A Cost-Benefit Analysis of Carsharing in the Car-free Neighbourhood of Merwede

# SETTING THE PRICE FOR CARSHARING

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ARCADIS | OVER MORGEN

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## A Cost-Benefit Analysis of Equitable Carsharing in the Car-free Neighbourhood of Merwede

by

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# Preface

This thesis – 'Setting the Price for Carsharing: A Cost-Benefit Analysis of Equitable Carsharing in the Car-free Neighbourhood of Merwede' – is the final product to complete the master's programme Transport, Infrastructure & Logistics at the TU Delft. It represents the work I have done during the foregoing seven months in cooperation with the TU Delft and Arcadis | Over Morgen. I feel very fortunate that I have been given the opportunity to spend these past months working with a supportive and inspiring group of people towards this final product.

When I started my MSc studies in 2021, I did not know I would finalise my study time in Delft by extensively looking into carsharing and car-free neighbourhoods, although my passion for sustainability and city-building video games was indicative. While it felt like a strenuous process at times, most of the time it felt like an exciting and informative journey during which I learned more about the subject but also about my professional self.

I would not have been able to finalise this thesis without the help of some wonderful people. I would like to thank Edvard Hendriksen and Hannah Habekotté for their guidance throughout the process as well as for giving me the freedom to shape my own thesis. In addition, I would like to thank all my other colleagues at Arcadis (and formerly Over Morgen) for the nice, inspiring conversations, and helpful feedback. I am sincerely thankful to my supervisors Jan-Anne Annema and Gonçalo Homem de Almeida Correia for always making time for me and for providing valuable feedback on my work. I would also like to extend my appreciation to Bart van Arem for allowing me to partake in the XCARCITY programme kick-off in May 2023. This event inspired me to delve into car-free neighbourhoods.

Finally, I would also like to express my gratitude to my wonderful family, friends, and partner who have supported me throughout every breakthrough and breakdown I have had during my study period. As this chapter of my academic journey closes, I am excited to see what the future holds. For now, I hope you enjoy reading my thesis, may it be as insightful to read as it was to write.

*Leonardo Lucasius*
*Rotterdam, April 2024*

# Summary

Intensified urbanisation requires efficient land utilisation. This is complicated due to the extensive footprint of private cars as these vehicles occupy significant space – in terms of both infrastructure and parking areas – hindering efficient land allocation. In the Netherlands, it has been reported that in the twenty largest municipalities, approximately 55% of the available public street space is allocated to cars – of which 10% is reserved for parking facilities. Moreover, private cars are estimated to be parked 96% of the time and parking incurs a significant opportunity cost as it occupies valuable space that could be utilised more efficiently. To ensure more efficient land allocation, urban mobility is undergoing a transition towards sustainable and shared transportation alternatives. In line with this, carsharing as well as car-free neighbourhoods have emerged as promising solutions.

The carsharing market is promising yet novel, making it interesting but also difficult for governments and area developers to integrate this mode of transportation into mobility plans for future area developments. Literature regarding carsharing pricing tends to be focused on profit-maximisation. Not many studies account for a holistic social-welfare-focused picture of carsharing including carsharing service operators, users, and municipalities. The outcome of this is that in many cases only certain socio-economic groups have access to carsharing services, leaving a disparity for lower-income individuals. Specifically, there appears to be a lack of comprehensive knowledge regarding equitable pricing strategies for carsharing, especially in car-free neighbourhoods.

Car-free neighbourhoods are a promising and more space-efficient alternative to car-centric neighbourhoods. In these neighbourhoods, governments often enforce high parking fees to ensure low car ownership rates. However, this leaves a disparity for lower-income residents of these neighbourhoods who cannot afford to pay these fees yet still rely on a (private) car to satisfy their mobility needs. In the end, these more vulnerable residents may be even more reliant on carsharing services as an alternative to car ownership than their higher-income counterparts. Therefore, this thesis posits the following main research question:

**What pricing strategies could be implemented for business-to-consumer carsharing services in car-free residential neighbourhoods to align with the diverse needs and preferences of potential users?**

To answer the main research question this thesis employs an overarching case study methodology. Specifically, carsharing service pricing in the car-free neighbourhood of Merwede is investigated more thoroughly to reveal equitable pricing strategies for carsharing whilst keeping practical considerations in mind.

Additionally, to aid in answering the main research question, four objectives are considered. Firstly, factors that influence carsharing adoption are defined. Secondly, municipal, and governmental policies and interventions that can support carsharing services are identified. Thirdly, the effect of a service price change on the demand for carsharing services per income group is estimated for the Dutch population. Lastly, a cost-benefit analysis is conducted to determine i) the added value of carsharing in a car-free neighbourhood, and ii) whether providing lower-income Merwede residents with a trip credit incentive in the form of a monthly subsidy would be favourable.

To answer the research objectives, several methodologies are applied. First, literature research is conducted to describe the state of carsharing as well as car-free neighbourhoods. The result is a proposed theoretical framework for carsharing adoption determinants – including personal, temporal, spatial, political, economic, and service factors – along with an overview of policies and interventions that stimulate or reinforce carsharing adoption – categorised by their target groups.

Then, the attention is shifted to the case study neighbourhood of Merwede. To determine current carsharing service prices in Utrecht, market research is conducted. This includes the following business-to-consumer carsharing service operators: A2B, Greenwheels, Hely, MyWheels, and OnzeAuto. At the time of this research, the average kilometre price, hourly price, and subscription price of carsharing services is reported to respectively be 0.29, 3.23, and 12.78 euros. Additionally, using data from Arcadis | Over Morgen and Whooz, a data analysis is carried out to identify neighbourhood attributes as well as socio-demographic characteristics of future Merwede residents. Whooz data provides insight into levels of car ownership, the purpose of travel, and the modal split among various transportation means including (private) cars, taxis, buses, trams, metros, trains, and bicycles. This data is segmented by socio-economic characteristics, allowing for predictions to be made regarding future residents' mobility needs (i.e., modal split).

In Merwede, high parking fees are enforced to keep car ownership down, making it expensive for lower-income residents to own a car in the neighbourhood based on their typical mobility budgets. Therefore, the cost-benefit analysis employed in this thesis to determine the net present value of carsharing also includes scenarios in which a subsidy for carsharing is provided to lower-income residents. This policy aims to promote carsharing adoption by ensuring service prices are equitable, offering fair equality of opportunity, and enhancing transportation equity.

To test the effect of price changes on carsharing service demand it is necessary to determine the price elasticity – i.e., the effect of a service price change on the demand – for carsharing of different income groups. Using literature and the relative differences between income groups in mode shift elasticity, different price elasticities for carsharing are estimated for low-, middle-low-, middle-high-, and high-income groups residing in Utrecht. These values respectively yielded -0.8, -0.5, -0.4, and -0.1, indicating general inelasticity to carsharing across income groups but higher sensitivity to price changes in lower-income groups. There is no consensus in literature regarding whether carsharing demand is elastic or inelastic when it comes to price since this is highly dependent on many factors and varies across populations. Additionally, findings may be constrained by self-selection.

To assess what pricing strategy would be favourable in Merwede, a cost-benefit analysis is formulated and applied. This analysis determined the net present value – i.e., the total benefits minus total costs for all stakeholders – of carsharing in a car-free context in addition to determining the value of a monthly carsharing subsidy for lower-income residents of Merwede. The stakeholders considered in the analysis are carsharing service operators, users, and the municipality. The costs and benefits considered in the analysis are displayed in Figure 1. Notably, increased transportation equity was not included in the analysis as a quantifiable benefit and the calculated consumer surplus only considers the change in consumer surplus resulting from the subsidy, not the added value or utility from using carsharing in general as this specific data was not available.

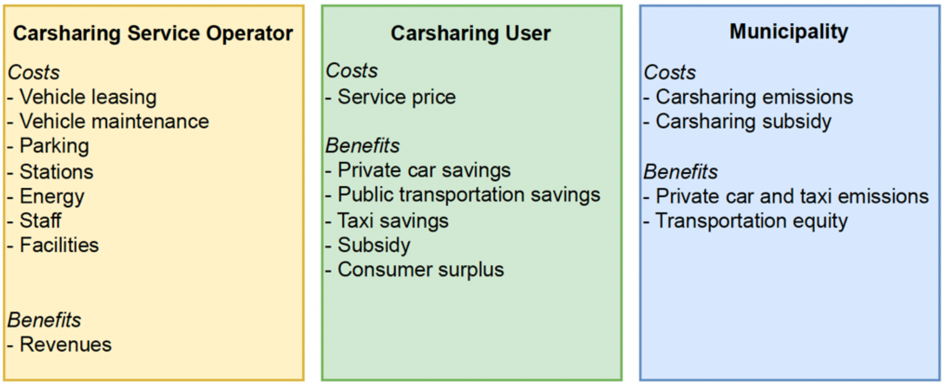


**Figure 1.** Costs and benefits for carsharing and subsidy policy.

The seven scenarios for the cost-benefit analysis include one baseline and six variants:

- S0: baseline scenario, no carsharing (modal split 0.0%)
- S1-1: moderate carsharing (modal split 3.8%), no subsidy
- S1-2: moderate carsharing (modal split 3.9%), 50-euro monthly subsidy per lower-income resident
- S1-3: moderate carsharing (modal split 4.0%), 100-euro monthly subsidy per lower-income resident
- S2-1: high carsharing (modal split 7.5%), no subsidy
- S2-2: high carsharing (modal split 7.8%), 50-euro monthly subsidy per lower-income resident
- S2-3: high carsharing (modal split 8.0%), 100-euro monthly subsidy per lower-income resident

The analysis (see Table 1) reveals that carsharing service operators see negative net present values in moderate carsharing scenarios without subsidies (S1-1) and with a 50-euro subsidy (S1-2) but achieve the highest net present value (S2-3) with high adoption and a 100-euro subsidy. In Merwede, the business case for carsharing service operators becomes positive – i.e., profitability is realised – between a 3.9% (S1-2) and 4.0% (S1-3) carsharing modal split, corresponding to 293,026 and 302,235 annual trips, respectively. This highlights the balance between providing sufficient carsharing services in Merwede and these services being used by enough users to break-even or become profitable.

For users, net present values are lowest without subsidies (S1-1) and highest in the high-adoption and 100-euro subsidy scenario (S2-3), indicating the added value of subsidies and increase in carsharing resulting from this. The municipality's net present value peaks in the high adoption without subsidy scenario (S2-1), while environmental benefits outweigh subsidy costs in other scenarios.

The total yearly net present value is greatest at high carsharing levels with a 100-euro subsidy (S2-3), despite the municipality's annual subsidy cost of 617,489.43 euros. The lowest total net present value corresponds to the moderate adoption without subsidy scenario (S1-1). These findings suggest that optimal benefits for all stakeholders arise from high carsharing utilisation balanced with targeted subsidies to support equitable access and environmental gains.

**Table 1.** Yearly net present values (NPVs) for the different scenarios included in the CBA.

| | NPV CSOs | NPV Users | NPV Municipality | NPV Total |
|---|---|---|---|---|
| ***S1-1*** | € -46,520.15 | € 30,184,866.17 | € 382,710.93 | € 30,521,056.96 |
| ***S1-2*** | € -6,005.00 | € 30,351,975.83 | € 245,012.12 | € 30,590,982.96 |
| ***S1-3*** | € 33,596.25 | € 30,531,766.15 | € 97,843.55 | € 30,663,205.95 |
| ***S2-1*** | € 1,174,684.89 | € 30,263,977.21 | € 782,963.22 | € 32,221,625.32 |
| ***S2-2*** | € 1,255,716.70 | € 30,600,040.36 | € 507,566.06 | € 32,363,323.12 |
| ***S2-3*** | € 1,334,919.02 | € 30,957,776.47 | € 213,228.86 | € 32,505,924.35 |

In sum, the CBA outcomes suggest income-group-specific subsidies could serve as an effective tool to stimulate equitable carsharing (in Merwede). The implementation of this policy allows for a pricing strategy that is beneficial for all stakeholders included in the analysis. Still, careful consideration must be given to the dynamic nature of carsharing and the necessity for continuous adaptation to evolving urban mobility needs and trends.

This thesis offers a detailed examination of carsharing pricing strategies within a distinct car-free neighbourhood, considering varying income groups. Its specificity enriches the novelty of the research but also narrows the scope of generalisation. The insights gained – particularly relevant to Merwede and potentially the Netherlands – might not directly extend to car-free areas with divergent socio-economic and transportation structures. Further studies are essential for broader applicability of these conclusions. Nonetheless, the thesis contributes an empirically validated cost-benefit analysis model sensitive to pricing and subsidy variations, advancing transport, infrastructure, and logistics research. Moreover, the results of this research can provide helpful guidance for carsharing companies and governmental institutions.

Considering the limitations of this thesis, several considerations for future research are expanded upon. Firstly, a more extensive and systematic examination of policies and interventions that could influence the adoption of carsharing is crucial. In relation to the present thesis, the duration, and the effect of subsidies on specific target groups' mobility behaviour warrant better examination. Alternative interventions to reduce the service costs of carsharing deserve exploration, potentially making the business case for carsharing more compelling. These additional interventions include – but are not limited to – carsharing service operators using second-hand cars in their fleet, generating ad revenue, implementing dynamic pricing strategies, or forming strategic business partnerships. Secondly, perhaps more accurate estimations of price elasticities for carsharing across different income groups would arise from a combination of stated- and revealed-preference surveys – e.g., using historical data from carsharing service operators. Moreover, fluctuations in the carsharing market that may influence service prices should be taken into consideration. This detailed data could enhance price setting and forecasting accuracy. Thirdly, this thesis presumes electric carsharing vehicles are emissions-free. However, the frequency of use and the subsequent maintenance and replacement needs suggest a more complex environmental impact. To refine the environmental assessments for these shared mobility services, future research should account for lifecycle emissions, from vehicle production to end-of-life disposal. This could be integrated by following a wheel-to-wheel emissions framework. Lastly, the modal split predictions made in this thesis should be validated in the future. Understanding the activity-end of mobility – such as trip purpose – is also imperative for accurate mode-choice modelling. In order words, the influence of trip purpose on mode choice should be integrated into modal split estimations. Additionally, future research should delve deeper into the effects of modalities not included in the present study such as (shared) scooters as these also effect carsharing usage.

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# List of Abbreviations

**B2B:** business-to-business
**B2C:** business-to-consumer
**CBA:** cost-benefit analysis
**$CO_2$:** carbon dioxide
**CSO:** carsharing service operator
**EV:** electric vehicle
**IDT:** innovation diffusion theory
**MaaS:** mobility as a service
**MCDA:** multi-criteria decision analysis
**$NO_x$:** nitrogen oxides
**NPV:** net present value
**PM:** particulate matter
**P2P:** peer-to-peer
**TAM:** technology acceptance model
**TPB:** theory of planned behaviour
**UMT**: utility maximisation theory
**VAT:** value added tax
**VoT:** value of time

# 1. Introduction

Globally, current population and urban growth requires the densification of residential areas and amenities within city boundaries (Angel et al., 2011). This intensified urbanisation requires efficient land utilisation, a challenge that is complicated in numerous urban centres due to the extensive footprint of private cars. These vehicles occupy significant space – in terms of both infrastructure and parking areas – hindering efficient land allocation. Looking at the Netherlands, it has been reported that in the twenty largest municipalities, approximately 55% of the available public street space is allocated to cars – of which 10% is reserved for parking facilities (van Liere et al., 2017; van der Linden, 2023). Private cars are estimated to be parked 96% of the time (Zijlstra et al., 2022) and parking incurs a significant opportunity cost – i.e., the foregone potential of alternative land-use choices (Buchanan, 1991) – as it occupies valuable space that could be better utilised (Ostermeijer et al., 2019; Rogers et al., 2016). The proliferation of parking can further contribute to heat islands, urban sprawl, and greenhouse gas emissions (Andrews, 2008). Additionally, an excessive need for parking can lead to increased separation between buildings, amplifying distances between destinations and subsequently fostering greater car reliance (Rogers et al., 2016; Cervero et al., 2010). Thus, a reduction of car ownership and usage in urbanised areas is indeed considered to be desirable to make space for other, more sustainable purposes.

The Dutch STOMP-principle (see Figure 2) – which is an acronym for 'Space-efficient Transportation Optimisation Management Principles' – states space-efficient and environmentally friendly transportation modes are preferred in new area developments. A reduction in (private) cars, associated infrastructure, and parking can yield more space for greenery, enhancing urban landscapes and promoting active modes of transportation like walking, biking, and public transportation, thus offering potential health advantages (Mueller et al., 2017; Nieuwenhuijsen, 2016; Nieuwenhuijsen & Khreis, 2016). To ensure more efficient land allocation, urban mobility is undergoing a transition towards sustainable and shared transportation solutions. In line with this, carsharing has emerged as a promising alternative to traditional car ownership.

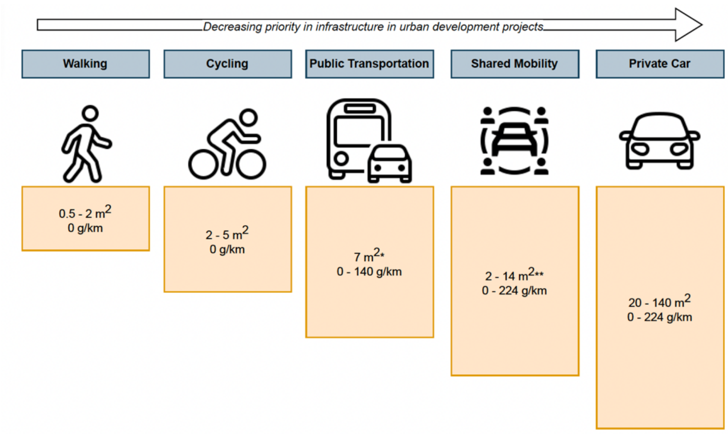


**Figure 2.** The STOMP-principle, which prioritises environmentally friendly and space-efficient transportation modes. *Pertains to trams with an average passenger capacity of 50 individuals. **Derived from an average of 10 users per shared vehicle. Adapted from den Hartog (2023).

## 1.1. Current State of Carsharing

Carsharing is a form of mobility that offers an alternative to owning private car. On a household level, carsharing has been proven to reduce the need for an (additional) private car (Jorritsma et al., 2021; Martin & Shaheen, 2011a). It has become a key transportation trend, particularly in metropolitan areas as the number of carsharing users in the world have increased from 350,000 in 2006 to 4,940,000 (Prieto et al., 2017). In most instances, carsharing should not necessarily be seen as a full substitute of car ownership, but rather it is convenient for a specific group of consumers – particularly that of infrequent car users, who also make use of alternative mobility options such as bikes and public transportation (Münzel, 2020).

According to Rijkswaterstaat (n.d.) carsharing services are increasing in popularity in the Netherlands, especially in urban areas. This reflects a transition in societal values towards sustainability, collaborative consumption, and cost-effectiveness (Petzer et al., 2021). Additionally, reduced private car use allows for less car-centric urban developments as the need for infrastructure such as roads and parking lots is reduced (Golalikhani et al., 2021). Based on the number of carsharing users that sell their private car or do not acquire one, it has been estimated that one carsharing vehicle replaces approximately fourteen private cars and thus saves 300 square metres of space (Goudappel, 2023).

Apart from the spatial savings, carsharing is also more accessible to formerly carless households (Shaheen et al., 2019). Lucas (2012) shows how social and transportation disadvantages intertwine to create transport poverty, leading to inaccessibility of essential resources and consequent social exclusion. Carsharing – by offering affordable vehicle access – directly addresses this issue, making a significant social impact. Thus, fairly priced carsharing stimulates social inclusion and combats transportation poverty by encouraging transportation equity (Hönnige, 2022) – which refers to the fair and moral allocation of mobility benefits and costs across society, considering both social groups and geographic areas (Bruzzone et al., 2023).

## 1.2. Car-free Neighbourhoods & Merwede

In accordance with peak car theory (Stolk, 2022) – which states that the distance travelled by car per capita has peaked and will now decline in a sustained manner – and less car-centric urban development, car-reduced and car-free neighbourhoods have emerged as trends in urban planning (Ortegon-Sanchez et al., 2017). Like carsharing, these car-reduced and car-free areas align with sustainability goals and result in more efficient and green spatial allocation. In these areas – where residents have a reduced private vehicle-dependence – there is an opportunity for carsharing to flourish.

In the Netherlands, an example of a car-free mixed-use residential neighbourhood currently being developed with 6,000 residences is Merwede. This neighbourhood exemplifies the Dutch interest in creating less car-centric residential neighbourhoods as Merwede prioritises green spaces, public transportation, and integral shared mobility options, while implementing low parking standards (Bloom Merwede, 2023). Parking is rare and expensive due to low parking norms – 0.3 as opposed to a minimum of 1.6 per resident (Mingardo et al., 2015) – making it costly to own a car (Stolk, 2022). For those who still want or need a car but cannot afford to pay the relatively high parking fees – of approximately 200 euros per parking spot per month – there is the option to park more distant at locations like P+R Westraven and the Papendorp Hub. However, this requires more effort to get to the car, reducing the convenience of owning one (Jorrtisma et al., 2021). As an alternative to private car use, Merwede strives to stimulate the use of shared modes of transportation such as public transportation and carsharing; making the car-free neighbourhood a model for the integration of sustainable urban planning and carsharing solutions. Merwede is intended to be home to a diverse socio-economic mix of future residents as the neighbourhood intends to accommodate all types of residents from social housing tenants to residents in the highest income groups. For low-, middle-low-, middle-high-, and high-income residents this respectively amounts to approximately 20, 23, 49, and 8 percent of the neighbourhood (Over Morgen, n.d.; Woonprogramma Merwede, 2022). A challenge the Municipality of Utrecht is faced with as it pertains to Merwede, is that due to the expensive and scarce parking options, lower-income residents who are currently often reliant on private cars, need cost-effective mobility solutions such as carsharing. However, it is likely that the regular dependence on this service will also be too expensive for lower-income groups in Merwede. This sets the stage for an interesting case study as it relates to equitable carsharing in a Dutch car-free neighbourhood.

## 1.3. Problem Statement

Literature regarding carsharing and car-free neighbourhoods is quite broad. Much has been reported regarding the determinants of carsharing adoption as well as policies and interventions influencing carsharing. Literature research revealed that socio-economic characteristics – such as age, education, family composition, gender, and income – influence travel behaviour and carsharing use specifically (Becker et al., 2017; Aguilera-Garcia et al., 2020; Ampudia-Renuncio et al., 2020; Bieliński & Wazna, 2020; Liao & Correira, 2022; Magdolen et al., 2022; den Hartog, 2023). Literature also highlights the importance of carsharing service price as a critical determinant of carsharing adoption (El-Assi et al., 2015; den Hartog, 2023). Studies have delved into exploring cost components (Meijer & Witteveen, 2015; Liang et al., 2021), optimised pricing and product strategies (Jorge et al., 2015; Xu et al., 2018; Soppert al., 2019), and dynamic pricing mechanisms (Chow et al., 2015; Qui, 2017; Qui et al., 2018; Giorgione et al., 2019; Nansubuga & Kowalkowski, 2021). However, carsharing service pricing is often researched from the – profit-maximising – perspective of the carsharing service operator (CSO), but not often from the perspective of the user or from a holistic point of view. There is a noticeable gap in literature regarding how (potential) carsharing users respond to changes in service pricing. Particularly in urban centres in the Netherlands – where carsharing services are popular – it would be interesting to uncover how demand for the service changes in response to changes in service price (Kim et al., 2019). Therefore, this thesis aims to gain a better understanding of the price elasticity for carsharing as well as pricing strategies for carsharing services that satisfy the needs, preferences, and capabilities of all potential users.

According to Meelen et al. (2019), high density neighbourhoods with close facilities and lower ownership rates are potential carsharing hotspots, making car-free neighbourhoods – where car ownership rates are low – promising areas for carsharing to emerge as a sustainable shared mobility solution. Regarding car-free areas in the Netherlands, studies have investigated effective policies for municipalities to convert towards a car-free or low-car city (Floor, 2020); success factors of specific car-free neighbourhoods (Oost, 2022); and how to reduce car ownership in neighbourhoods (Schouten, 2019). However, there is limited literature regarding integrating carsharing services in car-free environments. Moreover, not much is reported regarding pricing strategies for carsharing services that cater to residents of car-free neighbourhoods, particularly pertaining to carsharing pricing strategies that ensure these services are available to (i.e., affordable for) all socio-economic groups of the neighbourhood.

Addressing the complexities of carsharing pricing within car-free neighbourhoods may yield interesting insights into how to foster more equitable transportation systems that integrate carsharing. Furthermore, examining carsharing service pricing in a real-world context would shed light on how to balance economic viability and social inclusivity – critical components of sustainable urban living (Svennevik et al., 2021). The car-free neighbourhood Merwede presents an interesting case study as it strives to stimulate the use of sustainable and shared modes of transportation such as carsharing (Stolk, 2022).

An issue that is often the case for car-free neighbourhoods – and holds true for Merwede – is as follows. To reduce private vehicle ownership, municipalities often use financial incentives such as a significant increase in parking fees in car-free neighbourhoods (van den Hurk et al., 2021; Yacoub, 2018). This leaves a disparity for the lower-income residents of this area as they may not be able to pay these fees but are still dependent on (private) cars. An alternative for these residents would be to use alternative mobility services such as biking, public transportation, and carsharing services. That is, if these services are accessible and affordable. Research highlights that while carsharing systems are recognised as environmentally beneficial transport alternatives, comprehensive assessments that combine their environmental impacts with financial performance are uncommon (Vasconcelos et al., 2017). Moreover, the application of cost-benefit analyses (CBAs) to gain insight into the value of carsharing systems – especially in car-free areas – is not commonly practiced. Therefore, by conducting a CBA on the case study neighbourhood of Merwede, this thesis aims to explore the net present value of carsharing in the car-free neighbourhood as well as which pricing strategies should be implemented to ensure equitable access to carsharing services. The case study conducted in this thesis may provide valuable insights for carsharing companies and governmental institutions pertaining to – equitable service pricing for – carsharing in car-free neighbourhoods.

## 1.4. Research Questions

This thesis strives to explore and analyse factors and policies influencing the adoption of carsharing services, ultimately aiming to propose an equitable pricing strategy for carsharing in the car-free neighbourhood of Merwede. Therefore, the main research question this thesis aims to answer is:

**What pricing strategies could be implemented for business-to-consumer carsharing services in car-free residential neighbourhoods to align with the diverse needs and preferences of potential users?**

The present thesis intends to answer the research question by answering the following sub-questions:

1. Which factors influence the adoption of carsharing?
2. Which municipal and national governmental policies and interventions can support carsharing services within and beyond car-free residential neighbourhoods?
3. What is the effect of a service price change on the demand for carsharing services per income group in the Netherlands?
4. What are the costs and benefits of subsidising carsharing services for low- and middle-low-income residents of Merwede?

The subsequent section describes the scope of this thesis. In this, first the definitions of carsharing and car-free neighbourhoods are outlined, followed by a section regarding carsharing service typology and another regarding CSOs in Utrecht. The scope concludes with a section regarding the stakeholders involved – particularly in Merwede.

## 1.5. Scope

### 1.5.1. Definition of Carsharing & Car-free Neighbourhoods

Carsharing in this thesis is defined as the practice of sharing a car or using carsharing services for regular travelling, especially for commuting. An important distinction between carsharing, car renting, car leasing, and car ownership, is that carsharing offers short-term access to a vehicle for as little as a few minutes or hours, typically with a focus on convenience and lower upfront costs. Contrary, car renting and leasing regard use of an exclusive vehicle. The former generally involves longer periods like days or weeks, and the latter requires a longer-term commitment often spanning several years. Car ownership involves purchasing and maintaining a vehicle with all associated long-term responsibilities and costs (Shaheen & Cohen, 2012).

In this thesis car-free neighbourhoods are defined as residential zones explicitly designed to minimise the use of private cars by restricting access to non-essential vehicular traffic (Toersche, 2023). These areas prioritise pedestrian and bicycle traffic, public transportation, and shared modes of transportation, thereby creating a safer and more environmentally friendly space for residents and visitors. Low-car or car-reduced neighbourhoods follow a similar philosophy but allow for limited car use, aiming to substantially reduce vehicular traffic rather than eliminate it entirely. This thesis does not distinguish between car-free, low-car, and car-reduced neighbourhoods but rather views them as a singular concept.

### 1.5.2. Carsharing Service Typology

Carsharing services are categorised as illustrated in Figure 3. They can be defined as business-to-business (B2B), business-to-consumer (B2C), or peer-to-peer (P2P) carsharing services (Münzel et al., 2019a; Münzel et al., 2020). Firstly, B2B carsharing involves companies providing shared vehicle fleets to other businesses for employee use, offering a cost-effective and flexible transportation solution for corporate needs. Secondly, B2C carsharing systems involve commercial car rental services where vehicles are owned and operated by a centralised carsharing provider, offering users access to a fleet of shared vehicles for a fee. Thirdly, P2P carsharing systems, entail private vehicle owners making their personal cars available for short-term rentals to other individuals, facilitated through a P2P platform. The key distinction lies in ownership and operation, with B2B and B2C systems being managed by professional carsharing companies, while P2P systems rely on private individuals sharing their own vehicles (often via an intermediate application).

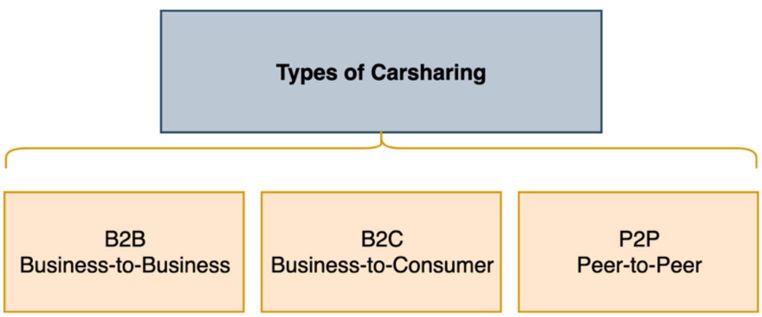


**Figure 3.** Carsharing typologies.

As mentioned in Figure 3, there are three categories of carsharing services – namely, B2B, B2C, and P2P. Furthermore, we can distinguish between free-floating and station-based systems (Münzel et al., 2020). Free-floating carsharing systems – characterised by the flexibility of vehicle pick-up and return within a specified service area – tend to experience higher utilisation rates in regions where ample on-street parking is accessible. In contrast, station-based carsharing systems – necessitating the return of vehicles to designated parking spots – are typically favoured in areas characterised by limited or regulated parking infrastructure. This preference is attributed to the convenience offered by station-based carsharing, as users are relieved of concerns regarding the availability of parking spaces for shared vehicles. Additionally, as owning a driver's license is a prerequisite for using carsharing services, the relevant target group is 18 years or older and possesses a driver's license. The focus in the present thesis is on B2C carsharing because it is the most inclusive option and has demonstrated effectiveness in fulfilling various policy objectives while alleviating urban space constraints (Habekotté, 2021). This focus is further reinforced by the substantial market size of B2C carsharing and the decision-making challenges it presents, including critical considerations around pricing strategies (Golalikhani et al., 2021). Additionally, emphasis is put on round-trip station-based carsharing as Merwede has car-free streets within the neighbourhood and four main neighbourhood mobility hubs (i.e., stations). This approach is preferred to avoid the complexities associated with non-station-based (i.e., free-floating) systems.

### 1.5.3. Carsharing Service Operators

Regarding the CSOs of interest, several criteria were enforced to ensure applicability to Merwede. Specifically, these operators must be B2C CSOs that provide vehicles for personal use and have station-based pickup points in the province of Utrecht. The CSOs that were included and excluded are listed in Table 2.

**Table 2.** Carsharing service operators in the province of Utrecht and their reasons for inclusion or exclusion in the present thesis.

| | |
|---|---|
| **Included** | |
| *A2B* | Shared mobility component of Katapult Mobility providing flexible residential mobility solutions, including business-to-consumer carsharing services. |
| *Greenwheels* | A well-known station-based, business-to-consumer carsharing service operating in various Dutch cities, including Utrecht. |
| *Hely* | Provides a diverse range of shared mobility options through a single app, offering convenient access to vehicles located at Hely Hubs in residential areas, apartment complexes, and business sites across the Netherlands. |
| *MyWheels* | Offers both peer-to-peer and business-to-consumer station-based carsharing options in the Netherlands, including in Utrecht. |
| *OnzeAuto* | Business-to-consumer car provider, facilitating carsharing among residents in neighbourhoods and communities through a cooperative approach. |
| **Excluded** | |
| *Amber* | A business-to-business subsidiary of MyWheels. |
| *ConnectCar* | Merged with MyWheels and is now known as KAV2GO Bestelbusverhuur, specialised in renting out vans. |
| *DEEL* | A peer-to-peer carsharing provider. |
| *Share Now* | Merger of Car2Go and DriveNow that primarily offers a free-floating carsharing service. |
| *Sixt Share* | While Sixt offers station-based rentals, their service is more like traditional car rental than typical business-to-consumer carsharing models. Also, they are known for their free-floating model. |
| *SnappCar* | An intermediate platform for peer-to-peer carsharing. |
| *Stapp.in* | A business-to-business carsharing service provider. |
| *StudentCar* | Only offers vans and no other types of cars. |
| *WeDriveSolar* | Recently merged with MyWheels and are known for placing their own charging infrastructures. |

As a result of the selection criteria, the CSOs included in the present thesis are A2B, Greenwheels, Hely, MyWheels, and OnzeAuto. Furthermore, significance is put on (mixed-use) residential neighbourhoods rather than full-fledged cities as these have a larger scale and more dynamic and unpredictable mobility patterns. Moreover, the focus is on electric vehicles (EVs) sharing rather than fuel-dependent carsharing as the former are the more sustainable alternative (Jorritsma et al., 2021).

#### 1.5.4. Stakeholders Involved

The stakeholders involved in carsharing in Merwede particularly and their responsibilities (see Figure 4) are as follows (Boshouwers et al., 2018; van den Hurk et al., 2021). Firstly, carsharing users are of interest, these are mainly future Merwede residents who will use or rely on the carsharing and other mobility services available in Merwede. Secondly, CSOs are of interest. Apart from providing the carsharing services, they are responsible for providing memberships/subscriptions and collecting service fees; as well as for operating digital platforms for their services and maintaining their fleet. Moreover, these operators must pay parking fees within Merwede for their carsharing vehicles. Thirdly, the Municipality of Utrecht is responsible for investing in public infrastructure, implementing mobility policies that support Merwede's mobility concept (i.e., parking policy), and ensuring equitable access to mobility services in Merwede for all residents.

Aside from these three key stakeholders – for the sake of transparency – it is necessary to mention two other stakeholders who stand to benefit from this thesis. Namely, Arcadis | Over Morgen and Merwede Mobiliteitsbedrijf. Arcadis | Over Morgen is an engineering consultant specialised in sustainable urban development and mobility solutions that is involved in the Merwede neighbourhood. Furthermore, certain mobility services in Merwede will be managed by an overseeing entity named Merwede Mobiliteitsbedrijf. This entity oversees interests from real estate developers involved in Merwede as well as governments and municipalities. The entity holds a comprehensive responsibility to ensure efficient operation and ongoing enhancement of the mobility concept in Merwede. This includes quality management, traffic control, and the management of parking spaces and the mobility shop. Additionally, Merwede Mobiliteitsbedrijf is responsible for contracting CSOs, a function essential for the deployment of carsharing services within the neighbourhood. This entity also plays a pivotal role in delivering benefits to users – critical for ensuring the successful sale of residences in Merwede. Moreover, they are tasked with covering the costs associated with carsharing subsidies for lower-income residents – discussed in Section 7.1.3 – aligning with the objectives of enhancing transportation equity and accessibility for all residents of Merwede. These functions emphasise their significant role in coordinating partnerships with stakeholders such as landowners and the Municipality of Utrecht.

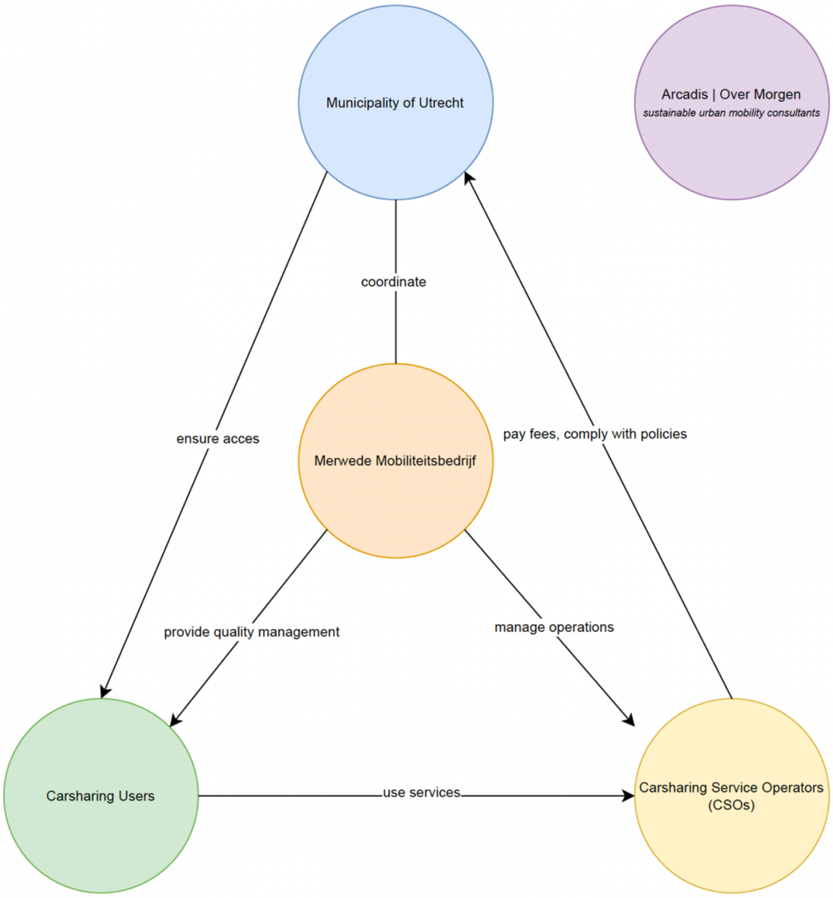


**Figure 4.** Stakeholders pertaining to carsharing in Merwede and their responsibilities.

## 1.6. Relevance & Structure

As highlighted in Section 1.3, the significance of this thesis emerges from its focused exploration of making carsharing services in Merwede's car-free environment accessible and affordable for all income groups. This thesis aims to devise a pricing strategy that promotes equitable access to carsharing services, thereby stimulating transportation equity. The insights gathered from this thesis may provide valuable knowledge for future car-reduced and car-free area developments as well as for carsharing service operators, users, and municipalities aiming to integrate these services into area developments in an equitable manner.

carsharing service pricing is often researched from the – profit-maximising – perspective of the CSO, but not often from the perspective of the user or from a holistic point of view. There is a noticeable gap in literature regarding how (potential) carsharing users respond to changes in service pricing. Particularly in urban centres in the Netherlands – where carsharing services are popular – it would be interesting to uncover how demand for the service changes in response to changes in service price

Following this Introduction, the Methodology chapter describes the methodologies employed to answer the research questions. The Literature Research chapter provides context, followed by a detailed Case Description of Merwede. Then, the Results chapter presents findings from the price elasticity determination, market research, and CBA analysis. These findings inform the subsequent Discussion, which critically reflects on the implications. Finally, the Conclusion synthesises the findings and reflects on carsharing's role in advancing a car-free urban landscape.

