles. Frequently, cycling is coupled to physical and mental health benefits to persuade people into cycling (Vandenbulcke et al., 2011). Lastly, promoting bicycles with financial incentives is likely to stimulate bicycle use, but policies favouring free fuel and company cars will reduce the possibility of a shift from the car to the bicycle (Kingham, Dickinson, & Copsey, 2001).

6.1.4 Applicability of the Copenhagen system in Ghent

As a city of choice to transfer learning points from Copenhagen, the Belgian city of Ghent is an excellent choice. The main difference between Ghent and other Belgian cities is the level of public and especially political support that is present for cycling. Other Belgian cities such as Antwerp, Brussels and Liège have prioritized other forms of transport, or try to pursue a policy which encourages all forms of transport equally. Antwerp has a high public support for a good bicycle policy and has already taken infrastructural measures to accommodate bicycles. For example, the "Velo" bicycle sharing system provides bicycles for Antwerp's citizens almost everywhere within the city's boundaries. According to insurance company Coya, Antwerp actually has the most shared bicycles per capita in the world. However, Antwerp's authorities aim to make the city a multimodal city and thus focus on all transport forms including the car. A good example of this multimodal focus is the "Zuiderdokken" project. What previously was a gigantic street level parking will become an underground car park, with a public park on top of it. This is indisputably an improvement in urban open space, yet at the same time it forces the city towards extra commitments. To be economically viable, the underground parking will probably have to attain a high occupancy rate, which means that cars are still lured towards the city centre. In Brussels the average commuting distance is high, and the modal split shows that public transport is gaining in favour of car use (Geurts, 2014).

In Walloon cities such as Liège, the use of the car is still dominant, although they recognize the need for more cycling and public transport.

The Ghentian policy is thus favourable for the implementation of a Copenhagen-like bicycle policy. The environmental determinants are not entirely unambiguous. First of all, the population density of the city of Ghent, is far lower than the population density of Copenhagen. However, in the city centre the Ghentian density equals overall Copenhagen urban density which is roughly 7000 inhabitants per square km. From a climatological point of view Ghent and Copenhagen are quite comparable. The climatologic graphs in figure 6.2 show winter in Copenhagen is slightly colder and dryer than in Ghent. Overall, it also rains more in Ghent.

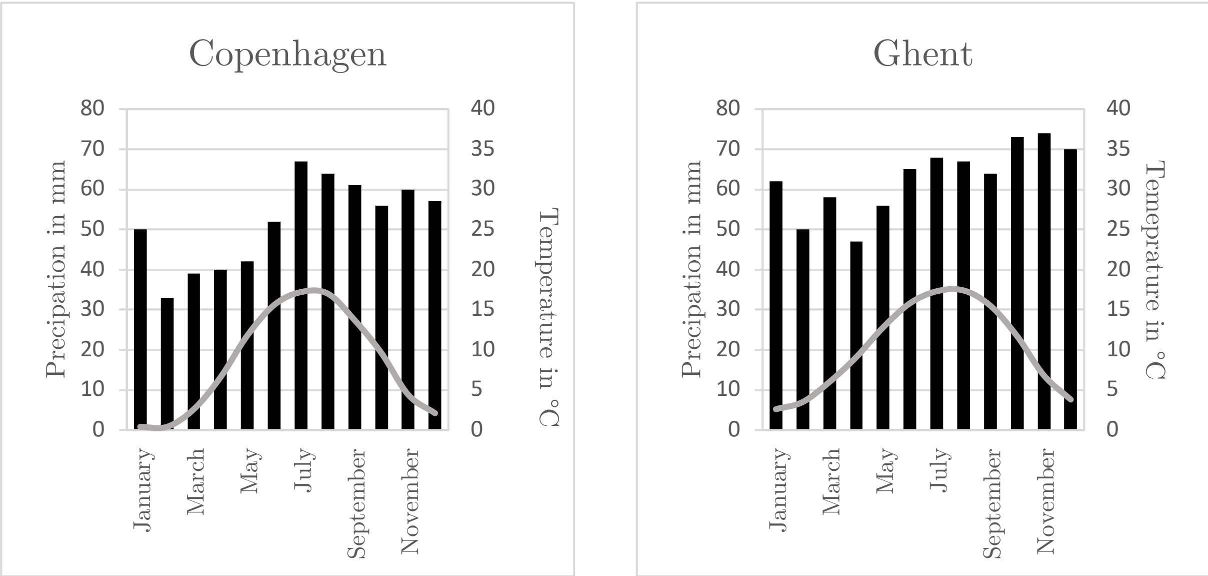


Figure 6.2: Climatologic graphs for Ghent and Copenhagen, Source: climate-data.org

Being at sea-level the absence of hilly terrain makes it easy to travel by bicycles. Laying in East-Flanders, and being host to a sea harbour, the city of Ghent is also relatively flat. For both cities, hilliness should not be a barrier for cycling. Socio-economic and cultural differences are expected to be minimal, because Denmark and Belgium are both part of the European Union, thus sharing most of the same values and ensuring a level of legislation conformity. Ghent also has the benefit of being an academic city, home to a lot of students who use a bicycle as their primary means of transport.