# 2. Methodology

This chapter presents the methodologies applied in this thesis. It starts with an overview of the employed methods in the form of a table (Table 3) and flowchart (Figure 5). The literature research sets the stage, followed by a data analysis. Then, the methodology for determining price elasticity across different income groups is described. Also, the procedure of the market research is elaborated upon. The choice of evaluation method and the cost-benefit analysis (CBA) approach are also clarified. The overarching methodological choice is a case study of carsharing in the car-free neighbourhood Merwede.

## 2.1. Overview of Methodologies

### 2.1.1. Methodology per Sub-question

Table 3 provides an overview of the various methods used per sub-question as well as the final deliverable associated with each sub-question.

**Table 3.** Sub-questions, methods, and deliverables for this thesis.

| | Sub-question | Method(s) | Deliverable |
|---|---|---|---|
| *1* | Which factors influence the adoption of carsharing? | • Literature research<br>• Data analysis | • Proposed Theoretical Framework (Section 3.2)<br>• Case Description of Merwede (Chapter 4) |
| | | | |
| *2* | Which municipal and national governmental policies and interventions can support carsharing services within and beyond car-free residential neighbourhoods? | • Literature research | • Policies Impacting Carsharing Adoption (Section 3.6)<br>• Table 15. Overview of policies and interventions that stimulate carsharing adoption. |
| | | | |
| *3* | What is the effect of a service price change on the demand for carsharing services per income group in the Netherlands? | • Extracted Dutch carsharing elasticity from studies<br>• Compensated data gaps with public transport and global insights<br>• Refined with guiding principles (Table 5) | • Carsharing Price Elasticity per Income Group (Section 6.1) |
| | | | |
| *4* | What are the costs and benefits of subsidising carsharing services for low- and middle-low-income residents of Merwede? | • Cost-benefit analysis | • Cost-Benefit Analysis (Chapter 5)<br>• CBA (Section 6.4) |

### 2.1.2. Flowchart of Methodologies

Figure 5 maps out the methods used in this thesis, starting with a review of the literature on car-free neighbourhoods and carsharing. The next steps are understanding the factors that affect carsharing adoption, market research, price elasticity determination, and a data analysis of future residents' socio-economic characteristics and mobility preferences. These steps help determine the examined policies. Lastly, a CBA is considered. In this, the costs are carefully considered against the benefits, with the aim being to ensure equitable access to carsharing services in Merwede.

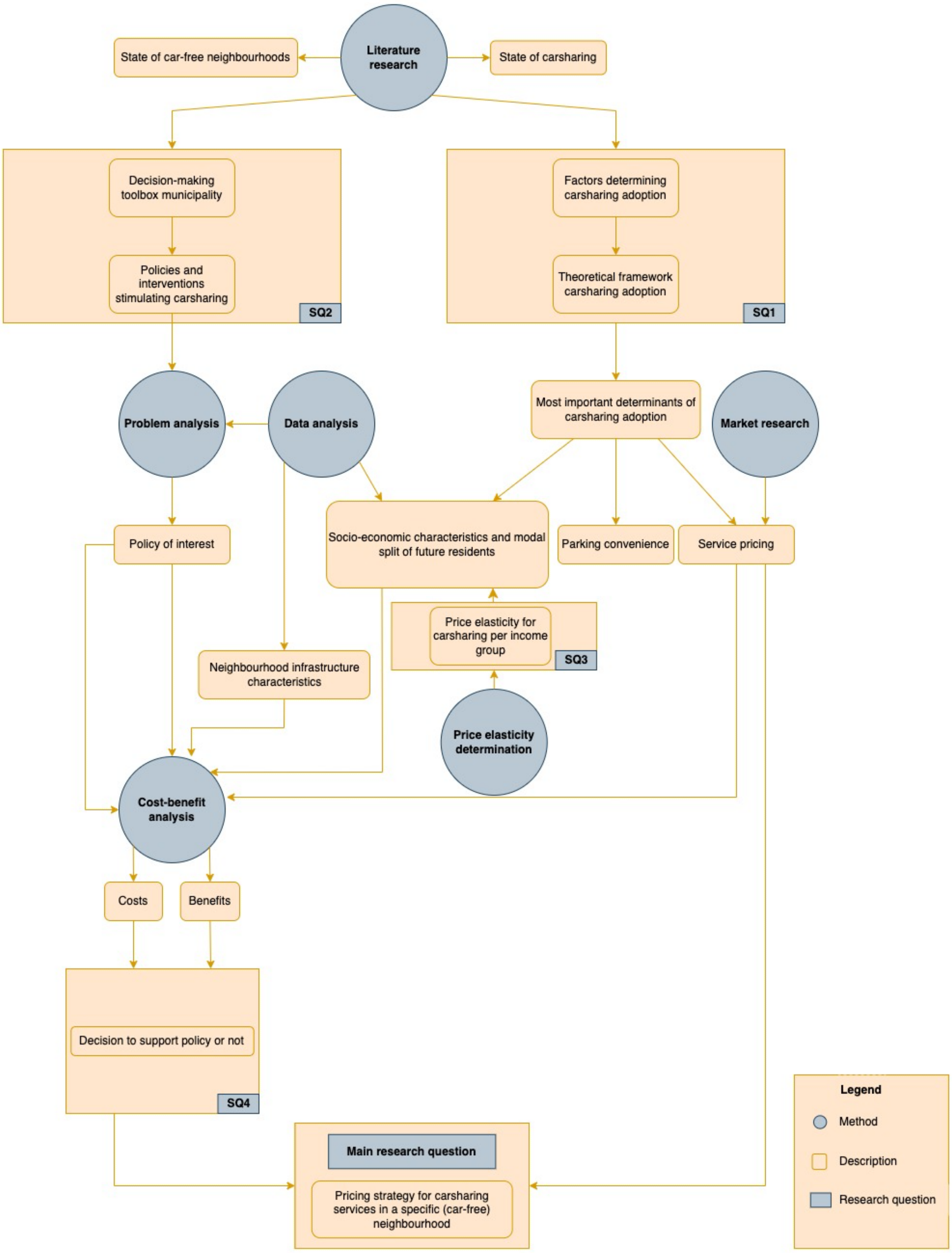


**Figure 5.** Flowchart of methodologies employed to determine a pricing strategy for carsharing services in a yet-to-be-populated residential neighbourhood. In this thesis, the specific context refers to the car-free neighbourhood of Merwede, Utrecht. In this, 'SQ' stands for sub-question.

## 2.2. Literature Research

This thesis employs comprehensive literature research to various ends. This is used to establish the general current state of car-free neighbourhoods and within the context of the Netherlands. Specifically, determinants of carsharing adoption are reported in the form of a theoretical framework (Figure 6 and Table 8). Moreover, emphasis is put on discussing various policies and interventions at the municipality's disposal that may affect carsharing adoption in (Sections 3.6 and 4.4).

The literature research in this thesis adheres to the four steps suggested by Bryman (2016). Initially, the purpose and scope are clearly defined. Subsequently, relevant studies are systematically identified. Then, the list of literature is refined to meet the criteria established in the first step. Finally, the gathered results are comprehensively analysed and synthesised.

Studies considered relevant for this study are scientific research papers, theses, or case studies published within the last 15 years. Broadly speaking, these papers should include information about car-free neighbourhoods (in the Netherlands), user needs and preferences related to carsharing adoption, and pricing strategies for carsharing. Significance is put on (mixed-use) residential neighbourhoods rather than full-fledged cities, as smaller scale neighbourhoods like Merwede often exhibit less dynamic and more predictable mobility patterns compared to the larger and more complex urban environments (Litman, 2020b). Furthermore, with Merwede's central sustainability goal, the focus is primarily on EV carsharing rather than fuel-dependent carsharing. This preference aligns with the broader sustainability aims, as EVs represent a more environmentally friendly alternative, contributing to reduced emissions and supporting urban sustainability initiatives (Martin & Shaheen, 2011b; Shaheen & Cohen, 2012).

To identify the relevant literature, the following online journal libraries, search engines, and repositories were consulted: SAGE Journals, Science Direct (Elsevier), Scopus, Taylor & Francis Journals, and the TU Delft Repository. The search terms used for these search engines can be found in Table 4.

**Table 4.** Keywords used in various library search engines.

| Keywords | |
|---|---|
| *'Carsharing' OR 'car sharing'* | AND 'adoption' OR 'economic' OR 'personal' OR 'political' OR 'service' OR 'spatial' OR 'temporal' AND 'factors' |
| | AND 'benefits' |
| | AND 'business-to-consumer' OR 'B2C' |
| | AND 'costs' |
| | AND 'cost-benefit analysis' |
| | AND 'economic factors' |
| | AND 'mathematical model' |
| | AND 'mode choice' |
| | AND 'Netherlands' |
| | AND 'policies' AND/OR 'interventions' |
| | AND 'pricing' AND/OR 'product' AND strategies' |
| | AND 'social cost-benefit analysis' |
| | AND 'station-based' |
| | AND 'user' AND 'needs' AND/OR 'preferences' |
| *'Car-free'* | AND 'carsharing' OR 'car sharing' |
| | AND 'neighbourhood' |
| | AND 'success factors' |
| *'Car ownership'* | AND 'benefits' |
| | AND 'costs' |
| | AND 'equity' |
| | AND 'motivations' |
| | AND 'needs' AND/OR 'preferences' |

In the end, the search and selection process yielded many sources, which are primarily elaborated upon further in Chapter 3. Aside from the sources identified using selection criteria, additional relevant sources– such as those regarding pricing data from CSOs and from Arcadis | Over Morgen – were consulted to clarify certain knowledge gaps. These sources are listed in Table 5. Additionally, a backward search was conducted by reviewing key references of the studies identified in the previous steps, along with a forward search to identify relevant literature citing the key articles identified in the earlier steps.

## 2.3. Data Analysis

Pertaining to the case study in this thesis, to identify the main concerns regarding carsharing within Merwede, previous studies as well as analyses carried out by Arcadis | Over Morgen were used. These documents are somewhat confidential. It should be noted that there may be a bias since this thesis was commissioned by a commercial consultancy (Arcadis | Over Morgen). Whilst attempting to remain as objective as possible, confidential company data and documents may possibly have skewed the findings of this thesis. Thus, final results of this research – particularly pertaining to the case study neighbourhood – may not be as objective as they ought to be.

The documents used in Chapter 4 to describe the case of Merwede, are shown in Table 5. Bloom Merwede (2023) provides information about local amenities and transport plans, while Citisens (2021) contributes survey data on mobility preferences of future Merwede residents. The Municipality of Utrecht's report from 2020 details urban planning and demographic projections. Additionally, van den Hurk et al. (2021), Pakhuis de Zwijger (2023), and Woonprogramma Merwede (2022) offer quantitative details regarding the neighbourhood's anticipated development and Whooz (2023) data from households in Utrecht informs the modal split of future residents.

This thesis does not conduct an original data analysis but synthesises conclusions from these existing documents to inform the 'Socio-economic Characteristics and Modal Split of Future Residents' and 'Problem Analysis' components in Figure 5. The former assesses future residents' needs and preferences regarding mobility options and is reported in Section 4.3, whilst the latter examines challenges and opportunities for carsharing implementation in Merwede specifically and is reported in Section 4.4.

**Table 5.** Sources consulted for data analysis.

| Source | Data Obtained |
|---|---|
| *Boshouwers et al., 2018* | • Stakeholders involved in Merwede |
| *Bloom Merwede, 2023* | • Information on amenities and (planned) transportation options in Merwede<br>• Emphasis on green spaces, squares, and social interaction in the neighbourhood |
| *Citisens, 2021* | • Survey data on preferences for shared mobility usage<br>• Details on the inclinations of residents towards carsharing versus private car usage<br>• Data on preferred payment strategies for shared mobility |
| *Goudappel, 2023* | • Estimation that one carsharing vehicle replaces approximately fourteen private cars and thus saves 300 square metres of space |
| *Over Morgen, 2021* | • Projections of private vehicle ownership in Merwede per income group.<br>• Monthly mobility budgets per income group for citizens of Utrecht. |
| *Van den Hurk et al., 2021* | • Quantitative details about Merwede including area size, previous and envisioned functions, and the number of buildings |
| *Municipality of Utrecht, 2020* | • Urban development plan Merwede<br>• Overview of the Merwede area development and its surroundings |
| *Pakhuis de Zwijger, 2023* | • Additional quantitative details about Merwede such as the number of residents, buildings, services, and mobility figures |
| *Stolk, 2022* | • Description of Merwede's geographical location and potential as a multifunctional urban area |
| *Whooz, 2023* | • The probability that a certain (type of) household uses a certain modality compared to the Dutch average<br>• Predicted modal split per income group in Merwede |
| *Woonprogramma Merwede, 2022* | • Number of different types of residences and developers responsible |

## 2.4. Price Elasticity per Income Group

A common way to determine the effect of a service price change on the demand for carsharing services is to use price elasticity. Price elasticity of demand measures the responsiveness – or elasticity – of the quantity demanded of a product or service to a change in its price. It is a key economic concept that quantifies the change in demand as prices increase or decrease, usually expressed as a percentage change. This measurement is often applied to understand how price changes affect demand for a certain product or service. In turn, this understanding allows for predictions of usage patterns (i.e., service demand) under different pricing conditions. As there is limited literature regarding price elasticities for Dutch carsharing services, an estimation must be made to assess how potential price changes could influence consumer behaviour and service adoption in Utrecht.

Han & Li (2009) suggest three methods for calculating transportation price elasticity. Namely, the shrinkage ratio, midpoint arc elasticity, and log arc elasticity. Which method is most suitable varies per circumstance. By analysing the statistical properties of these methods and comparing their relative efficiencies, the suitable method per circumstance can be selected. Since price elasticity is described as a relative difference between price and demand over time, point-to-point aggregate data is required. Specifically, data regarding the price of a mobility service and demand for a mobility service before and after a certain period.

In this thesis, differences in price elasticity between different income groups are also of interest, as the carsharing services pertain to a neighbourhood (Merwede) with specific socio-economic characteristics and transportation equity problems (Section 4.4) were indicated for low- and middle-low-income residents in particular (Over Morgen, n.d.).

Unfortunately, data regarding Dutch carsharing service price and demand – specifically pertaining to the five CSOs of interest (i.e., A2B, Greenwheels, Hely, MyWheels, and OnzeAuto) – was not readily available. Therefore, the following methodology is applied to estimate the price elasticities of demand for Dutch carsharing services in passenger kilometres per income group. First, a general Dutch carsharing price elasticity is determined based on literature (Kim et al., 2017). However, as not much literature is available regarding this topic, the price elasticity for public transportation in the Netherlands (Planbureau voor de Leefomgeving, 2010; Bakker et al., 2018) as well as carsharing price elasticities from other countries (Cartenì et al., 2016; Papu Carrone et al., 2020) are used as a reference. Second, to obtain price elasticities differentiated per income group, the range of relative difference between the four income groups is determined using a study by Vasudevan et al. (2021) – which gives an example of how to determine mode shift elasticity based on household income and travel cost. This provides a factor with which the general Dutch carsharing price elasticity can be multiplied, resulting in an estimated carsharing price elasticity per income group in the Netherlands. Additionally, to qualitatively inform the estimated price elasticities, various principles – regarding price and demand relations – identified from literature are applied, these are listed in Table 6. These principles collectively provide a framework for understanding how economic, behavioural, and situational factors shape the observed price elasticities within the mobility market. For the results of the price elasticity determination, please refer to Section 6.1.

**Table 6.** Guiding principles to determine carsharing price elasticities.

| | Principle | Description | Source |
|---|---|---|---|
| *1* | *Behavioural Economic Influences* | Perceptions of value and convenience significantly influence transportation choices, impacting price sensitivity. | Thaler, 1999 |
| *2* | *Diverse Mobility Preferences* | Mobility needs and preferences vary across income groups, affecting sensitivity to price changes in transportation modes. | Becker et al., 2017 |
| *3* | *Market Saturation Effects* | In saturated markets, the demand for transportation modes may exhibit lower price elasticity due to high dependence or limited alternatives. | Becker et al., 2017 |
| *4* | *Income Sensitivity* | Lower-income individuals exhibit greater price sensitivity as transportation costs constitute a larger income proportion. Therefore, there is a monotonic relationship between elasticity and income. | Cohen & Shaheen, 2018 |
| *5* | *Urban-Rural Dynamics* | Elasticity responses differ in urban versus rural areas due to the availability of transportation options and urban planning strategies. | Litman, 2020a |
| *6* | *Uniform Public Transport Elasticity* | Public transportation's essential nature results in similar price elasticity across all income groups, regardless of economic status. | Bakker, 2018 |
| *7* | *Ridesharing and Public Transport Complementarity* | Ridesharing services complement public transportation, affecting adoption rates by income level in urban settings. | Alonso-González et al., 2020 |
| *8* | *Transferability of Travel Demand Relationships* | The difference between income groups is relative and people respond similarly to variations in their money and time costs, the basic relationships that affect travel demand tend to be durable and thus transferable. | Litman, 2022 |

## 2.5. Market Research

As service pricing was proven to be an important determinant of carsharing adoption (Table 8), market research was carried out to ascertain the current average kilometre, hourly, and monthly subscription prices of carsharing services in Utrecht. As mentioned, the CSOs included in this thesis are A2B, Greenwheels, Hely, MyWheels, and OnzeAuto. To obtain pricing schemes and service rates, first and foremost publicly available websites and carsharing mobile applications/platforms were analysed. Furthermore, the included CSOs were contacted by email to schedule an informal meeting to discuss service pricing, Greenwheels is the only CSO that participated.

All in all, this procedure allowed for the determination of the average kilometre price (*Pkm*), hourly price (*Pt*), and monthly subscription price (*Psub*) of carsharing services for the CBA (described in Section 5.1). To calculate the averages, a few values were seen as a given, namely: days per month (30); hours per day (24); and average kilometres per hour in a carsharing vehicle (40). The values obtained from the market research are reported in Section 6.3.

## 2.6. Existing Evaluation Methodologies

Selecting an appropriate pricing strategy for carsharing services necessitates a thorough assessment of economic viability and social welfare implications. A pricing strategy should ideally align with the diverse needs and preferences of potential users whilst ensuring the economic and environmental sustainability of the service. To this end, several methodologies exist for evaluating pricing strategies – each offering unique insights – the most prevalent of which are listed below:

- **Econometric modelling** provides quantitative insights into economic impacts, yet it often lacks the scope to encompass the social welfare considerations (Efron & Tibshirani, 1993).
- **Competitive analysis** can reveal market trends (Porter, 2004), but lacks an aspect of policy evaluation.
- **Cost-benefit analysis** (CBA) has the capacity to integrate externalities and a wide array of impacts – including policies – aligning with public sector decision-making and policy formulation needs (Boardman et al., 2017).
- **Surveys** and **market research** are instrumental in understanding consumer preferences (Brown & Reingen, 1987; Hair et al., 2019), but they cannot alone capture the complete economic and social implications of pricing strategies.
- **Multi-Criteria Decision Analysis** (MCDA) addresses a variety of factors, yet its complexity may lead to challenges in implementation and could introduce subjective biases (Belton & Stewart, 2002).

The choice of CBA over other methodologies – such as econometric modelling, competitive analysis, surveys, and MCDA – is informed by its adaptability as well as its capacity to balance economic viability with social welfare considerations. Moreover, CBA allows for factoring in diverse stakeholder interests, alongside the unique characteristics of specific neighbourhoods. Therefore, the CBA methodology is employed to analyse the case study neighbourhood (Merwede) in this thesis, offering an empirical basis for decision-making.

## 2.7. Cost-Benefit Analysis

In the present thesis, the focus is on developing a suitable pricing and product strategy for carsharing services. In this, governmental and municipal pricing policies are also considered. The CBA methodology serves as a crucial tool for the preliminary assessment of policy alternatives. This methodology quantifies the social welfare impacts of policies such as environmental concerns. By monetising these impacts, CBA aids in balanced decision-making between economic and social costs and benefits (Romijn & Renes, 2013). Additionally, whilst CBA does not assign specific values to the experiences of different socio-economic groups, it does illuminate distributional impacts.

Existing CBAs regarding carsharing are elaborated upon in Section 3.5. In the end, following a structured eight-step process (Romijn & Renes, 2013) – outlined in Table 7 – this thesis utilises a CBA to deliver a clear, quantified, and stakeholder-inclusive analysis with values estimated for the base year (2024) and after a 10-year period for the year 2034 (Table 23). In addition to the proposed theoretical framework, the costs and benefits included in the CBA are based on a mathematical model by Vasconcelos et al. (2017), which is adapted and built upon.

**Table 7.** Cost-benefit analysis steps.

| Step | Description | Deliverable |
|---|---|---|
| *1: Problem analysis* | • Describe the problem or opportunity and how it is expected to develop<br>• What is the policy objective in response to this?<br>• What are the most promising options? | • Sections 1.3 and 4.4 |
| *2: Establish the baseline scenario* | • Determine the most likely scenario in the absence of a policy<br>• The effect = policy scenario – baseline scenario | • Section 5.1.4.1 |
| *3: Define policy scenarios* | • Describe measures to be taken<br>• Unravel packages of measures to identify individual elements<br>• Define several scenarios and variants | • Section 4.4 |
| *4: Determine effects and benefits* | • Identify, quantify, and monetise effects | • Section 5.1.2 and Figure 9 |
| *5: Determine costs* | • Resources consumed to implement the solution<br>• Costs may be one-off or recurring, fixed or variable<br>• Only costs additional to the baseline scenario | • Section 5.1.2 and Figure 9 |
| *6: Analyse variants and risks* | • Identify the main uncertainties and risks<br>• Analyse the consequences for the outcomes | • Sections 2.7.1, 5.1.4.2, and 6.4.3 |
| *7: Overview of costs and benefits* | • Calculate all costs and benefits discounted to the same base year and calculate the balance<br>• Present all effects including non-quantified and/or non-monetised effects | • Table 23 |
| *8: Presentation of the results* | • Relevant, understandable, and clear<br>• Explain transparency and reproducibility<br>• Interpret: what can the decision-maker learn from the CBA? | • Sections 6.4.1 and 7.1.3 |

### 2.7.1. Discount Rate, Risk Premium & Uncertainty

A critical component of the CBA is the use of a discount rate (*r*) to calculate the present value of future costs and benefits. This is essential as it accounts for factors like inflation and individual time preference for current consumption over future consumption (Romijn & Renes, 2013). In the Netherlands, the government sets a real risk-free discount rate, reviewed periodically. The most recent decision established a real risk-free discount rate at 2.5%, with a standard macroeconomic risk premium of 3%, leading to an overall discount rate of 5.5%. Based on both the standard practice, a standard discount rate of 5.5% is used in the present CBA. This approach aligns with the principles outlined by de Zeeuw et al. (2008) and Harrison (2010).

Boardman et al. (2017) delineate three distinct types of uncertainty: knowledge uncertainty, policy uncertainty, and future uncertainty. To deal with knowledge uncertainties, a sensitivity analysis (elaborated upon further in Sections 5.2 and 6.4.3) is employed to examine the robustness of the CBA by ascertaining the impact of percentage changes in specific inputs on the final outcomes. Policy uncertainty is considered by exploring various subsidy scenarios and their respective consequences. The uncertainties of future developments – intrinsic to the project's long-term focus – are managed by applying a general risk premium to the discount rate. Also, to account for the unpredictability of future developments, scenarios are examined with varying degrees of carsharing modal split – varying from 0.0%, 3.8%, and 7.5% – whereby considering potential fluctuations in carsharing usage by future residents. Additionally, the CBA examined the implications of different amounts of monthly subsidies for lower-income residents.

# 3. Literature Research

This chapter begins with a review of the available literature regarding factors influencing carsharing adoption and car-free neighbourhoods. Following this, emphasis is put on pricing and product strategies for carsharing as well as policies impacting carsharing adoption. Moreover, CBAs that have been carried out relating to carsharing are discussed. The chapter ends with a conclusion, linking the various sections. Notably, the literature research is also used to underpin the knowledge gap described in Section 1.3.

## 3.1. Underlying Theories for the Proposed Theoretical Framework

This section synthesises key psychological and behavioural theories shaping the adoption of carsharing services, which are used to inform the proposed theoretical framework for carsharing adoption (Figure 6 and Table 8) elaborated upon in the subsequent section. These theories include the Theory of Planned Behaviour (TPB), Technology Acceptance Model (TAM), Innovation Diffusion Theory (IDT), and Utility Maximisation Theory (UMT).

TPB highlights the influence of attitudes, subjective norms, and perceived control on behaviour – essential for understanding habitual use patterns that may impede the shift to carsharing (Ajzen, 1991). Furthermore, TAM – through its emphasis on perceived usefulness and ease of use – aligns with customer attitudes and the practicality of carsharing, indicative of the technology's acceptance potential (Buschmann et al., 2020; Davis, 1989; Venkatesh et al., 2003). Chen & Chao (2011) applied TPB and TAM to transportation modes, highlighting how habitual behaviours – such as private car use – can inhibit individuals' intentions to switch. Moreover, IDT examines how innovation attributes and societal norms shape the assimilation of carsharing into daily routines (Ahn & Park, 2022; Rogers, 2003; Venkatesh et al., 2003), whereas UMT focuses on the rational allocation of resources for maximum utility, aligning spending with user satisfaction (Curwen, 1976). In line with this, Machado et al. (2018) define shared mobility as trip alternatives that aim to maximise the utilisation of the mobility resources that a society can pragmatically afford – disconnecting their usage from ownership.

Collectively, these theories contribute to a primary understanding of factors that motivate the adoption of carsharing. Together, they inform the proposed theoretical framework for carsharing adoption described below. Notably, in this thesis emphasis is put on utility maximisation – as a function of various factors such as income, cost of services, and availability of parking, whilst considering municipal budget constraints – which plays a critical role in user choice within car-free neighbourhoods. The proposed theoretical framework – in addition to the available information regarding the case study area (Merwede) – in turn helps define the items included in the CBA described in Chapter 5.

## 3.2. Proposed Theoretical Framework for Carsharing Adoption

The proposed theoretical framework for carsharing adoption serves to describe various influential components regarding user needs and preferences for carsharing, particularly in the context of residential neighbourhoods.

Regarding mobility and carsharing services, "needs" represent the fundamental transportation requirements individuals have, including commuting, accessing services, running errands, and recreational travel. Recognising and addressing these needs is essential to ensure that carsharing services meet essential travel purposes, making them a convenient and dependable choice for users. On the other hand, "preferences" involve subjective choices related to mobility – such as the type of vehicle preferred, desired convenience levels, willingness to share rides, and choice of pricing plans (Bojković et al., 2019; Hinkeldein et al., 2015). Understanding and accounting for these preferences plays an important role in tailoring carsharing services to align with individual tastes and priorities, ultimately enhancing user satisfaction and fostering loyalty.

The proposed theoretical framework – shown in Figure 6 – focuses on the interplay of needs and preferences in the context of carsharing services. As highlighted by – among others – Habekotté (2021), Magdolen et al. (2022), and den Hartog (2023), (potential) carsharing users' needs and preferences are influenced by a complex interplay of internal (personal) and external (temporal, spatial, political, economic, and service) factors. These factors – which encompass a wide range of considerations – shape how individuals perceive and choose mobility services. The relationships included in the proposed theoretical framework are described in Table 8. Notably, the linear life stage as described by Magdolen et al. (2022) was not included in this framework as this concept is covered by the factors of age, family composition, and income. Moreover, employment – which is included separately in the model proposed by den Hartog (2023) – is considered in the present model with the income factor.

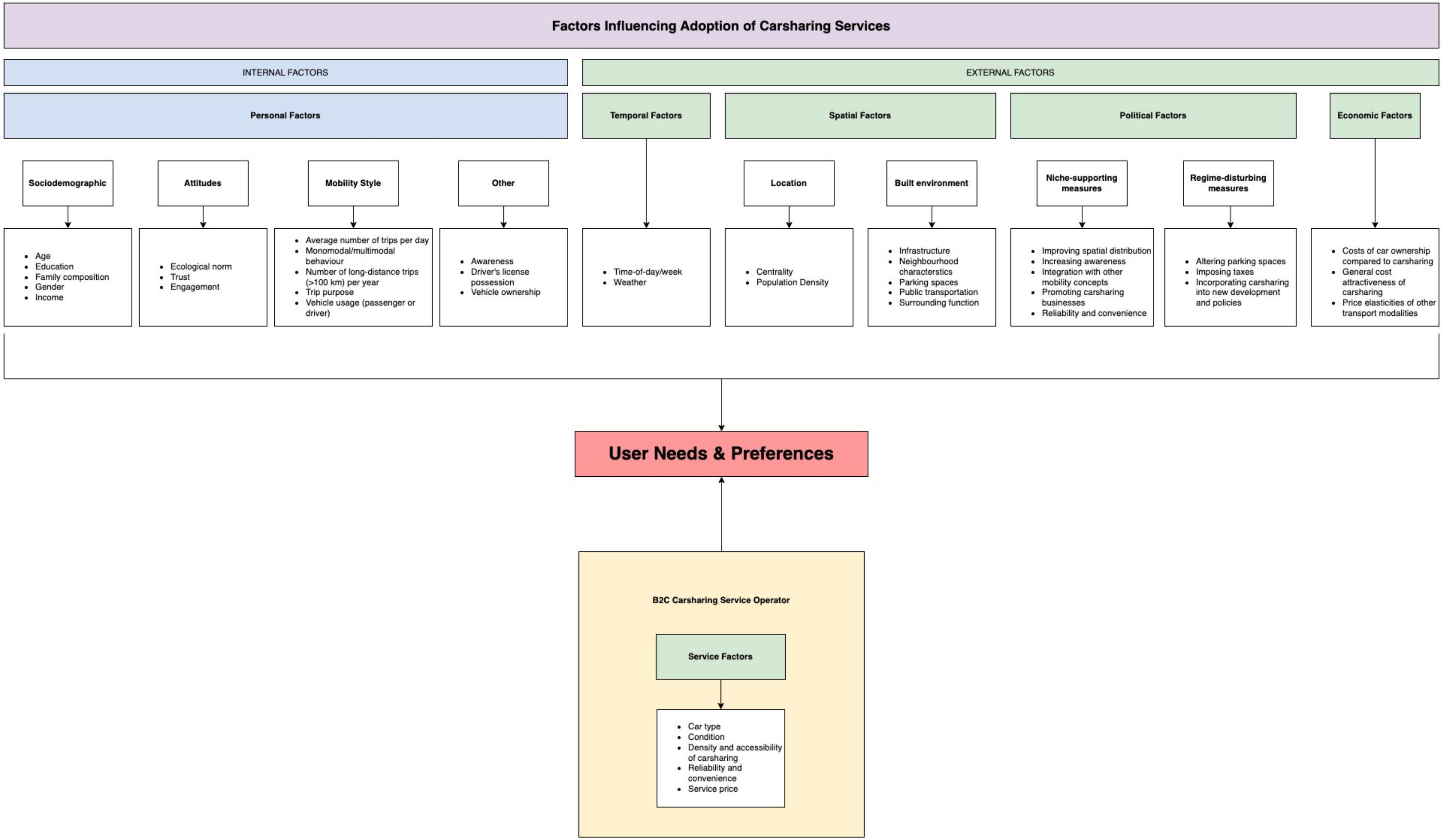


**Figure 6.** Proposed theoretical framework of internal and external factors influencing carsharing adoption ordered by domains (external and internal), categories (blue and green boxes), and factors (white boxes).

**Table 8.** Factors influencing carsharing adoption and their relationships as described in literature.

| Personal Factors | Factor | Remarks |
|---|---|---|
| | Age | Carsharing users are typically aged 30-50 years old. However, age variations exist based on service modes, with free-floating carsharing users being slightly younger than station-based carsharing users (Becker et al., 2017). |
| | Education | Higher levels of education are associated with greater carsharing adoption across various modes (Aguilera-Garcia et al., 2020; Becker et al., 2017); 60-70% of electric vehicle users have a university degree (Liao & Correia, 2022). Interestingly, for environmentally oriented multi-modal travellers, education shows no apparent relation to car ownership (Magdolen et al., 2022). |
| | Family Composition | Carsharing users are often found in small households, particularly for shared micro-mobility (Bieliński & Wazna, 2020). Life events, such as retirement or having children, can trigger changes in travel behaviour and attitudes (Magdolen et al., 2022). |
| | Gender | Gender has a significant effect on potential carsharing demand. Users are most often male; however, this is not necessarily the case for electric vehicles (den Hartog, 2023). |
| | Income | Higher income levels increase the likelihood of carsharing adoption, especially for certain service modes (Ampudia-Renuncio et al., 2020; Liao & Correia, 2022). High income users are more likely to choose B2C than P2P carsharing. Household income is also closely related to car ownership (Magdolen et al., 2022). |
| *Attitudes* | Ecological Norm | Environmental concerns significantly impact the adoption of shared mobility options, such as shared electric mopeds and electric cars (Aguilera-Garcia et al., 2020; Kopplin et al., 2021; Liao & Correia, 2022). This is in line with the strong relationship between ecological norm orientation and sustainable mode use (Magdolen et al., 2022). |
| | Engagement | Carsharing is used more often when there is strong community engagement (den Hartog, 2023) |
| | Trust | Trust in the service provider is essential for adoption, particularly in P2P carsharing services (Priya Uteng et al., 2019). |
| *Mobility Style* | Average Number of Trips per Day | Trip frequency varies by mode, with commuting modes primarily used during commuting hours (Ampudia-Renuncio et al., 2020; Liao & Correia, 2022). Trip frequency is typically calculated based on information about trips in a typical week (Magdolen et al., 2022). |
| | Monomodal/ Multimodal Behaviour | Monomodal behaviour indicates a preference for using a single mode, while multimodal behaviour suggests using multiple modes. The Herfindahl-Hirschman Index is often used to measure mode stability (Magdolen et al., 2022). |
| | Number of Long-Distance Trips (>100 km) per Year | Long-distance trips (>100 km) can influence carsharing adoption, with electric vehicle users often being younger (Wielinski et al., 2017). This metric is calculated based on annual long-distance trip counts (Magdolen et al., 2022). |
| | Trip Purpose | Trip purposes significantly affect mode choice. For example, users of shared micro-mobility often engage in leisure trips on weekends (Mehzabin Tuli et al., 2021). The share of trips to work or school out of all trips in a typical week is a common metric used to assess this factor (Magdolen et al., 2022). Compared to P2P, B2C is more often used for daily routines instead of special purposes/situations (Münzel et al., 2019b). |
| | Vehicle Usage (Passenger or Driver) | Individuals who require a car daily may find carsharing less attractive (Liu et al., 2014) and people who are the main driver of the household are less likely to adopt (Prieto et al., 2017). Vehicle usage is calculated as the share of car use in the individual modal split during a typical week (Magdolen et al., 2022). |
| *Other* | Awareness | Awareness of vehicle sharing services is crucial for adoption and can be improved through educational campaigns (Zhou et al., 2020). |
| | Driver's License Possession | Possession of a driver's license is a necessary condition for carsharing, and it impacts adoption. Additionally, income and urbanity influence car ownership (Safdar et al., 2022). |
| | Vehicle Ownership | The ownership of a vehicle significantly influences carsharing adoption. Typically, carsharing users own fewer cars than non-users (Liao & Correia, 2022). Car-ownership is lower for station-based users than for free-floating users. P2P users are former car owners whereas B2C users are not (den Hartog, 2023). |
| **Temporal Factors** | **Factor** | **Remarks** |
| | Time-of-day/week | Carsharing services are used most often on Fridays. Most often used during morning and afternoon peaks on weekdays. Use peaks occur a bit after commuting peaks for private cars whilst no use peaks occur during the weekend (den Hartog, 2023). |
| | Weather | Carsharing services are used more often when it is raining. Electric vehicles particularly, are used less often in colder temperatures (den Hartog, 2023; Liao & Correia, 2022). |

| Spatial Factors | Factor | Remarks |
|---|---|---|
| *Location* | Centrality | High centrality – defined as strategic positioning enhancing transportation efficiency and accessibility – is positively associated with increased demand for vehicle sharing services. Free-floating carsharing is more often used in less central areas (Ampudia-Renuncio et al., 2020; Becker et al., 2017). |
| | Population Density | Carsharing is used most often in areas with high population densities. Free-floating carsharing is more often used in less dense areas (Ampudia-Renuncio et al., 2020; Becker et al., 2017). |
| *Built Environment* | Infrastructure | Infrastructure and public transportation access significantly influence shared micro-mobility adoption (den Hartog, 2023). Public transportation and carsharing services are suggested to complement each other, particularly in urban areas (Habekotté, 2021). |
| | Neighbourhood Characteristics | High density neighbourhoods with close facilities and lower ownership rates are potential carsharing hotspots (Habekotté et al., 2021; Meelen et al., 2019). |
| | Parking Spaces | Limited parking availability makes carsharing attractive, especially if shared cars have reserved parking spots (Hu et al., 2018). |
| | Public Transportation | The presence of public transportation locations can influence shared micro-mobility adoption positively but may decrease demand for certain carsharing services (den Hartog, 2023). Discounted public transportation cards amongst students ('studentenreisproduct') makes public transportation very attractive, potential to include carsharing (Habekotté, 2021). |
| | Surrounding Function | Mixed or business areas attract vehicle sharing services, especially shared micro-mobility (Fiorini et al., 2022; Liao & Correia, 2022). |
| **Political Factors** | **Factor** | **Remarks** |
| *Niche-Supporting Measures* | | These measures focus on awareness, reliability, promotion, spatial distribution, and integration with sustainable mobility. |
| *Regime-Disturbing Measures* | | These measures aim to challenge the status quo, involving parking space alterations, taxes, and incorporation into new development and mobility policies. |
| **Economic Factors** | **Factor** | **Remarks** |
| | Cost of Car Ownership Compared to Carsharing | The general mindset towards car ownership and transaction costs can affect the attractiveness of carsharing (Bardhi & Eckhardt, 2012; Habekotté, 2021). Transaction costs for carsharing are often experienced to be higher compared to owning a car. Framing of costs influences attractiveness (Liu et al., 2014; Papu Carrone et al., 2020). |
| | General Cost Attractiveness of Carsharing | Affordability largely depends on the carsharing provider and is influenced by the frequency of car usage (personal factor) and potential for discounts. Affordable pricing contributes to higher adoption (den Hartog, 2023; El-Assi et al., 2015). |
| | Price Elasticities of Other Transport Modalities | Market mechanisms, regime-disturbing measures (political factor) such as congestion fees and parking fares, and competitive pricing can impact carsharing adoption, especially when car use becomes expensive (Habekotté, 2021; Zhou et al., 2020). |
| **Service Factors** | **Factor** | **Remarks** |
| | Car Type | Possibility to choose from several options stimulates use (Liyanage et al., 2019). |
| | Condition | Availability and well-maintained vehicles increase carsharing adoption (El-Assi et al., 2015; Torrisi et al., 2021). A good condition of the car positively influences use (Liyanage et al., 2019). |
| | Density and Accessibility of Carsharing | The availability of shared cars within a short distance is essential, particularly in urban areas with multiple mobility options (Celsor & Millard-Ball, 2007; Habekotté, 2021). |
| | Reliability & Convenience | A reliable and convenient carsharing platform attracts and retains users (Kent & Dowling, 2018). Better access and close-by vehicles stimulate use (Namazu et al., 2018; Liao & Correia, 2022). Possibility to choose from several options stimulates use (Liyanage et al., 2019). |
| | Service Price | The price levels (membership and usage fees) influence the willingness to use (den Hartog, 2023; Liao & Correia, 2022). |

In conclusion, by compiling the most important determinants of carsharing adoption, the proposed framework provides a perspective on the factors influencing carsharing adoption. For the case study included in this thesis, emphasis is put on the socio-economic profiles of future Merwede residents and their likely mobility choices – as this particularly affects modal split. Additionally, the number of parking spaces – informed by the low parking norm in Merwede – as well as service pricing – informed by market research – emerge as critical factors in carsharing adoption rates in Merwede. In line with the case study, the next section describes existing car-free neighbourhoods.