6.2 Bicycle policy in the city of Ghent

Ghent is a good student when it comes to bicycle policy. In 2015 Ghent drafted an urban sustainable mobility plan in which it exhibits its goals for 2030 and beyond. In general Ghent aims for a decrease in car use and a significant rise in bicycle and public transport use. Additionally, Ghent has the ambition to become carbon neutral by 2050. The most important feature of the plan was the implementation of a circulation plan, which was executed in April 2017. The circulation plan prevents cars from travelling through the city centre because several roads are inaccessible for non-commercial vehicles. In figure 6.3 a camera-controlled boundary that may not be crossed unless the car owner has a permit is shown. This measure has led to a more pleasant city centre for pedestrians and cyclist, while in most cases, cycling has become the fastest way to traverse the city.

Figure 6.3: Camera-controlled boundary of the Ghentian circulation plan

Since 1993 Ghent is working on a bicycle route network that connects the city with the surrounding municipalities. However, the bicycle routes where quite linear (D. Pelckmans, personal interview, April 24, 2019), there were a lot of missing links and there were no real goals in terms of modal split. In the 2015 plan, Ghent aims for a more integrated, management based, visible and competitive bicycle policy. The modal split goals and the 2012 modal split are portraited in figure 6.4 on the next page.

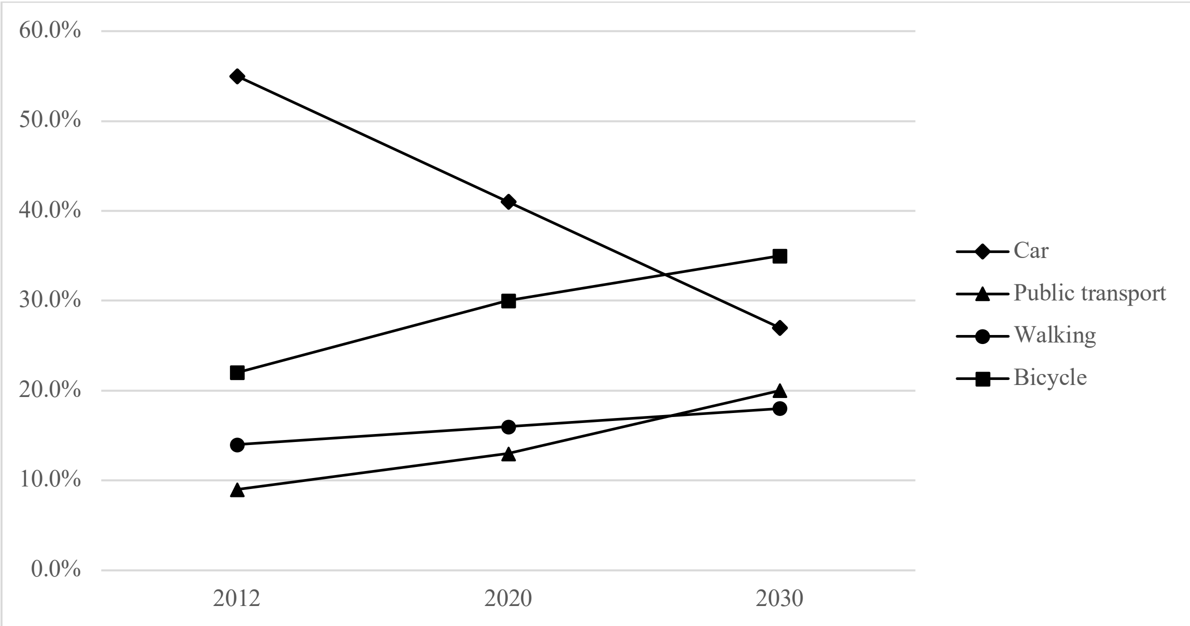


Figure 6.4: Modal split goals for Ghent for all trips within the city

Although the decrease of car use might seem optimistic, because of the circulation plan, Ghent is doing well in terms of attaining their goals. In table 6.1 the 2018 modal split for all trips within the city of Ghent is compared to the 2020 and 2030 goals. The bicycle counts take place every three years, on a working day in September.

Table 6.1: Modal split in 2018, desired modal split in 2020 and 2030

Mode	**2020**	**2030**	***2018***
Car	41%	27%	39%
Public transport	13%	20%	14%
Walk	16%	18%	13%
Bicycle	30%	35%	35%

The 2020 modal split goals have already been met for everything besides walking. Interestingly the desired bicycle modal split is already at the desired 2030 level. The Ghentian citizens are thus embracing the new bicycle policy rapidly. A reason for this could be the fact that all infrastructure for cyclists is entirely managed by the city departments while public transport is operated by several government funded agencies.

The policy department is one of four departments under the IVA mobility company. IVA or "Intern Verzelfstandigd Agentschap" means that mobility in Ghent is regulated by a company that is partly autonomous and has no legal personality. The mobility company works with its own revenues from car parking, operational subsidies and a set amount of budget by the City of Ghent. One of the entities working under the policy department is the "bicycle cell". The bicycle cell points out where infrastructural adaptations should take place to make the city more bicycle friendly. In appendix B the full organisational structure of the mobility company is portraited.

Currently the bicycle cell states that the main driver for infrastructural adaptations is safety rather than economic gains. For now, only big projects require economic analysis, which is usually not CBA but takes into account the economic impact of the newly served commuters. Also, the bicycle planners use their own experience and requests from citizens to point out where the infrastructure needs improvement. The required traffic data is gathered through own traffic counts and counts from independent bicycle organisations. Every three years there is a study for the travel behaviour of the Ghentian citizens. All available data is used in a GIS application to make a cycling-heatmap. Based on this heatmap potential points of interest can also be identified for infrastructural adaptations.

6.3 Possible measures for Ghent

The city of Ghent already has already a very decent plan to increase the bicycle modal share in the coming years. Several potential areas where Ghent could learn from Copenhagen were identified.

First of all, there is a considerable opportunity for Ghentian urban planners to professionalize bicycle planning. There are several points where this could be realised. Professionalizing usually means quantifying several effects to be able to analyse them more objectively. Thus, a good starting point for Ghent could be making sure that traffic data is available almost real time. A good way to do this are automated bicycle counters, but also information of people using a Waze-like application could be used. This could provide urban planners with important insights about cyclists' travel behaviour.

Another noticeable difference with Copenhagen is most probably that there is less cooperation between several stakeholders in Ghent. While, the modelling of bicycle traffic has been suspended in Ghent because of an outdated model (D. Pelckmans, personal interview, April 24, 2019), Copenhagen is cooperating with the Danish Technical University to implement route choice modelling for bicycles and bicycle demand modelling in their traffic model. This will allow the city of Copenhagen to use ex-ante CBA for bicycle projects. A likewise cooperation between the University of Ghent and the city administration to be able to predict cyclist behaviour could definitely be mutually beneficial. With a more quantitative approach Ghent would be able to invest in a more focused way, thus having a bigger impact.

Ghent is changing its system fairly rapidly but should be aware that there is a potential to improve more on comfort, safety and directness for bicycles. Although, a 3-lane Copenhagen-like bicycle track in each direction might not be possible because of lack of space Ghent should be ready to make compromises in terms of public transport or car use.

Lastly, the promotional mechanism of the city of Copenhagen is very impressive and in part the reason why it is a frequently investigated example for bicycle policies. Copenhagen has labelled itself the best bicycle city in the world for several purposes among which evoking increased support from its citizens. Copenhagen's promotional mechanism is arguably an elaboration of Banister's (2008) statement that the implementation of sustainable mobility requires the support of key stakeholders. In Ghent, promotion is mainly achieved through the external agency "de fietsenambassade". This cooperation between the City of Ghent and Ghent university is already quite successful but could really be on top of their game by also increasing their level of bicycle promotion through for example including the economic benefits of cycling for Ghent.

7 Conclusion

Copenhagen has made its ambition clear to become the world's best bicycle city and frequently uses cost-benefit analysis to promote the economic benefit of its bicycle policy. This dissertation aimed to provide an answer to the question whether or not the Copenhagen bicycle policy has been effective and whether the policy benefits have outweighed the costs.

In the first sections it became clear that it is the Danish culture that is vital for the success of the bicycle in Copenhagen. Citizen-centred policies such as a thorough bicycle strategy have had more support among politicians and other stakeholders than in most other European cities. Copenhagen has also committed to ambitious goals in terms of bicycle infrastructure, perception and modal share within the city. Although in the past the policy results were impressive, the current goals are within reach but most likely require a significant effort. It can be concluded that up until now, the policy has indeed been effective.

According to a rough estimate of the benefits and costs for the bicycle policy between 1996 and 2017, the policy has also proven to be efficient (i.e. the benefits outweigh the costs). The estimated economic net present value of the bicycle policy equals 4,5 billion DKK or 607 million euros. Since it is an estimate, little importance should be attached to these numbers. Due to the fact that the greater part of the benefit from cycling comes from the improved health it generates, it could be interesting to thoroughly calculate these benefits and their consequences for different labour markets in the European union. Additionally, it would be interesting to correlate cycling levels to healthcare savings for several diseases.