## 3.3. Examples of Car-free Neighbourhoods

Typically, car-free mixed-use residential areas are neighbourhoods that have high population densities, cyclist-friendly layouts, and convenient access to daily necessities, shared vehicles, and public transportation. Additionally, parking regulations significantly impact car ownership, with limited availability requiring resident parking purchases and car ownership abstinence contracts. Notably, parking accessibility, public transportation, and shared car availability also hold significance. Below, nine car-reduced and car-free neighbourhoods and cities are elaborated upon.

The car-reduced and car-free neighbourhoods discussed first – GWL Terrain, Amsterdam; Stellwerk 60, Cologne; Florisdorf, Vienna; and Vauban, Freiburg – share a common focus on discouraging car ownership through parking constraints, extensive service access, alternative transportation accessibility, and biking promotion. The communities stimulate a sense of belonging and engagement through resident involvement. A recurring feature across these neighbourhoods is limited and spatially segregated car parking, often requiring purchase. In GWL Terrain, car-free streets and edge-based parking discourage car ownership, while Vauban's primary roadway accommodates public transportation, and a few edge streets offer limited car parking. Moreover, non-car ownership contracts in Florisdorf and mandatory parking space acquisition in Stellwerk 60 have proven to be effective. This aligns with findings that linking parking costs to their real value can deter car ownership. Access to daily needs and alternative transportation modes emerges as a factor consistent with literature, facilitated by shared cars and walkable public transport. Notably, all four neighbourhoods uphold relatively high population densities and proximity to city centres, offering diverse facilities and services. Moreover, the significance of income is uncertain since information regarding the income of residents is limited. Additionally, unexpected high average household sizes and proportions of families contrast typical expectations based on literature, hinting at subjective variables and residential self-selection impacting car ownership reduction in these neighbourhoods (Schouten, 2019; Floor, 2020).

Three other examples of low-car or car free neighbourhoods in the Netherlands specifically include: Westerpark, Breda; Assendorp, Zwolle; and Ebbingekwartier, Groningen. Firstly, Westerpark – situated in Breda – was constructed in the late 1990s as an initial move towards sustainable urban development. While originally designed as a car-free neighbourhood, parking issues emerged as new residents with car preferences moved in. Parking spaces were reintroduced at the neighbourhood's edges, causing narrow roads. Pedestrians are permitted, but cyclists must dismount in certain areas. Secondly, Assendorp – located in Zwolle – features narrow streets and houses near the city centre. Although not initially planned as car-free, an initiative driven by residents sought to decrease car presence. A "Mobipunt" with facilities like electric vehicle charging, bicycle racks, and a shared car was established, encouraging voluntary parking at its edge. Future plans include additional Mobipunten and added services. If households opt to park at the Mobipunt, parking spaces can be replaced with greenery. Cars, pedestrians, and bicycles coexist in the neighbourhood. Thirdly, Ebbingekwartier – situated in Groningen – is mostly car-free, allowing only edge parking. Completed in mid-2013, residents must park their vehicles in an underground garage. Some discontent has arisen due to high parking fees, yet the neighbourhood's car-free design remains intact. Both pedestrians and cyclists are welcome in the area (Oost, 2022).

Urban planners have also extended the idea of car-free to full-fledges cities. Two examples include Masdar City and Venice. Masdar City – in Abu Dhabi, United Arab Emirates – is a prime example of a car-free city with sustainability at its core. Powered by solar and sustainable energy sources, it was originally designed to be entirely car-free, although a limited number of vehicles are now allowed.  Meanwhile, Venice – Italy – showcases a classic car-free urban model. The city is connected to the mainland via a lengthy bridge that permits cars only up to Piazzale Roma – a square located on the edge of the city. From there, people must continue their journeys by walking, using water taxis, or opting for boats as their primary means of transportation (Floor, 2020).

These diverse car-reduced and car-free neighbourhood and city examples illustrate the complexities and varying degrees of success in achieving sustainable urban mobility by restraining car ownership while accommodating residents' needs and preferences. One way in which residents' mobility needs and preferences can be accommodated in car-free areas is by means of offering shared mobility, such as carsharing. Whilst there are some general guidelines, determining the best carsharing price and product strategies for specific residential area developments, remains a case-by-case puzzle based on the specific needs and preferences of diverse (potential) user groups. Some commonly used pricing strategies for carsharing services are elaborated upon in the following section.

## 3.4. Pricing and Product Strategies for Carsharing

Carsharing pricing involves more than simply monetary costs; it includes variables like travel time, risk, and discomfort, affecting user behaviour such as route choice, mode preference, and trip frequency (Perboli et al., 2018). Still, as illustrated by the proposed theoretical framework above, service pricing is an important determinant of carsharing adoption. The effects of service price changes on demand are commonly assessed using price elasticities – which gauge the percentage change in demand for carsharing services resulting from a 1% price shift. Perboli et al. (2018) explored the significance of customised tariff plans for different segments of customers in Turin, highlighting the role of tailored pricing in the success of CSOs. Their simulation-based study compared existing pricing plans with new tariffs, emphasising the complexity of serving diverse customer needs effectively. Similarly, Litman (2022) considers both short-run and long-run price effects and noted that car use within carsharing exhibits elasticity, largely due to the influence of fixed costs.

Product strategies must cater to diverse urban customer needs, with heterogeneity in customer valuation significantly impacting carsharing pricing (Liu & Cooper, 2015; Bellos et al., 2017; Pei et al., 2021). Meijer & Witteveen (2015) and Liang et al. (2021) explored cost components, with the former highlighting factors such as kilometres covered, car type, and average speed; and the latter comparing platform pricing to market pricing, considering factors like the influence of private car owners, operation costs, collaborative consumption, customer demand, and revenue-sharing contract.

Profitability in carsharing relies on optimised pricing and product strategies (Jorge et al., 2015; Xu et al., 2018). Models proposed by Jorge et al. (2015) and Xu et al. (2018) employ linear and non-linear programming to maximise profits by addressing vehicle fleet imbalance and considering vehicle and staff relocation operations. Private CSOs – driven by profitability goals – adopt diverse payment frameworks like subscriptions and pay-per-use models (Over Morgen, 2022). Hörcher and Graham (2020) compare subscriptions to dynamic pricing mechanisms. Furthermore, Chow et al. (2015) and Giorgione et al. (2019) contribute to dynamic pricing research, exploring availability-based and auction-based pricing models.

Dynamic pricing approaches – such as minute-specific pricing – have been proposed for increased profitability (Chow et al., 2015; Giorgione et al., 2019). However, Qui (2017) and Qui et al. (2018) state that these methods could lead to congestion and service reduction, stressing aligning profit motives with system efficiency. Supporting this, Zoba (2020) leverages historical data to formulate pricing models that balance supply and demand, aiming for superior service and profitability. Adding to advanced pricing models, Soppert et al. (2019) introduce a unique profit-maximising pricing model – integrating network flow modelling and mixed-integer programming – resulting in a significant profit boost compared to standard pricing. Di Febbraro et al. (2012) propose a user-based relocation mechanism for fleet optimisation.

To improve profitability, Nansubuga & Kowalkowski (2021) propose strategies like dynamic pricing, tiered membership schemes, bundled offerings, fleet variety, user-focused designs, and sustainability emphasis. Amirnazmiafshar & Diana (2022) discuss the potential effects of carsharing on car ownership and travel habits. Pantuso (2022) advocates for user-based incentives, and Zhang & Wang (2023) explore factors influencing profits in carsharing. Amsterdam's policy of providing CSOs with public parking spaces at a low fee significantly influences cost structures and pricing strategies (Lagadic et al., 2019), representing a key factor in CSOs' profitability.

## 3.5. Existing Cost-Benefit Analyses Regarding Carsharing

In recent years, there has been a growing emphasis on evaluating the cost-benefit implications of carsharing, especially with the introduction and adoption of EVs in Europe. Several scholars have explored this, delving into mathematical models, operational strategies, and evaluation criteria relevant for CBAs.

Vasconcelos et al. (2017) conducted a comprehensive evaluation of the environmental and financial impacts of alternative vehicle technologies and relocation strategies in station-based one-way carsharing. Their research – applied to Lisbon, Portugal – is notable for its multi-dimensional approach, encompassing vehicle relocation, technology choices, and financial viability, offering a dynamic model for diverse urban scenarios (Vasconcelos et al., 2017). Corinaldesi et al. (2022) developed an optimisation framework for operating shared EVs, proposing a mathematical method for optimal vehicle functioning. This framework, based on linear equations, aids in a comprehensive CBA for various scenarios (Corinaldesi et al., 2022). Xue et al. (2019) used a combinatorial method combining the analytic hierarchy process, CBA, and Voronoi diagram for EV carsharing. Their study identifies crucial evaluation criteria for EV carsharing, introducing thirteen sub-factors for assessing station network distribution and capacity (Xue et al., 2019). Huang et al. (2018) explored model formulations to understand the choice between private cars and carsharing. Their research, using a nonlinear logit model, focuses on capturing key parameters influencing user decisions (Huang et al., 2018). Lastly, Liang et al. (2021) investigated operational and pricing strategies of carsharing platforms, analysing B2C and P2P models and market and platform pricing strategies. Their study, employing a revenue-sharing contract and a Stackelberg game model, provides insights into equilibrium solutions under different pricing models (Liang et al., 2021).

While the current literature offers significant insights into the environmental and economic aspects of carsharing systems, there remains a gap when it comes to integrating the needs of diverse socio-economic groups. Studies often emphasise profitability, yet a holistic approach that encompasses social welfare – including the perspectives of carsharing service operators, users, and municipalities – is crucial for developing equitable carsharing strategies. Moving on, the following section will explore the various policies and interventions that may impact carsharing services.

## 3.6. Policies & Interventions Impacting Carsharing

Efforts to develop effective policies and interventions that impact the carsharing industry and foster its upscaling have been explored through interviews and scientific research. Habekotté (2021) highlights the upscaling potential of carsharing, stressing the need to address governmental barriers. Municipal policy differentiation is often cited as a major concern, but interviews suggest broader challenges such as capacity, knowledge, and policy fragmentation. Proposed solutions include standardising policies across municipalities and elevating certain policymaking aspects to a national level. Achieving these goals depends on stable governmental support and strong stakeholder collaboration (Habekotté, 2021).

There is a general reluctance toward disruptive policy, with most policies focusing on niche development rather than challenging the existing transportation regime (Habekotté, 2021). Political barriers often hinder transformative measures, leading to doubts about significant upscaling. Interviews suggest a need for a transportation regime transition to facilitate disruptive policies for sustainable mobility.

Niche-supporting measures in carsharing focus on awareness, reliability, promotion, spatial distribution, and integration with sustainable mobility. User group policy initiatives include awareness campaigns and discounts for specific groups (Zhou et al., 2020), while economic measures involve subsidies and parking benefits. Spatial policies include reserved parking and integrating carsharing with other mobility services (Jorritsma et al., 2015; Papu Carrone et al., 2020). Policies related to integrating carsharing with other sustainable mobility concepts promote integration with other mobility services, such as mobility as a service (MaaS) concepts or public transportation cards (Zhou et al., 2020).

Regime-disturbing measures, on the other hand, aim to challenge the status quo, involving parking space alterations, taxes, and incorporation into new development and mobility policies. These include increasing parking fares for private cars and integrating carsharing into urban planning (Zhou et al., 2020). Tax measures involve raising taxes for car possession or implementing urban congestion taxes. Carsharing in new development and mobility spatial policy initiatives entails integrating carsharing into future policy visions and urban spatial planning, actively aligning it with broader sustainable mobility goals (Habekotté, 2021).

Incentive and penalty mechanisms are crucial for policy adoption (Cantelmo et al., 2022). In Lisbon, free parking for EVs and VAT exemptions enhance electric carsharing appeal (Vasconcelos et al., 2017). Carsharing operators also use incentives – e.g., for inviting new customers, refuelling, or cleaning vehicles – and penalties – e.g., for traffic fines, additional cleaning fees, or towing fees – to promote responsible usage (Golalikhani et al., 2021).

Collaboration with local governments and adherence to regulations can enhance the viability of private carsharing models. However, complete privatisation of transit services may lead to agency conflicts and insufficient service extension, making some economic and noneconomic incentives to private operators necessary to reduce conflicts and improve overall system performance (Cohen & Kietzmann, 2014). Measures perceived as impactful include changing parking policies, promoting carsharing, and integrating it into urban planning (Münzel, 2020).

To promote carsharing, partnerships with local administrators and public transport providers are recommended, along with special discounts and subsidies. Local administrators can support carsharing through parking discounts, dedicated spots, and access permits to limited traffic zones (Rotaris, 2021).

Carsharing services can influence travel behaviour, necessitating policy interventions (Amirnazmiafshar & Diana, 2022). Monitoring market developments is crucial for effective policymaking. Additionally, Chicco et al. (2022) highlight that carsharing is still spreading in urban areas, and its impacts may change over time, affecting research comparability across different cities. Government policies like congestion pricing and peak/off-peak tolls can significantly impact carsharing usage, and regulatory frameworks should enable innovative pricing and service models (Pantuso, 2022; Zhang & Wang, 2023). Moreover, Zhang & Wang (2023) suggest that price promotions, surge pricing, and worker incentives can be employed to manage on-demand carsharing services effectively. Carsharing platforms can benefit from implementing policies that enhance product quality to counterbalance price competition. The policies and interventions discussed in this section are summarised in Table 15.

## 3.7. Conclusion of the Literature Research

In conclusion, literature research has uncovered a critical gap in understanding how carsharing pricing strategies affect diverse socioeconomic groups within car-free neighbourhoods. Although numerous studies have examined the determinants of carsharing adoption and the financial mechanics of service pricing, there is a noticeable lack of comprehensive analysis from the user perspective – particularly in the context of equitable access to these services. Studies often prioritise profit maximisation, overlooking the broader implications for social welfare and urban sustainability. This oversight becomes especially significant in diversely populated car-free neighbourhoods like Merwede, where equitable access to mobility services is essential.

To contribute to the research field, this thesis emphasises UMT and social-welfare to conduct a CBA regarding carsharing pricing strategies and policies for the case study car-free neighbourhood of Merwede. Factors influencing carsharing adoption are reported in the proposed theoretical framework which includes personal, temporal, spatial, political, economic, and service factors. This framework serves to help define the items included in the CBA– see Figure 9. Based on the available information regarding Merwede, the factors brought to the forefront are socio-economic characteristics, number of parking spaces, and service pricing. In the following chapter, a case description of Merwede is provided, at the end of the subsequent chapter the policies and interventions discussed in Section 3.6 are summarised (Table 14) and a policy of interest is chosen.

# 4. Case Description of Merwede

As the overarching methodology employed in this thesis is a case study, this chapter gives a detailed description of the car-free neighbourhood Merwede – examining its current state, transportation framework, and the anticipated socio-economic characteristics that inform future mobility needs. First, a general description of Merwede is provided, followed by values regarding transportation in Merwede. Then, future residents of Merwede and their predicted mobility patterns are expanded upon. Lastly, the policies identified in Section 3.6 are summarised (Table 14) and a policy of interest is chosen.

## 4.1. Description of Merwede

Merwede is the largest neighbourhood being developed within the Merwede-Kanaalzone in Utrecht. It is a former business district with a lot of empty ground. Geographically, it is located between Transwijk and Rivierenwijk, making it the central point of the district South-West of the city centre. This makes this area suitable to be a multifunctional, living city part in Utrecht (Stolk, 2022). Merwede offers a diverse range of amenities, including recreational and daily necessities, transforming a former bicycle depot into a vibrant space with a market hall, catering, and creative activities. The neighbourhood prioritises green spaces, squares, and social interactions, aiming for a balanced urban experience (Bloom Merwede, 2023). Plans envision enhanced active mobility, public transport, and shared mobility adoption, while a low parking standard ensures approximately 1 parking spot for every 3 households (Toussaint, 2020). With 22,900 bicycle parking spaces and four neighbourhood mobility hubs – of which two are logistic hubs as well – facilitating shared mobility services, Merwede emphasises sustainable alternatives. Moreover, public transportation options include high-quality bus stops along Europalaan (Bloom Merwede, 2023). Figure 7 provides an overview of the Merwede area development and its surroundings.

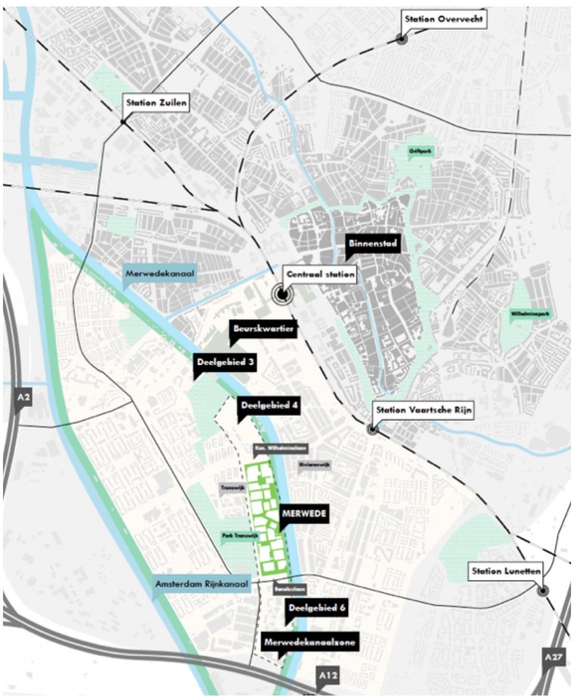


**Figure 7.** Overview of Merwede and its surrounding area. Retrieved from Municipality of Utrecht (2020).

## 4.2. Transportation in Merwede

Table 9 provides a non-exhaustive overview of descriptive characteristics in numbers regarding Merwede (van den Hurk et al., 2021); Pakhuis de Zwijger, 2023). Table 10 illustrates how Merwede is relatively well-connected to the already existing infrastructure grid by describing various travel time approximations departing from Merwede. The possibility of using various modes and routes indicates the mobility network is robust – meaning that the network can maintain the function for which it was originally designed under all circumstances that deviate from the normal conditions (Snelder et al., 2012).

**Table 9.** Descriptive characteristics of Merwede.

| *Characteristics* | *Mobility in Numbers* |
|---|---|
| **Location**: Utrecht | **Parking norm**: 0.3 per residence |
| **Area**: 34 hectares | **Parking spaces**: 1,700 |
| **Previous functions**: light industry; logistics/distribution; offices | *For private cars*: 1400; *For shared cars*: 250; *For disability parking*: 50 |
| **Envisioned functions**: mixed-use area such as housing, offices, and public amenities | **Number of shared cars**: 250 |
| **Residences**: 6,000 total in 18 residential blocks | **Bicycle parking spaces**: 22,900 |
| **Buildings**: ± 200 | |
| **Services**: 100,000 m$^2$ | |

**Table 10.** Travel time approximations for popular destinations from Utrecht per travel mode departing from Merwede.

| **Walk** | **Bike** | **Public Transportation** *From Utrecht Central Station* | **Car** |
|---|---|---|---|
| Merwedepark 1 min | Jaarbeursplein 8 min | Amsterdam 26 min | Amsterdam 30 min |
| Park Transwijk 3 min | Utrecht Central Station 9 min | Schiphol 30 min | Arnhem 45 min |
| Stadsboerderij 3 min | Tivoli Vredenburg 9 min | Arnhem 34 min | Rotterdam 40 min |
| Rijnlaan 7 min | Papendorp 10 min | Rotterdam 37 min | Zwolle 60 min |
| Sportpark 12 min | Domplein 11 min | Zwolle 51 min | |
| | Neude 13 min | Keulen 150 min | |

## 4.3. Socio-economic Characteristics of Future Merwede Residents

Demographically, Merwede offers various types of residences, with social housing rentals, middle rentals, and affordable owner-occupied houses. In terms of number of residences, these percentages respectively translate to 1,800; 1,500; and 2,700. Together, these 6,000 residences allow for a total of 12,000 residents. Furthermore, it has been established that income class influences car ownership, and this in turn influences carsharing adoption. In Merwede, four annual income classes emerge, namely: low (0 – 30,000 euros), middle-low (30,000 – 74,000 euros), middle-high (74,000 – 88,500 euros), and high (88,500+ euros) (Over Morgen, n.d.; Whooz, 2023). From the 12,000 total expected future residents of Merwede, the respective percentage of residents per income group are: 20%, 23%, 49%, and 8% (Over Morgen, 2021) – as shown in Table 11.

**Table 11.** Number of residents per income group in Merwede.

| | **Number of Residents** | **% of Total** |
|---|---:|---:|
| *Low* | 1187 | 20% |
| *Middle-low* | 1961 | 23% |
| *Middle-high* | 2364 | 49% |
| *High* | 479 | 8% |

Parking pricing is employed in Merwede as a tactic to reduce private car ownership. This is reflected in the high cost of circa 200 euros per month for parking within one of the neighbourhood's mobility hubs. More economical options like distant parking (at e.g., Westraven) are available at about 50 euros per month (Over Morgen, n.d.). This pricing model effectively deters low- and middle-low-income residents from using nearby parking due to affordability issues – substantiated by projections made by project developers at Merwede (Over Morgen, 2021), see Table 12. The resulting situation is that whilst higher-income groups can access convenient parking, those with tighter budgets – who may need a car for family or work reasons – are left with less desirable options. This not only presents a financial challenge but also risks social exclusion for those compelled to park further away.

**Table 12.** Projections of private vehicle ownership in Merwede per income group.

| | **Portion** | **Projection 0** | **Projection 1** | **Projection 2** | **Projection 3** |
|---|---|---|---|---|---|
| *Low* | 20% | 230 | 0 | 0 | 0 |
| *Middle-low* | 23% | 1030 | 0 | 0 | 0 |
| *Middle-high* | 49% | 3450 | 1725 | 1345 | 1117 |
| *High* | 8% | 659 | 494 | 384 | 314 |
| **Total** | 100% | 5369 | 2219 | 1729 | 1431 |

To gain a better understanding of the extent of the financial disparity between different income groups, monthly mobility budgets of Utrecht residents per income are reported and displayed in Table 13 (Over Morgen, n.d.). This illustrates that the monthly vehicle use costs for the low- and middle-low-income brackets – respectively 82 and 164 euros per month – are significantly below the steep approximate parking fee of 200 euros per month in Merwede. The disparity between vehicle use costs and parking fees reveals an economic disincentive for these groups to maintain private vehicle ownership.

**Table 13.** Monthly mobility budgets per income group for citizens of Utrecht.

| | **Vehicle Purchase** | **Vehicle Use** | **Public Transportation** | **Air Travel** | ***Total*** |
|---|---|---|---|---|---|
| *Low* | € 41.00 | € 82.00 | € 21.00 | € 14.00 | € 158.00 |
| *Middle-low* | € 110.00 | € 164.00 | € 17.10 | € 22.90 | € 314.00 |
| *Middle-high* | € 206.00 | € 316.00 | € 25.30 | € 31.70 | € 579.00 |
| *High* | € 397.00 | € 523.00 | € 34.00 | € 65.00 | € 1,019.00 |

The travel patterns of future Merwede residents suggest a distinct modal split. The predicted mobility patterns of these future residents were estimated using 2023 data from Whooz for typical mobility behaviours per income group in Utrecht. This data was aggregated (weighted averages) within Merwede to infer future travel behaviour. The predicted modal split for the baseline scenario of the CBA (S0) – elaborated on further in Section 5.1.4.1 – is depicted in Figure 8. In this, the modal split focuses on private cars, taxis, public transportation (bus, tram, metro, and train), and biking. In the baseline scenario – using mobility data regarding typical Utrecht residents – private car use is expected to constitute 50% of the modal split. Moreover, biking is expected to constitute 38% of the modal split, whilst public transportation and taxis are expected to make up 11% and 2%, respectively. The determined baseline modal split is not based on data specific to car-free neighbourhoods nor does it consider carsharing as a mode. Thus, to account for the car-free nature of the neighbourhood and the availability of carsharing, assumptions are made for the modal splits of the variant scenarios. This is elaborated upon in the paragraph below and in Section 5.1.4.

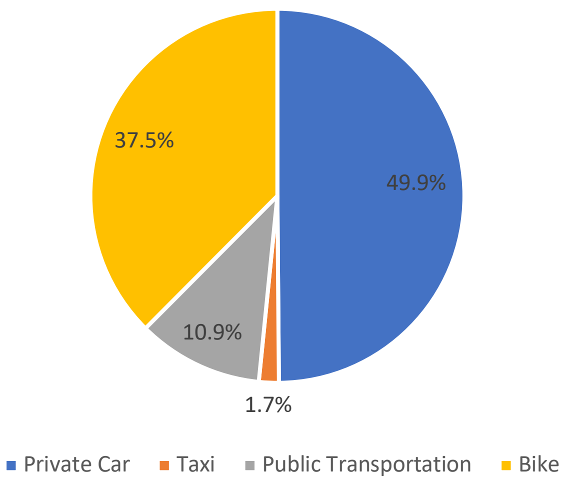


**Figure 8.** Weighted average assumed modal split for all income groups of Merwede residents without carsharing (baseline scenario (S0)).

For the baseline scenario (described in Section 5.1.4.1), carsharing is not taken into consideration. Yet, Merwede Mobiliteitsbedrijf – the company responsible for managing certain mobility services in Merwede – does intend to provide carsharing services in the car-free neighbourhood. Thus, the variant scenarios (Section 5.1.4.2) do include the carsharing modality. For this, the number of parking spaces available for private cars, shared cars, and taxis are used to estimate the proportion of the car modality that consists of private car, carsharing, and taxi users. Not included in this analysis are scooters and walking due to data limitations within the Whooz (2023) dataset, and because walking – as a micro-mobility option – is not directly comparable to carsharing in its purpose and utility.

Building on the projected modal split, further insights from a Citisens (2021) survey shed light on the actual preferences of residents in the Utrecht region regarding shared mobility options, a crucial consideration for the development of transportation policies in Merwede. This survey study – with 3,076 respondents, of which 948 were from the province of Utrecht – outlines preferences for shared mobility usage per class (see Table 14) throughout the Netherlands. Regarding Merwede specifically, 46% of respondents reported being inclined towards using carsharing in Merwede, and 54% preferred to use a private car. Respondents' preferred payment strategy for shared mobility various, including fixed subscriptions (22.25%) or price per kilometre (28.5%) options (Citisens, 2021). Moreover, shared mobility trends highlight the demand for shared cars among different demographics and the desirability of shared bicycles and scooters in Merwede.

**Table 14**. Shares of respondents who reported using shared mobility.

| | Middle rental and private sector | Social housing |
|---|---|---|
| *No* | 82% | 87% |
| *Yes, I use shared bicycles* | 12% | 8% |
| *Yes, I use shared cars* | 7% | 5% |
| *Yes, I use shared scooters* | 2% | 2% |
| *Yes, I use shared cargo bicycles* | 0% | 0% |

In tandem with the built characteristics of Merwede, the socio-economic characteristics of future residents of Merwede and their dependent mobility patterns are essential for understanding the potential uptake and impact of carsharing services in the context of the neighbourhood's overall transport strategy. Moreover, a problem statement specific to the case study can be formulated. Namely, lower-income groups are the group most financially strained by Merwede's parking fees and therefore may rely more on carsharing services rather than private car use. However – as previously mentioned – one main issue is ensuring affordable access to B2C carsharing services for low- and middle-low-income residents in Merwede. Taking this into account, previously identified policy alternatives (Section 3.6) are summarised and a policy of interest is chosen in the subsequent section.

## 4.4. Policy Alternatives

Several policies for stimulating carsharing adoption are identified and described in Section 3.6, resulting in the fourteen policies which are summarised in Table 15. Out of these policies, many – e.g., P4, P5, P12, and P13 – are already enforced in the Merwede neighbourhood.

**Table 15.** Policies and interventions that stimulate carsharing adoption.

| | Description | Target |
|---|---|---|
| **P1** | Standardising policies across municipalities through regional cooperation and knowledge sharing (Habekotté, 2021) | Broad |
| **P2** | Elevating certain aspects of carsharing policymaking to a national level to provide external support, knowledge-sharing mechanisms, and standardisation (Habekotté, 2021) | Broad |
| **P3** | Congestion pricing and (off-)peak tolls (Pantuso, 2022; Zhang & Wang, 2023) | Broad |
| **P4** | Integration of carsharing with other sustainable mobility concepts such as mobility-as-a-service (MaaS), public transit, etc. (Jorritsma et al., 2015; Papu Carrone et al., 2020; Zhou et al., 2020) | Broad |
| **P5** | Incorporating carsharing into new developments (Zhou et al., 2020) | Broad |
| **P6** | Awareness campaigns (Zhou et al., 2020) | User group |
| **P7** | Subsidies, vouchers, discounts, or trip credit incentives (Zhou et al., 2020; Rotaris, 2021; Cantelmo et al., 2022) | User group |
| **P8** | Penalties to enforce responsible use of vehicles (Golalikhani et al., 2021) | User group |
| **P9** | Subsidies for carsharing businesses (Cohen & Kietzmann, 2014) | CSOs |
| **P10** | A VAT tax exemption for electric vehicles (Vasconcelos et al., 2017) | CSOs |
| **P11** | Subsidised or free parking spaces for carsharing vehicles (Jorritsma et al., 2015; Vasconcelos et al., 2017; Münzel, 2020; Papu Carrone et al., 2020; Rotaris, 2021) | Parking (carsharing vehicles) |
| **P12** | Reserved and easily accessible parking spaces (Jorritsma et al., 2015; Papu Carrone et al., 2020) | Parking (carsharing vehicles) |
| **P13** | Altering parking spaces and changing parking norms; e.g., a reduced number of parking spaces for private cars, and increased parking fees (Zhou et al., 2020) | Parking (private vehicles) |
| **P14** | Imposing more taxes on private vehicles (Habekotté, 2021) | Parking (private vehicles) |

To ensure equitable access to carsharing services, a user group-targeted policy seems most effective to address the economic disparities between residents of different income groups. Therefore, P1-P5 and P9-P14 are not viable in the current context. The effect of awareness campaigns (P6) is almost impossible to quantify and study (Shaheen et al., 2009), and penalties to enforce responsible use of vehicles (P8) are a measure that can be employed only after carsharing has already been adopted (Midgley, 2009). Thus, P7 – i.e., subsidies, vouchers, discounts, or trip credit incentives – seems most effective as it is a user-group specific and quantifiable solution that aims to positively reinforce carsharing adoption and stimulate transportation equity (Martin & Shaheen, 2011b). Therefore, the CBA (described in the subsequent chapter) will include the costs and benefits of a pricing policy in which low-income groups receive trip credit incentives for carsharing services – provided by the Municipality of Utrecht. For the sake of simplification, it is assumed that the municipality provides the subsidies, however, in reality this is the responsibility of Merwede Mobiliteitsbedrijf.

Like the public transportation funding scheme for Dutch students in the Netherlands – also known as the 'studentenreisproduct' – P7 regards a mobility service or policy provided to a specific financially "disadvantaged" user group. Like the public transportation funding scheme, the implementation of carsharing subsidies for Merwede's low-income residents would involve a hierarchical stakeholder structure. This structure potentially includes the Ministry of Transport, city region authorities, and possibly the Ministry of Social Affairs for alignment with social equity programs. The Municipality of Utrecht would play a key role in allocating these subsidies, ensuring that funding extends to the carsharing domain. Notably, the proposal to subsidise carsharing services is an optional strategy that requires careful consideration and commitment from the Municipality of Utrecht. Therefore, demonstrating the potential positive impacts of such a measure is critical.

In conclusion, a particularly pressing issue is to guarantee affordable access to carsharing services for the low- and middle-low-income groups in Merwede. These residents – who depend on (private) cars for essential activities – are confronted with prohibitive parking expenses near their homes. Subsidising carsharing (P7) for low- and middle-low-income residents aligns with Merwede's objectives of maintaining low car ownership rates whilst ensuring that mobility remains inclusive, allowing residents of all income levels fair access to transportation without the burden of excessive parking costs. The subsequent chapter expands on this by formulating a CBA model that allows for the critical examination of the value (i.e., the associated costs and benefits) of carsharing as well as carsharing subsidies for lower income groups within the context of Merwede.

# 5. Cost-Benefit Analysis

This chapter describes the model description for a CBA regarding carsharing pricing (policy). This CBA was carried out following the methodological steps described in Section 2.7. First, a written as well as a mathematical description are discussed. This is accompanied by a description of the baseline scenario and the variant scenarios. An overview of the inputs used for the CBA can be found in Appendix B and the input values and calculations for each scenario are detailed in Appendix C. Next, details of the sensitivity analyses – that evaluate the model's performance under different conditions – are outlined. The results of the CBA are reported in Section 6.4.

## 5.1. Model Description

In this section, a written description of the model is provided – accompanied by the assumptions included in the model – as well as a mathematical model and its associated inputs. Several existing CBAs are reported in Section 3.5. The CBA included in the study by Vasconcelos et al. (2017) is particularly notable for its depth in assessing the financial and environmental implications of various vehicle technologies (gasoline, electric, and hybrid) in carsharing systems. Unlike the other studies that were reported – and which focus on narrower aspects – their model holistically accounts for urban transport demands and user preferences. This comprehensive approach provides a flexible framework for conducting CBAs. Its application to a real-world context – illustrated by Lisbon's urban environment – further highlights its usefulness and robustness. Therefore, the model proposed by Vasconcelos et al. (2017) serves as a foundation for developing the present CBA. However, adjustments were made to tailor the model to this specific thesis.

### 5.1.1. Model Overview

As mentioned in the previous chapter, the Merwede neighbourhood is not yet inhabited at the time of this research. Thus, the available data regarding residents – i.e., sociodemographic characteristics and composition – is mainly based on estimations and predictions using extrapolated data – from e.g., Whooz (2023) and Woonprogramma Merwede (2022). Although Merwede area development consists of two phases – first 4,200 then 1,800 residences – for the sake of this thesis it is assumed that the neighbourhood is fully operational and inhabited by approximately 12,000 residents. Accounting for these two phases as well as growth dynamics could yield different CBA outcomes. As the model described by Vasconcelos et al. (2017) is a model for one-way carsharing systems, a notable difference is that the present case study involves a round-trip carsharing system – as residents will have one of the Merwede mobility hubs as their first departure and final arrival node – and regards a smaller scale – since the case pertains to a neighbourhood (Merwede) rather than a city (Lisbon). The present case study assumes a station-based system without relocation. Moreover, the CBA methodology in this thesis is applied from the perspective of three stakeholders: the CSOs, carsharing users (i.e., the future Merwede residents), and the Municipality of Utrecht (i.e., the perspective of society at large). All the benefits and costs presented are based on values available in March 2024.