The Copenhagen policy is certainly not transferable to a Belgian city like Ghent in its entirety. However, the determinants for bicycle use indicate that from an environmental, societal and cultural point of view, there is not much difference between Denmark and Belgium. Thus, using a design paradigm like the Dutch CROW principles could allow Ghent to roll out a Copenhagen-like bicycle policy. Currently, policy differences on a national level is what makes the implementation of a good bicycle policy somewhat difficult. In Belgium, the allowance of free fuel and company cars for employees as a fiscal benefit poses a barrier for the use of bicycles. Ghent has tried to counter this by making it impossible for cars to cross the city centre and providing improved infrastructure for cyclists.

The main lesson that can be learned from Copenhagen is that cooperation between academic instances, companies, non-governmental organizations and the city administration can be beneficial for professionalising bicycle planning. A more quantitative approach with modelling of bicycle traffic, ex-ante cost-benefit analysis and automated traffic counts could allow a city like Ghent to invest in a more focused way, hence having a larger impact with the same funds. Also promoting the economic benefits under the veal of health benefits increases the number of people a bicycle policy appeals to and will likely evoke increased support among a number of stakeholders.

As a final remark, in subsequent research it would be interesting to investigate the effectiveness of traffic modelling for bicycles and its ability to provide ex-ante CBA's with traffic data. This would allow urban planners to estimate the value of a project even better.

References

Banister, D. (2008). The sustainable mobility paradigm. *Transport Policy*, *15*(2), 73–80. doi:10.1016/j.tranpol.2007.10.005

Basner, M., Babisch, W., Davis, A., Brink, M., Clark, C., Janssen, S., & Stansfeld, S. (2014). Auditory and non-auditory effects of noise on health. *The Lancet*, *383*(9925), 1325–1332. doi:10.1016/S0140-6736(13)61613-X

Beria, P., Maltese, I., & Mariotti, I. (2012). Multicriteria versus Cost Benefit Analysis: A comparative perspective in the assessment of sustainable mobility. *European Transport Research Review*, *4*(3), 137–152. doi:10.1007/s12544-012-0074-9

Bike2Work. (2016). Grants and tax-breaks. Retrieved 7 May 2019, from http://www.bike2work-project.eu/en/Cycle-friendly-employers/Grants-and-tax-breaks/Overview/

Browne, D., & Ryan, L. (2011). Comparative analysis of evaluation techniques for transport policies. *Environmental Impact Assessment Review*, *31*(3), 226–233. doi:10.1016/j.eiar.2010.11.001

Building and Construction Administration City of Copenhagen. (2002). *Cykelpolitik 2002-2012*. Copenhagen. Retrieved from http://divritenis.lv/box/files/webpage.pdf

Butlin, R. N. (1990). Effects of air pollutants on buildings and materials. *Proceedings of the Royal Society of Edinburgh, Section B: Biological Sciences*, *97*, 255–272. doi:10.1017/S0269727000005376

Carstensen, T. A., & Ebert, A.-K. (2012). Chapter 2 Cycling Cultures in Northern Europe: From ‘Golden Age’ to ‘Renaissance’. In *Transport and Sustainability* (Vol. 1, pp. 23–58). doi:10.1108/S2044-9941(2012)0000001004

Carstensen, T. A., Olafsson, A. S., Bech, N. M., Poulsen, T. S., & Zhao, C. (2015). The spatio-temporal development of Copenhagen’s bicycle infrastructure 1912–2013. *Geografisk Tidsskrift-Danish Journal of Geography*, *115*(2), 142–156. doi:10.1080/00167223.2015.1034151

Chiesura, A. (2004). The role of urban parks for the sustainable city. *Landscape and Urban Planning*, *68*(1), 129–138. doi:10.1016/j.landurbplan.2003.08.003

City of Copenhagen. (2011). *Copenhagen Climate adaptation Plan*. Copenhagen. Retrieved from https://international.kk.dk/artikel/climate-adaptation

Copenhagenize Design Co. (2017). Bicycle friendly city index 2017. Retrieved from https://copenhagenizeindex.eu/index.html

COWI. (2004). *External Costs of Transport 1st Report - Review of European Studies*. Retrieved from https://www.trm.dk/~/media/files/publication/english/1streport.pdf

COWI. (2009). *Economic Evaluation of Cycle Projects - Methodology and Unit Prices*. Retrieved from http://www.cycling-embassy.dk/wp-content/uploads/2010/06/COWI_Economic-evaluation-of-cycle-projects.pdf

Danish Cyclists' Federation. (2019). CYCLINGAND.NU: The Cyclists' Federation presents political vision and four proposals to the Folketing's politicians. Retrieved 7 May 2019, from https://via.ritzau.dk/pressemeddelelse/cykellandnu-cyklistforbundet-praesenterer-politisk-vision-og-fire-forslag-til-folketingets-politikere?publisherId=12123893&releaseId=13565385

Danish Technical University, & COWI. (2018). Transportøkonomiske Enhedspriser til brug for samfundsøkonomiske analyser v1.8. Retrieved from https://www.cta.man.dtu.dk/modelbibliotek/teresa/transportoekonomiske-enhedspriser

de Groot, R. (2007). *Design Manual for Bicycle Traffic*. CROW.

Duggal, N. A., Pollock, R. D., Lazarus, N. R., Harridge, S., & Lord, J. M. (2018). Major features of immunesenescence, including reduced thymic output, are ameliorated by high levels of physical activity in adulthood. *Aging Cell*, *17*(2), 1–13. doi:10.1111/acel.12750

European Commission. (2011). *COMMISSION STAFF WORKING PAPER IMPACT ASSESSMENT Accompanying document to the WHITE PAPER Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system*. Brussels: European Comission. Retrieved from https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52011DC0144

Geurts, K. (2014). *Modal choice for travel to work and school: recent trends and regional differences in Belgium*. Retrieved from http://www.plan.be/admin/uploaded/201410200828210.WP_1407_10826-1.pdf

Gössling, S. (2013). Urban transport transitions: Copenhagen, city of cyclists. *Journal of Transport Geography*, *33*, 196–206. https://doi.org/10.1016/j.jtrangeo.2013.10.013

Gössling, S., & Choi, A. S. (2015). Transport transitions in Copenhagen: Comparing the cost of cars and bicycles. *Ecological Economics*, *113*, 106–113. doi:10.1016/j.ecolecon.2015.03.006

Harms, L., Bertolini, L., & te Brömmelstroet, M. (2014). Spatial and social variations in cycling patterns in a mature cycling country exploring differences and trends. *Journal of Transport & Health*, *1*(4), 232–242. doi:10.1016/j.jth.2014.09.012

Heinen, E., van Wee, B., & Maat, K. (2010). Commuting by Bicycle: An Overview of the Literature. *Transport Reviews*, *30*(1), 59–96. doi:10.1080/01441640903187001

Hill, A. (2011). Copenhagen's novel problem: too many cyclists. Retrieved 13 November 2018, from https://www.theguardian.com/environment/bike-blog/2011/sep/09/copenhagen-cycling-congestion

Hüging, H., Glensor, K., & Lah, O. (2014). Need for a Holistic Assessment of Urban Mobility Measures - Review of Existing Methods and Design of a Simplified Approach. *Transportation Research Procedia*, *4*, 3–13. doi:10.1016/j.trpro.2014.11.001

Hull, A., & O'Holleran, C. (2014). Bicycle infrastructure: can good design encourage cycling? *Urban, Planning and Transport Research*, *2*(1), 369–406. doi:10.1080/21650020.2014.955210

Jensen, J. S., Cashmore, M., & Elle, M. (2017). Reinventing the bicycle: how calculative practices shape urban environmental governance. *Environmental Politics*, *26*(3), 459–479. doi:10.1080/09644016.2017.1311089

Johnston, R. J., Rolfe, J., Rosenberger, R. S., & Brouwer, R. (2015). Introduction to Benefit Transfer Methods. In R. J. Johnston, J. Rolfe, R. S. Rosenberger, & R. Brouwer (Eds.), *Benefit Transfer of Environmental and Resource Values* (Vol. 14, pp. 19–60). Dordrecht: Springer Netherlands. doi:10.1007/978-94-017-9930-0

Kaufmann, V., Bergman, M. M., & Joye, D. (2004). Motility: mobility as capital. *International Journal of Urban and Regional Research*, *28*(4), 745–756. doi:10.1111/j.0309-1317.2004.00549.x

Kingham, S., Dickinson, J., & Copsey, S. (2001). Travelling to work: will people move out of their cars. *Transport Policy*, *8*(2), 151–160. doi:10.1016/S0967-070X(01)00005-1

Knudsen, W. B., & Krag, T. (2005). *På cykel i 100 år: Dansk cyklist forbund 1905-2005.* Dansk cyklist forbund. Retrieved from https://books.google.be/books?id=YKVRYgEACAAJ

Martin, E., Oldenziel, R., & Veraart, F. (2016). Branding the Cycling City. In *Cycling Cities: The European Experience* (pp. 77–88). Eindhoven: Foundation for the History of Technology.