To determine the (future) demand for carsharing services in Merwede, several sources are used. The primary data regards residents living in the Municipality of Utrecht and stems from Whooz (2023), which provides insight into levels of car ownership, the purpose of travel – categorised as private or work-related – and the modal split among various transportation means including (private) cars, taxis, buses, trams, metros, trains, and bicycles. It also includes income data which is crucial for understanding travel patterns within different socio-economic segments (Whooz, 2023). Additionally, the 'Woonprogramma Merwede' (2022) document offers supplementary data on the types of housing available, which is extrapolated to predict the income brackets of prospective residents and their corresponding mobility choices. This extrapolation necessitates assumptions about the distribution of income groups within Merwede, forming the basis for estimating modal demand by income segment. The alignment of housing types with expected income levels will influence the demand per mode within each income group. Subsequently, the carsharing demand is inferred from the overall demand for car modes, adjusted by the proportion of expected carsharing use derived from other documents and predictions about parking and carsharing. Moreover, varying demand for the variant scenarios was calculated using price elasticity estimates (reported in Section 6.1) to determine the effect of price changes on modal split.

Carsharing systems require user decisions, travellers select pick-up and drop-off locations based on available vehicle distribution. Correia et al. (2013) suggest users typically opt for the nearest viable station – i.e., neighbourhood mobility hub. In the present thesis, it is assumed that the neighbourhood mobility hubs are always located within a reasonable walking (or biking) distance from Merwede residents. In the station-based carsharing system in Merwede, carsharing users can pick up a shared car at one of the two mobility hubs with available vehicles. Total parking capacity for carsharing vehicles was described in Section 4.2, and is estimated to be 250. Once a carsharing vehicle is secured, the user initiates the rental period, which is concluded when the user arrives at their destination. It is assumed that users are mode-consistent throughout their rental period – i.e., that users use the same mode at the beginning and end of their round-trip. Thus, if users opt for carsharing to depart from Merwede, they will also use carsharing to arrive back at Merwede. Returning the vehicle at the end of the round-trip involves parking the car in a designated spot in one of the neighbourhood mobility hubs.

Typically, the operational cycle for a vehicle within a system involves various maintenance checks (Ciari et al., 2017). Upon each return to a station, the car undergoes an assessment to determine the necessity of maintenance, refuelling or recharging, cleaning, or inspection. Specific thresholds trigger these services: refuelling is required after 300 kilometres, and a comprehensive inspection is required after 2500 kilometres of usage. Cleaning is generally performed after every 18 trips (Barth & Todd, 2016; Vasconcelos et al., 2017). Additionally, carsharing services usually depends on the efficient allocation of staff to ensure smooth operational workflows. However, neither vehicle maintenance nor staff operations are not considered in this thesis as this is a static analysis.

### 5.1.2. Mathematical Model, Definition of Costs and Benefits, and Inputs

This CBA integrates perspectives from the carsharing users, operators, and the municipality (i.e., society at large), in accordance with analytical guidelines from the UK Department for Transport (Department for Transport, 2006). These guidelines – while not carsharing-specific – provide a standard approach to transport-related project assessments and have been supplemented with insights from broader CBA literature to fit the specificities of carsharing scenarios (Litman, 2009; Maibach et al., 2008; Romijn & Renes, 2013).

This analysis assumes a steady state carsharing system, avoiding the complexities of growth dynamics to focus on a mature network. By doing so, it provides a clear picture of the costs and benefits under stable operational conditions, which is crucial for evaluating the long-term viability of carsharing within the neighbourhood of Merwede (Litman, 2009). The costs and benefits included in the CBA are described in Figure 9.

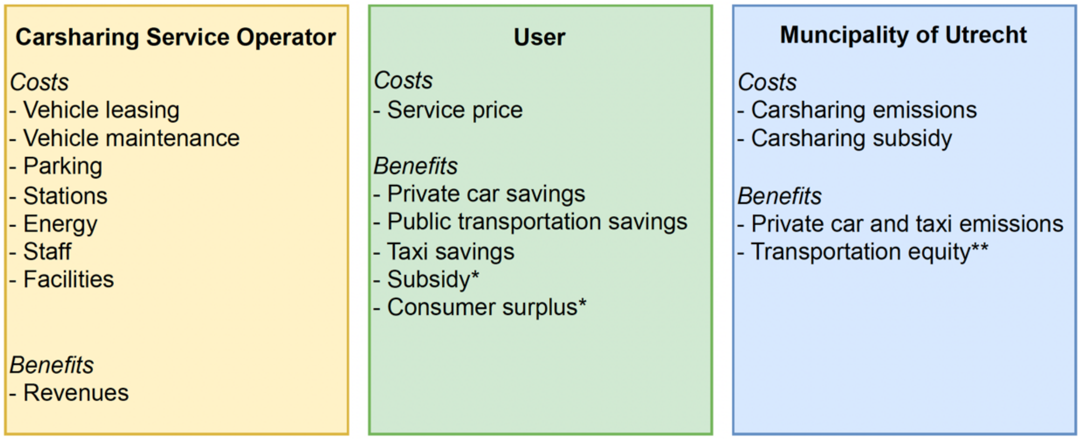


**Figure 9.** Cost-benefit analysis for the user, the carsharing service operator, and the Municipality of Utrecht. (*): subsidy-related benefits are only allocated to low- and middle-low-income users. (**): transportation equity is not quantified in the CBA model.

The net present value (NPV) is estimated using *Equation 1*.

$$NPV = \sum Benefits - \sum Costs \tag{1}$$

### 5.1.2.1. Carsharing Service Operator

From the CSO's perspective, the benefits and costs are defined by *Equations 2* and *3*, respectively. Note that the actual benefits for the CSO can only be considered after taxes. Additionally, the monthly external parking cost (*Ep*) has no cost to the user but is covered by the CSO. Moreover, this analysis did not differentiate between user preferences for various carsharing vehicle technologies. It is certain that there will only be electric carsharing vehicles in Merwede, thus the electric vehicle parameter (*fe*) is always equal to 1.

$$\sum Benefits_{CSO} = (Nusers \times Psub + Tcs \times P_t + Kcs \times Pkm) \times T \tag{2}$$

*where*

*Nusers* – Number of carsharing users [# per year]
*Psub* – Subscription pricing, price for carsharing subscription per year [€ per year]
*Tcs* – Total hours travelled by carsharing vehicles [hours per year]
$P_t$ – Time pricing, hourly fee charged to the user [€ per hour]
*Kcs* – Total kilometres travelled by carsharing vehicles [km per year]
*T* – 1 – Tax [%]

$$\begin{aligned}\sum Costs_{CSO} = {} & (L \times F \times 12) + (Ep \times F \times 12) + (C \times F \times 12) \\ & + (Pc \times Ps \times 12 + fe \times Ci \times Ps) + (Fc_1 \times Vp \times Ud \times F \times D) \\ & + (S1 + S2 + S3 + S4 \times W) + (Mk + O + Cm)\end{aligned} \tag{3}$$

*where*

$L \times F \times 12$ – Vehicle leasing costs
$Ep \times F \times 12$ – External parking costs
$C \times F \times 12$ – Vehicle cleaning costs
$Pc \times Ps \times 12 + fe \times Ci \times Ps$ – Location setup/stations costs
$Fc_1 \times Vp \times Ud \times F \times D$ – Energy costs
$S1 + S2 + S3 + S4 \times W$ – Staff costs
$Mk + O + Cm$ – Facilities costs

*with*

*L* – Monthly vehicle leasing costs [€ per shared vehicle per month]
*F* – Fleet size, number of vehicles [#]
*Ep* – Monthly external parking cost [€ per shared vehicle per month]
*C* – Monthly cleaning costs per vehicle [€ per shared vehicle per month]
*Pc* – Parking space costs at the station [€ per parking space per month]
*Ps* – Number of parking spaces of the entire carsharing network [#]
*fe* – Electric vehicle parameter (1 if vehicle used is electric, 0 if other) [-]
*Ci* – Electric vehicle charging infrastructure cost [€ per parking space per year]
$Fc_1$ – Average fuel/energy cost [€ per km]
*Vp* – Vehicle performance [%]
*Ud* – Average daily vehicle utilisation in distance per carsharing vehicle [km per shared vehicle per day]
*D* – Days of use of carsharing vehicles per year [days per year]
*S1, S2, S3,* and *S4* – Manager/CEO, customer services staff, marketing staff and normal staff salary [€ per year]
*W* – Number of workers of S4 category [#]
*Mk* – Marketing costs per year [€ per year]
*O* – Typical office rent in the case study [€ per year]
*Cm* – Communication costs [€ per year]

#### 5.1.2.2. Users

For carsharing users, the benefits and costs are respectively defined by *Equations 4 and 5*. In this, the benefits are calculated from the expenses that users would have incurred from owning a private car or using taxis or public transportation. The costs for the users are the extra expenses associated with utilising the carsharing system.

$$\sum Benefits_{Users} = (PC_f \times PC_{off} + d_{PV} \times Fc_2) + (t_{PV} \times P_p \times h_p \times D \times PPc) + (d_{taxi} \times C_{taxi}) + (t_{PT} \times C_{PT} \times D) + (Sub_{low} \times N_{low} \times 12) \qquad (4)$$

*where*

$PC_f \times PC_{off} + d_{PV} \times Fc_2$ – Yearly private car savings
$t_{PV} \times P_p \times h_p \times D \times PPc$ – Yearly parking savings
$d_{taxi} \times C_{taxi}$ – Yearly taxi savings
$t_{PT} \times C_{PT} \times D$ – Yearly public transport savings
$Sub_{low} \times N_{low} \times 12$ –Yearly carsharing subsidy for (middle-)low-income users

*with*

$PC_f$ – Average private car costs [€ per private vehicle per year]
$PC_{off}$ – Number of vehicles taken off the street after the implementation of the carsharing system [# per year]
$d_{PV}$ – Travelled distance variation by private car [km per year]
$Fc_2$ – Average fuel and energy cost [€ per km]
$t_{PV}$ – Trips in private car variation [# per day]
$P_p$ – Percentage of trips with paid parking [%]
$h_p$ – Average time paying for parking [hours per day]
$PPc$ – Average hourly cost of parking [€ per hour]
$d_{taxi}$ – Travelled distance variation by taxi [km per year]
$C_{taxi}$ – Cost of taxi [€ per km]
$t_{PT}$ – Trips in public transport variation [# per day]
$C_{PT}$ – Average public transport trips cost [€ per trip]
$Sub_{low}$ – Monthly subsidy provided per (middle-)low-income user [€ per month]
$N_{low}$ – Number of users eligible for the subsidy per year [# per year]

$$\sum Costs_{Users} = (Nusers \times Psub + Tcs \times P_t + Kcs \times Pkm) \tag{5}$$

To capture the extra benefit of the carsharing subsidy policy for low- and middle-low-income residents, a consumer surplus approach is used. This surplus is reported in terms of monetary benefits. In accordance with the framework provided by Romijn & Renes (2013), the calculation of changes in consumer surplus for scenarios involving subsidies of 50 and 100 euros (S1-2, S1-3, S2-2, and S2-3; described below) adhered to the following steps. First, the average price per carsharing trip for each income group with and without the subsidy was determined, denoted as $p_0$ and $p_1$, respectively. Subsequently, the change in the number of carsharing trips attributable to the introduction of the subsidy was quantified, represented as $q_0$ and $q_1$. Finally, employing the 'rule of half', as stipulated by Romijn & Renes (2013), the change in consumer surplus was computed using *Equation 6*.

$$\Delta CS = (p_0 - p_1) \times q_0 + \frac{1}{2} \times (p_0 - p_1) \times (q_1 - q_0) = \frac{1}{2} \times (p_0 - p_1) \times (q_1 + q_0) \tag{6}$$

This approach could not be applied to the baseline scenario without carsharing (S0) or without subsidies (S1-1 and S2-1) due to the absence of a consumer surplus benchmark. This methodological approach ensures that the calculated consumer surplus accurately reflects the welfare change experienced by consumers due to the subsidy-induced price variation. The consumer surplus is reported in Section 6.4.

#### 5.1.2.3. Municipality of Utrecht

The adoption of carsharing and pricing policy thereof does not only affect the CSOs and users but carsharing also has societal effects. Therefore, it is important to consider the perspective of the Municipality of Utrecht. This is done by taking the environmental impact and the costs incurred by introducing a subsidy policy into account.

*Equation 7* represents the total benefits for the municipality. Other municipal (i.e., societal) benefits include a reduced need for parking space – and thus more space for green, housing, or other more sustainable transport options – improved living quality; lower car production and usage; and improved social inclusion and transportation equity. However, as not all benefits were quantifiable, some have been omitted from the present CBA. This is discussed in more depth in Section 7.2.6.

The carsharing system's environmental impact is evaluated in terms of carbon dioxide ($CO_2$), nitrogen oxides ($NO_x$), and particulate matter (PM) emissions, following the UK's Transport Analysis Guidance (Department for Transport, 2006). Emission variations were calculated according to *Equation 8*. The assessment of emissions was based on the change in kilometres travelled by private cars or taxis due to increased or decreased carsharing use. The valuation of pollutants per tonne is based on comprehensive figures from van Essen et al. (2019). Notably, to simplify the approach, contributions to emissions of modes other than private vehicles and taxis (such as public transportation emissions), were not considered. Moreover, subsidy costs represent opportunity costs for the municipality and government, as these funds could potentially be allocated to alternative public services or investments. However, these opportunity costs are not explicitly included in the CBA to maintain a manageable level of complexity.

$$\sum Benefits_{Municipality} = (1 - T) \times (Nusers \times Psub + Tcs \times P_t + Kcs \times Pkm) + \Delta Pi \qquad (7)$$

*where*

$(1 - T) \times (Nusers \times Psub + Tcs \times P_t + Kcs \times Pkm)$ – Income taxes from CSOs [€ per year]
$\Delta Pi$ – Yearly environmental savings (if positive (+)) related to pollution [€ per year]

*with*

$$\Delta Pi = \Delta Kcs \times f_{i,CS} \times €t_i + \Delta Kpv \times f_{i,pv} \times €t_i + \Delta Ktaxi \times f_{i,taxi} \times €t_i \qquad (8)$$

*where*

*Pi* – Cost of pollutant *i* [€ per year]
*Kcs* – Total kilometres travelled by carsharing vehicles [km per shared vehicle per year]
$f_{i,CS}$ – Emission factor of the carsharing vehicles for pollutant *i* [tonne per shared vehicle per km]
$€t_i$ – Price per tonne of pollutant *i* [€ per tonne]
*Kpv* – Total kilometres travelled by private vehicle [km per private vehicle per year]
$f_{i,pv}$ – Emission factor of the private vehicle for pollutant *i* [tonne per private vehicle per km]
*Ktaxi* – Total kilometres travelled by taxi [km per taxi per year]
$f_{i,taxi}$ – Emission factor of the taxi for pollutant *i* [tonne per taxi per km]

*and*

*i* = $CO_2$, $NO_x$, and PM

*Equation 9* calculates the total cost for the Municipality of Utrecht associated with carsharing – including subsidies provided to low-income users and environmental costs (i.e., negative emission variations). Costs for building and maintaining parking spaces for carsharing vehicles are excluded as these costs are covered by area developers and not by the Municipality of Utrecht.

$$\sum Costs_{Municipality} = (Sub_{low} \times N_{low} \times 12) - \Delta Pi \quad (9)$$

*where*

$\Delta Pi$ – Yearly environmental costs (if negative (-)) related to pollution [€ per year]

#### 5.1.3. Subsidy Estimations per Scenario

In the context of subsidising carsharing services, the analysis for the Municipality of Utrecht focusses on facilitating access for low- and middle-low-income residents of Merwede. The determination of a fair subsidy amount requires a comprehensive method, considering the dynamic interplay between carsharing demand, economic constraints (i.e., mobility budgets) of low- and middle-low-income populations, and the intended social benefits. In the present thesis, the amounts of subsidy were somewhat arbitrarily determined based on the described mobility budgets (Table 13) and the average carsharing service price, as well as the average number of monthly carsharing trips. This resulted in subsidy values of 50 and 100 euros per month – 600 and 1200 euros per year – per low- and middle-low-income carsharing user.

#### 5.1.4. Model Scenarios

As mentioned in Section 2.7.1, different model scenarios account for unpredictability in future developments. These scenarios are elaborated on below, beginning with the baseline scenario and then expanding on the variant scenarios.

##### 5.1.4.1. Baseline Scenario

Scenario S0 serves as a baseline scenario, thus there is no carsharing in this scenario – i.e., the modal split for carsharing is 0.0%. The modal splits for private car (49.9%), taxi (1.7%), public transportation (10.9%), and biking (37.5%) were determined using Whooz (2023) data and the number of parking spots available for private cars (1450) and taxis in Merwede (50). Additionally, to estimate the modal split of carsharing for the variant scenarios, the number of parking spots intended for carsharing in Merwede (250) was used.

##### 5.1.4.2. Variant Scenarios

Building upon the baseline scenario, six variants were formulated. Two alternative scenarios are one in which there is moderate adoption (modal split: 3.8%) of carsharing services (S1-1) and one alternative in which there is high adoption (modal split 7.5%) of carsharing services (S2-1) in Merwede. Neither S1-1 nor S2-1 contained the subsidy intervention. Then, the interventions of 50- and 100-euro monthly subsidies for carsharing for low- and middle-low-income-residents were included, yielding a scenario in which there is moderate adoption of carsharing and a 50-euro subsidy per lower-income user (S1-2) as well as one in which there is moderate adoption of carsharing and a 100-euro subsidy per lower-income user (S1-3). Furthermore, scenarios with high carsharing adoption and a 50-euro subsidy per lower-income user (S2-2) and with a 100-euro subsidy per lower-income user (S2-3), were also included. Table 16 provides an overview of the characteristics of the scenarios included in the analysis. In this, the number of users eligible for the monthly carsharing subsidy is based on the percentage of low- and middle-low-income residences present in Merwede (see Table 11). As these percentages are 20% and 23%, respectively, the number of users eligible for subsidy is determined by multiplying *Nusers* with 0.43 for each relevant scenario. Moreover, Table 17 illustrates the predicted modal split per scenario, this is assumed to stay constant over the 10-year timeframe of the CBA.

**Table 16.** Scenarios included in CBA. In this, modal split, number of carsharing users, and number of (lower income) users eligible for the monthly subsidy are expressed per year.

| | Description | Carsharing Modal Split | Carsharing Users | Number of Users Eligible for Subsidy |
|---|---|---|---|---|
| *S0* | Baseline, no carsharing, no subsidy | 0.0% | 0 | 0 |
| *S1-1* | Moderate carsharing, no subsidy | 3.8% | 567 | 0 |
| *S1-2* | Moderate carsharing, 50-euro monthly subsidy per lower-income resident | 3.9% | 586 | 250 |
| *S1-3* | Moderate carsharing, 100-euro monthly subsidy per lower-income resident | 4.0% | 604 | 257 |
| *S2-1* | High carsharing, no subsidy | 7.5% | 1,134 | 0 |
| *S2-2* | High carsharing, 50-euro monthly subsidy per lower-income resident | 7.8% | 1,172 | 499 |
| *S2-3* | High carsharing, 100-euro monthly subsidy per lower-income resident | 8.0% | 1,208 | 515 |

**Table 17.** Predicted modal split of Merwede residents per scenario for 2024.

| | S0 | S1-1 | S1-2 | S1-3 | S2-1 | S2-2 | S2-3 |
|---|---|---|---|---|---|---|---|
| *Private Car* | 49.9% | 47.1% | 47.1% | 47.0% | 43.5% | 43.4% | 43.3% |
| *Carsharing* | 0.0% | 3.8% | 3.9% | 4.0% | 7.5% | 7.8% | 8.0% |
| *Taxi* | 1.7% | 1.6% | 1.6% | 1.6% | 1.5% | 1.5% | 1.5% |
| *Public Transportation* | 10.9% | 10.4% | 10.4% | 10.3% | 10.4% | 10.3% | 10.2% |
| *Bike* | 37.5% | 37.0% | 37.0% | 37.0% | 37.0% | 37.0% | 37.0% |

## 5.2. Sensitivity Analysis

The inherent uncertainty of future events means that the preliminary projections of costs and benefits carry a margin of variability. Sensitivity analyses – which explore the potential variability of key inputs – are crucial to understanding the robustness of the results of the CBA under varying conditions. Thus, for the present CBA, a sensitivity analysis is carried out, which is reported in Section 6.4.3. In the present sensitivity analysis, the included inputs – *Pkm*, *Psub*, *Pt*, *Number of Parking Spots Private Car*, *Number of Parking Spots Carsharing* (+ Equal Change in Fleet Size (*F*)) – are compared to S1-1. Notably, the sensitivity analysis for price elasticities for low- and middle-low-income residents of Merwede was carried out using S1-2 as a reference as these components were not relevant for or included in S1-1. The elasticities are only in the model after the carsharing service price change resulting from the subsidy is introduced. In the following chapter, the results are synthesised, followed by a discussion, conclusion, and recommendations in the subsequent chapters.

# 6. Results

In previous sections, the sub-questions regarding the determinants of carsharing adoption (Section 3.2) and policies and interventions that support carsharing services (Section 3.6) were answered. This chapter aims to answer the sub-questions regarding price elasticity of carsharing per income group and what the costs and benefits are of subsidising carsharing services for low- and middle-low-income residents of Merwede. To this end, first the carsharing price per income group is reported. Then, to determine the modal splits in the variant scenarios, the effects of carsharing on other modes – and the resulting modal split – is presented. This is followed by the results of the market research conducted to determine pricing inputs for the CBA. Finally, the outcomes of the CBA used to determine the net present value of carsharing in Merwede – with and without the subsidy policy – are reported. This chapter concludes with the results of the sensitivity analysis.

## 6.1. Carsharing Price Elasticity per Income Group

As elaborated on in Section 2.4, using a general Dutch carsharing price elasticity derived from literature and guiding principles (Table 6), income-specific carsharing price elasticities are estimated. Economic, behavioural, and situational factors further refined these estimates (Kim et al., 2017; Planbureau voor de Leefomgeving, 2010; Bakker et al., 2018; Cartenì et al., 2016; Papu Carrone et al., 2020; Vasudevan et al., 2021).

Carsharing and public transportation are both cost-efficient and eco-friendly travel options (principle 7), justifying the use of Dutch public transportation price elasticity as a proxy for carsharing as data regarding the latter is scarce. Research by Bakker (2018) indicates that the price elasticity of demand for public transportation in the Netherlands is -0.45 for train transport, and 0.36 for bus, tram, and metro, resulting in an average value of -0.41. These values are applied across all income groups due to public transportation's uniform pricing (principle 6), essential nature, and broad accessibility, making it challenging to segment elasticity by income (Bakker, 2018). Moreover, a 2010 report used literature to identify several short-term and long-term price elasticities for public transportation in the Netherlands (Planbureau voor Leefomgeving, 2010). To compare these to the previously reported values, the average values of the reported ranges are used, resulting in a price elasticity of -0.68 for train and -0.46 for bus, tram, and metro, resulting in an overall average value of -0.57. This indicates that public transportation is inelastic as the value is smaller than one module.

Regarding carsharing, studies by Firnkorn & Müller (2011) and Münzel et al. (2018) suggest that carsharing's growing popularity – especially among environmentally conscious and cost-sensitive users – is a key trend in urban mobility. For the Netherlands, Kim et al. (2017) found the price elasticity for demand for carsharing services to be -0.463. In China this value was -0.660 (Duan et al., 2020), in Italy this value was -0.850 (Cartenì et al., 2016), and in Denmark this value was determined to be -1.060 (Papu Carrone et al., 2020). The variation in carsharing price elasticity between the Netherlands, China, Italy, and Denmark likely reflects differing levels of service integration, cultural attitudes towards sharing, and the maturity of carsharing markets (Shaheen & Cohen, 2012). This aligns with principle 3.

A study by Vasudevan et al. (2021) determines mode shift elasticity based on household income and travel cost. In this, they distinguish between four income groups. It should be noted that this study was carried out in a rural area in India (principle 5). However, as principle 8 states, the difference between income groups is relative and people respond similarly to variations in their money and time costs, the basic relationships that affect travel demand tend to be durable and thus transferable (Litman, 2022). Thus, this should not influence the estimate significantly.

As mentioned in Section 4.3, the yearly income groups in the case study are defined as follows: low (0 – 30.000 euros per year), middle-low (30,000 – 74,000 euros per year), middle-high (74,000 – 88,500 euros per year), high (88,500+ euros per year). Based on the provided elasticities (Vasudevan et al., 2021), the range of relative differences between the four income groups regarding price elasticity, can be determined. This is then applied to the general price elasticity for carsharing services in the Netherlands of -0.463 to obtain the best estimates of Dutch carsharing price elasticity per income group. Specifically, to estimate carsharing demand price elasticities for the Netherlands by income group, a two-step approach was utilised. First, the average elasticity for middle-income groups was calculated, with middle-low and middle-high groups divided evenly around the general Dutch value (-0.463), yielding -0.51 and -0.41, respectively. Notably, price elasticities for the middle-income groups were interchanged to ensure a monotonic relationship between elasticity and income (principle 4). Subsequently, these values served as reference points and the high-income elasticity was proportionally adjusted using the middle-high income elasticity, resulting in -0.13, whilst the low-income elasticity was extrapolated from the middle-low, culminating in -0.82. Table 18 provides an overview of the relevant values as well as the estimates for the Dutch population.

**Table 18.** Estimates of Dutch carsharing price elasticity specific to income group.

| | Percentage of Future Merwede Residences (%) | Average Elasticity Across All Percentage Increments in Travel Expenses (Vasudevan et al., 2021) | Factor Relative to General Dutch Carsharing Price Elasticity | Estimate of Dutch Carsharing Price Elasticity |
|---|---|---|---|---|
| *Low* | 20 | -0.750 | 1.620 | -0.82 |
| *Middle-low* | 33 | -0.528 | 0.919 | -0.51 |
| *Middle-high* | 39 | -0.426 | 1.140 | -0.41 |
| *High* | 8 | -0.148 | 0.319 | -0.13 |
| *Simple Average* | | | | -0.47 |
| *Weighted Average* | | | | -0.50 |

The price elasticity values for carsharing are estimated as -0.82, -0.51, -0.41, and -0.13 for the low-income, middle-low, middle-high, and high-income groups, respectively. These values should be interpretated as follows: a price elasticity of -0.82 for the low-income group in carsharing means that a 1% increase in the price of carsharing services is expected to result in a 0.82% decrease in demand among this group. The values for middle-low, middle-high, and high-income groups, can be interpreted in the same way. The differentiated price elasticities of carsharing demand across various income groups in the Netherlands reflect the diverse responses to changes in transportation costs, suggesting that carsharing is inelastic across all income groups.

For the low-income group, a price elasticity of -0.82 indicates a relatively heightened sensitivity to price changes, likely due to transportation costs consuming a larger share of their budget, as outlined by Litman (2020a). This observation supports the notion that financial constraints significantly influence transportation choices (principle 4). In contrast, the middle-low-income group's elasticity of -0.51 suggests a diminished sensitivity to price, possibly because of their marginally higher disposable income which reduces the budgetary impact of transportation costs. For the middle-high-income group, a price elasticity of -0.41 hints at a more complex interplay of factors beyond mere financial considerations. According to Litman (2020a), this group's carsharing usage may be less about cost and more about the perceived value of convenience, lifestyle choices, and possibly environmental considerations. This aligns with behavioural economic principles, indicating that middle-high-income earners may prioritise aspects like convenience or eco-friendliness over cost, reflecting a broader range of mobility preferences (principle 1) and a diversification in transportation needs and choices (principle 2).

The high-income group demonstrates the lowest elasticity of -0.13, aligning with principle 4 which is the notion that higher-income individuals are less affected by price fluctuations due to their larger disposable income (Schaller, 2015). Moreover, the overall average elasticity of -0.47 as well as the weighted average of -0.50 being near the general carsharing price elasticity of -0.463 for the Dutch market indicates a balanced representation of price sensitivities. The minor deviations are expected as higher-income groups exhibit lower price sensitivity and thus moderate the average, whilst lower-income groups have the opposite effect (Litman, 2020a).

Overall, a trend of higher price sensitivity among lower-income groups compared to higher-income groups can be indicated. Still, these elasticity values are simply estimates, for precise empirical comparisons, revealed or stated choice experiments or detailed market research specific to the area of interest would be necessary. The provided estimates are conceptual and should be used as a starting point. Table 19 provides an overview of all price elasticities mentioned in this section.

**Table 19.** Estimated price elasticities for carsharing and public transportation.

| | Income Group | Price Elasticity |
|---|---|---|
| *Carsharing* | Low | -0.82 |
| | Middle-Low | -0.51 |
| | Middle-High | -0.41 |
| | High | -0.13 |
| *Carsharing (Simple Average)* | All | -0.47 |
| *Carsharing (Weighted Average)* | All | -0.50 |
| *Public Transportation (Train)* | All | -0.57 |
| *Public Transportation (Bus, Tram, Metro)* | All | -0.41 |
| *Public Transportation (Average)* | All | -0.49 |

The subsequent section elaborates on how carsharing demand affects the modal split of the other modes included in this case study. Specifically, private car, taxi, public transportation, and biking.

## 6.2. Effect of Carsharing on Other Modes

How carsharing service price changes affect the other modes of transportation (i.e., modal split) is mediated by means of price elasticities. As carsharing use affects the use of other transportation modes and vice versa, it is also relevant to acknowledge the redistribution of trips across different mobility options due to shifts in the carsharing modal split. As mentioned, the reallocation affects the following modes: private car, taxi, public transportation, and biking.

Using data from Rijkswaterstaat (2023), an adjustment is made where 20% of the trips categorised as 'other' or 'not made' are proportionally distributed among the available modes, accounting for shifts brought about by carsharing. The allocation method uses a straightforward formula: for each mode, the base percentage is added to half of the 'other' percentage and then multiplied by 20 to estimate the redistribution impact on the carsharing modal split. Table 20 presents this redistribution in clear terms, showing that private cars and public transportation absorb most of the shift, each with 48.75% of the change, while bicycles account for a smaller fraction, at 2.5%. No discernible shift towards taxis was noted.

**Table 20.** Effect of changes in carsharing modal split on other modalities.

| | Calculation | Portion of Change in Carsharing Modal Split |
|---|---|---|
| *Private car* | $39 + \frac{39}{(39+39+2)} \times 20$ | 48,75% |
| *Taxi* | – | 0,00% |
| *Public Transportation* | $39 + \frac{39}{(39+39+2)} \times 20$ | 48,75% |
| *Bike* | $2 + \frac{2}{(39+39+2)} \times 20$ | 2,50% |

To determine the average kilometre price (*Pkm*), hourly price (*Pt*), and monthly subscription price (*Psub*) of carsharing services, market research was carried out for the CSOs considered in this thesis (namely: A2B, Greenwheels, Hely, MyWheels, and OnzeAuto). This is elaborated upon in the subsequent section.

## 6.3. Market Research Findings

As described in Section 2.5, for the market research several websites were consulted. The pricing information available on each CSOs' website allowed for the determination of an average kilometre price (*Pkm*), hourly price (*Pt*), and monthly subscription price (*Psub*) of carsharing services for the CBA (Table 21). In this, the outliers – not used to calculate the average – are highlighted with red. The average values for each pricing component are used for the baseline and variant scenarios and remain unchanged throughout the analysis.

Regarding the CSOs, some particularities stood out, they display unique pricing models. A2B integrates the hourly cost into the monthly subscription fee, diverging from per-hour charges and resulting in comparatively higher subscription prices. OnzeAuto's monthly subscription price translates to a ride allowance, yet the portion of this monthly allowance that is unutilised by users remains unclear. Lastly, Hely provides rates based on time without per-kilometre pricing.

**Table 21.** Average carsharing service prices, values in red boxes are excluded from the average value calculations.

| | **Kilometre Price (*Pkm*)** | **Hourly Price (*Pt*)** | **Monthly Subscription Price (*Psub*)** |
|---|---|---|---|
| *A2B* | € 0.16 | N.A. | € 32.49 |
| *Greenwheels* | € 0.36 | € 3.13 | € 11.67 |
| *Hely* | N.A. | € 8.38 | € 15.00 |
| *MyWheels* | € 0.34 | € 3.40 | € 11.67 |
| *OnzeAuto* | € 0.28 | € 3.15 | € 162.50 |
| **Average** | **€ 0.29** | **€ 3.23** | **€ 12.78** |

## 6.4. Cost-benefit Analysis

In the present thesis, the main research question is explored by means of a case study in Merwede. Emphasis is put on ensuring transportation equity (i.e., accessibility to carsharing services for all income groups residing in Merwede). Therefore, the CBA presented below specifically aims to answer whether carsharing services should be subsidised for low and middle-low-income residents of Merwede. The choice of subsidy as the policy of interest is based on its effectiveness in enhancing transportation equity – which is especially relevant considering the high monthly parking prices in Merwede. An overview of the scenarios included in the CBA can be found in Table 16.

### 6.4.1. Results

Table 22 provides an overview of the results of the CBA in the form of NPVs – i.e., (total) benefits minus (total) costs – for the CSOs, carsharing users, and Municipality of Utrecht for the year 2024. For CSOs, NPV values are negative in scenarios with moderate carsharing adoption and no subsidy (S1-1) or a subsidy of 50 euros per month for lower-income users (S1-2). This is due to insufficient carsharing adoption resulting in revenues failing to cover operational costs. The highest NPVs for CSOs is reported in the scenario with high carsharing adoption and a subsidy of 100 euros per month for lower-income users (S2-3). In this scenario, higher adoption rates likely contribute to better economies of scale and higher revenues. In accordance with this finding, for carsharing users the lowest NPV is reported for the scenario where there is moderate carsharing adoption and no subsidy (S1-1) and the highest NPV results from high carsharing use and a monthly subsidy of 100 euros for lower-income users (S2-3). The latter can be attributed to the direct financial incentives promoting carsharing, with these benefits going to lower-income users.

Contradictory to the other stakeholders, the highest NPV for the Municipality of Utrecht is reported for the scenario in which there is high carsharing adoption and no subsidy (S2-1) whilst the lowest NPV results from a scenario in which there is moderate carsharing adoption and a monthly subsidy of 100 euros for lower-income users (S1-3). This indicates that while subsidies represent a direct cost to the municipality, the environmental savings generated from increased carsharing use – as opposed to less sustainable modes of transportation – offer substantial financial benefits.

Regarding the yearly total NPV, this value is highest for the scenario in which there is high carsharing and a 100-euro monthly subsidy for lower-income users (S2-3). The lowest yearly total NPV is reported for the scenario in which there is moderate carsharing adoption and no monthly subsidy (S1-1). These findings suggest that all three stakeholders benefit from carsharing service use. CSOs benefit from revenues, users benefit from savings on alternative transportation modes (predominantly from private cars), and the municipality benefits from environmental savings resulting from electric carsharing rather than less sustainable modes of transportation. Ideally, an optimum would be achieved in which the modal split for carsharing is high enough to ensure maximum utilisation rates of the services (CSOs) whilst as little trip credit incentive – i.e., subsidy (municipality) – is required to ensure transportation equity (users). For CSOs in Merwede – as seen from S1-2 and S1-3 – the tipping point where carsharing becomes profitable lies between a modal split of 3.9% and 4.0%, which respectively equal 293,026 and 302,235 carsharing trips per year.

**Table 22.** Net present values for the year 2024 of the three stakeholders and different scenarios included in the CBA.

| | NPV CSOs | NPV Users | NPV Municipality | NPV Total |
|---|---|---|---|---|
| *S1-1* | € -46,520.15 | € 30,184,866.17 | € 382,710.93 | € 30,521,056.96 |
| *S1-2* | € -6,005.00 | € 30,351,975.83 | € 245,012.12 | € 30,590,982.96 |
| *S1-3* | € 33,596.25 | € 30,531,766.15 | € 97,843.55 | € 30,663,205.95 |
| *S2-1* | € 1,174,684.89 | € 30,263,977.21 | € 782,963.22 | € 32,221,625.32 |
| *S2-2* | € 1,255,716.70 | € 30,600,040.36 | € 507,566.06 | € 32,363,323.12 |
| *S2-3* | € 1,334,919.02 | € 30,957,776.47 | € 213,228.86 | € 32,505,924.35 |

Table 23 shows the detailed results of the costs and benefits included in the CBA, providing insights into the components that make up the NPVs for each stakeholder. For the scenario with the highest yearly total NPV (S2-3), the subsidy costs amount to 617,489.43 euros per year. This is also the scenario in which the NPV is highest for the CSOs and users. However, in the scenario in which the NPV is highest for the Municipality of Utrecht (S2-1), the subsidy costs amount to 0 euros per year. Moreover, in the case of moderate carsharing adoption the Municipality of Utrecht also has the highest NPV in the scenario in which no subsidy is introduced (S1-1). This suggests that the additional environmental savings the municipality incurs (from increased carsharing use due to the subsidy) do not outweigh the subsidy costs incurred by the municipality. However, it should be noted that the increase in transportation equity resulting from the subsidy provided to lower-income residents is not fully captured. Thus, certain societal benefits remain unaccounted for in the present analysis but may very well significantly increase the NPV for the municipality once quantified. Furthermore, as shown in the lower part of Table 23, results indicate that with a 10-year time horizon (i.e., in the year 2034) the total NPV remains positive for all scenarios.