Metz, D. (2008). The Myth of Travel Time Saving. *Transport Reviews*, *28*(3), 321–336. doi:10.1080/01441640701642348

Münzel, T., Gori, T., Babisch, W., & Basner, M. (2014). Cardiovascular effects of environmental noise exposure. *European Heart Journal*, *35*, 829–836. doi:10.1093/eurheartj/ehu030

Nielsen, T. A. S., Skov-Petersen, H., & Agervig Carstensen, T. (2013). Urban planning practices for bikeable cities – the case of Copenhagen. *Urban Research & Practice*, *6*(1), 110–115. doi:10.1080/17535069.2013.765108

OECD. (2018). *Cost-Benefit Analysis and the Environment*. OECD. doi:10.1787/9789264085169-en

OECD, & ECMT. (2005). *National Systems of Transport Infrastructure Planning*. OECD Publishing. doi:10.1787/9789282123423-en

Oja, P., Titze, S., Bauman, A., de Geus, B., Krenn, P., Reger-Nash, B., & Kohlberger, T. (2011). Health benefits of cycling: a systematic review. *Scandinavian Journal of Medicine & Science in Sports*, *21*(4), 496–509. doi:10.1111/j.1600-0838.2011.01299.x

Persky, J. (2001). Retrospectives: Cost-Benefit Analysis and the Classical Creed. *Journal of Economic Perspectives*, *15*(4), 199–208. doi:10.1257/jep.15.4.199

Pineda, A. F. V., & Vogel, N. (2014). Transitioning to a Low Carbon Society? The Case of Personal Transportation and Urban Form in Copenhagen: 1947 to the Present. *Transfers*, *4*(2), 4–22. doi:10.3167/TRANS.2014.040202

Pucher, J., & Buehler, R. (2008). Making cycling irresistible: Lessons from the Netherlands, Denmark and Germany. *Transport Reviews*, *28*(4), 495–528. doi: 10.1080/01441640701806612

Rietveld, P., & Daniel, V. (2004). Determinants of bicycle use: do municipal policies matter? *Transportation Research Part A: Policy and Practice*, *38*(7), 531–550. doi:10.1016/j.tra.2004.05.003

Rosen, S. (1974). Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition. *Journal of Political Economy*, *82*(1), 34–55.

Saelens, B. E., Sallis, J. F., & Frank, L. D. (2003). Environmental correlates of walking and cycling: Findings from the transportation, urban design, and planning literatures. *Annals of Behavioral Medicine*, *25*(2), 80–91. doi:10.1207/S15324796ABM2502_03

Sælensminde, K. (2004). Cost-benefit analyses of walking and cycling track networks taking into account insecurity, health effects and external costs of motorized traffic. *Transportation Research Part A: Policy and Practice*, *38*(8), 593–606. doi:10.1016/j.tra.2004.04.003

Sartori, D., Catalano, G., Genco, M., Pancotti, C., Sirtori, E., Vignetti, S., & Del Bo, C. (2014). *Guide to Cost-benefit Analysis of Investment Projects: Economic appraisal tool for Cohesion Policy 2014-2020*. Brussels. doi:10.2776/97516

Sørensen, C. H. (2018). A typology of inter-organisational coordination in public transport: The case of timetable planning in Denmark. *Research in Transportation Economics*, *69*(June), 411–419. doi:10.1016/j.retrec.2018.06.015

Technical and Environmental Administration Copenhagen. (2011). *The City of Copenhagen's Bicycle Strategy 2011-2025*. Copenhagen.

Technical and Environmental Administration Copenhagen. (2013). *Focus on cycling Copenhagen guidelines for the design of road projects*. Copenhagen.

Technical and Environmental Administration Copenhagen. (2017a). *Copenhagen City of Cyclists: Facts & Figures 2017. Bicycle Account*. Copenhagen.

Technical and Environmental Administration Copenhagen. (2017b). *The Bicycle Account 2016*. Copenhagen.

van Oort, N., van der Bijl, R., & Verhoof, F. (2017). The wider benefits of high quality public transport for cities. Barcelona: Association for European Transport. Retrieved from https://nielsvanoort.weblog.tudelft.nl/files/2017/09/Van-Oort-et-al-Wider-benefits-of-PT-5E-framework-ETC-proceedings2017.pdf

Van Wee, B., & Börjesson, M. (2015). How to make CBA more suitable for evaluating cycling policies. *Transport Policy*, *44*, 117–124. doi:10.1016/j.tranpol.2015.07.005

Vandenbulcke, G., Dujardin, C., Thomas, I., Geus, B. de, Degraeuwe, B., Meeusen, R., & Panis, L. I. (2011). Cycle commuting in Belgium: Spatial determinants and 're-cycling' strategies. *Transportation Research Part A: Policy and Practice*, *45*(2), 118–137. doi:10.1016/j.tra.2010.11.004

Walta, L. (2018). On the methodologies and transferability of bicycle research: A perspective from outside academia. *Journal of Transport and Land Use*, *11*(1), 811–814. doi:10.5198/jtlu.2018.1458

Wefering, F., Rupprecht, S., Bührmann, S., & Böhler-Baedeker, S. (2013). *Guidelines - Developing and implementing a sustainable urban mobility plan*. Retrieved from http://www.eltis.org/sites/eltis/files/sump_guidelines_en.pdf

Weisbrod, G., & Weisbrod, B. (1997). Assessing the Economic Impact of Transportation Projects. *Transportation Research CIRCULAR*, *477*, 34.