**Table 23.** Overview of calculated yearly costs and benefits in various scenarios. In this, values are calculated for the base year 2024 and the values presented on a 10-year time horizon are for the year 2034. All scenarios are compared to the baseline scenario (S0) in which there is no carsharing.

| | | | S1-1 (Moderate CS, No Sub) | S1-2 (Moderate CS, 50 Sub) | S1-3 (Moderate CS, 100 Sub) | S2-1 (High CS, No Sub) | S2-2 (High CS, 50 Sub) | S2-3 (High CS, 100 Sub) |
|---|---|---|---|---|---|---|---|---|
| **CSOs** | Benefits | Income from carsharing use after taxes | € 1,318,234.10 | € 1,361,962.78 | € 1,404,710.97 | € 2,636,359.98 | € 2,723,818.98 | € 2,809,315.17 |
| | | *Sum of Benefits CSOs* | € 1,318,234.10 | € 1,361,962.78 | € 1,404,710.97 | € 2,636,359.98 | € 2,723,818.98 | € 2,809,315.17 |
| | Costs | Vehicle leasing costs | € 525,000.00 | € 525,000.00 | € 525,000.00 | € 525,000.00 | € 525,000.00 | € 525,000.00 |
| | | External parking costs | € 292,500.00 | € 292,500.00 | € 292,500.00 | € 292,500.00 | € 292,500.00 | € 292,500.00 |
| | | Vehicle cleaning costs | € 60,000.00 | € 60,000.00 | € 60,000.00 | € 60,000.00 | € 60,000.00 | € 60,000.00 |
| | | Location setup/stations costs | € 213,000.00 | € 213,000.00 | € 213,000.00 | € 213,000.00 | € 213,000.00 | € 213,000.00 |
| | | Energy costs | € 96,929.25 | € 100,142.78 | € 103,289.72 | € 193,850.09 | € 200,277.28 | € 206,571.15 |
| | | Staff costs | € 122,695.00 | € 122,695.00 | € 122,695.00 | € 122,695.00 | € 122,695.00 | € 122,695.00 |
| | | Facilities costs | € 54,630.00 | € 54,630.00 | € 54,630.00 | € 54,630.00 | € 54,630.00 | € 54,630.00 |
| | | *Sum of Costs CSOs* | € 1,364,754.25 | € 1,367,967.78 | € 1,371,114.72 | € 1,461,675.09 | € 1,468,102.28 | € 1,474,396.15 |
| | | NPV CSOs | € -46,520.15 | € -6,005.00 | € 33,596.25 | € 1,174,684.89 | € 1,255,716.70 | € 1,334,919.02 |
| | | Plus or Minus | -- | - | + | ++ | +++ | ++++ |
| **Users** | Benefits | Private car savings | € 30,656,693.66 | € 30,665,185.51 | € 30,673,501.40 | € 31,164,548.14 | € 31,181,532.18 | € 31,198,163.92 |
| | | Parking savings | € 609,120.00 | € 623,160.00 | € 636,120.00 | € 1,420,200.00 | € 1,447,200.00 | € 1,474,200.00 |
| | | Taxi savings | € 306,520.14 | € 306,520.14 | € 306,520.14 | € 714,354.05 | € 714,354.05 | € 714,354.05 |
| | | Public transportation savings | € 260,325.00 | € 295,425.00 | € 333,450.00 | € 260,325.00 | € 333,450.00 | € 406,575.00 |
| | | Carsharing subsidy | € - | € 149,771.86 | € 308,744.72 | € - | € 299,543.72 | € 617,489.43 |
| | | Change in consumer surplus | € - | € 14,366.80 | € 29,318.60 | € - | € 28,734.14 | € 58,638.02 |
| | | *Sum of Benefits Users* | € 31,832,658.80 | € 32,054,429.31 | € 32,287,654.86 | € 33,559,427.19 | € 34,004,814.09 | € 34,469,420.43 |
| | Costs | Subscription costs of carsharing | € 86,940.00 | € 89,853.33 | € 92,613.33 | € 173,880.00 | € 179,706.67 | € 185,226.67 |
| | | Kilometre costs of carsharing | € 1,212,932.93 | € 1,253,145.74 | € 1,292,525.28 | € 2,425,760.74 | € 2,506,187.94 | € 2,584,946.85 |
| | | Time costs of carsharing | € 347,919.70 | € 359,454.41 | € 370,750.10 | € 695,809.24 | € 718,879.12 | € 741,470.45 |
| | | *Sum of Costs Users* | € 1,647,792.62 | € 1,702,453.48 | € 1,755,888.71 | € 3,295,449.98 | € 3,404,773.73 | € 3,511,643.96 |
| | | NPV Users | € 30,184,866.17 | € 30,351,975.83 | € 30,531,766.15 | € 30,263,977.21 | € 30,600,040.36 | € 30,957,776.47 |
| | | Plus or Minus | + | +++ | ++++ | ++ | +++++ | ++++++ |
| **Municipality of Utrecht** | Benefits | Environmental savings | € 53,152.41 | € 54,293.29 | € 55,410.53 | € 123,873.22 | € 126,155.03 | € 128,389.50 |
| | | Income from taxes CSOs | € 329,558.52 | € 340,490.70 | € 351,177.74 | € 659,090.00 | € 680,954.75 | € 702,328.79 |
| | | *Sum of Benefits Municipality* | € 382,710.93 | € 394,783.98 | € 406,588.27 | € 782,963.22 | € 807,109.77 | € 830,718.29 |
| | Costs | Environmental costs | € - | € - | € - | € - | € - | € - |
| | | Carsharing subsidy | € - | € 149,771.86 | € 308,744.72 | € - | € 299,543.72 | € 617,489.43 |
| | | *Sum of Costs Municipality* | € - | € 149,771.86 | € 308,744.72 | € - | € 299,543.72 | € 617,489.43 |
| | | NPV Municipality | € 382,710.93 | € 245,012.12 | € 97,843.55 | € 782,963.22 | € 507,566.06 | € 213,228.86 |
| | | Plus or Minus | ++++ | +++ | + | ++++++ | +++++ | ++ |
| **Total** | | NPV Total | **€ 30,521,056.96** | **€ 30,590,982.96** | **€ 30,663,205.95** | **€ 32,221,625.32** | **€ 32,363,323.12** | **€ 32,505,924.35** |
| | | Benefit/Cost Ratio (BCR) | 11.131 | 10.500 | 9.925 | 7.773 | 7.257 | 6.801 |
| | | | | *Effects on Time Horizon Y10* | | | | |
| | | | S1-1 (Moderate CS, No Sub) | S1-2 (Moderate CS, 50 Sub) | S1-3 (Moderate CS, 100 Sub) | S2-1 (High CS, No Sub) | S2-2 (High CS, 50 Sub) | S2-3 (High CS, 100 Sub) |
| **CSOs** | *Benefits* | | € 814,179.95 | € 841,188.07 | € 867,590.60 | € 1,628,293.07 | € 1,682,310.31 | € 1,735,115.25 |
| | *Costs* | | € 842,912.16 | € 844,896.93 | € 846,840.57 | € 902,773.31 | € 906,742.93 | € 910,630.21 |
| | *NPV* | | € -28,732.20 | € -3,708.86 | € 20,750.03 | € 725,519.76 | € 775,567.38 | € 824,485.05 |
| | *Plus or Minus* | | -- | - | + | ++ | +++ | ++++ |
| **Users** | *Benefits* | | € 19,660,781.54 | € 19,797,753.49 | € 19,941,800.42 | € 20,727,284.23 | € 21,002,368.20 | € 21,289,322.68 |
| | *Costs* | | € 1,017,724.94 | € 1,051,485.08 | € 1,084,488.25 | € 2,035,366.34 | € 2,102,887.88 | € 2,168,894.07 |
| | *NPV* | | € 18,643,056.60 | € 18,746,268.41 | € 18,857,312.17 | € 18,691,917.89 | € 18,899,480.32 | € 19,120,428.61 |
| | *Plus or Minus* | | + | +++ | ++++ | ++ | +++++ | ++++++ |
| **Municipality of Utrecht** | *Benefits* | | € 236,373.47 | € 243,830.14 | € 251,120.81 | € 483,580.99 | € 498,494.61 | € 513,075.93 |
| | *Costs* | | € - | € 92,503.48 | € 190,689.77 | € - | € 185,006.96 | € 381,379.54 |
| | *NPV* | | € 236,373.47 | € 151,326.66 | € 60,431.04 | € 483,580.99 | € 313,487.65 | € 131,696.38 |
| | *Plus or Minus* | | ++++ | +++ | + | ++++++ | +++++ | ++ |
| **Total** | *NPV* | | **€ 18,850,697.86** | **€ 18,893,886.21** | **€ 18,938,493.24** | **€ 19,901,018.64** | **€ 19,988,535.35** | **€ 20,076,610.04** |
| | *Plus or Minus* | | + | ++ | +++ | ++++ | +++++ | ++++++ |

The CBA combines both financial and societal costs and benefits. However, it is important to distinguish between these two types as they have different implications. Thus, to provide a more detailed overview of the latter type, Table 24 breaks down the societal costs and benefits, including environmental, subsidies, and change in consumer surplus. In this, environmental savings for the other scenarios are relative to the baseline scenario (S0) in which there is no carsharing.

**Table 24.** Breakdown of calculated yearly societal benefits and costs (environmental savings, subsidy costs, and consumer surplus) for the base year 2024.

| Environment | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **S0** | **S1-1** | **S1-2** | **S1-3** | **S2-1** | **S2-2** | **S2-3** |
| *Carhsaring CO2 emissions* | € - | € - | € - | € - | € - | € - | € - |
| *Carsharing NOx emissions* | € - | € - | € - | € - | € - | € - | € - |
| *Carsharing PM emissions* | € - | € - | € - | € - | € - | € - | € - |
| *Private vehicle CO2 emissions* | € 745,898.24 | € 705,133.36 | € 704,226.43 | € 703,338.29 | € 650,894.50 | € 649,080.60 | € 647,304.34 |
| *Private vehicle NOx emissions* | € 166,569.97 | € 83,189.89 | € 83,082.89 | € 82,978.11 | € 76,790.92 | € 76,576.93 | € 76,367.37 |
| *Private vehicle PM emissions* | € 25,841.04 | € 6,173.22 | € 6,165.28 | € 6,157.50 | € 5,698.37 | € 5,682.49 | € 5,666.94 |
| *Taxi CO2 emissions* | € 27,227.07 | € 25,739.06 | € 25,739.06 | € 25,739.06 | € 23,759.21 | € 23,759.21 | € 23,759.21 |
| *Taxi NOx emissions* | € 6,080.20 | € 3,036.63 | € 3,036.63 | € 3,036.63 | € 2,803.05 | € 2,803.05 | € 2,803.05 |
| *Taxi PM emissions* | € 943.26 | € 225.34 | € 225.34 | € 225.34 | € 208.00 | € 208.00 | € 208.00 |
| *Environmental savings* | € - | € 149,062.30 | € 150,084.17 | € 151,084.86 | € 212,405.73 | € 214,449.50 | € 216,450.88 |
| **Subsidy & Consumer Surplus** | | | | | | | |
| | | **S1-1** | **S1-2** | **S1-3** | **S2-1** | **S2-2** | **S2-3** |
| *Carsharing subsidy costs* | € - | € - | € 149,771.86 | € 308,744.72 | € - | € 299,543.72 | € 617,489.43 |
| *Change in consumer surplus* | € - | € - | € 14,366.80 | € 29,318.60 | € - | € 28,734.14 | € 58,638.02 |

## 6.4.2. Transportation Equity Implications

To determine whether the subsidies are effective – i.e., beneficial to the low- and middle-low-income groups – the (change in) consumer surplus and the minimum number of carsharing are reported. How the change in consumer surplus resulting from the subsidy was calculated, is elaborated upon in Section *5.1.2.2*. In *Equation 6*, the price ($p_0$ and $p_1$) and demand ($q_0$ and $q_1$) values refer to the average price per trip per income group per scenario and the number of carsharing trips per income group per month. These values are shown in Table 25 and Table 26. Calculating the change in consumer surplus for the relevant scenarios (S1-2, S1-3, S2-2, and S2-3) resulted in the following respective yearly consumer surplus values: 14,366.80 euros; 29,318.60 euros; 28,734.14 euros; and 58,638.02 euros (as shown in Table 24).

**Table 25.** Average price per trip per income group in euros.

| | **S0** | **S1-1** | **S1-2** | **S1-3** | **S2-1** | **S2-2** | **S2-3** |
|---|---|---|---|---|---|---|---|
| *Low* | € - | € 5.81 | € 4.61 | € 3.41 | € 5.81 | € 4.61 | € 3.41 |
| *Middle-low* | € - | € 5.81 | € 4.61 | € 3.41 | € 5.81 | € 4.61 | € 3.41 |
| *Middle-high* | € - | € 5.81 | € 5.81 | € 5.81 | € 5.81 | € 5.81 | € 5.81 |
| *High* | € - | € 5.81 | € 5.81 | € 5.81 | € 5.81 | € 5.81 | € 5.81 |
| **Average Price per Trip** | **€ -** | **€ 5.81** | **€ 5.21** | **€ 4.61** | **€ 5.81** | **€ 5.21** | **€ 4.61** |

**Table 26**. Number of carsharing trips per income group per month.

| | S0 | S1-1 | S1-2 | S1-3 | S2-1 | S2-2 | S2-3 |
|---|---|---|---|---|---|---|---|
| *Low* | 0 | 3555 | 3945 | 4233 | 7110 | 7889 | 8467 |
| *Middle-low* | 0 | 5895 | 6541 | 7020 | 11790 | 13082 | 14039 |
| *Middle-high* | 0 | 6863 | 6741 | 6741 | 13726 | 13482 | 13482 |
| *High* | 0 | 7322 | 7192 | 7192 | 14643 | 14383 | 14383 |
| | | | | | | | |
| **Total Monthly Trips** | **0** | **23635** | **24419** | **25186** | **47269** | **48836** | **50370** |

Moreover, Table 27 shows the estimated minimum number of users per income group per scenario. In this, it is assumed that there are 250 shared cars in Merwede and approximately 12,000 residents. To calculate this for each scenario (see Appendix C for the calculations), the principle that carsharing is only beneficial for users travelling less than 7,500 kilometres a year (Rijkswaterstaat, n.d.) is used. Specifically, the total kilometres travelled using carsharing (an output of the model dependent on the modal split) is divided by 7,500 and then rounded down. As the total number of carsharing kilometres per scenario is divided by the maximum number of kilometres per user, this results in an estimation of the minimum number of carsharing users. The observed variation in the use of carsharing services across income groups – notably higher usage among low- and middle-low-income residents resulting from subsidies – supports the municipality's goal of ensuring more equitable access to and use of carsharing services.

**Table 27.** Estimated minimum number of carsharing users per income group per year per scenario.

| | Low | Middle-low | Middle-high | High | Total |
|---|---|---|---|---|---|
| *S0* | 0 | 0 | 0 | 0 | 0 |
| *S1-1* | 66 | 76 | 366 | 59 | 567 |
| *S1-2* | 76 | 87 | 366 | 59 | 588 |
| *S1-3* | 82 | 96 | 366 | 59 | 603 |
| *S2-1* | 132 | 152 | 731 | 119 | 1134 |
| *S2-2* | 150 | 172 | 731 | 119 | 1172 |
| *S2-3* | 166 | 192 | 731 | 119 | 1208 |

### 6.4.3. Sensitivity Analysis

To determine how robust the findings of the CBA are, it is important to gather some insights into how the CBA responds to changes in input values. This thesis regards pricing strategies, and there is some uncertainty in price-related inputs as these were determined by means of literature and market research. Thus, inputs related to pricing were emphasised. Specifically, *Pkm*, *Psub*, *Pt*, *Number of Parking Spots Private Car*, and *Number of Parking Spots Carsharing* (with an equal change in fleet size (*F*)). Additionally, the price elasticities for low- and middle-low-income groups were also included in the sensitivity analysis. The results of this analysis are displayed in Table 28 and discussed below.

**Table 28**. Results of the sensitivity analysis.

| Input Value | Value & % Change | | NPVCSOs & % Change | | NPVUsers & % Change | | NPVMunicipality & % Change | | NPVTotal & % Change | | Modal SplitCarsharing & % Change | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Relative to S1-1 Starting Values* | | | | | | | | | | | | |
| Kilometre Pricing ( *Pkm* ) | € 0.34 | +20% | € 147,549.12 | -417.2% | € 29,942,279.59 | -0.8% | € 431,228.25 | 12.7% | € 30,521,056.96 | 0.0% | 3.752% | 0.0% |
| | € 0.31 | +10% | € 50,514.49 | -208.6% | € 30,063,572.88 | -0.4% | € 406,969.59 | 6.3% | € 30,521,056.96 | 0.0% | 3.752% | 0.0% |
| | € 0.26 | -10% | € -143,554.78 | 208.6% | € 30,306,159.47 | 0.4% | € 358,452.27 | -6.3% | € 30,521,056.96 | 0.0% | 3.752% | 0.0% |
| | € 0.23 | -20% | € -240,589.42 | 417.2% | € 30,427,452.76 | 0.8% | € 334,193.61 | -12.7% | € 30,521,056.96 | 0.0% | 3.752% | 0.0% |
| Subscription Pricing ( *Psub* ) | € 15.33 | +20% | € -32,609.75 | -29.9% | € 30,167,478.17 | -0.1% | € 386,188.53 | 0.9% | € 30,521,056.96 | 0.0% | 3.752% | 0.0% |
| | € 14.06 | +10% | € -39,564.95 | -15.0% | € 30,176,172.17 | 0.0% | € 384,449.73 | 0.5% | € 30,521,056.96 | 0.0% | 3.752% | 0.0% |
| | € 11.50 | -10% | € -53,475.35 | 15.0% | € 30,193,560.17 | 0.0% | € 380,972.13 | -0.5% | € 30,521,056.96 | 0.0% | 3.752% | 0.0% |
| | € 10.22 | -20% | € -60,430.55 | 29.9% | € 30,202,254.17 | 0.1% | € 379,233.33 | -0.9% | € 30,521,056.96 | 0.0% | 3.752% | 0.0% |
| Time Pricing ( *Pt* ) | € 3.87 | +20% | € 9,147.00 | -119.7% | € 30,115,282.23 | -0.2% | € 396,627.72 | 3.6% | € 30,521,056.96 | 0.0% | 3.752% | 0.0% |
| | € 3.55 | +10% | € -18,686.57 | -59.8% | € 30,150,074.20 | -0.1% | € 389,669.32 | 1.8% | € 30,521,056.96 | 0.0% | 3.752% | 0.0% |
| | € 2.91 | -10% | € -74,353.72 | 59.8% | € 30,219,658.14 | 0.1% | € 375,752.54 | -1.8% | € 30,521,056.96 | 0.0% | 3.752% | 0.0% |
| | € 2.58 | -20% | € -102,187.30 | 119.7% | € 30,254,450.11 | 0.2% | € 368,794.14 | -3.6% | € 30,521,056.96 | 0.0% | 3.752% | 0.0% |
| Number of Parking Spots Private Car | 1740 | +20% | € -232,488.72 | 399.8% | € 30,138,606.06 | -0.2% | € 321,752.63 | -15.9% | € 30,227,869.97 | -1.0% | 3.181% | -15.2% |
| | 1595 | +10% | € -147,153.19 | 216.3% | € 30,157,383.07 | -0.1% | € 349,722.93 | -8.6% | € 30,359,952.81 | -0.5% | 3.443% | -8.2% |
| | 1305 | -10% | € 73,927.33 | -258.9% | € 30,225,937.46 | 0.1% | € 422,199.58 | 10.3% | € 30,722,064.37 | 0.7% | 4.122% | 9.9% |
| | 1160 | -20% | € 220,698.10 | -574.4% | € 30,287,205.45 | 0.3% | € 470,324.96 | 22.9% | € 30,978,228.51 | 1.5% | 4.573% | 21.9% |
| Number of Parking Spots Carsharing (+ Equal Change in Fleet Size (*F*)) | 300 | +20% | € 1,620.68 | -103.5% | € 36,254,845.84 | 20.1% | € 456,007.98 | 19.2% | € 36,712,474.50 | 20.3% | 4.439% | 18.3% |
| | 275 | +10% | € -21,701.89 | -53.3% | € 33,219,437.15 | 10.1% | € 419,608.07 | 9.6% | € 33,617,343.33 | 10.1% | 4.098% | 9.2% |
| | 225 | -10% | € -72,989.05 | 56.9% | € 27,150,224.34 | -10.1% | € 345,275.15 | -9.8% | € 27,422,510.44 | -10.2% | 3.401% | -9.4% |
| | 200 | -20% | € -101,141.81 | 117.4% | € 24,115,530.24 | -20.1% | € 307,289.69 | -19.7% | € 24,321,678.12 | -20.3% | 3.045% | -18.8% |
| *Relative to S1-2 Starting Values* | | | | | | | | | | | | |
| **Input Value** | **Value & % Change** | | **NPVCSOs & % Change** | | **NPVUsers & % Change** | | **NPVMunicipality & % Change** | | **NPVTotal & % Change** | | **Modal SplitCarsharing & % Change** | |
| Price Elasticity Low | -0.98 | +20% | € -23.91 | -99.6% | € 30,352,823.82 | 0.0% | € 246,288.28 | 0.5% | € 30,599,088.19 | 0.0% | 3.895% | 0.5% |
| | -0.90 | +10% | € -3,014.45 | -49.8% | € 30,352,939.93 | 0.0% | € 245,650.20 | 0.3% | € 30,595,575.68 | 0.0% | 3.885% | 0.2% |
| | -0.73 | -10% | € -9,118.21 | 51.8% | € 30,351,123.22 | 0.0% | € 244,598.96 | -0.2% | € 30,586,603.98 | 0.0% | 3.867% | -0.2% |
| | -0.65 | -20% | € -12,108.75 | 101.6% | € 30,353,083.95 | 0.0% | € 243,960.89 | -0.4% | € 30,584,936.09 | 0.0% | 3.857% | -0.5% |
| Price Elasticity Middle-low | -0.62 | +20% | € 352.79 | -105.9% | € 30,353,533.34 | 0.0% | € 246,139.81 | 0.5% | € 30,600,025.94 | 0.0% | 3.896% | 0.5% |
| | -0.57 | +10% | € -2,887.44 | -51.9% | € 30,352,810.17 | 0.0% | € 245,688.42 | 0.3% | € 30,595,611.16 | 0.0% | 3.886% | 0.3% |
| | -0.46 | -10% | € -9,245.22 | 54.0% | € 30,351,252.95 | 0.0% | € 244,560.74 | -0.2% | € 30,586,568.47 | 0.0% | 3.866% | -0.3% |
| | -0.41 | -20% | € -12,362.78 | 105.9% | € 30,350,418.37 | 0.0% | € 243,884.44 | -0.5% | € 30,581,940.03 | 0.0% | 3.857% | -0.5% |

| *Starting Values* | *S1-1* | *S1-2* |
|---|---|---|
| NPV CSOs | € -46,520.15 | € -6,005.00 |
| NPV Users | € 30,184,866.17 | € 30,351,975.83 |
| NPV Municipality of Utrecht | € 382,710.93 | € 245,012.12 |
| NPV Total | € 30,521,056.96 | € 30,590,982.96 |
| Modal Split Carsharing | 3.752% | 3.876% |

#### 6.4.3.1. Kilometre Pricing (*Pkm*), Subscription Pricing (*Psub*), and Time Pricing (*Pt*)

The sensitivity analysis shows that a 20% increase in *Pkm* leads to a notable -417.2% change in NPV CSOs – indicating that the CBA is quite sensitive to changes in *Pkm*. Bear in mind that the original value of NPV CSOs (S1-1) that this percentage change is based on, is a negative value. Thus, for these values, negative percentage changes reflect increases in NPV rather than decreases. Relative to the other price components (*Psub* and *Pt*), the kilometre price of carsharing weighs heaviest as changes in this component affect the NPV of CSOs, users, and the Municipality of Utrecht most. Furthermore, time pricing is the price component the model is second-most-sensitive to, followed by subscription pricing. Interestingly, changes in these pricing components do not result in changes in carsharing modal split. All in all, the analysis indicates that even modest increases or reductions in – particularly kilometre – pricing can enhance or diminish outcomes for all stakeholders.

#### 6.4.3.2. Parking Spot Availability

A 20% reduction in the number of parking spots available for private cars results in a -574.4% change in NPV CSOs. Additionally, the NPV for the Municipality of Utrecht also increases by 22.9%. Interestingly, the NPV of users and the total NPV decrease marginally whilst the modal split of carsharing also increases by 21.9%. Additionally, for carsharing spots and an equivalent change in fleet size (*F*), both the increase and reduction of 20% have the largest impacts on the NPVs of all stakeholders, with the reduction weighing a bit more on the overall outcomes than the increase – with the average difference being 2.98%.

#### 6.4.3.3. Price Elasticity

Regarding the changes in low- and middle-low price elasticity, these have an impact on NPV CSOs and a negligible impact on NPV Users and NPV Municipality. In this, changes in the price elasticity of the middle-low-income group weigh slightly more on the NPV CSOs. This is likely due to the small difference between the percentages low- and middle-low future Merwede residents – specifically, 20% will be low-income whilst 23% will be middle-low. The effects of price elasticity changes on the other outcomes – NPV Users, NPV Municipality, NPV total, and Modal Split Carsharing – are not as significant as all other percentage changes are below 1.0% in absolute terms.

The findings presented in this chapter inform the discussion in the following chapter. Afterwards, a conclusion is drawn, and recommendations as well as directions for future research are presented.

# 7. Discussion

This chapter reflects on the results of the present thesis. This thesis employed a case study of Merwede to gain a better understanding of carsharing pricing in car-free neighbourhoods in practice. The structure of this chapter is as follows. First the results from the data analysis, carsharing price elasticity determination, and CBA are discussed. Subsequently, the methodologies applied in this thesis are reflected upon. The chapter concludes with a discussion about the generalisability of the findings.

## 7.1. Discussion of Results

### 7.1.1. Data Analysis

To gain insight into Merwede, a data analysis was carried out using utilising company data from Arcadis | Over Morgen (Table 5) and modal split data from Whooz (2023). This is elaborated upon in Chapter 4. Merwede's mobility strategy enforces a notably low parking norm (0.3) and extensive provisions for bicycle parking. Typically, in the context of Dutch urban development, such a low parking norm is a clear deviation from the once common standards in suburban areas, which ranged from a minimum of 1.6 to a maximum of 2.5 spaces per residential unit (Mingardo et al., 2015). This trend is particularly pronounced in the inner-city areas of the largest Dutch cities like Amsterdam, Rotterdam, and The Hague, where a provision of 0.2 or 0.3 spaces per housing unit is becoming increasingly common. However, the extent to which existing private car usage habits will be discouraged and carsharing adoption will be promoted, remains to be revealed.

Mobility in Merwede – as detailed in Section 4.2 – aims to support the car-free initiative with a mix of public and shared mobility options. The planned low parking norm, high parking prices – approximately 200 euros per month – alongside well-connected public transportation services, aims to prevent private car reliance. The integration of carsharing as a service – illustrated by the availability of 250 parking spaces for shared cars – offers an alternative (shared) mobility solution.

Regarding the predicted modal split of future Merwede residents predicted, several points of discussion should be brought to the forefront. First, the group of interest for carsharing use is residents 18 years of age or older. However, some trip data (CBS, 2023) that was used to determine the total number of trips per year – an estimation of the total number of trips using private car (driver or passenger), train, bus/tram/metro, and bike – regarded residents of Utrecht 6 years or older. This may result in an overestimation of the number of trips. Second, while policies and projections point towards a sustainable, car-free living environment, the expected 49.9% (Figure 8) modal split for private cars signifies a discrepancy between policy objectives and the reality of residents' transportation preferences. Thirdly, the availability of cheaper parking – 50 euros per month – at external hubs like P+R Westraven, may be more practical for low- and middle-low-income residents in practice than carsharing as private car ownership offers a flexibility, convenience, and privacy (Kent & Dowling, 2013) unparalleled to carsharing. This could mean that the actual modal split of carsharing is much lower than the predicted values of 7.5% (or 3.8%).

Furthermore, the phenomenon of residential self-selection – which states that people tend to choose residential locations based on their travel abilities, needs and preferences – could also influence the actual modal split in Merwede. In other words, inhabitants may automatically be less inclined to own a private car as those who choose to live there are already opting for a car-free neighbourhood and may therefore have a stronger preference for more sustainable modes such as biking and public transportation. Additionally, data collection presented challenges and limitations, such as uncertainties regarding the data used to determine the predicted mobility budgets (Table 13) and that from Whooz (2023).

All in all, there are many influential factors and uncertainties inherent to making predictions. Thus, it remains to be seen if the predicted modal split aligns with the actual modal split when Merwede is fully functional and inhabited. It will then also be revealed whether the available transportation services are sufficient or if they need to be adapted. Gaining a better understanding about the needs and preferences of Merwede residents in practice may provide insights into the mobility needs of other future inhabitants of car-free neighbourhoods in general.

### 7.1.2. Carsharing Price Elasticity Determination

In Section 6.1 – which aimed to answer the third sub-question – Table 19 of this thesis presents a picture of carsharing price elasticity across different income groups. The values – all smaller than one module – indicate a general inelasticity of carsharing services for users in the Netherlands, suggesting Dutch users' demand for carsharing is relatively unresponsive to price changes. This is in line with studies conducted by Cartenì et al (2016), Kim et al. (2017), and Duan et al. (2020). This finding suggests that Dutch users' carsharing habits are not significantly influenced by price fluctuations. This observations aligns with a broader pattern observed in private car usage where – despite rising fuel costs – there is typically no corresponding decrease in driving. This inelasticity in carsharing may be due to various factors, including the high value placed on mobility, the lack of alternative transportation options that meet user needs for convenience and flexibility, or the perception of carsharing as a premium service. Further research into cultural attitudes towards shared mobility, urban planning that affects transport options, and individual mobility requirements could clarify the underlying reasons for this inelastic response.

Contradictory to the findings of this thesis, Litman (2022) found that carsharing does exhibit elasticity, largely due to the influence of fixed costs. Notably, in this thesis the high-income group demonstrates the lowest elasticity (-0.13), which may indicate that carsharing services are predominantly used by individuals who can afford them without significant sensitivity to price fluctuations. This pattern suggests a potential self-selection bias, where only those who are not constrained by the budget are currently using the services, thereby possibly skewing the data. This raises the question of whether carsharing would appear more elastic if it were more affordable to the low- and middle-low-income groups, who are underrepresented among carsharing users. Thus, future research should ensure that elasticities are calculated across the entire population and not solely the user segments that already use carsharing services. Changes in the estimated price elasticities could bear different implications for carsharing adoption rates (i.e., carsharing modal split).

Several limitations influenced the price elasticity determination. A thorough exploration of databases and expert consultations was conducted, yet the literature on this topic remains scarce. The challenge here lies in the specificity of elasticity. Specifically, it is contingent on the price point at the time of the research. Moreover, besides distinguishing between point- and arc-elasticity, a distinction suggested by Planbureau voor de Leefomgeving (2010) is long-term versus short-term elasticity. Additionally, as mentioned, a study by Vasudevan et al. (2021) conducted in India was used to infer the relative differences in price elasticity between income groups. While using data from a different country may seem less than ideal, the underlying economic principles – limited money and time impacting mobility choices – remain consistent, allowing for some degree of transferability (principle 8). This assumption is supported by Litman (2022) who states that the general relationships that influence travel demands tend to be durable and therefore transferable.

### 7.1.3. Cost-benefit Analysis

The CBA conducted in this thesis and reported in Section 6.4 aims to answer the fourth sub-question and provides a systematic evaluation of the environmental and economic implications of (subsidising) carsharing services in Merwede. Table 23 reveals that in both instances of moderate (modal split 3.8 percent) and high (modal split 7.5 percent) carsharing adoption in Merwede, the two scenarios in which a 100-euro monthly subsidy – for low- and middle-low-income residents – is introduced (S1-3 and S2-3) result in the highest total NPVs. Moreover, Table 27 substantiates the fact that these subsidies would indeed increase the number of carsharing users in the groups of interest – namely, low- and middle-low-income groups – whereby increasing transportation equity.

To gain more insight into the results, the average yearly and monthly prices of owning a private car as opposed to the cost of carsharing per resident, were compared. In this thesis, it was assumed that carsharing users travel less than 7,500 kilometres per year whilst private car users travel approximately 10,000 kilometres per year (Over Morgen, 2021); therefore, a correction is applied to account for this. The details of this calculation are expanded upon in Appendix E. The monthly expenses for private car ownership (with parking in Merwede), private car ownership (with distant parking), and carsharing usage are as follows, respectively: 920.83, 770.83, and 305.59 euros. Thus, the cost of carsharing is significantly cheaper than private car ownership – and parking both in and distant from Merwede – at approximately half the monthly price. This indicates that in Merwede, carsharing services are far more attractive than private car ownership in monetary terms. However, the roles of convenience, comfort, and privacy – typically higher with private cars – should not be understated.

The CBA model utilised for Merwede, which is available in an adaptive Excel format, provides a practical tool for policymakers. However, it simplifies some realities of carsharing services, such as not accounting for simultaneous use and the unavailability of vehicles or the varying number of residents with driver's licenses. These factors, alongside the involvement of multiple competing CSOs, necessitate careful interpretation of the results, as they may not fully reflect the complexity of Merwede's mobility system. Additionally, while carsharing subsidies are considered a municipal expense, they fall under the responsibility of Merwede Mobiliteitsbedrijf. Moreover, while the direct effect of the carsharing subsidy on transportation equity is recognised, capturing the full spectrum of societal benefits remains challenging. The omission of specific environmental and societal benefits in the CBA – such as savings from reduced public parking space (construction and maintenance) requirements and public health benefits due to lower emissions – suggests that the true value of carsharing to society may extend beyond the monetary figures presented. Furthermore, accurately assessing the subsidy's potential to enhance CSOs' efficiency or to contribute to safety improvements from less private car usage necessitates careful evaluation. These additional benefits – along with the variability introduced by factors like weather, and holidays – influence the exact outcomes of the CBA.

Regarding the (change in) consumer surplus described in Section 5.1.2.2 and reported in Section 6.4.2, an atypical approach – tailored to the present investigation – is applied. Typically, consumer surplus is captured using utility equations (Vasconcelos et al., 2017). However, in this thesis, general relationships between supply (i.e., service price) and demand (i.e., number of carsharing trips) are enforced to estimate the consumer surplus according to, *Equation 6*. Thus, it should be noted that applying a different approach to determine the consumer surplus, may yield different values. Moreover, the calculated consumer surplus only considers the change in consumer surplus resulting from the subsidy, not the added value or utility from using carsharing in general as this specific data was not available.

The sensitivity analysis – reported in Section 6.4.3 – highlights the significant impact of pricing strategies on carsharing services. It revealed that out of the service pricing components, kilometre pricing (*Pkm*) most profoundly affects the NPV, suggesting that even small adjustments in per-kilometre costs could markedly influence stakeholders' outcomes. While time pricing (*Pt*) and subscription pricing (*Psub*) also affect NPV, they do so to a lesser degree. It should be noted, that the high sensitivity to *Pkm* and *Pt* – as opposed to *Psub* – is likely due to the fact that these inputs are multiplied with the yearly number of kilometres and hours driven, resulting in large changes in the overall NPV – especially that of CSOs whilst the NPV for the users does not change as much since the benefits outweigh the costs by a lot (thus, resulting in relatively little change in the NPV of users). Regarding parking, a reduction in spots for private vehicles significantly boosts the NPV and carsharing modal split, indicating a potential shift from private car usage to carsharing in response to (limited) parking availability. The least sensitivity was noted in price elasticity changes, with the inelastic demand affirming the limited effect of subsidies on user behaviour within the examined income groups. Overall, from the sensitivity analysis, stability of decision outcomes among NPV fluctuations is observed. Notably, negative total NPVs are only observed for scenarios in which carsharing modal split is 3.9% or lower (S1-1 and S1-2). Whilst variations in NPV values indicate the extent to which each factor can influence the financial outcomes, the overarching conclusion remains unaffected for the remaining scenarios (S1-3, S2-1, S2-2, and S2-3): carsharing subsidies for lower-income residents are favourable. This overall stability in decision outcomes highlights the resilience of the CBA model under the tested scenarios and affirms the utility of the subsidies in fostering equitable mobility services in Merwede.

In sum, the CBA outcomes suggest income-group-specific subsidies could serve as an effective instrument to stimulate equitable carsharing in Merwede. This may seem counterintuitive given the estimated inelasticity of carsharing across income groups. However, subsidies targeted at lower-income groups can alleviate affordability barriers, thereby giving a wider segment of the population access to carsharing services. Such financial support addresses economic disparities directly – rather than relying on price sensitivity – ensuring that the benefits of carsharing can be more widely distributed among all socioeconomic groups. The implementation of a targeted subsidy allows for a pricing strategy that is beneficial for all stakeholders included in the analysis. Specifically, CSOs, carsharing users, and the Municipality of Utrecht. Nonetheless, careful consideration must also be given to the dynamic nature of carsharing and the necessity for continuous adaptation to evolving urban needs and trends. In this thesis, Merwede provides a case study environment from which future car-free neighbourhoods aiming to utilise carsharing as a sustainable alternative to private car ownership may learn. Especially pertaining to pricing strategies for these mobility services that align with the needs and preferences of all potential (future) users.

## 7.2. Reflection on the Methodology

Reflecting on the methodologies employed in this thesis provides valuable insights into the robustness of the findings and areas for potential refinement. This section discusses the various methodological approaches taken across different stages of this research and acknowledges their strengths and limitations.

### 7.2.1. Literature Research

The literature research process was largely successful, albeit constrained by the relatively novel nature of both car-free neighbourhoods and carsharing adoption. This thesis required the synthesis of a proposed theoretical framework for carsharing adoption due to the lack of existing models. For policy identification, the process could benefit from a more structured or robust methodology in the future, including a comprehensive survey of existing policies and interventions that promote carsharing. Moreover, this thesis may have benefited from investigating one or multiple existing (car-free) neighbourhoods where carsharing is already enforced, to better understand how pricing impacts adoption and usage rates among different income groups. However, such data was not readily available or accessible, presenting a significant constraint.

### 7.2.2. Data Analysis

The predicted socio-economic characteristics of the future Merwede residents are based on estimations made by Arcadis | Over Morgen and depend on the expected purchase and rental prices of residences in Merwede. This may be subject to change if the housing market fluctuates unexpectedly or if for example residences sell unexpectedly less or more, sale prices may be lowered or increase. This in turn affects the socio-economic landscape and, by extension, transportation preferences – i.e., the modal split. Furthermore, whilst Whooz (2023) data provided mobility data based on household income specific to Utrecht, it still provided information limited to the following modalities: private car, biking, and public transportation (train, tram, bus, metro). This data was then used to infer a modal split for carsharing, and taxi based on the number of available parking spots for each. In the future, the effects of other modalities – such as (shared) scooters – should also be considered.