Wenande, C. (2019, January 14). Tax deduction for cycling to work? New campaign gaining momentum. Retrieved from http://cphpost.dk/news/tax-deduction-for-cycling-to-work-new-campaign-gaining-momentum.html

WHO. (1990). *Healthy Cities Project: a project becomes movement.* (A. D. Tsouros, Ed.). Copenhagen: FADL Publishers.

WHO. (2011). *Burden of disease from Burden of disease from.* (L. Fritschi, A. L. Brown, R. Kim, D. Schwela, & S. Kephalopoulos, Eds.). Copenhagen.

Wrighton, S., Rzewnicki, R., & Reiter, K. (2012). *Results of survey among stakeholders and practitioners.* Retrieved from http://one.cyclelogistics.eu/docs/116/D5_2_Results_of_surveys_among_stakeholders_21042013_Web_1.pdf

Zhao, C., Carstensen, T. A., Nielsen, T. A. S., & Olafsson, A. S. (2018). Bicycle-friendly infrastructure planning in Beijing and Copenhagen - between adapting design solutions and learning local planning cultures. *Journal of Transport Geography*, *68*(March), 149–159. doi:10.1016/j.jtrangeo.2018.03.003

Appendix A

Total net benefit of the policy, irrespective of investment costs

Year	CPI	Benefit/new cycle-km [DKK]	Cost/new car-km [DKK]	Cycling distance/weekday [km]	Additional cycling distance/weekday [km]	Additional cycling distance/year [km]	Migrated from cars (33%) [km]	Total yearly benefit [DKK]	Actualised yearly benefit [DKK]
1996	69,46	2,19	2,92	930.000	0	0	0	0	0
1997	70,98	2,24	2,98	925.000	-5.000	-1.547.500	-510.675	-4.992.488	-11.831.791
1998	72,29	2,28	3,04	920.000	-10.000	-3.095.000	-510.675	-8.617.702	-19.637.745
1999	74,09	2,34	3,11	985.000	55.000	17.022.500	6.638.775	60.508.621	132.581.840
2000	76,24	2,41	3,20	1.050.000	120.000	37.140.000	6.638.775	110.709.296	233.247.790
2001	78,03	2,46	3,28	1.080.000	150.000	46.425.000	3.064.050	124.455.764	252.124.542
2002	79,92	2,52	3,36	1.110.000	180.000	55.710.000	3.064.050	150.909.306	293.956.311
2003	81,58	2,58	3,43	1.120.000	190.000	58.805.000	1.021.350	155.011.200	290.333.071
2004	82,52	2,61	3,47	1.130.000	200.000	61.900.000	1.021.350	164.866.814	296.915.818
2005	84,02	2,65	3,53	1.140.000	210.000	64.995.000	1.021.350	176.076.641	304.907.772
2006	85,63	2,70	3,60	1.150.000	220.000	68.090.000	1.021.350	187.835.618	312.760.111