### 7.2.3. Carsharing Price Elasticity Determination

A more common manner of determining carsharing price elasticity would be to use stated-preference or revealed-preferences methodologies such as surveys. However, due to time and budget constraints the former was not possible; and because Merwede is currently still being developed the latter was not possible either. Moreover, to achieve a more accurate representation of price elasticity for carsharing, obtaining historical data from CSOs would be beneficial. However, CSOs are reluctant to provide such data due to their own business interests. This resistance presents a significant obstacle to research and leaves a gap in the understanding of carsharing price elasticity among different income groups, which may be critical for designing equitable transportation policies. Furthermore, several institutions and researchers were contacted, but there was limited data about user responses to price changes in carsharing in the Netherlands, let alone such data with differences between income groups. As a result, a more nuanced approach was employed using literature and basic guiding principles (Table 6) to substantiate the estimated carsharing price elasticities per income group.

### 7.2.4. Market Research

Market research began with identifying current CSOs in Utrecht (Table 2), followed by an examination of their service prices by consulting their websites and applications. This provided foundational pricing data for the CBA. However, this method did not account for potential future changes in the market that could influence carsharing adoption.

### 7.2.5. Policy Selection & Additional Interventions

To address the issue of equitable access to carsharing services, several policy alternatives are discussed. In Section 4.4, the choice for focussing on a user group-targeted quantifiable policy (i.e., P7 – subsidies, vouchers, discounts, or trip credit incentives) in the CBA is substantiated. Apart from the policies identified from literature in Section 3.6 and summarised in Table 15, some interventions were omitted from the present thesis. These interventions – also aiming to stimulate carsharing adoption whilst accounting for transportation equity – were not identified using literature but rather emerged conceptually throughout the research process. Primarily due to time constraints, these interventions were not included in the present analysis. However, they should still be mentioned.

Firstly, rather than stimulating equitable carsharing, an intervention could be to provide subsidies for public transportation rather than carsharing for lower-income residents. This may be more favourable as cities and municipalities have a better understanding for these types of policies – such as for example the 'studentenreisproduct' briefly mentioned in Section 4.4. Moreover, this type of intervention may be even more equitable than carsharing subsidies as no driver's license is required to partake in public transportation. Yet, one could still argue that the degree to which the user is free in terms of geographic and temporal mobility is more limited as public transportation has fixed routes and schedules. Secondly, a possible intervention to reduce the service price of carsharing is the use of second- and/or third-hand cars by CSOs. This would lower the purchasing costs of vehicles and as opposed to leasing is a one-time expenditure rather than a recurring cost. Thus, as CSOs would have lower investment costs, the service price for carsharing could be reduced. However, a life-cycle analysis would be required to determine whether the operational costs for second- and/or third-hand cars would be lower as well as these may require more maintenance and repairs throughout their remaining lifetime. In other words, until further analyses are conducted, it remains uncertain if this intervention would actually be more sustainable and cost-effective in the long run. Notably, for the monthly vehicle leasing costs ($L$) included in the current CBA (elaborated on in Appendix C), a rough assumption is made that the CSO owns half (125 cars) of their fleet and that they get a bulk leasing discount. This results in an average vehicle leasing cost of 175 euros per vehicle per month.

Thirdly, another possible intervention to reduce the service price of carsharing is integrating advertising into carsharing operations, which would offer a new channel for revenue generation for CSOs. Vehicles could be wrapped with advertisements, transforming them into mobile billboards that generate income. Furthermore, digital screens inside the cars could display ads, offering advertisers targeted outreach opportunities. This not only provides a constant revenue stream that can help offset the costs of carsharing operations but also keeps user fees more affordable. The key would be to balance the commercial aspect with user experience, ensuring that advertisements enhance rather than detract from the service provided. Fourthly, as discussed in Section 3.4 a possible intervention that could make the business case of carsharing services more attractive, is dynamic pricing, which could optimise carsharing operations by adjusting prices in real-time based on user demand. This allows CSOs to maximise fleet utilisation and increase revenue during typically slower periods. For example, lower rates could be offered during off-peak hours to encourage usage, while peak times could demand a premium. However, as reported in the aforementioned section, dynamic pricing methods add an additional level of complexity and could also lead to congestion and service reduction. This illustrates the trade-off between profit-maximising motives and system efficiency.

Lastly, developing partnerships with local businesses presents a strategic intervention to increase the attractiveness of carsharing services by fostering a mutual customer base. For example, CSOs could offer discount vouchers for local shops, or businesses could provide promotional rates to carsharing users, which could lead to increased usage rates for carsharing, driving down operational costs due to economies of scale whilst promoting community engagement. A community-centred approach would not only enhance the value of carsharing but also embed the service within the local socio-economic landscape.

### 7.2.6. Cost-benefit Analysis

As mentioned in Section 2.6, several analytical methodologies were considered to identify and assess appropriate carsharing pricing strategies, these included: econometric modelling, competitive analysis, surveys, and multi-criteria analysis. In the end, the CBA methodology was selected for its comprehensive nature, which considers economic viability alongside social welfare. The choice of CBA reflects the necessity to evaluate pricing strategies within the specific context of a car-free urban neighbourhood like Merwede. Yet, this approach does have its limitations. It is influenced by the accuracy of the data and assumptions made, suggesting that future CBAs could integrate a broader range of data sources and analytical perspectives to enhance their precision and reliability. As noted by Seerden (2022) – while the CBA is rigorous – it is important to acknowledge its inherent limitations and uncertainty of its outcomes. Intangible effects – such as the reduced public parking space (construction and maintenance) requirements and public health benefits due to lower emissions – and those beyond immediate welfare impacts often remain unaccounted for due to their complex nature. Moreover, the reliance on estimations and projections into the future introduces a layer of uncertainty; assumptions are necessary yet are inherently speculative. Standard numbers and rules of thumb are often employed as a practical means to quantify effects, which may not fully capture the specific nuances of the project in question. Consequently, effects that are more challenging to quantify or monetise may not be represented as strongly in CBA reports, highlighting the need for continuous refinement in evaluative methodologies. Thus, future research may consider employing another method to analyse pricing strategies and policies, as it may be interesting to compare the outcomes of various approaches.

## 7.3. Generalisability

In the case of Merwede, it is demonstrated by means of the CBA (Section 6.4.1), that a subsidy for carsharing services of 100 euros per month per lower-income resident results in benefits for both CSOs and carsharing users. Notably, a smaller but still positive NPV is noted for the Municipality of Utrecht, indicating that the subsidy policy is also favourable for society at large due to its environmental benefits. Moreover, it is illustrated that transportation equity is improved as lower-income residents are expected to use carsharing services in scenarios with the carsharing subsidy (Section 6.4.2). However, more research regarding carsharing pricing and policies in different car-free environments is required before findings can be generalised.

The value in this thesis lies within its specificity, it is focussed on carsharing pricing strategies in a specific car-free neighbourhood, differentiating between income groups. However, whilst its specificity may be a strength as this is a relatively novel research topic, it also presents its drawbacks – particularly in relation to the generalisability of the findings. Consequently, this thesis acknowledges the limitations inherent in its context-specific analysis. While the findings provide valuable insights for the Netherlands – particularly for Merwede – the applicability of these results to other neighbourhoods, cities, or countries with different socio-economic dynamics, transportation systems, and sizes, may be constrained. Nonetheless, this thesis contributes to the field of transport, infrastructure, and logistics by offering an empirically validated CBA model – responsive to different service pricing (and subsidy) levels. This model not only assesses economic factors but also integrates environmental implications of carsharing, making it a relevant and adaptable tool for policymakers.

# 8. Conclusion

In this chapter, the findings from the present thesis are concluded. To summarise the key takeaways, the highlights are presented first, these can be categorised in terms of general and case-study-specific findings (see Table 29). These findings are more thoroughly expanded upon in the remainder of this chapter.

**Table 29.** Key findings from this thesis.

| **General Findings** |
|---|
| • Determinants of carsharing adoption include personal, temporal, spatial, political, economic, and service factors. |
| • Policies and interventions that stimulate or reinforce carsharing adoption are plentiful and have different targets. |
| • A general inelasticity to carsharing is estimated across income groups in the Netherlands, with higher sensitivity to price changes in lower-income groups. |
| • Which pricing strategy is most favourable for carsharing depends on the (predicted) carsharing modal split. |
| **Case Study Findings** |
| • At the time of this research, the average kilometre price, hourly price, and monthly subscription price of carsharing services in Utrecht, is reported to respectively be 0.29, 3.23, and 12.78 euros. |
| • Cost-benefit analysis results suggest that carsharing is a financially and environmentally beneficial form of shared mobility to implement in Merwede. |
| • High parking fees are used to keep car ownership down within Merwede. |
| • There is inequality in how residents are affected by the high parking fees in Merwede. |
| • Income-group-specific subsidies provide a tool to achieve equitable access to carsharing services within Merwede. |
| • Profitability is realised for carsharing service operators in Merwede between a carsharing modal split of 3.9% and 4.0%, corresponding to circa 293,026 and 302,235 annual trips, respectively. |
| • The yearly total costs of a 100-euro monthly subsidy per lower-income resident – aimed at achieving transportation equity in Merwede – would be approximately:<br>o 617,489.43 euros with a high modal split of 8.0% (circa 604,445 annual trips).<br>o 309,744.72 euros with a low modal split of 4.0% (circa 302,235 annual trips). |

Below, first a more generalisable overarching conclusion is presented, which aims to answer the main research question. This is followed by some suggestions for future research. Lastly, recommendations specific to the case study are provided.

## 8.1. General Conclusion

This thesis has critically examined the potential implementation of equitable pricing strategies for B2C carsharing services utilising a case study set in the car-free neighbourhood of Merwede. It aimed to investigate how these strategies could be aligned with the diverse needs and preferences of potential users. Through an exploration encompassing comprehensive literature research, a data analysis, market research, and a CBA, this thesis sought to answer four sub-questions.

Firstly, it was deduced that the factors influencing the adoption of carsharing are multifaceted. An extensive proposed theoretical framework (Figure 6) – containing the most prevalent carsharing adoption determinants from literature – was synthesised. Of these determinants, socio-economic characteristics, parking convenience, and service pricing are brought to the forefront in this thesis. However, it is noted that actual carsharing adoption is complex and influenced by additional variables and biases such as residential self-selection.

Secondly, the crucial role of municipal and national policies on carsharing services is deduced. Strategic policy interventions are imperative in stimulating carsharing adoption and fostering a shift towards sustainable mobility. Several policies that stimulate carsharing are discussed and reported in Section 3.6 and summarised in Table 15. Moreover, additional interventions that may make the business case for carsharing more appealing, are reported in Section 7.2.5. In the case of Merwede, specific policies such as monthly subsidies – i.e., trip credit incentives – for low- and middle-low-income groups were identified as a possibly promising tools to stimulate carsharing adoption and allow for equitable access to carsharing services.

Thirdly, the price elasticity estimation (Section 6.1) revealed that – whilst there are differences between income groups – demand for carsharing is generally inelastic in the Netherlands, with users' decisions being relatively unresponsive to price changes. However, this finding is constrained by potential self-selection bias which may skew the data, since it is likely that only those not constrained by their mobility budgets – i.e., middle-high- and high-income groups – use carsharing services.

Lastly, it can be concluded that a monthly subsidy of 100 euros per month per low- and middle-low-income carsharing user for residents of Merwede presents a compelling case. Despite associated costs, the CBA results highlight the subsidies' role in fostering carsharing adoption amongst those with lower incomes, whereby increasing transportation equity and yielding a positive NPV for all stakeholders involved. Specifically, CSOs generate increased revenue, (potential) carsharing users benefit from affordable access to carsharing services, and the Municipality of Utrecht benefits from the environmental gains of carsharing as opposed to private car use as well as the (unquantified) benefits of increased transportation equity.

In sum, this thesis highlights the interplay between carsharing user needs and preferences, pricing strategies, and policy interventions in car-free neighbourhoods. Moreover, the transformative potential of carsharing as an alternative (shared) mobility solution as well as car-free neighbourhoods as a space-efficient manner of urban planning, are brought to the forefront. Throughout this thesis, it becomes evident that identifying pricing strategies that align with the diverse needs, preference, and capabilities of (potential) carsharing users, requires a case-specific approach. Which pricing strategies are feasible relies on the economy, available market prices, and pricing schemes of CSOs. Yet, tailored policies and interventions must accommodate income disparities to ensure inclusivity and equitable access. Moreover, continued adaptability to urban dynamics, mobility needs, stakeholder engagement, and policy responsiveness are essential to align carsharing services with the evolving needs of the community. Merwede presents an invaluable case study that, through careful consideration and strategic planning, could set a precedent for carsharing service pricing in car-free neighbourhoods globally. In the subsequent section, recommendations for future research are discussed.

## 8.2. Future Research

Several key considerations for future research have been highlighted. Many of these considerations are incorporated in the discussion in Chapter 7. Specifically: the need to investigate the implications of other policies and interventions that affect carsharing adoption; the benefit of using stated-preference surveys and revealed-preference (e.g., using historical data from CSOs) to better predict the price elasticity for carsharing per income group; the effect of modalities not included in the present thesis such as (shared) scooters; and fluctuations in the carsharing market that may influence service prices. Besides these points, there are a few additional considerations for future research.

Firstly, the scope of this thesis was limited to B2C carsharing models and thus did not explore the impacts of other carsharing types such as P2P – which could significantly contribute to the diversity of shared mobility offerings. Considering the evolving business models in shared mobility, future research should explore how different carsharing types – including B2C, B2B, P2P, and shared scooters – integrate and compete in car-free urban environments. Secondly, the modal split predictions made in this thesis should be validated in the future. Also, understanding the activity-end of mobility – such as trip purpose – is imperative for accurate mode-choice modelling. Thus, the influence of trip purpose on mode choice should be integrated into modal split estimations. Thirdly, this thesis assumes that electric carsharing vehicles do not produce any emissions. Additionally, carsharing vehicles endure more frequent use and consequently more wear-and-tear than private vehicles. As a result, they often require more frequent maintenance and replacements. In other words, the production and maintenance processes of these vehicles result in emissions. Therefore, future research may consider these emissions by considering the wheel-to-wheel emissions and applying a life-cycle assessment approach as suggested by Curtale & Liao (2023). Fourthly, the duration and extent of subsidies for specific carsharing user groups deserve attention. Investigating a transition model that examines the longevity and timeline of carsharing subsidies could offer insights into the sustainable promotion of shared mobility. Lastly, some other interventions to reduce the service costs of carsharing were briefly mentioned in Section 7.2.5. These additional interventions include – but are not limited to – carsharing service operators using second-hand cars in their fleet, generating ad revenue, implementing dynamic pricing strategies, or forming strategic business partnerships. Future research should delve deeper into the effectiveness and feasibility of these interventions as they may make the business case for carsharing in car-free contexts more appealing. In the next section, recommendations specific to the case study in this thesis are provided.

## 8.3. Recommendations for Merwede

This section discusses recommendations specific to the case study conducted in this thesis. It begins with recommendations regarding the carsharing market research, followed by a recommended pricing strategy. Lastly, some specific recommendations are provided.

### 8.3.1. Market Research

Regarding the carsharing market research reported in Section 6.3 and Table 21, the average values reported for the price of carsharing per kilometre (*Pkm*), the hourly price (*Pt*), and the monthly subscription price (*Psub*) are 0.29 euros, 3.23 euros, and 12.78 euros, respectively. Furthermore, across CSOs, service prices were relatively similar (Table 21), reflecting the competitive nature of the carsharing industry. However, the concern arises that the costs of carsharing may still pose a significant burden for low- and middle-low-income residents, potentially worsening transportation inequity within Merwede. The challenge for – among others – the Municipality of Utrecht lies in devising a pricing strategy that not only maintains carsharing's viability as a service but also ensures its accessibility to those with constrained mobility budgets. Given the findings from this thesis and the present market research, several points warrant further examination. Firstly, the potential volatility of the carsharing service industry and the robustness of current pricing models in response to economic fluctuations. Second, the practical considerations and effectiveness of municipal subsidies in addressing the carsharing affordability gap for lower-income residents and in fostering more equitable mobility. Lastly, the impact of these pricing strategies on the broader goal of reducing private car dependency. Perhaps future research could delve deeper into these points to gain a better understanding of the dynamics of carsharing service pricing.

### 8.3.2. Pricing Strategy Recommendation

The CBA conducted to assess the costs and benefits of a pricing subsidy policy in Merwede considers the characteristics of Merwede – socio-economic composition, low parking norm, and car-free nature – as well as market prices for B2C carsharing service operators in Utrecht. The analysis shows the largest positive total NPVs in instances where a subsidy of 100 euros for carsharing services for low- and middle-low-income users is introduced (S1-3 and S2-3). Moreover, the results show that this subsidy would ensure social inclusion and higher adoption rates of carsharing services in Merwede. Therefore, introducing such a subsidy seems to be favourable for all stakeholders involved. Table 30 provides an overview of the suggested policy in numbers for both scenarios S1-3 – assuming a carsharing modal split of 7.5% – and S2-3 – assuming a carsharing modal split of 3.8%.

**Table 30.** Overview of values relevant for the suggested policy.

| Constants | | |
|---|---|---|
| *Psub* (carsharing subscription pricing) | €12.78 per month | |
| *Pt* (carsharing hourly pricing) | €3.23 per hour | |
| *Pkm* (carsharing kilometre pricing) | €0.29 per kilometre | |
| *D* (days of use of carsharing vehicles, from operator's perspective) | 180 days per year | |
| **S1-3 and S2-3** | | |
| | **S1-3** | **S2-3** |
| Assumed modal split of carsharing | 3.8% | 7.5% |
| Distance travelled per carsharing vehicle per day | 49.68 km | 99.36 km |
| Usage time per carsharing vehicle per day | 1.26 hours | 2.52 hours |
| Number of carsharing trips per user per month | 41.7 trips | 41.7 trips |
| Subsidy costs | €309,744.72 | €617,489.43 |
| Total NPV | €30,663,205.95 | €32,505,924.35 |

### 8.3.3. Specific Recommendations

Specific recommendations have been formulated to fortify the potential of carsharing in Merwede and align the service with the needs of all residents.

1. *Implementing Carsharing Subsidy Policy*
   - An in-depth implementation timeline of carsharing subsidies for low- and middle-low-income residents should be developed once the area development of Merwede is in a more advanced stage and more is certain about the future residents and their mobility needs.
   - The form in which the subsidy is introduced should also be investigated in more depth as there may be more logical transactions than those included now. For example, rather than asking users to pay a subscription fee and providing lower-income residents with a subsidy, perhaps the subscription cost for carsharing could be set at zero for lower-income residents whilst they receive the difference of the subscription cost and subsidy (roughly 87 euros) in the form of a trip credit incentive.

2. *Addressing Price Elasticity and Carsharing Adoption Uncertainties*
   - To address price elasticity uncertainty, it is advised to monitor the relationship between pricing and demand for carsharing – particularly among low- and middle-low-income residents – and the available literature regarding this topic in the Netherlands.
   - To address service adoption uncertainty, it is recommended to conduct an interim review after a defined period to revisit the assumptions, refine scenarios with new data, and update strategies. This ongoing assessment will ensure the CBA model adapts to real-world changes and continues to offer relevant insights.

3. *Specific for the Decision-Maker (Merwede Mobiliteitsbedrijf)*
   - A portion of Merwede Mobiliteitsbedrijf's budget should be allocated to ensuring transportation equity, especially pertaining to carsharing services by providing subsidies (i.e., credit incentives) to low- and middle-low-income residents.
   - To enhance carsharing service uptake, early and clear communication with residents about available shared mobility options should be prioritised as establishing awareness from the beginning is crucial for fostering service adoption.
   - It is essential to implement measures to address potential user concerns such as trust issues, coordination problems, and the need for support during malfunctions. These measures could include creating a robust user rating and feedback system and encouraging community engagement through social networking tools. As the overseeing entity, Merwede Mobiliteitsbedrijf should monitor these measures to guide necessary adjustments to maintain the appeal and effectiveness of carsharing services in Merwede.

These recommendations are designed to stimulate carsharing in Merwede, enhancing service accessibility and aligning with residents' needs and preferences. Strategic communication, vigilant monitoring, and user-focused improvements will be essential. Through these recommendations, policymakers can stimulate a sustainable and equitable mobility system that aligns with Merwede's vision of social inclusivity and car-free nature.

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# Appendix

## Appendix A – Scientific Article

# Setting the Price for Carsharing

## *A Cost-Benefit Analysis of Equitable Carsharing in the Car-free Neighbourhood of Merwede*

L. E. Lucasius

***Abstract*** – Private cars are inefficient in terms of land allocation. Car-free neighbourhoods offer a solution to this inefficiency by enforcing less car-centric urban design, expensive parking fees, and prioritising more sustainable and space-efficient modes of transportation. Carsharing services emerge as an alternative to private car ownership by providing vehicles available for short-term use. Notably, not much is known regarding carsharing services as an alternative mobility solution in car-free neighbourhoods. The present study investigates pricing strategies that could be implemented for business-to-consumer carsharing services in car-free residential neighbourhoods to align with the diverse needs and preferences of potential users. To this end, the study employs a case study of the car-free neighbourhood Merwede. Specifically, a cost-benefit analysis is conducted to estimate the potential value of carsharing in a car-free context. Emphasis is put on policies that may stimulate carsharing adoption and on determining equitable service pricing strategies. To predict the modal split of future Merwede residents, datasets – containing mobility information for Utrecht residents clustered by income group – are used. To determine the influence of a service price change on carsharing demand, per-income-group price elasticities are estimated. This resulted in the following values for low-, middle-low-, middle-high-, and high-income groups, respectively: -0.8, -0.5, 0.4, and -0.1. Three stakeholders are considered in the analysis: carsharing service operators, users, and the Municipality of Utrecht. Results indicate that subsidies for lower-income residents in the form of a trip credit incentive (of 50 or 100 euros per month per user) yield positive total net present values and higher carsharing adoption rates. This study concludes by stating that while the generalisability of these findings may be limited, the CBA model synthesised for Merwede provides a case study from which future car-free neighbourhoods – aiming to implement carsharing – may learn.

**Keywords** – Car-Free Neighbourhoods, Carsharing, Pricing Strategies, Subsidy, Transportation Equity, Cost-Benefit Analysis, Merwede

## 1 Introduction

Globally, current population and urban growth requires the densification of residential areas and amenities within city boundaries (Angel et al., 2011). This intensified urbanisation requires efficient land utilisation, a challenge that is complicated in numerous urban centres due to the extensive footprint of private cars. These vehicles occupy significant space – in terms of both infrastructure and parking areas – hindering efficient land allocation.

To ensure more efficient land allocation, urban mobility is undergoing a transition towards sustainable and shared transportation solutions. In line with this, carsharing has emerged as a promising alternative to traditional car ownership. Based on the number of carsharing users that sell their private car or do not acquire one, it has been estimated that one carsharing vehicle replaces approximately fourteen private cars and thus saves 300 square metres of space (Goudappel, 2023). Apart from the spatial savings, carsharing is also more accessible to all income groups as this service is less expensive than buying a car. Therefore, carsharing stimulates social inclusion and combats transportation poverty by encouraging transportation equity (Hönnige, 2022) – which refers to the fair and moral allocation of mobility benefits and costs across society, considering both social groups and geographic areas (Bruzzone et al., 2023).

In accordance with peak car theory (Stolk, 2022) – which states that the distance travelled by car per capita has peaked and will now decline in a sustained manner – and less car-centric urban development, car-reduced and car-free neighbourhoods have emerged as trends in urban planning (Ortegon-Sanchez et al., 2017). Like carsharing, these car-reduced and car-free areas align with sustainability goals as they result in more efficient and green spatial allocation. In these areas – where residents have a reduced private vehicle-dependence – there is an opportunity for carsharing to flourish.

In the Netherlands, an example of a car-free mixed-use residential neighbourhood currently being developed is Merwede. The neighbourhood strives to stimulate the use of shared modes of transportation such as public transportation and the use of carsharing for those occupying its 6,000 residences. This makes the car-free neighbourhood a model for the integration of sustainable urban planning and carsharing solutions.

### 1.1 Problem Statement

From analysing literature regarding carsharing, it becomes clear that there is a notable knowledge gap in the relatively novel field of carsharing in car-free environments. Specifically, not much is known regarding pricing strategies for carsharing services that cater to residents of car-free neighbourhoods. Particularly pertaining to carsharing pricing strategies that ensure these services are available to (i.e., affordable for) all socio-economic groups of the neighbourhood.

Addressing the complexities of carsharing pricing within car-free neighbourhoods may yield valuable insights into how to foster more equitable transportation systems. Examining carsharing service pricing in a real-world context would shed light on how to balance economic viability and social inclusivity – critical components of sustainable urban living (Svennevik et al., 2021). Furthermore, a specific challenge the Municipality of Utrecht is faced with as it pertains to Merwede, is that due to the expensive and scarce parking options, lower-income residents who are currently often reliant on private cars, need cost-effective mobility solutions such as carsharing. However, it is likely that the regular dependence on this service will also be too expensive for lower-income groups in Merwede. This sets the stage for an interesting case study as it relates to pricing strategies and policy interventions that can be implemented for carsharing to ensure equitable carsharing in car-free neighbourhoods.

In conclusion, it is recognised that the challenge in Merwede extends beyond simply encouraging residents to choose carsharing over private vehicle ownership. A particularly pressing issue is to guarantee affordable access to carsharing services for the low- and middle-low-income groups. These residents – who depend on private vehicles for essential daily activities – are confronted with prohibitive parking expenses near their homes. Subsidising carsharing for low- and middle-low-income residents aligns with Merwede's objectives of maintaining low car ownership rates while ensuring that mobility remains inclusive, allowing residents of all income levels fair access to transportation without the burden of excessive parking costs.

## 1.2 Research Objectives

An overarching objective of this study is to investigate pricing strategies that could be implemented for business-to-consumer carsharing services in car-free residential neighbourhoods to align with the diverse needs and preferences of potential users. To this end, this study has the following objectives, namely to: i) identify factors that influence the adoption of carsharing; ii) report municipal and national governmental policies and interventions that can support carsharing services within and beyond car-free residential neighbourhoods; iii) determine the effect of a service price change on the demand for carsharing services per income group in the Netherlands; and iv) determine the costs and benefits of subsidising carsharing services for low- and middle-low-income residents of Merwede.

## 1.3 Scope

The scope of this study is as follows. Carsharing in this study is defined as the practice of sharing a car or using carsharing services for regular travelling, especially for commuting. Moreover, the focus in this study is on B2C carsharing because it is the most inclusive option and has demonstrated effectiveness in fulfilling various policy objectives while alleviating urban space constraints (Habekotté, 2021). This focus is further reinforced by the substantial market size of B2C carsharing and the decision-making challenges it presents, including critical considerations around pricing strategies (Golalikhani et al., 2021). As a result of the selection criteria, the CSOs included in the case study are A2B, Greenwheels, Hely, MyWheels, and OnzeAuto. Additionally, emphasis is put on round-trip station-based carsharing as Merwede has car-free streets within the neighbourhood and two main neighbourhood mobility hubs (i.e., stations). Additionally, significance is put on (mixed- use) residential neighbourhoods rather than full-fledged cities as these have a larger scale and more dynamic and unpredictable mobility patterns. Also, the focus is on electric vehicles (EVs) sharing rather than fuel-dependent carsharing as the former are the more sustainable alternative (Jorritsma et al., 2021).

Regarding the overarching case study, this was limited to certain stakeholders. The stakeholders involved in carsharing in Merwede and their responsibilities (see Figure 1) are as follows (Boshouwers et al., 2018; van den Hurk et al., 2021). Firstly, carsharing users are of interest, these are mainly future Merwede residents who will use or rely on the carsharing and other mobility services available in Merwede. Secondly, CSOs are of interest. Apart from providing the carsharing services, they are responsible for providing memberships/subscriptions and collecting service fees; as well as for operating digital platforms for their services and maintaining their fleet. Moreover, these operators must pay parking fees within Merwede for their carsharing vehicles. Thirdly, the Municipality of Utrecht is responsible for investing in public infrastructure, implementing mobility policies that support Merwede's mobility concept (i.e., parking policy), and ensuring equitable access to mobility services in Merwede for all residents. Aside from these three key stakeholders – for the sake of transparency – it is necessary to mention two other stakeholders who stand to benefit from this study. Namely, Arcadis | Over Morgen and Merwede Mobiliteitsbedrijf. Over Morgen is an engineering consultant specialised in sustainable urban development and mobility solutions that is involved in the Merwede neighbourhood. This entity oversees interests from real estate developers involved in Merwede as well as governments and municipalities. The entity holds a comprehensive responsibility to ensure efficient operation and ongoing enhancement of the mobility concept in Merwede. This includes quality management, traffic control, and the management of parking spaces and the mobility shop. Additionally, Merwede Mobiliteitsbedrijf is responsible for contracting CSOs, a function essential for the deployment of carsharing services within the neighbourhood. This entity also plays a pivotal role in delivering benefits to users – critical for ensuring the successful sale of residences in Merwede. These functions emphasise their significant role in coordinating partnerships with stakeholders such as landowners and the Municipality of Utrecht.

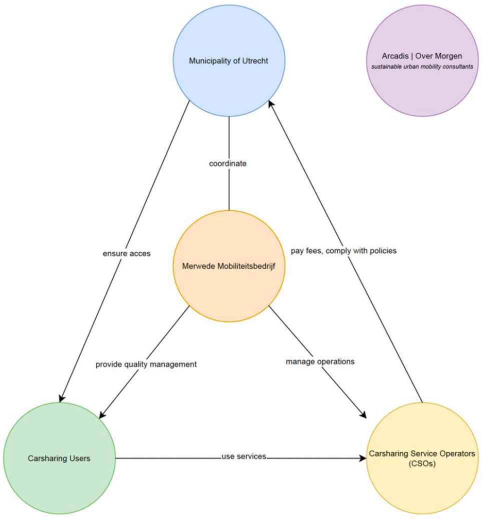


**Figure 1.** Stakeholders pertaining to carsharing in Merwede and their responsibilities.

Using literature, several policies stimulating carsharing adoption have been identified (see Table 1).

**Table 1.** Policies that stimulate carsharing adoption.

| | Description | Target |
|---|---|---|
| **P1** | Standardising policies across municipalities through regional cooperation and knowledge sharing (Habekotté, 2021) | Broad |
| **P2** | Elevating certain aspects of carsharing policymaking to a national level to provide external support, knowledge-sharing mechanisms, and standardisation (Habekotté, 2021) | Broad |
| **P3** | Congestion pricing and (off-)peak tolls (Pantuso, 2022; Zhang & Wang, 2023) | Broad |
| **P4** | Integration of carsharing with other sustainable mobility concepts such as mobility-as-a-service (MaaS), public transit, etc. (Jorritsma et al., 2015; Papu Carrone et al., 2020; Zhou et al., 2020) | Broad |
| **P5** | Incorporating carsharing into new developments (Zhou et al., 2020) | Broad |
| **P6** | Awareness campaigns (Zhou et al., 2020) | User group |
| **P7** | Subsidies, vouchers, discounts, or trip credit incentives (Zhou et al., 2020; Rotaris, 2021; Cantelmo et al., 2022) | User group |
| **P8** | Penalties to enforce responsible use of vehicles (Golalikhani et al., 2021) | User group |
| **P9** | Subsidies for carsharing businesses (Cohen & Kietzmann, 2014) | CSOs |
| **P10** | A VAT tax exemption for electric vehicles (Vasconcelos et al., 2017) | CSOs |
| **P11** | Subsidised or free parking spaces for carsharing vehicles (Jorritsma et al., 2015; Vasconcelos et al., 2017; Münzel, 2020; Papu Carrone et al., 2020; Rotaris, 2021) | Parking (carsharing vehicles) |
| **P12** | Reserved and easily accessible parking spaces (Jorritsma et al., 2015; Papu Carrone et al., 2020) | Parking (carsharing vehicles) |
| **P13** | Altering parking spaces and changing parking norms; e.g., a reduced number of parking spaces for private cars, and increased parking fees (Zhou et al., 2020) | Parking (private vehicles) |
| **P14** | Imposing more taxes on private vehicles (Habekotté, 2021) | Parking (private vehicles) |

For the present case study, P7 – i.e., subsidies, vouchers, discounts, or trip credit incentives – seems most effective as it is a user-group specific and quantifiable solution that aims to positively reinforce carsharing adoption and stimulate transportation equity (Martin & Shaheen, 2011b).

# 2 Methodology

The overarching methodology employed in this study is a case study of Merwede. The aim is to use the neighbourhood as a practical example to gain more insight into equitable pricing strategies for carsharing services in car-free residential neighbourhoods. Takeaways from the case study may offer insights valuable for future car-free neighbourhoods striving to integrate carsharing as a mobility solution.

## 2.1 Overview of Methodologies

Figure 2 maps out the methods used in this study, starting with a review of the literature on car-free neighbourhoods and carsharing. The next steps are understanding the factors that affect carsharing adoption, market research, price elasticity determination, and a data analysis of future residents' socio-economic characteristics and mobility preferences. These steps help determine the examined policies. Lastly, a cost-benefit analysis (CBA) is considered. In this, the costs are carefully considered against the benefits, with the aim being to ensure equitable access to carsharing services in Merwede.

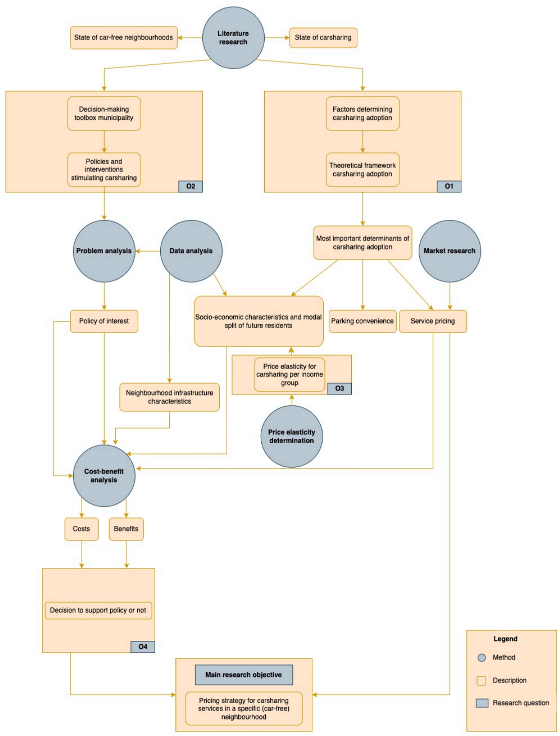


**Figure 2.** Flowchart of methodologies employed to determine a pricing strategy for carsharing services in a yet-to-be-populated residential neighbourhood.

Whilst other methodologies were supplementary, the focus of this study was primarily on developing a CBA capable of determining the costs and benefits of carsharing and carsharing service pricing and policy. Having defined a clear scope for this study, the CBA can be elaborated upon further.

## 2.2 CBA

The CBA methodology serves as a tool for the preliminary assessment of policy alternatives. This methodology quantifies the social welfare impacts of policies such as environmental concerns. By monetising these impacts, CBA aids in balanced decision-making between economic and social costs and benefits (Romijn & Renes, 2013). In addition to other literature research and case-specific considerations, the costs and benefits included in the CBA are based on a mathematical model by Vasconcelos et al. (2017), which is adapted and built upon. Vasconcelos et al. (2017) conducted a comprehensive evaluation of the environmental and financial impacts of alternative vehicle technologies and relocation strategies in station-based one- way carsharing.

### *2.2.1 Description*

This study assumes a steady state carsharing system, avoiding the complexities of growth dynamics to focus on a mature network. By doing so, it provides a clear picture of the costs and benefits under stable operational conditions, which is crucial for evaluating the long-term viability of carsharing within the neighbourhood of Merwede. The CBA model used in this study assumes a hypothetical station-based carsharing system in Merwede. Users can pick up a shared car at one of the two mobility hubs with available vehicles and are free to drop the car off at one of the two mobility hubs with available parking spaces. Parking capacity for carsharing in Merwede is estimated to be 250. All the benefits and costs presented are based on (input) values available in March 2024. As mentioned, the CBA methodology in this study is applied from the perspective of three stakeholders: the CSOs, carsharing users (i.e., the future Merwede residents), and the Municipality of Utrecht (i.e., the perspective of society at large).

### *2.2.2 Discount Rate, Risk, and Uncertainty*

Based on standard practice, a standard discount rate of 5.5% is used in the present CBA (Romijn & Renes, 2013). To deal with knowledge uncertainties, a sensitivity analysis is employed to examine the robustness of the CBA by ascertaining the impact of percentage changes in specific inputs on the final outcomes. Policy uncertainty – particularly the potential effects of different levels of carsharing subsidies – is considered by exploring various subsidy scenarios and their respective consequences. Moreover, the uncertainties of future developments – intrinsic to the project's long-term focus – are managed by applying a general risk premium to the discount rate (Romijn & Renes, 2013). Also, to account for the unpredictability of future developments, scenarios were examined with varying degrees of carsharing modal split – varying from 0.0%, 3.8%, and 7.5% – whereby considering potential fluctuations in carsharing usage by future residents. Additionally, the CBA examined the implications of a spectrum of subsidy policy measures – no subsidy, and subsidies of 50 and 100 euros. Together, these steps ensure a comprehensive assessment of risks and uncertainties.

### *2.2.3 Estimating Modal Split*

The primary data used to determine the (future) demand for carsharing services in Merwede stems from Whooz (2023), which provides insights into levels of car ownership, the purpose of travel – categorised as private or work-related – and the modal split among various transportation means – including (private) cars, taxis, buses, trams, metros, trains, and bicycles – for residents of the Municipality of Utrecht. It also includes income data which is crucial for understanding travel patterns within different socio- economic segments (Whooz, 2023). Additionally, the 'Woonprogramma Merwede' (2022) document offers supplementary data on the types of housing available, which is extrapolated to predict the income brackets of prospective residents and their corresponding mobility choices. This extrapolation necessitates assumptions about the distribution of income groups within Merwede, forming the basis for estimating modal demand by income segment. The alignment of housing types with expected income levels will influence the demand per mode within each income group. The carsharing demand is inferred from the overall demand for car modes, adjusted by the proportion of expected carsharing use derived from other documents and predictions about parking and carsharing. Varying demand for the variant scenarios was calculated using carsharing price elasticity estimates (per income group) and cross-elasticities to determine the effect of price changes on modal split.

### *2.2.4 Mathematical Model*

The costs and benefits included in the CBA are described in Figure 3. Below, the equations used to calculate these costs and benefits are expanded upon. Appendix A provides an overview of all the inputs, their definitions, and units.

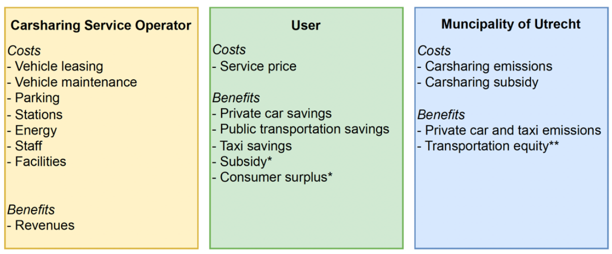


**Figure 3.** CBA for the user, the carsharing service operator, and the Municipality of Utrecht. (*): subsidy-related benefits are only allocated to low- and middle-low- income users. (**): transportation equity is not quantified in the CBA model.

The net present value (NPV) is estimated using (1).

$$NPV = \sum Benefits - \sum Costs \tag{1}$$

#### 2.2.4.1 Carsharing Service Operator (CSO)

From the CSO's perspective, the benefits and costs are defined by (2) and (3), respectively. Note that the actual benefits for the CSO can only be considered after taxes.

$$\sum Benefits_{CSO} = (Nusers \times Psub + Tcs \times P_t + Kcs \times Pkm) \times T \tag{2}$$

$$\sum Costs_{CSO} = (L \times F \times 12) + (Ep \times F \times 12) + (C \times F \times 12) + (Pc \times Ps \times 12 + fe \times Ci \times Ps) + (Fc_1 \times Vp \times Ud \times F \times D) + (S1 + S2 + S3 + S4 \times W) + (Mk + O + Cm) \tag{3}$$

#### 2.2.4.2 Users

For carsharing users, the benefits and costs are respectively defined by (4) and (5). In this, the benefits are calculated from the expenses that users would have incurred from owning a private car, or using taxis, or public transportation, whilst the costs are the extra expenses associated with utilising the carsharing system.

$$\sum Benefits_{Users} = \left(PC_f \times PC_{off} + d_{PV} \times Fc_2\right) + \left(t_{PV} \times P_p \times h_p \times D \times PPc\right) + (d_{taxi} \times C_{taxi}) + (t_{PT} \times C_{PT} \times D) + (Sub_{low} \times N_{low} \times 12) \tag{4}$$

$$\sum Costs_{Users} = (Nusers \times Psub + Tcs \times P_t + Kcs \times Pkm) \tag{5}$$

To capture the extra benefit of the carsharing subsidy policy for low- and middle- low-income residents, a consumer surplus approach is used. This surplus is reported in terms of monetary benefits. The calculation of changes in consumer surplus for scenarios involving subsidies of 50 and 100 euros (S1-2, S1-3, S2-2, and S2-3; described below) adhered to the following steps (Romijn & Renes, 2013). First, the average price per carsharing trip for each income group with and without the subsidy was determined, denoted as *p0* and *p1*, respectively. Subsequently, the change in the number of carsharing trips attributable to the introduction of the subsidy was quantified, represented as *q0* and *q1*. Finally, employing the 'rule of half', the change in consumer surplus was computed using (6).

$$\Delta CS = (p_0 - p_1) \times q_0 + \frac{1}{2} \times (p_0 - p_1) \times (q_1 - q_0) = \frac{1}{2} \times (p_0 - p_1) \times (q_1 + q_0) \tag{6}$$

This approach is not applied to the baseline scenario without carsharing (S0) or without subsidies (S1-1 and S2-1) due to the absence of a consumer surplus benchmark. This methodological approach ensures that the calculated consumer surplus accurately reflects the welfare change experienced by consumers due to the subsidy-induced price variation.

#### 2.2.4.3 Municipality of Utrecht

The adoption of carsharing and pricing policy thereof does not only affect the CSOs and users but carsharing also has societal effects. Therefore, it is important to consider the perspective of the Municipality of Utrecht. This is done by taking the environmental impact and the costs incurred by introducing a subsidy policy into account. Equation (7) represents the total benefits and solely consists of environmental benefits. Other municipal (i.e., societal) benefits include a reduced need for parking space – and thus more space for green, housing, or other more sustainable transport options – improved living quality; lower car production and usage; and improved social inclusion and transportation equity. However, as these additional benefits were complex to quantify, they have been omitted from the present CBA. The carsharing system's environmental impact is evaluated in terms of carbon dioxide ($CO_2$), nitrogen oxides (NOx), and particulate matter (PM) emissions, following the UK's Transport Analysis Guidance (Department for Transport, 2006). Emission variations were calculated according to (8). Moreover, subsidy costs represent opportunity costs for the municipality and government, as these funds could potentially be allocated to alternative public services or investments. However, these opportunity costs are not explicitly included in the CBA to maintain a manageable level of complexity.

$$\sum Benefits_{Municipality} = (1 - T) \times (Nusers \times Psub + Tcs \times P_t + Kcs \times Pkm) + \Delta Pi \tag{7}$$

$$\Delta Pi = \Delta Kcs \times f_{i,CS} \times €t_i + \Delta Kpv \times f_{i,pv} \times €t_i + \Delta Ktaxi \times f_{i,taxi} \times €t_i \tag{8}$$

Equation (9) calculates the total cost for the Municipality of Utrecht associated with carsharing – including subsidies provided to low-income users and environmental costs (i.e., negative emission variations).

$$\sum Costs_{Municipality} = (Sub_{low} \times N_{low} \times 12) - \Delta Pi \tag{9}$$

#### 2.2.4.4 *Subsidy Estimations per Scenario*

As mentioned previously, P7 seems most effective to tackle the case-specific problem statement. Therefore, the CBA will include the costs and benefits of a pricing policy in which low-income groups receive discounts on carsharing services subsidised by the Municipality of Utrecht. In the context of subsidising carsharing services, the analysis for the Municipality of Utrecht focusses on facilitating access for low- and middle-low-income residents of Merwede. In this study, the amounts of subsidy were somewhat arbitrarily determined based on estimated mobility budgets of future Merwede residents, the average carsharing service price, and average number of monthly carsharing trips. This resulted in subsidy values of 50 and 100 euros per month – 600 and 1200 euros per year – per low- and middle-low-income carsharing user.

#### 2.2.4.5 *Model Scenarios*

Scenario S0 serves as a baseline scenario, thus there is no carsharing in this scenario – i.e., the modal split for carsharing is 0.0%. The modal splits for private car (49.9%), taxi (1.7%), public transportation (10.9%), and biking (37.5%) were determined using Whooz (2023) data and the number of parking spots available for private cars (1450) and taxis in Merwede (50). Additionally, to estimate the modal split of carsharing for the variant scenarios, the number of parking spots intended for carsharing in Merwede (250) was used. Building upon the baseline scenario, six variants were formulated. Two alternative scenarios are one in which there is moderate adoption (modal split: 3.8%) of carsharing services (S1-1) and one alternative in which there is high adoption (modal split 7.5%) of carsharing services (S2-1) in Merwede. Neither S1-1 nor S2-1 contained the subsidy intervention. Then, the interventions of 50- and 100-euro monthly subsidies for carsharing for low- and middle-low-income-residents were included, yielding a scenario in which there is moderate adoption of carsharing and a 50-euro subsidy per lower-income user (S1-2) as well as one in which there is moderate adoption of carsharing and a 100-euro subsidy per lower-income user (S1-3). Furthermore, scenarios with high carsharing adoption and a 50-euro subsidy per lower-income user (S2-2) and with a 100-euro subsidy per lower-income user (S2-3), were also included. Table 2 provides an overview of the characteristics of the scenarios included in the analysis whilst Table 3 illustrates the predicted modal split per scenarios, this is assumed to stay constant over the 10-year timeframe of the CBA.

**Table 2.** Overview of scenarios included in CBA. In this, modal split, and number of carsharing users are expressed per year and subsidy is estimated per low- and middle-low-income carsharing user per month.

| | Description | Carsharing Modal Split | Carsharing Users per Year | Number of Users Eligible for Subsidy |
|---|---|---|---|---|
| *S0* | Baseline, No CS | 0.0% | 0 | 0 |
| *S1-1* | Moderate Carsharing, No Subsidy | 3.8% | 567 | 0 |
| *S1-2* | Moderate Carsharing, 50 Subsidy | 3.9% | 586 | 250 |
| *S1-3* | Moderate Carsharing, 100 Subsidy | 4.0% | 604 | 257 |
| *S2-1* | High Carsharing, No Subsidy | 7.5% | 1,134 | 0 |
| *S2-2* | High Carsharing, 50 Subsidy | 7.8% | 1,172 | 499 |
| *S2-3* | High Carsharing, 100 Subsidy | 8.0% | 1,208 | 515 |

**Table 3.** Predicted modal split of Merwede residents per scenario for 2024.

| | S0 | S1-1 | S1-2 | S1-3 | S2-1 | S2-2 | S2-3 |
|---|---|---|---|---|---|---|---|
| **Private Car** | 49.9% | 47.1% | 47.1% | 47.0% | 43.5% | 43.4% | 43.3% |
| **Carsharing** | 0.0% | 3.8% | 3.9% | 4.0% | 7.5% | 7.8% | 8.0% |
| **Taxi** | 1.7% | 1.6% | 1.6% | 1.6% | 1.5% | 1.5% | 1.5% |
| **Public Transportation** | 10.9% | 10.4% | 10.4% | 10.3% | 10.4% | 10.3% | 10.2% |
| **Bike** | 37.5% | 37.0% | 37.0% | 37.0% | 37.0% | 37.0% | 37.0% |

#### 2.2.4.6 *Sensitivity Analysis*

In the sensitivity analysis, the included inputs – *Pkm*, *Psub*, *Pt*, *Number of Parking Spots Private Car*, *Number of Parking Spots Carsharing* (+ Equal Change in Fleet Size (*F*)) – are compared to S1-1. Notably, the sensitivity analysis for price elasticities for low- and middle-low-income residents of Merwede was carried out using S1-2 as a reference as these components were not relevant for or included in S1-1. The elasticities are only in the model after the carsharing service price change resulting from the subsidy is introduced.

## 2.3 Price Elasticity Determination

To determine the impacts of service price changes on carsharing demand (i.e., modal split) – particularly in lower-income groups – the price elasticity for carsharing must be determined. This demand

The yearly income groups in the case study are defined as follows: low (0 – 30.000 euros per year), middle-low (30,000 – 74,000 euros per year), middle-high (74,000 – 88,500 euros per year), high (88,500+ euros per year). Based on mode shift elasticities per income-group (Vasudevan et al., 2021), the range of relative differences between the four income groups regarding price elasticity, can be determined. This is then applied to the general price elasticity for carsharing services in the Netherlands of -0.463 (Kim et al., 2017) to obtain the best estimates of Dutch carsharing price elasticity per income group. Specifically, to estimate carsharing demand price elasticities for the Netherlands by income group, a two-step approach was utilised. First, the average elasticity for middle-income groups was calculated, with middle-low and middle-high groups divided evenly around the general Dutch value, yielding -0.51 and -0.41, respectively. Notably, price elasticities for the middle-income groups were interchanged to ensure a monotonic relationship between elasticity and income (Cohen & Shaheen, 2018). Subsequently, these values served as reference points and the high-income elasticity was proportionally adjusted using the middle-high income elasticity, resulting in -0.13, whilst the low-income elasticity was extrapolated from the middle-low, culminating in -0.82. These estimates are rounded down and presented in Table 4.

**Table 4.** Estimates of Dutch carsharing price elasticity per income group.

| Income Group | Price Elasticity Estimate |
|---|---|
| Low | -0.8 |
| Middle-low | -0.5 |
| Middle-high | -0.4 |
| High | -0.1 |

# 3 Results

The most prevalent results of this study are as follows. The price elasticity values for carsharing are estimated as -0.82, -0.51, -0.41, and -0.13 for the low- income, middle-low, middle-high, and high-income groups, respectively. These values should be interpretated as follows: e.g., a price elasticity of -0.82 for the low-income group in carsharing means that a 1% increase in the price of carsharing services is expected to result in a 0.82% decrease in demand among this group. The differentiated price elasticities of carsharing demand across various income groups in the Netherlands reflect the diverse responses to changes in transportation costs, suggesting that carsharing is inelastic across all income groups.I Furthermore, the market research resulted in the following average values reported for the price of carsharing per kilometre (*Pkm*), the hourly price (*Pt*), and the subscription price (*Psub*): 0.29 euros, 4.51 euros, and 12.78 euros, respectively. Additionally, across CSOs, service prices were relatively similar, reflecting the competitive nature of the carsharing industry.

## 3.1 CBA

The CBA employed in this study specifically aims to answer what the NPV is for carsharing services in Merwede and whether these should be subsidised for low- and middle-low-income residents. Table 5 provides an overview of the results of the CBA in the form of NPVs for the CSOs, carsharing users, and Municipality of Utrecht for the year 2024. For CSOs, NPV values are negative in scenarios with moderate carsharing adoption and no subsidy (S1-1) or a subsidy of 50 euros per month for lower-income users (S1-2). This is due to insufficient carsharing adoption resulting in revenues failing to cover operational costs The highest NPVs for CSOs is reported in the scenario with high carsharing adoption and a subsidy of 100 euros per month for lower-income users (S2-3). In accordance with this, for carsharing users the lowest NPV is reported for the scenario where there is moderate carsharing adoption and no subsidy (S1-1) and the highest NPV results from high carsharing use and a monthly subsidy of 100 euros for lower-income users (S2- 3). The latter can be attributed to the direct financial incentives promoting carsharing, with these benefits going to lower-income users.

Contradictory to the other stakeholders, the highest NPV for the Municipality of Utrecht is reported for the scenario in which there is high carsharing adoption and no subsidy (S2-1) whilst the lowest NPV results from a scenario in which there is moderate carsharing adoption and a monthly subsidy of 100 euros for lower-income users (S1-3). This indicates that while subsidies represent a direct cost to the municipality, the environmental savings generated from increased carsharing use – as opposed to less sustainable modes of transportation – offer substantial financial benefits.

Regarding the yearly total NPV, this value is highest for the scenario in which there is high carsharing and a 100-euro monthly subsidy for lower-income users (S2-3). The total subsidy costs for the Municipality of Utrecht amount to 617,489.43 euros per year. Moreover, the lowest yearly total NPV is reported for the scenario in which there is moderate carsharing adoption and no monthly subsidy (S1-1).

All in all, these findings suggest that all three stakeholders benefit from carsharing service use. CSOs benefit from revenues, users benefit from savings on alternative transportation modes (predominantly from private cars), and the municipality benefits from environmental savings resulting from electric carsharing rather than less sustainable modes of transportation. Ideally, an optimum would be achieved in which the modal split for carsharing is high enough to ensure maximum utilisation rates of the services (CSOs) whilst as little trip credit incentive – i.e., subsidy (municipality) – is required to ensure transportation equity (users). For CSOs in Merwede – as seen from S1-2 and S1-3 – the tipping point where carsharing becomes profitable lies between a modal split of 3.9% and 4.0%, which respectively equal a total of 293,026 and 302,235 carsharing trips per year.

**Table 5.** Yearly net present values (NPVs) of the three stakeholders included in the CBA.

| | NPV CSOs | NPV Users | NPV Municipality | NPV Total |
|---|---|---|---|---|
| *S1-1* | € -46,520.15 | € 30,184,866.17 | € 382,710.93 | € 30,521,056.96 |
| *S1-2* | € -6,005.00 | € 30,351,975.83 | € 245,012.12 | € 30,590,982.96 |
| *S1-3* | € 33,596.25 | € 30,531,766.15 | € 97,843.55 | € 30,663,205.95 |
| *S2-1* | € 1,174,684.89 | € 30,263,977.21 | € 782,963.22 | € 32,221,625.32 |
| *S2-2* | € 1,255,716.70 | € 30,600,040.36 | € 507,566.06 | € 32,363,323.12 |
| *S2-3* | € 1,334,919.02 | € 30,957,776.47 | € 213,228.86 | € 32,505,924.35 |

Whilst this is not visualised, results also indicated that with a 10-year time horizon (i.e., in the year 2034) the total NPV remains positive for all scenarios. Additionally, a variation was observed in the use of carsharing services across income groups because of the subsidies. Specifically, there was higher usage among low- and middle-low-income residents due to the subsidies. This supports the municipality's goal of ensuring more equitable access to and use of carsharing services.

#### *3.1.1 Sensitivity Analysis*

The sensitivity analysis reveals that out of the service pricing components, kilometre pricing (*Pkm*) most profoundly affects the NPV, suggesting that even small adjustments in per-kilometre costs could markedly influence stakeholders' outcomes. While time pricing (*Pt*) and subscription pricing (*Psub*) also affect NPV, they do so to a lesser degree. It should be noted, that the high sensitivity to *Pkm* and *Pt* – as opposed to *Psub* – is likely due to the fact that these inputs are multiplied with the yearly number of kilometres and hours driven, resulting in large changes in the overall NPV – especially that of CSOs whilst the NPV for the users does not change as much since the benefits outweigh the costs by a lot (thus, resulting in relatively little change in the NPV of users). Regarding parking, a reduction in spots for private vehicles significantly boosts the NPV and carsharing modal split, indicating a potential shift from private car usage to carsharing in response to (limited) parking availability. The least sensitivity was noted in price elasticity changes, with the inelastic demand affirming the limited effect of subsidies on user behaviour within the examined income groups.

# 4 Discussion

## 4.1 Data Analysis

A few points of discussion should be noted regarding the data analysis conducted to gain insight into socio-demographics and mobility patterns of future Merwede residents. Specifically, there are uncertainties about the predicted modal split as this was done using data non-specific to a car-free neighbourhood. Additionally, residential self-selection – which states that people tend to choose residential locations based on their travel abilities, needs and preferences – could also influence the actual modal split in Merwede. In other words, inhabitants may automatically be less inclined to own a private car as those who choose to live there are already opting for a car-free neighbourhood and may therefore have a stronger preference for more sustainable modes such as biking and public transportation. Lastly, it remains to be seen in practice whether the available transportation services are sufficient or if they need to be adapted.

## 4.2 Carsharing Price Elasticity Determination

The estimates reported in Table 4 suggest a general inelasticity of carsharing services for users in the Netherlands, suggesting Dutch users' demand for carsharing is relatively unresponsive to price changes. This is in line with studies conducted by Cartenì et al (2016), Kim et al. (2017), and Duan et al. (2020). However, this finding is contradictory to Litman (2022), who found that carsharing exhibits elasticity, largely due to the influence of fixed costs. Notably, in this thesis the high-income group demonstrates the lowest elasticity (-0.13), which may indicate that carsharing services are predominantly used by individuals who can afford them without significant sensitivity to price fluctuations. This pattern suggests a potential self-selection bias, where only those who are not constrained by the budget are currently using the services, thereby possibly skewing the data. This raises the question of whether carsharing would appear more elastic if it were more affordable to the low- and middle-low-income groups, who are underrepresented among carsharing users. Thus, future research should ensure that elasticities are calculated across the entire population and not solely the user segments that already use carsharing services.

It is apparent that literature and data regarding the carsharing price elasticity of carsharing (especially per income group) remain scarce. Also, to avoid self-selection bias, future research should ensure that elasticities are calculated across the entire population and not solely the user segments that already use carsharing services.

## 4.3 CBA

The CBA model utilised for Merwede, which is available in an adaptive Excel format, provides a practical tool for policymakers. In both instances of moderate (modal split 3.8 percent) and high (modal split 7.5 percent) carsharing adoption in Merwede, the two scenarios in which a 100-euro monthly subsidy – for low- and middle-low-income residents – is introduced (S1-3 and S2-3) result in the highest total NPVs. Moreover, it is reported that these subsidies would indeed increase the number of carsharing users in the groups of interest – namely, low- and middle- low-income groups – whereby increasing transportation equity.

The omission of specific environmental and societal benefits in the CBA – such as savings from reduced public parking space (construction and maintenance) requirements and public health benefits due to lower emissions – suggests that the true value of carsharing to society may extend beyond the monetary figures presented. Additionally, variability in CBA outcomes may result from by factors like weather and holidays.

Overall, from the sensitivity analysis, the stability of decision outcomes among NPV fluctuations is a critical finding. Notably, negative total NPVs are only observed for scenarios in which carsharing modal split is 3.9% or lower (S1-1 and S1-2). Whilst variations in NPV values indicate the extent to which each factor can influence the financial outcomes, the overarching conclusion remains unaffected for the remaining scenarios (S1-3, S2-1, S2-2, and S2-3): carsharing subsidies for lower-income residents are favourable. This overall stability in decision outcomes highlights the resilience of the CBA model under the tested scenarios and affirms the utility of the subsidies in stimulating equitable mobility services in Merwede.

# 5 Conclusion

In sum, the CBA outcomes suggest income-group-specific subsidies could serve as an effective instrument to stimulate equitable carsharing (in Merwede). The implementation of this policy allows for a pricing strategy that is beneficial for all stakeholders included in the analysis. Specifically, CSOs, carsharing users, and the Municipality of Utrecht. Nonetheless, careful consideration must also be given to the dynamic nature of carsharing and the necessity for continuous adaptation to evolving urban needs and trends. In this study, Merwede provides a case study environment from which future car-free neighbourhoods aiming to implement carsharing may learn. Specifically, pertaining to pricing strategies for these mobility services that align with the needs, preferences, and capabilities of all potential (future) users.

## 5.1 Generalisability

The value in this study lies within its specificity, it is focussed on carsharing pricing strategies in a specific car-free neighbourhood, differentiating between income groups. However, whilst its specificity may be a strength as this is a relatively novel research topic, it also presents its drawbacks – particularly in relation to the generalisability of the findings. Consequently, this study acknowledges the limitations inherent to its context-specific analysis. Whilst the findings provide valuable insights for the Netherlands – particularly for Merwede – the applicability of these results to other neighbourhoods, cities, or countries with different socio-economic dynamics, transportation systems, and sizes, may be constrained. Therefore, more research regarding carsharing pricing and policies in different car-free environments is required before findings can be generalised. Nonetheless, this study contributes to the field of transport, infrastructure, and logistics by offering an empirically validated CBA model – responsive to different service pricing (and subsidy) levels.

## 5.2 Future Research

Considering the limitations of the present study, several considerations for future research are subsequently expanded upon.

An extensive examination of policies and interventions that could influence the adoption of carsharing is crucial. In relation to the present study, the duration, and the effect of subsidies on specific target groups' mobility behaviour warrant better examination. Additionally, alternative methods to reduce the service costs of carsharing deserve exploration, potentially making the business case for carsharing more appealing.

Perhaps more accurate estimations of price elasticities for carsharing across different income groups would arise from a combination of stated- and revealed-preference surveys – e.g., using historical data from CSOs. Moreover, fluctuations in the carsharing market that may influence service prices should be taken into consideration. This detailed data could enhance price setting and forecasting accuracy.

This research presumes electric carsharing vehicles are emissions-free. However, the frequency of use and the subsequent maintenance and replacement needs suggest a more complex environmental impact. To refine the environmental assessments for these shared mobility services, future research should account for lifecycle emissions, from vehicle production to end-of-life disposal. This could be integrated by following a wheel-to-wheel emissions framework as outlined by Curtale & Liao (2023).

Lastly, the modal split predictions made in this study should be validated in the future. Also, understanding the activity-end of mobility – such as trip purpose – is imperative for accurate mode-choice modelling. In order words, the influence of trip purpose on mode choice should be integrated into modal split estimations. Also, future research should delve deeper into the effects of modalities not included in the present study such as (shared) scooters.

# Appendix A – Inputs for the CBA

| Symbol | Description | Unit |
|---|---|---|
| *C* | Monthly cleaning costs per vehicle | *€ per shared vehicle per month* |
| *Ci* | Electric vehicle charging infrastructure cost | *€ per parking space per year* |
| *Cm* | Communication costs | *€ per year* |
| $C_{PT}$ | Average public transport trip cost | *€ per trip* |
| *Ctaxi* | Cost of taxi | *€ per km* |
| *D* | Days of use of carsharing vehicles per year | *days per year* |
| *dPV* | Travelled distance variation by private car | *km per year* |
| *dtaxi* | Travelled distance variation by taxi | *km per year* |
| *Ep* | Monthly external parking cost | *€ per shared vehicle per month* |
| *F* | Fleet size, number of vehicles | *#* |
| *Fc1* | Average energy cost | *€ per km* |
| *Fc2* | Average fuel and energy cost | *€ per km* |
| *fe* | Electric vehicle parameter (= 1 if vehicle technology used is electric, = 0 if other) | – |
| *fi,CS* | Emission factor of the carsharing vehicle for pollutant *i* (= $CO_2$) | *tonne per shared vehicle per km* |
| | Emission factor of the carsharing vehicle for pollutant *i* (= $NO_x$) | *tonne per shared vehicle per km* |
| | Emission factor of the carsharing vehicle for pollutant *i* (= PM) | *tonne per shared vehicle per km* |
| *fi,pv* | Emission factor of the private vehicle for pollutant *i* (= $CO_2$) | *tonne per private vehicle per km* |
| | Emission factor of the private vehicle for pollutant *i (= $NO_x$)* | *tonne per private vehicle per km* |
| | Emission factor of the private vehicle for pollutant *i* (= PM) | *tonne per private vehicle per km* |
| *fi,taxi* | Emission factor of the taxi for pollutant *i (= $CO_2$)* | *tonne per taxi per km* |
| | Emission factor of the taxi for pollutant *i* (= $NO_x$) | *tonne per taxi per km* |
| | Emission factor of the taxi for pollutant *i* (= PM) | *tonne per taxi per km* |
| *hp* | Average time paying for parking | *hours per day* |
| *Kcs* | Total kilometres travelled by carsharing vehicles | *km per year* |
| *Kpv* | Total kilometres travelled by private vehicle | *km per year* |
| *Ktaxi* | Total kilometres travelled by taxi | *km per year* |
| *L* | Monthly vehicle leasing costs | *€ per shared vehicle per month* |
| *Mk* | Marketing costs per year | *€ per year* |
| *Nlow* | Number of users eligible for the subsidy | *# per year* |
| *Nusers* | Number of carsharing users per year | *# per year* |
| *O* | Typical office rent in the case study | *€ per year* |
| *Pc* | Parking space costs | *€ per shared vehicle per month* |
| *PCf* | Average private car costs | *€ per private vehicle per year* |
| *PCoff* | Number of vehicles taken off the street after the implementation of the carsharing system | *# per year* |
| *Pi* | Cost of pollutants *i* ($CO_2$, $NO_x$, PM) for CS | *€ per year* |
| | Cost of pollutants *i* ($CO_2$, $NO_x$, PM) for PV | *€ per year* |
| | Cost of pollutants *i* ($CO_2$, $NO_x$, PM) for taxi | *€ per year* |
| *ΔPi* | *Delta Pi (From Baseline) for P*ollutants *i* ($CO_2$, $NO_x$, PM) for CS, PV, and taxi | *€ per year* |
| *Pkm* | Kilometre pricing, price charged to user per kilometre for carsharing vehicle (average of all CSOs) | *€ per km* |
| *Pp* | Percentage of trips with paid parking | *%* |
| *PPc* | Average hourly cost of parking | *€ per hour* |
| *Ps* | Number of parking spaces of the entire carsharing network | *#* |
| *Psub* | Subscription pricing, price for carsharing subscription per year (average of all CSOs) | *€ per year* |
| *Pt* | Time pricing, hourly fee charged to the user | *€ per hour* |
| *Sublow* | Subsidy provided per low- and middle-low-income user | *€ per user per month* |
| *S1* | Manager/CEO salary | *€ per year* |
| *S2* | Customer services staff salary | *€ per year* |
| *S3* | Marketing staff salary | *€ per year* |
| *S4* | Normal staff salary | *€ per year* |
| *T* | 1 - Tax | *%* |
| *Tcs* | Total hours travelled by carsharing vehicles | *hours per year* |
| *tPT* | Trips in public transport variation | *# per day* |
| *tPV* | Trips in private car variation | *# per day* |
| *Ud* | Average daily vehicle utilisation in distance per carsharing vehicle | *km per shared vehicle per day* |
| *Vp* | Vehicle performance | *%* |
| *W* | Number of workers of S4 category | *#* |
| *€ti* | Price per tonne of pollutant *i* (= $CO_2$) | *€ per tonne* |
| | Price per tonne of pollutant *i* (= $NO_x$) | *€ per tonne* |
| | Price per tonne of pollutant *i* (= PM) | *€ per tonne* |

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# Appendix B – Overview of Model Inputs

Table 31 provides an overview of the above-mentioned constants, parameters, and variables. The exact values used as inputs for the CBA model and their sources are elaborated upon in Appendix C.

**Table 31.** Overview of inputs for the CBA.

| Symbol | Description | Unit |
|---|---|---|
| ***C*** | Monthly cleaning costs per vehicle | *€ per shared vehicle per month* |
| ***Ci*** | Electric vehicle charging infrastructure cost | *€ per parking space per year* |
| ***Cm*** | Communication costs | *€ per year* |
| $C_{PT}$ | Average public transport trip cost | *€ per trip* |
| ***Ctaxi*** | Cost of taxi | *€ per km* |
| ***D*** | Days of use of carsharing vehicles per year | *days per year* |
| ***dPV*** | Travelled distance variation by private car | *km per year* |
| ***dtaxi*** | Travelled distance variation by taxi | *km per year* |
| ***Ep*** | Monthly external parking cost | *€ per shared vehicle per month* |
| ***F*** | Fleet size, number of vehicles | # |
| ***Fc1*** | Average energy cost | *€ per km* |
| ***Fc2*** | Average fuel and energy cost | *€ per km* |
| ***fe*** | Electric vehicle parameter (= 1 if vehicle technology used is electric, = 0 if other) | – |
| ***fi,CS*** | Emission factor of the carsharing vehicle for pollutant *i* (= CO2) | *tonne per shared vehicle per km* |
| | Emission factor of the carsharing vehicle for pollutant *i* (= NOx) | *tonne per shared vehicle per km* |
| | Emission factor of the carsharing vehicle for pollutant *i* (= PM) | *tonne per shared vehicle per km* |
| ***fi,pv*** | Emission factor of the private vehicle for pollutant *i* (= CO2) | *tonne per private vehicle per km* |
| | Emission factor of the private vehicle for pollutant *i (= NOx)* | *tonne per private vehicle per km* |
| | Emission factor of the private vehicle for pollutant *i* (= PM) | *tonne per private vehicle per km* |
| ***fi,taxi*** | Emission factor of the taxi for pollutant *i (= CO2)* | *tonne per taxi per km* |
| | Emission factor of the taxi for pollutant *i* (= NOx) | *tonne per taxi per km* |
| | Emission factor of the taxi for pollutant *i* (= PM) | *tonne per taxi per km* |
| ***hp*** | Average time paying for parking | *hours per day* |
| ***Kcs*** | Total kilometres travelled by carsharing vehicles | *km per year* |
| ***Kpv*** | Total kilometres travelled by private vehicle | *km per year* |
| ***Ktaxi*** | Total kilometres travelled by taxi | *km per year* |
| ***L*** | Monthly vehicle leasing costs | *€ per shared vehicle per month* |
| ***Mk*** | Marketing costs per year | *€ per year* |
| ***Nlow*** | Number of users eligible for the subsidy | *# per year* |
| ***Nusers*** | Number of carsharing users per year | *# per year* |
| ***O*** | Typical office rent in the case study | *€ per year* |
| ***Pc*** | Parking space costs | *€ per shared vehicle per month* |
| ***PCf*** | Average private car costs | *€ per private vehicle per year* |
| ***PCoff*** | Number of vehicles taken off the street after the implementation of the carsharing system | *# per year* |

| | | |
|---|---|---|
| ***Pi*** | Cost of pollutants *i* ($CO_2$, NOx, PM) for CS | *€ per year* |
| | Cost of pollutants *i* ($CO_2$, NOx, PM) for PV | *€ per year* |
| | Cost of pollutants *i* ($CO_2$, NOx, PM) for taxi | *€ per year* |
| ***ΔPi*** | *Delta Pi (From Baseline) for P*ollutants *i* ($CO_2$, NOx, PM) for CS, PV, and taxi | *€ per year* |
| ***Pkm*** | Kilometre pricing, price charged to user per kilometre for carsharing vehicle (average of all CSOs) | *€ per km* |
| ***Pp*** | Percentage of trips with paid parking | *%* |
| ***PPc*** | Average hourly cost of parking | *€ per hour* |
| ***Ps*** | Number of parking spaces of the entire carsharing network | *#* |
| ***Psub*** | Subscription pricing, price for carsharing subscription per year (average of all CSOs) | *€ per year* |
| ***Pt*** | Time pricing, hourly fee charged to the user | *€ per hour* |
| ***Sublow*** | Subsidy provided per low- and middle-low-income user | *€ per user per month* |
| ***S1*** | Manager/CEO salary | *€ per year* |
| ***S2*** | Customer services staff salary | *€ per year* |
| ***S3*** | Marketing staff salary | *€ per year* |
| ***S4*** | Normal staff salary | *€ per year* |
| ***T*** | 1 - Tax | *%* |
| ***Tcs*** | Total hours travelled by carsharing vehicles | *hours per year* |
| ***tPT*** | Trips in public transport variation | *# per day* |
| ***tPV*** | Trips in private car variation | *# per day* |
| ***Ud*** | Average daily vehicle utilisation in distance per carsharing vehicle | *km per shared vehicle per day* |
| ***Vp*** | Vehicle performance | *%* |
| ***W*** | Number of workers of S4 category | *#* |
| ***€ti*** | Price per tonne of pollutant *i* (= $CO_2$) | *€ per tonne* |
| | Price per tonne of pollutant *i* (= NOx) | *€ per tonne* |
| | Price per tonne of pollutant *i* (= PM) | *€ per tonne* |

## Appendix C – CBA Input Values Calculations

In this Appendix, the how the various inputs for the CBA were obtained, calculated, or estimated is elaborated upon. Table 32 and Table 33 provide an overview of all final input values used to determine the costs and benefits defined for this thesis. In this, 'GW' refers to Greenwheels data that was obtained from an informal interview with Colin Bom, a product marketing manager at Greenwheels (GW). Notably, several inputs (Cm, Mk, O, S1, S2, S3, and S4), namely the operational costs, were adjusted for company scale as it is assumed that a CSO has a larger fleet than solely the 250 vehicles placed in Merwede. For reference, Greenwheels (a medium-sized CSO in the Netherlands) is used. They have a fleet of 2,700 vehicles. Thus, the inputs are adjusted by a factor of 250/2.700. Below, the input values per scenario are defined.