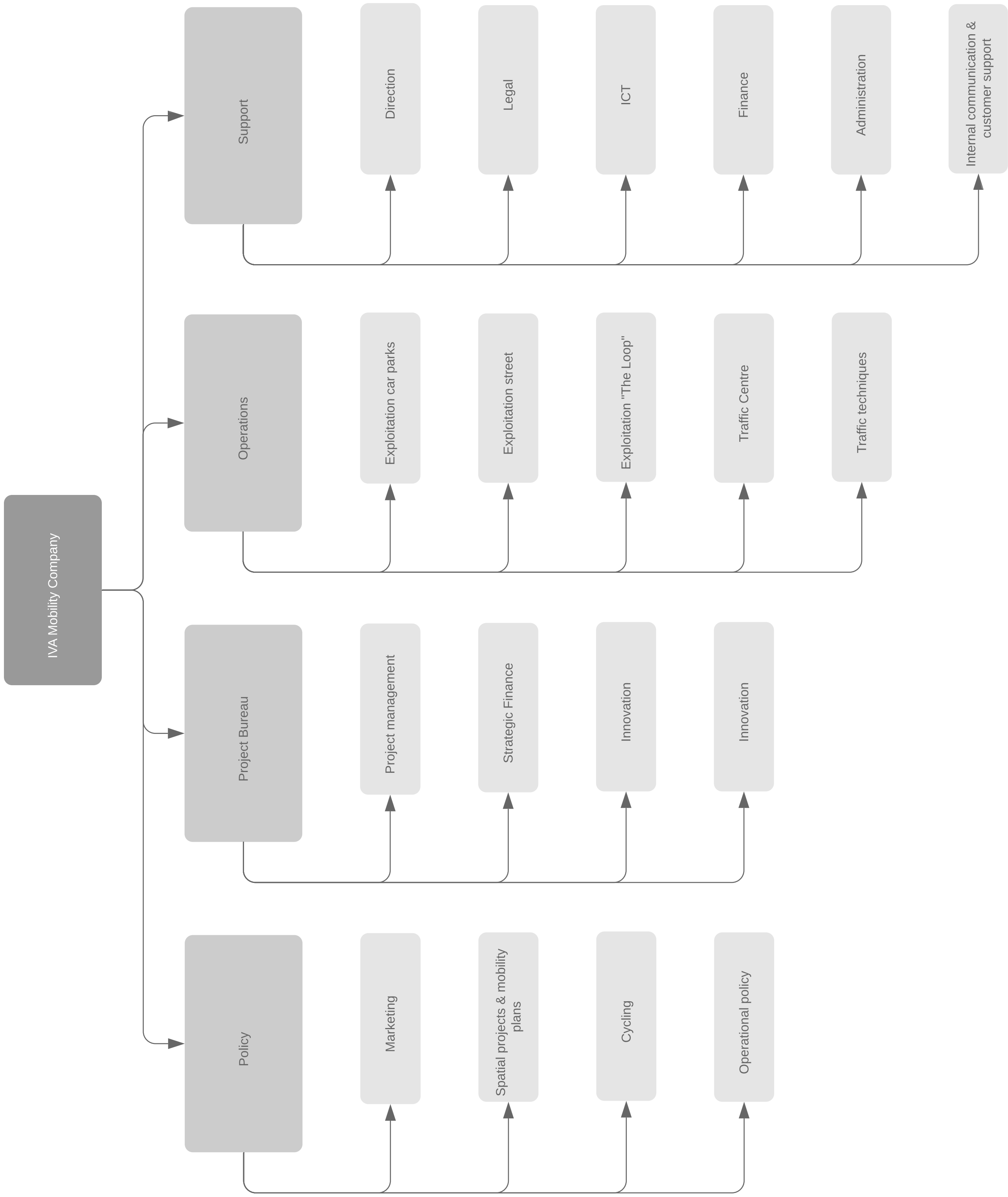
2007	87,08	2,75	3,66	1.160.000	230.000	71.185.000	1.021.350	199.528.826	319.452.079
2008	90,06	2,84	3,79	1.170.000	240.000	74.280.000	1.021.350	215.148.684	331.211.514
2009	91,23	2,88	3,83	1.190.000	260.000	80.470.000	2.042.700	239.708.861	354.827.671
2010	93,34	2,95	3,92	1.210.000	280.000	86.660.000	2.042.700	263.497.164	375.038.626
2011	95,92	3,03	4,03	1.240.000	310.000	95.945.000	3.064.050	303.012.070	414.692.940
2012	98,22	3,10	4,13	1.270.000	340.000	105.230.000	3.064.050	339.080.899	446.207.331
2013	98,99	3,13	4,16	1.305.000	375.000	116.062.500	3.574.725	377.749.722	477.973.907
2014	99,55	3,14	4,18	1.340.000	410.000	126.895.000	3.574.725	413.939.770	503.621.022
2015	100,00	3,16	4,20	1.370.000	440.000	136.180.000	3.064.050	442.990.298	518.235.992
2016	100,25	3,17	4,21	1.400.000	470.000	145.465.000	3.064.050	473.496.890	532.619.605
2017	101,40	3,20	4,26	1.390.000	460.000	142.370.000	-1.021.350	451.604.620	488.455.556
2018	102,23	3,23	4,30						
2019	102,90	3,25	4,33						

Total actualised benefit [DKK]	6.847.693.964
Total actualised benefit [€]	916.906.222

Total net investment costs

Year	Investment cost/year [DKK]	Actualised investment cost/year [DKK]		
1996	16.534.864	40.753.736		
1997	16.895.680	40.041.390		
1998	17.207.516	39.211.938		
1999	17.637.324	38.645.548		
2000	18.149.386	38.238.020		
2001	18.573.695	37.626.898		
2002	19.024.001	37.056.861		
2003	19.418.765	36.370.983		
2004	27.500.000	49.525.946		
2005	20.000.000	34.633.529		
2006	45.000.000	74.928.308		
2007	75.000.000	120.077.416		
2008	100.000.000	153.945.406		
2009	55.000.000	81.413.436		
2010	205.000.000	291.778.922		
2011	177.500.000	242.921.006		
2012	110.000.000	144.752.496		
2013	212.500.000	268.880.291		
2014	167.500.000	203.789.361		
2015	150.000.000	175.478.784		
2016	82.500.000	92.801.280	Total actualised investment cost [DKK]	2.313.175.555
2017	65.000.000	70.304.000	Total actualised investment cost [€]	309.734.207

Appendix B



IVA Mobility Company
Support
Direction
Legal
ICT
Finance
Administration
Internal communication & customer support
Operations
Exploitation car parks
Exploitation street
Exploitation "The Loop"
Traffic Centre
Traffic techniques
Project Bureau
Project management
Strategic Finance
Innovation
Innovation
Policy
Marketing
Spatial projects & mobility plans
Cycling
Operational policy