**Table 32.** CBA input values used for S0, S1-1 through S1-3.

| | Symbol | Description | Unit | Type | S0 | S1-1 | S1-2 | S1-3 |
|---|---|---|---|---|---|---|---|---|
| 1 | C | Monthly cleaning costs per vehicle | € per shared vehicle per month | O | € - | € 20.00 | € 20.00 | € 20.00 |
| 2 | Ci | Electric vehicle charging infrastructure cost | € per parking space per year | I | € - | € 252.00 | € 252.00 | € 252.00 |
| 3 | Cm | Communication costs | € per year | O | € - | € 926.00 | € 926.00 | € 926.00 |
| 4 | CPT | Average public transport trip cost | € per trip | G/L | € 16.25 | € 16.25 | € 16.25 | € 16.25 |
| 5 | Ctaxi | Cost of taxi | € per km | G/L | € 2.20 | € 2.20 | € 2.20 | € 2.20 |
| 6 | D | Days of use of carsharing vehicles per year | days per year | O | 0 | 180 | 180 | 180 |
| 7 | dPV | Travelled distance variation by private car | km per year | G | 0 | 3816937 | 3901855 | 3985014 |
| 8 | dtaxi | Travelled distance variation by taxi | km per year | G | 0 | 139327 | 139327 | 139327 |
| 9 | Ep | Monthly external parking cost | € per shared vehicle per month | G/I | € 97.50 | € 97.50 | € 97.50 | € 97.50 |
| 10 | F | Fleet size, number of vehicles | # | O | 0 | 250 | 250 | 250 |
| 11 | Fc1 | Average energy cost | € per km | L | € 0.06 | € 0.06 | € 0.06 | € 0.06 |
| 12 | Fc2 | Average fuel and energy cost | € per km | L | € 0.10 | € 0.10 | € 0.10 | € 0.10 |
| 13 | fe | Electric vehicle parameter (= 1 if vehicle technology used is electric, = 0 if other) | – | I/O | 1 | 1 | 1 | 1 |
| 14 | fi,CS | Emission factor of the carsharing vehicle for pollutant i (= CO2) | tonne per shared vehicle per km | L | 0 | 0 | 0 | 0 |
| 15 | | Emission factor of the carsharing vehicle for pollutant i (= NOx) | tonne per shared vehicle per km | | 0 | 0 | 0 | 0 |
| 16 | | Emission factor of the carsharing vehicle for pollutant i (= PM) | tonne per shared vehicle per km | | 0 | 0 | 0 | 0 |
| 17 | fi,pv | Emission factor of the private vehicle for pollutant i (= CO2) | tonne per private vehicle per km | L | 0.0001068 | 0.0001068 | 0.0001068 | 0.0001068 |
| 18 | | Emission factor of the private vehicle for pollutant i (= NOx) | tonne per private vehicle per km | L | 0.00000009 | 0.00000009 | 0.00000009 | 0.00000009 |
| 19 | | Emission factor of the private vehicle for pollutant i (= PM) | tonne per private vehicle per km | L | 2.5E-09 | 2.5E-09 | 2.5E-09 | 2.5E-09 |
| 20 | fi,taxi | Emission factor of the taxi for pollutant i (= CO2) | tonne per taxi per km | L | 0.0001068 | 0.0001068 | 0.0001068 | 0.0001068 |
| 21 | | Emission factor of the taxi for pollutant i (= NOx) | tonne per taxi per km | L | 0.00000009 | 0.00000009 | 0.00000009 | 0.00000009 |
| 22 | | Emission factor of the taxi for pollutant i (= PM) | tonne per taxi per km | L | 2.5E-09 | 2.5E-09 | 2.5E-09 | 2.5E-09 |
| 23 | hp | Average time paying for parking | hours per day | L | 3 | 3 | 3 | 3 |
| 24 | Kcs | Total kilometres travelled by carsharing vehicles | km per year | O | 0 | 4254350 | 4395396 | 4533519 |
| 25 | Kpv | Total kilometres travelled by private vehicle | km per year | G/L | 69840659 | 66023723 | 65938804 | 65855645 |
| 26 | Ktaxi | Total kilometres travelled by taxi | km per year | G/L | 2549351 | 2410024 | 2410024 | 2410024 |
| 27 | L | Monthly vehicle leasing costs | € per shared vehicle per month | O | € - | € 175.00 | € 175.00 | € 175.00 |
| 28 | Mk | Marketing costs per year | € per year | O | € - | € 50,000.00 | € 50,000.00 | € 50,000.00 |
| 29 | Nlow | Number of users eligible for the subsidy | # per year | G/A | 0 | 0 | 250 | 257 |
| 30 | Nusers | Number of carsharing users per year | # per year | | 0 | 567 | 586 | 604 |
| 31 | O | Typical office rent in the case study | € per year | O | € - | € 3,704.00 | € 3,704.00 | € 3,704.00 |
| 32 | Pc | Parking space costs | € per shared vehicle per month | G/I | € 50.00 | € 50.00 | € 50.00 | € 50.00 |
| 33 | PCf | Average private car costs | € per private vehicle year | G/L | € 8,650.00 | € 8,650.00 | € 8,650.00 | € 8,650.00 |
| 34 | PCoff | Number of vehicles taken off the street after the implementation of the carsharing system | # per year | I/L | € - | 3500 | 3500 | 3500 |
| | Pi | Cost of pollutants i (CO2, NOx, PM) for carsharing | € per year | G/L | € - | € - | € - | € - |
| | | Cost of pollutants i (CO2, NOx, PM) for private vehicle | € per year | G/L | € 938,309.26 | € 887,028.71 | € 885,887.83 | € 884,770.59 |
| | | Cost of pollutants i (CO2, NOx, PM) for taxi | € per year | G/L | € 34,250.54 | € 32,378.67 | € 32,378.67 | € 32,378.67 |
| | | Aggregated Pi | € per year | | € 972,559.79 | € 919,407.39 | € 918,266.51 | € 917,149.27 |
| | ΔPi | Delta Pi (From Base) for Pollutants i (CO2, NOx, PM) for CS, PV, and taxi | | | € - | € 53,152.41 | € 54,293.29 | € 55,410.53 |
| 35 | Pkm | Kilometre pricing, price charged to user per kilometre for carsharing vehicle | € per km | | € 0.29 | € 0.29 | € 0.29 | € 0.29 |
| 36 | Pp | Percentage of trips with paid parking | % | G | 40% | 40% | 40% | 40% |
| 37 | PPc | Average hourly cost of parking | € per hour | G/I | € 5.00 | € 5.00 | € 5.00 | € 5.00 |
| 38 | Ps | Number of parking spaces of the entire carsharing network | # | I | 0 | 250 | 250 | 250 |
| 39 | Psub | Subscription pricing, price for carsharing subscription per year | € per year | | € 153.33 | € 153.33 | € 153.33 | € 153.33 |
| 40 | Pt | Time pricing, hourly fee charged to the user | € per hour | O | € 3.23 | € 3.23 | € 3.23 | € 3.23 |
| 41 | Sublow | Subsidy provided per low- and middle-low-income user | € per user resident per year | G | € - | € - | € 50.00 | € 100.00 |
| 42 | S1 | Manager/CEO salary | € per year | O | € - | € 5,556.00 | € 5,556.00 | € 5,556.00 |
| 43 | S2 | Customer services staff salary | € per year | O | € - | € 2,778.00 | € 2,778.00 | € 2,778.00 |
| 44 | S3 | Marketing staff salary | € per year | O | € - | € 3,241.00 | € 3,241.00 | € 3,241.00 |
| 45 | S4 | Normal staff salary | € per year | O | € - | € 2,778.00 | € 2,778.00 | € 2,778.00 |
| 46 | T | 1- Tax | % | G | 80% | 80% | 80% | 80% |
| 47 | Tcs | Total hours travelled by carsharing vehicles | hours per year | | 0 | 107777 | 111350 | 114849 |
| 48 | tPT | Trips in public transport variation | # per day | G | 0 | 89 | 101 | 114 |
| 49 | tPV | Trips in private car variation | # per day | G | 0 | 564 | 577 | 589 |
| 50 | Ud | Average daily vehicle utilisation in distance per carsharing vehicle | km per shared vehicle per day | O | 0.00 | 46.62 | 48.17 | 49.68 |
| 51 | Vp | Vehicle performance | % | O/I | 77% | 77% | 77% | 77% |
| 52 | W | Number of workers of S4 category | # | O | 0 | 40 | 40 | 40 |
| 53 | €ti | Price per tonne of pollutant i (= CO2) | € per tonne | L | € 100.00 | € 100.00 | € 100.00 | € 100.00 |
| 54 | | Price per tonne of pollutant i (= NOx) | € per tonne | L | € 26,500.00 | € 14,000.00 | € 14,000.00 | € 14,000.00 |
| 55 | | Price per tonne of pollutant i (= PM) | € per tonne | L | € 148,000.00 | € 37,400.00 | € 37,400.00 | € 37,400.00 |

**Table 33.** CBA input values used for S0, S2-1 through S2-3.

| | Symbol | Description | Unit | Type | S0 | S2-1 | S2-2 | S2-3 |
|---|---|---|---|---|---|---|---|---|
| 1 | C | Monthly cleaning costs per vehicle | € per shared vehicle per month | O | € - | € 20.00 | € 20.00 | € 20.00 |
| 2 | Ci | Electric vehicle charging infrastructure cost | € per parking space per year | I | € - | € 252.00 | € 252.00 | € 252.00 |
| 3 | Cm | Communication costs | € per year | O | € - | € 926.00 | € 926.00 | € 926.00 |
| 4 | CPT | Average public transport trip cost | € per trip | G/L | € 16.25 | € 16.25 | € 16.25 | € 16.25 |
| 5 | Ctaxi | Cost of taxi | € per km | G/L | € 2.20 | € 2.20 | € 2.20 | € 2.20 |
| 6 | D | Days of use of carsharing vehicles per year | days per year | O | 0 | 180 | 180 | 180 |
| 7 | dPV | Travelled distance variation by private car | km per year | G | 0 | 8895481 | 9065322 | 9231639 |
| 8 | dtaxi | Travelled distance variation by taxi | km per year | G | 0 | 324706 | 324706 | 324706 |
| 9 | Ep | Monthly external parking cost | € per shared vehicle per month | G/I | € 97.50 | € 97.50 | € 97.50 | € 97.50 |
| 10 | F | Fleet size, number of vehicles | # | O | 0 | 250 | 250 | 250 |
| 11 | Fc1 | Average energy cost | € per km | L | € 0.06 | € 0.06 | € 0.06 | € 0.06 |
| 12 | Fc2 | Average fuel and energy cost | € per km | L | € 0.10 | € 0.10 | € 0.10 | € 0.10 |
| 13 | fe | Electric vehicle parameter (= 1 if vehicle technology used is electric, = 0 if other) | – | I/O | 1 | 1 | 1 | 1 |
| 14 | fi,CS | Emission factor of the carsharing vehicle for pollutant i (= CO2) | tonne per shared vehicle per km | L | 0 | 0 | 0 | 0 |
| 15 | | Emission factor of the carsharing vehicle for pollutant i (= NOx) | tonne per shared vehicle per km | | 0 | 0 | 0 | 0 |
| 16 | | Emission factor of the carsharing vehicle for pollutant i (= PM) | tonne per shared vehicle per km | | 0 | 0 | 0 | 0 |
| 17 | fi,pv | Emission factor of the private vehicle for pollutant i (= CO2) | tonne per private vehicle per km | L | 0.0001068 | 0.0001068 | 0.0001068 | 0.0001068 |
| 18 | | Emission factor of the private vehicle for pollutant i (= NOx) | tonne per private vehicle per km | L | 0.00000009 | 0.00000009 | 0.00000009 | 0.00000009 |
| 19 | | Emission factor of the private vehicle for pollutant i (= PM) | tonne per private vehicle per km | L | 2.5E-09 | 2.5E-09 | 2.5E-09 | 2.5E-09 |
| 20 | fi,taxi | Emission factor of the taxi for pollutant i (= CO2) | tonne per taxi per km | L | 0.0001068 | 0.0001068 | 0.0001068 | 0.0001068 |
| 21 | | Emission factor of the taxi for pollutant i (= NOx) | tonne per taxi per km | L | 0.00000009 | 0.00000009 | 0.00000009 | 0.00000009 |
| 22 | | Emission factor of the taxi for pollutant i (= PM) | tonne per taxi per km | L | 2.5E-09 | 2.5E-09 | 2.5E-09 | 2.5E-09 |
| 23 | hp | Average time paying for parking | hours per day | L | 3 | 3 | 3 | 3 |
| 24 | Kcs | Total kilometres travelled by carsharing vehicles | km per year | O | 0 | 8508331 | 8790429 | 9066675 |
| 25 | Kpv | Total kilometres travelled by private vehicle | km per year | G/L | 69840659 | 60945178 | 60775338 | 60609020 |
| 26 | Ktaxi | Total kilometres travelled by taxi | km per year | G/L | 2549351 | 2224645 | 2224645 | 2224645 |
| 27 | L | Monthly vehicle leasing costs | € per shared vehicle per month | O | € - | € 175.00 | € 175.00 | € 175.00 |
| 28 | Mk | Marketing costs per year | € per year | O | € - | € 50,000.00 | € 50,000.00 | € 50,000.00 |
| 29 | Nlow | Number of users eligible for the subsidy | # per year | G/A | 0 | 0 | 499 | 515 |
| 30 | Nusers | Number of carsharing users per year | # per year | | 0 | 1,134 | 1,172 | 1,208 |
| 31 | O | Typical office rent in the case study | € per year | O | € - | € 3,704.00 | € 3,704.00 | € 3,704.00 |
| 32 | Pc | Parking space costs | € per shared vehicle per month | G/I | € 50.00 | € 50.00 | € 50.00 | € 50.00 |
| 33 | PCf | Average private car costs | € per private vehicle year | G/L | € 8,650.00 | € 8,650.00 | € 8,650.00 | € 8,650.00 |
| 34 | PCoff | Number of vehicles taken off the street after the implementation of the carsharing system | # per year | I/L | € - | 3500 | 3500 | 3500 |
| | Pi | Cost of pollutants i (CO2, NOx, PM) for CS | € per year | G/L | € - | € - | € - | € - |
| | | Cost of pollutants i (CO2, NOx, PM) for PV | € per year | G/L | € 938,309.26 | € 818,798.47 | € 816,516.66 | € 814,282.19 |
| | | Cost of pollutants i (CO2, NOx, PM) for taxi | € per year | G/L | € 34,250.54 | € 29,888.11 | € 29,888.11 | € 29,888.11 |
| | | Aggregated Pi | € per year | | € 972,559.79 | € 848,686.57 | € 846,404.77 | € 844,170.29 |
| | ΔPi | Delta Pi (From Base) for Pollutants i (CO2, NOx, PM) for CS, PV, and taxi | | | € - | € 123,873.22 | € 126,155.03 | € 128,389.50 |
| 35 | Pkm | Kilometre pricing, price charged to user per kilometre for carsharing vehicle | € per km | | € 0.29 | € 0.29 | € 0.29 | € 0.29 |
| 36 | Pp | Percentage of trips with paid parking | % | G | 40% | 40% | 40% | 40% |
| 37 | PPc | Average hourly cost of parking | € per hour | G/I | € 5.00 | € 5.00 | € 5.00 | € 5.00 |
| 38 | Ps | Number of parking spaces of the entire carsharing network | # | I | 0 | 250 | 250 | 250 |
| 39 | Psub | Subscription pricing, price for carsharing subscription per year | € per year | | € 153.33 | € 153.33 | € 153.33 | € 153.33 |
| 40 | Pt | Time pricing, hourly fee charged to the user | € per hour | O | € 3.23 | € 3.23 | € 3.23 | € 3.23 |
| 41 | Sublow | Subsidy provided per low- and middle-low-income user | € per user resident per year | G | € - | € - | € 50.00 | € 100.00 |
| 42 | S1 | Manager/CEO salary | € per year | O | € - | € 5,556.00 | € 5,556.00 | € 5,556.00 |
| 43 | S2 | Customer services staff salary | € per year | O | € - | € 2,778.00 | € 2,778.00 | € 2,778.00 |
| 44 | S3 | Marketing staff salary | € per year | O | € - | € 3,241.00 | € 3,241.00 | € 3,241.00 |
| 45 | S4 | Normal staff salary | € per year | O | € - | € 2,778.00 | € 2,778.00 | € 2,778.00 |
| 46 | T | 1- Tax | % | G | 80% | 80% | 80% | 80% |
| 47 | Tcs | Total hours travelled by carsharing vehicles | hours per year | | 0 | 215544 | 222691 | 229689 |
| 48 | tPT | Trips in public transport variation | # per day | G | 0 | 89 | 114 | 139 |
| 49 | tPV | Trips in private car variation | # per day | G | 0 | 1315 | 1340 | 1365 |
| 50 | Ud | Average daily vehicle utilisation in distance per carsharing vehicle | km per shared vehicle per day | O | 0.00 | 93.24 | 96.33 | 99.36 |
| 51 | Vp | Vehicle performance | % | O/I | 77% | 77% | 77% | 77% |
| 52 | W | Number of workers of S4 category | # | O | 0 | 40 | 40 | 40 |
| 53 | €ti | Price per tonne of pollutant i (= CO2) | € per tonne | L | € 100.00 | € 100.00 | € 100.00 | € 100.00 |
| 54 | | Price per tonne of pollutant i (= NOx) | € per tonne | L | € 26,500.00 | € 14,000.00 | € 14,000.00 | € 14,000.00 |
| 55 | | Price per tonne of pollutant i (= PM) | € per tonne | L | € 148,000.00 | € 37,400.00 | € 37,400.00 | € 37,400.00 |

1. ***(C)* Monthly cleaning costs per vehicle (€ per vehicle per month)**
    - From Compostella et al. (2020) a price of $15.00 per vehicle cleaning is assumed. This can be converted to approximately €14. However, this value is rounded up to ensure that it is not assumed to be too low. Thus, a value of **€20** is used.
    - <u>GW</u>: No public data available, cars are cleaned by The Greenest.
2. **(*Ci*) Electric vehicle charging infrastructure cost (€ per year)**
    - Vasconcelos et al. (2017) considers one charging post for each two parking spaces divided by the post lifetime (ten years). This represents a value of €21 per space per month (Faira et al., 2017). This equals **€252** per space per year.
3. **(*Cm*) Communication costs (€ per year)**
    - <u>Estimate</u>: For a medium-sized carsharing operator, communication costs, which encompass customer service and other outreach efforts. A plausible annual range might be €5,000 to €15,000, depending on the scale of operations. An average value results in €10,000. Adjustment for company scale results in: 250/2700*10,000 = **€926**.

- GW: No public data available.

4. **($C_{PT}$) Average public transport trip cost (€ per day)**
   - To estimate the average daily cost of public transport in Utrecht, a range of €5 to €30 is considered, based on general public transport prices in the Netherlands (Nederlandse Spoorwegen, 2023). This estimate assumes either two single journey tickets (€2.50 each) or a day pass (approximately €30). For regular users, costs may be lower when averaged over a month with subscriptions or OV-chipkaart usage. On average this results in: **€16.25**.
5. **($C_{taxi}$) Cost of taxi (€ per km)**
   - In Utrecht, the average cost of a taxi can be estimated to range from €1.30 to €2.30 per kilometre, considering the initial flag fall price, distance travelled, and waiting times when applicable (Taxigator, 2023). On average this results in: **€2.20**.
6. **(*D*) Days of use of carsharing vehicles per year**
   - The average days of use for carsharing vehicles per year can fluctuate based on factors such as fleet size, membership, and urban transport dynamics. A study suggests that carsharing vehicles are typically utilised 2-5 days per week (Martin & Shaheen, 2011b), translating to approximately 100-260 days per year. On average this results in: **180** days per year.
   - GW: Our cars are available for use all-year round (i.e., 365 days per year). However, availability and utilisation rates are not the same.
7. **($d_{PV}$) Travelled distance variation by private car (km per year)**
   - This value was calculated in Excel using a linked input parameter (*Kpv*). This value is calculated in Excel and based on the assumed modal split.
   - The input values per scenario are displayed in Table 32 and Table 33.
8. **($d_{taxi}$) Travelled distance variation by taxi (km per year)**
   - This value was calculated in Excel using a linked input parameter (*Ktaxi*). This value is calculated in Excel and based on the assumed modal split.
9. **(*Ep*) Monthly external parking cost (€ per month)**
   - Municipality of Utrecht, 2024:
     i. P + R = ± €98 per month
     ii. Public Garages (Berlijnplein, de Grifthoek, Croeselaan, Kop van Lombok, Kruisstraat, en Vaartsche Rijn) = ± €246 per month (for 7-day-a-week parking)
     iii. Not Public Garages = ± €78 per month (zone A1 and A2)
     iv. Parking Spot Costs: ± €357 per month (zone A1, A2, and B1)
     v. ➔ On average this results in: (98 + 246 + 78 + 357)/4 = ± €195
   - Estimate: Assuming that shared cars are used approximately half the time (based on D = 180 days) and otherwise are parked internally with the CSO or at a much lower fee at their designated locations; this would mean that external parking costs amount to 195/2 = **€97.50**.
10. **(*F*) Fleet size number of vehicles**
    - From Merwede documents, we know the intention is to have **250** carsharing vehicles (Pakhuis de Zwijger, 2023).
    - GW: Current fleet size is 2700 cars. Thus, 250/2700 equals approximately 9% of their entire fleet; this value is used for the inputs that depend on company scale (*Cm*, *Mk*, *O*, *S1*, *S2*, *S3*, and *S4*).
11. **($Fc_l$) Average energy cost (€ per km)**
    - Public charging station = €0.50 per kWh on average (Vattenfall, n.d.); this translates to €0.10 per kilometre. Vasconcelos et al. (2017) states that the cost is €0.07 per kWh; and consumption = 16.7 kWh per 100 km. This results in €0.01 per kilometre.
    - An average value using these two sources results in (0,10 + 0,01)/2 = **€0.06** per kilometre.

12. **($Fc_2$) Average fuel and energy cost (€ per km)**
    - The average fuel and energy cost in Utrecht can vary depending on the type of vehicle. For a conventional gasoline car, the cost is approximately <u>€0.14</u> per kilometre (AutoCorsten, n.d.), considering fuel prices and fuel efficiency. For an electric vehicle (EV), the cost is approximately €0.06 per kilometre (Vattenfall, n.d. and Vasconcelos et al., 2017). Thus, the average cost is **€0.10** per kilometre.
13. **($fe$) Electric vehicle parameter**
    - <u>Assumption</u>: All carsharing vehicles in Merwede will be electric (Over Morgen, n.d.) = **1**.

**($f_{i,CS}$) Emission factor of the carsharing vehicles for pollutant i (tonne per km)**
For this input, it is known that all carsharing vehicles in Merwede will be electric.

14. $f_{CO2,CS}$: **0** tonne/km (simplification/assumption).
15. $f_{NOx,CS}$: **0** tonne/km (Vasconcelos et al., 2017).
16. $f_{PM,CS}$: **0** tonne/km (Vasconcelos et al., 2017).

**($f_{i,pv}$) Emission factor of the private vehicle for pollutant *i* (tonne per km)**
For this input, the average values gas and electric vehicles are used. The emission factors for private vehicles and taxis are the same.

17. $f_{CO2,PV}$: **0.0001068** tonne/km (Vasconcelos et al., 2017).
18. $f_{NOx,PV}$: **0.00000009** tonne/km (Vasconcelos et al., 2017).
19. $f_{PM,PV}$: **0.0000000025** tonne/km (Vasconcelos et al., 2017).

**($f_{i,taxi}$) Emission factor of the taxi for pollutant *i* (tonne per km)**
For this input, the average values gas and electric vehicles are used. The emission factors for private vehicles and taxis are the same.

20. $f_{CO2,taxi}$: **0.0001068** tonne/km (Vasconcelos et al., 2017).
21. $f_{NOx,taxi}$: **0.00000009** tonne/km (Vasconcelos et al., 2017).
22. $f_{PM,taxi}$: **0.0000000025** tonne/km (Vasconcelos et al., 2017).

23. **($h_p$) Average time paying for parking (hours per day)**
    - In both Amsterdam and Utrecht, most parking sessions lasted between <u>two and four</u> hours, independently of the location (Mingardo et al., 2022). Thus, an average value of **3** hours is used.
24. **($Kcs$) Total kilometres travelled by carsharing vehicles (km per year)**
    - This value was calculated in Excel using an average distance of 15 kilometres per trip. The number of trips per year is calculated in Excel based on the assumed modal split.
        i. "Half of the shared car journeys were longer than 50 km." (Rijskwaterstaat, n.d.).
        ii. Thus, let's assume this results in 75/2 = 37.5 km per journey. Roughly assuming each journey consists of 2.5 trips, this results in an estimate of 15 km per trip.
    - The input values per scenario are displayed in Table 32 and Table 33.
25. **($Kpv$) Total kilometres travelled by private vehicle (km per year)**
    - This value was calculated in Excel using an average distance of 18.525 kilometres per trip. The number of trips per year is calculated in Excel based on the assumed modal split.
        i. From CBS (2023) average from driver and passenger of personal vehicle use: (17.44 + 19.61)/2 = 18.525 km per trip.
    - The input values per scenario are displayed in Table 32 and Table 33.
26. **($Ktaxi$) Total kilometres travelled by taxi (km per year)**

i. This value was calculated in Excel using an average distance of 19.61 kilometres per trip. The number of trips per year is calculated in Excel based on the assumed modal split.
   1. From CBS (2023) "Personenauto als passagier" = 19.61 km.

ii. The input values per scenario are displayed in Table 32 and Table 33.

27. **(*L*) Monthly vehicle leasing costs (€ per month)**
    - Vehicle leasing costs for carsharing operators can vary based on factors like vehicle make and model, lease duration, and additional services included in the lease (e.g., maintenance, insurance). For Greenwheels, their low-end car is a 'VW Up!' and their high-end car is a 'VW Golf Variant'; this results in an average leasing cost of €414. Considering the average value of €414 and the fact that typically a CSO owns some of their fleet. Let's roughly assume they own half of their fleet of 250 vehicles; this results in: (414*125)/250 = €207. Moreover, as CSO use the vehicles for commercial use, let's assume they get a bulk discount. Thus, considering the CSO owns part of their fleet and that they get a bulk discount, let's say they spend roughly **€175** per vehicle per month.
    - <u>GW</u>: No public data available; check average lease costs for similar car types and add a quantity discount, please note that we not just lease cars, we also own part of our fleet.
      i. Leasing Cost (Lease Vergelijker, 2024)
         1. GW Low-end VW Up!: €239
         2. GW High-end VW Golf Variant: €589
         3. Average: €414

28. **(*Mk*) Marketing costs per year (€ per year)**
    - <u>Estimate</u>: Assuming average marketing allocation is approximately 10% of a company's actual revenue (WebStrategies, 2024); and roughly assuming that Greenwheels generates approximately €10.000.000 per year (Eisert, 2016); we can assume marketing costs amount to €1.000.000 per year. Adjustment for company scale amounts in: 250/2700*1.000.000 = €92.600. Moreover, as Merwede is a car-free neighbourhood, it is assumed most residents are already aware of the alternatives to private car that are available (including carsharing services). Thus, a rough estimate is that the marketing costs per year amount to **€50.000**.
    - <u>GW</u>: No public data available, would suggest using an industry average of a related industry.

29. **($N_{low}$) Number of users eligible for the subsidy**
    - As mentioned in Section 4.3, 20% of total residents are low-income and 23% are middle-low thus, *Nusers**0,43 for each scenario.
    - The input values per scenario are displayed in Table 32 and Table 33.

30. **(*Nusers*) Number of carsharing users per year (# per year)**
    - In order to calculate this for each scenario, the principle that carsharing is only beneficial for users travelling ≤7,500 kilometres a year (Rijkswaterstaat, n.d.) is used. Specifically, the total kilometres travelled using carsharing (an output of modal split) is divided by 7,500 (the maximum amount of yearly km's users use carsharing for) and then rounded down to estimate the <u>minimum</u> number of carsharing users.
    - The input values per scenario are displayed in Table 32 and Table 33.

31. **(*O*) Typical office rent in the case study (€ per year)**
    - Office rents in Utrecht's central areas might also range between €200 to €300 per square meter per year (Statista, 2023). For a medium-sized carsharing service operator, an office size of 100 to 200 square meters is reasonable. Thus,

the annual rent for an office in Utrecht could range from €20,000 (100 sqm at €200/sqm) to €60,000 (200 sqm at €300/sqm). This averages to approximately €40,000 per year. Adjusting this price for company scale results in 250/2,700*40.000 = **€3,704**.

- GW: No public data available, check average costs for an office in Amsterdam/Utrecht/Rotterdam Centre.

32. **(*Pc*) Parking space costs (€ per month)**
    - As for *Ep* (Municipality of Utrecht, 2024):
        i. P + R = ± €98 per month.
        ii. Public Garages (Berlijnplein, de Grifthoek, Croeselaan, Kop van Lombok, Kruisstraat, en Vaartsche Rijn) = ± €246 per month (for 7-day-a-week parking).
        iii. Not Public Garages = ± €78 per month (zone A1 and A2).
        iv. Parking Spot Costs: ± €357 per month (zone A1, A2, and B1).
        v. On average this results in: (98 + 246 + 78 + 357)/4 = ± €195 per month.
    - From Case Description chapter: Parking spaces in Merwede are estimated to cost about €200 (Over Morgen, n.d.).
    - Estimate: However, based on the assumption that for CSO the monthly parking price is significantly less than for residents; the monthly parking space costs are estimated to be approximately **€50**.
33. **($PC_f$) Average private car costs (€ per year)**
    - Vasconcelos et al. (2017): An average value for both gasoline and electric vehicles is €756 per month; which results in €9,072 per year.
    - From other sources, the average annual cost of owning a car in Europe is approximately €616 per month, including the cost of the car itself, taxes, insurance, maintenance, and more (N26, n.d.). This translates to an annual cost of about €7,392.
    - In the Netherlands, specifically in Amsterdam, the cost of owning a car averages around €10.000 per year, which includes insurance, registration, maintenance, parking, fuel, and other expenses (Expatrist, n.d.). After removing the parking costs from the equation (already accounted for by *Pc*), this results in 10.000-12*50 = €9,400.
    - On average this results in (9072 + 7392 + 9400)/3 = €8,621 per year. After rounding up, this equals **€8,650**. This figure provides a general estimate for both gas-based and electric cars, considering the diverse costs associated with each type of vehicle.
34. **($PC_{off}$) Number of vehicles taken off the street after the implementation of the carsharing system**
    - GW: 1 CS vehicle replaces 14 private vehicles (Goudappel, 2023)
        i. Thus, for 250 CS vehicles, 250*14 = **3,500** private vehicles are taken off the street after the implementation of the carsharing system.

**(*Pi*) Cost of pollutant i (€ per year)**

This value is determined based on *Equation 8* (Section 5.1.2.3); the calculated values per scenario are displayed in Table 32 and Table 33.

35. **(*Pkm*) Kilometre pricing, price charged to user per kilometre for carsharing vehicle (€ per km)**

- As mentioned in Section 6.3, the kilometre fee charged to the carsharing user is estimated to be **€0.29** per kilometre. This is an average of the hourly price of four CSOs (A2B, Greenwheels, MyWheels, and OnzeAuto).

36. **($P_p$) Percentage of trips with paid parking (% per year)**
    - Estimate: As a general estimate, considering the urban setting and the expansion of paid parking zones, it could be reasonable to assume that a significant portion, potentially around 30-50% of car trips from Utrecht/Merwede, might involve paid parking. This is speculative and should be validated with local transportation studies or data from the Municipality of Utrecht. On average, this results in (30 + 50)/2 = **40%**.
37. **(*PPc*) Average hourly cost of parking (€ per hour)**
    - The average hourly cost of parking in the Netherlands varies depending on the city. In most places, the average rate is around €2.80 per hour. However, in larger cities like The Hague, Utrecht, and Rotterdam, the cost is higher, typically averaging €3.50 per hour. In Amsterdam city centre, the rate can be as high as €7.50 per hour (DutchReview, 2023).
    - Furthermore, according to Municipality of Utrecht (2024), parking costs are €7.50; €6.50; €5.00 for zones A1, A2, and B1, respectively. This averages to (7.50 + 6.50 + 5.00)/3 = €6.33 per hour.
    - Thus, all in all, utilising both sources, an average hourly cost of parking is (2.80 + 3.50 + 7.50 + 6.33)/4 = €5.03 per hour. Rounding this down results in **€5.00** per hour.
38. **(*Ps*) Number of parking spaces of the entire carsharing network**
    - Based on Woonprogramma Merwede (2022) = **250**.
39. **(*Psub*) Subscription pricing, price for carsharing subscription per year (€ per year)**
    - As mentioned in Section 6.3, the yearly subscription price charged to the carsharing user is estimated to be 12*12.78 = **€153.36**. This is an average of the hourly price of three CSOs (Greenwheels, Hely, and MyWheels).
40. **($P_t$) Time pricing hourly fee charged to the user (€ per hour)**
    - As mentioned in Section 6.3, the hourly fee charged to the carsharing user is estimated to be **€3.23** per hour. This is an average of the hourly price of four CSOs (Greenwheels, Hely, MyWheels, and OnzeAuto).
41. **($Sub_{low}$) Subsidy provided per low-income user (€ per low-income resident per year)**
    - Roughly determined based on average price per month of carsharing use (€262.50) and financial feasibility for the Municipality of Utrecht. The options include either no subsidy (€0), €50, or €100 of carsharing subsidy per month per income group.
    - The input values per scenario are displayed in Table 32 and Table 33.

**(*S1*, *S2*, *S3*, and *S4*) Salaries of different staff categories (€ per year)**

42. Manager/CEO
    - Estimate: manager/CEO salary in the Netherlands = €60,000
    - *Adjustment for Company Scale*: 250/2700*60,000 = **€5,556**
43. Customer services staff
    - Estimate: customer services staff salary in the Netherlands = €30,000 Services Staff Salary in the Netherlands. [Assumption]
    - *Adjustment for Company Scale*: 250/2700*30.000 = **€2,778**
44. Marketing staff
    - Estimate: marketing staff salary in the Netherlands = €35.000
    - *Adjustment for Company Scale*: 250/2700*35,000 = **€3,241**
45. Normal staff salary
    - Estimate: average salary for normal staff in the Netherlands = €30.000
    - *Adjustment for Company Scale*: 250/2700*30,000 = **€2,778**

46. **(*T-1*) Tax (% per year)**
    - The tax rate on income/profits for a carsharing service operator in the Netherlands, as of 2023, is structured as follows:
        1. A lower corporate income tax rate of 15% applies to the first EUR 395.000 of taxable income.
        2. Any taxable income exceeding EUR 395.000 is subject to a standard rate of 25.8%.
        3. These rates are applicable to both public and private companies operating in the Netherlands (PwC, 2024; Government of the Netherlands, n.d.).
    - Thus, an average tax rate of (15 + 25.8)/2 = ±<u>20</u>% is used, making T = **80%**.
47. **(*Tcs*) Total hours travelled by carsharing vehicles (hours per year)**
    - Based on average distance of 15 kilometres per trip. Assuming an average car speed is 40 km/hour: 15/40 = <u>0.38</u> hours.
    - The input values per scenario are displayed in Table 32 and Table 33
48. **($t_{PT}$) Trips in public transport variation (# per day)**
    - This input depends on the difference in public transportation trips per scenario and is thus dependent on changes in modal split.
    - The input values per scenario are displayed in Table 32 and Table 33.
49. **($t_{PV}$) Trips in private car variation (# per day)**
    - This input depends on the difference in private car trips per scenario and is thus dependent on changes in modal split.
    - The input values per scenario are displayed in Table 32 and Table 33.
50. **(*Ud*) Average daily vehicle utilisation in distance per carsharing vehicle (km per vehicle per day)**
    - Dependent on modal split and total kilometres travelled by carsharing vehicles per year *(Kcs)* and automatically calculated in model by dividing this by the fleet size (*F)* and the number of days per year (365).
    - *Checking if value makes sense for the baseline scenario S0*
        1. Using total distance (hours) per year
            1. (8,508,331/250)/365 = **93,2** km per vehicle per day
        2. <u>GW</u>: 62 km <u>per trip</u>. Thus, approximately 31 km per trip.
            1. <u>Estimate</u>: Assuming 1 carsharing vehicle makes approximately 3 trips per day (on average) this results in 3*31 = <u>93</u> km per day.
    - The input values per scenario are displayed in Table 32 and Table 33.

51. **(*Vp*) Vehicle performance (% per year)**
    - Electric vehicles convert over **77%** of the electrical energy from the grid to power at the wheels (Glandorf, 2020).
52. **(*W*) Number of workers of S4 category**
    - <u>Estimate</u>: Normal staff for medium operation = **40**.
    - <u>GW</u>: No public data available, our total in-house team is 80 people (including manager/CEO, customer services staff, marketing staff, and normal staff).

**(*€$t_i$*) Price per tonne of pollutant i (€ per tonne)**: = **(*Pi*) Cost of pollutant *i* ($CO_2$) (€ per tonne)**

53. €$t_{CO2}$: **€100** per tonne (van Essen et al., 2019).
54. €$t_{NOx}$: **€26,500** per tonne (van Essen et al., 2019).
55. €$t_{PM}$: **€148,000** per tonne (van Essen et al., 2019).

## Appendix D – Carsharing Users per Income Group per Year per Scenario

The number of carsharing users per income group for each scenario was calculated manually. The typical carsharing user profile is of the higher-income group (Ampudia-Renuncio et al., 2020; Liao & Correia, 2022). Thus, the following assumption is used: ¼ of users are assigned to the low- and middle-low-income groups, and ¾ of users are assigned to the middle-high- and high-income groups. Additionally, the proportions of the different income groups in Merwede and the total number of carsharing users (*Nusers*) – which are respectively inputs and outputs of the model – are used. Throughout the calculations, users are rounded down or up per scenario to avoid non-integer values.

(1) Proportion of the income groups of the total Merwede residents (Over Morgen, 2021)
   a. (L + ML) = 20 + 23 = 43%
   b. (MH + H) = 49 + 8 = 57%

   Thus, the proportions are as follows for L, ML, MH, and H: 20/43; 23/43; 49/57; and 8/57. Moreover, new carsharing users in the different scenarios are always attributed to the low- and middle-low-income groups as the intervention (subsidy) only applies to them and it is assumed that there are no underlying effects.

(2) Calculations (examples provided for S1 scenarios, similar calculations done for S2 scenarios but just with a different starting number of *Nusers*)
   a. S0
      i. $N_{users,S0} = 0$
      ii. L, ML, MH, H = 0; 0; 0; 0
   b. S1-1
      i. $N_{users,S1-1} = 567$
      ii. L: ¼*(20/43)*567 = 66
      iii. ML: ¼*(23/43)*567 = 76
      iv. MH: ¾*(49/57)*567 = 366
      v. H: ¾*(8/57)*567 = 59
   c. S1-2
      i. $N_{users,S1-2} = 586$
      ii. $\Delta_{S1-1,S1-2} = 21$
      iii. L: (20/43)*21 + 66 = 76
      iv. ML: (23/43)*21 + 76 = 87
      v. MH, H = 366; 59
   d. S1-3
      i. $N_{users,S1-3} = 604$
      ii. $\Delta_{S1-1,S1-3} = 37$
      iii. L: (20/43)*37 + 66 = 82
      iv. ML: (23/43)*37 + 76 = 96
      v. MH, H = 366; 59
   e. S2-1
      i. $N_{users,S2-1} = 1134$
      ii. L, ML, MH, H = 132; 152; 731; 119
   f. S2-2
      i. $N_{users,S2-2} = 1134$
      ii. $\Delta_{S2-1,S2-2} = 38$
      iii. L, ML, MH, H = 150; 172; 731; 119
   g. S2-3
      i. $N_{users,S2-3} = 1208$
      ii. $\Delta_{S2-1,S2-3} = 74$
      iii. L, ML, MH, H = 166; 192; 731; 119

# Appendix E – Cost of Private Car and Carsharing per Resident

These values are specific to Merwede and the CBA Excel model used. Both monthly

To calculate the cost of carsharing, several model outputs of the CBA Excel model are used, this pertains to the total number of hours ($T_{CS}$) and the total number of kilometres ($K_{CS}$) driven using carsharing services. Additionally, the number of carsharing users ($N_{users}$) is used. It is assumed that carsharing users use these services for a maximum of 7500 kilometres per year (Rijkswaterstaat, n.d.) whilst the average private car user uses this mode for approximately 10,000 kilometres per year (Over Morgen, 2021).

Given (following market research): Psub = 153.33; Pt = 3.23; Pkm = 0.29

- $N_{Users,S1\text{-}1} = 567$
- $T_{CS,S1\text{-}1} = 107777/567 \approx 190$
- $K_{CS,S1\text{-}1} \approx 4254350/567 \approx 7503$

(1) Cost of Carsharing: Psub + Pt*[time] + Pkm * [km]

- For 7500 kilometres per year
    - = 153.33 + 3.23*190 + 0.29*7503 = 2942.90 euros per year (245.24 per month) per resident
- For 10,000 kilometres per year
    - = 153.33 + 3.23*190 + 0.29*10000 = 3667.03 euros per year (305.59 per month) per resident

(2) Cost of Private Car Ownership

To calculate the cost of private car ownership, the model input average private car cost (*PCf*) is used and summed with the yearly parking costs either i) in Merwede or ii) distant.

- Parking in Merwede
    - = 8,650 + 12*200 = 10,050 euros per year (920.83 euros per month) per resident
- Distant Parking
    - = 8,650 + 12*50 = 9,250 euros per year (770.83 euros per month) per resident