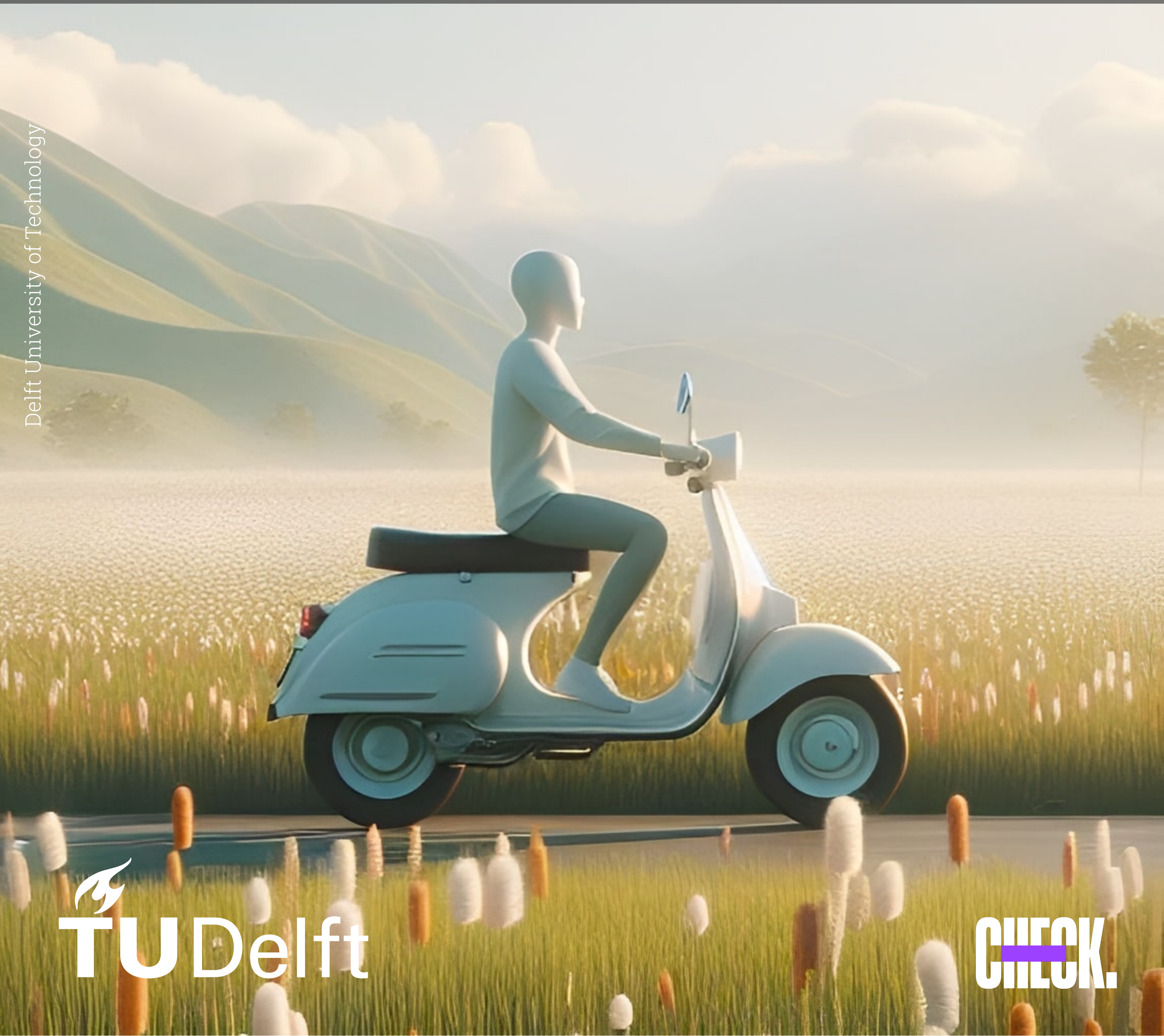
Suburban Shared Mopeds

Evaluating the Viability and Societal Impact Using a Societal Cost-Benefit Analysis Approach

MOT2910

Tim Brandt Corstius



Delft University of Technology

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Duration:	Q1-Q2 2024
Faculty:	Technology, Policy, and Management
Word Count:	26949

TU Delft

Abstract

In recent years, the introduction of shared micromobility options such as scooters, mopeds, and bikes has transformed transportation in densely populated urban areas. In the Netherlands, this is also the case and shared mopeds are available in many of the larger cities. Interestingly, when looking at shared moped availability, it can be observed that they are rarely available in less densely populated areas, such as the suburbs around large cities. This can be explained by the fact that financial viability for private operators is unlikely in these regions because of the lower demand compared to highly densely populated areas. Nevertheless, the introduction of shared mopeds to these suburban regions comes with many external societal effects, which can not be internalised by a private operator but could be internalised by a governmental body. From a governmental perspective, allowing and supporting shared mopeds in their region is only interesting if these external effects result in a societal welfare increase. At the same time, no research exists that investigates the external effects of the introduction of shared mopeds into a suburban region, making it unclear what the potential positive and negative externalities are.

To this extent, this research has investigated the viability and social impact of introducing shared mopeds into a suburban area. Using this impact analysis, an overview of the societal impact of shared mopeds and the profit/loss for an operator in a suburban region has been obtained. To achieve this, a case study method was used to provide an in-depth understanding of the effects of shared moped introduction in a suburban context. The investigated area is the municipality of Schiedam in the Netherlands, due to its proximity to a major city (Rotterdam), high population density, availability of operator data, and other demographic and infrastructural characteristics. This region therefore serves as a high-potential region that with minimal changes or support should become viable. If this region is not viable, more challenging regions are most likely also not viable. Furthermore, two shared moped operator business models have been investigated; free-floating and hub-based models. In a free-floating model, a shared moped is allowed to be parked anywhere within a suburban area, while in hub-based models a shared moped can only be parked in specific GPS-zoned areas. These models have been investigated as some municipalities require operators to switch from free-floating to hub-based models, which have differing characteristics and impact on the net societal benefit.

To verify if operator financial viability in suburban regions is negative, operator demand, revenue, and cost data have been used. This revealed that in the suburban region of Schiedam, shared mopeds are currently not financially viable because of insufficient ridership. This results in a large (discounted) shared moped operator loss for both free-floating and hub-based business models over 10 years in Schiedam. Refer to Table B.4 for the exact loss figures. From an operator perspective, there are no benefits to be gained from utilising hub-based models compared to free-floating models. Data shows that when switching to hub-based models, usage drops significantly while operating costs for re-distribution increase. From a municipality perspective, hub-based models could reduce the number of parking complaints, but, because of the resulting lower demand, the introduction of hub-based shared mopeds also has a lower societal impact compared to free-floating shared mopeds.

Since shared mopeds are demonstrated to not be viable in a suburban region for the operator, other strategies have been considered. One of the possible ways to make the business model viable would be through governmental support. However, governmental support towards shared mopeds would only be likely in the event it increases overall societal welfare. Therefore, it is essential to assess the net societal benefit of allowing shared mopeds in a suburban region. This exploration is the central theme throughout this research. To this end, a societal cost-benefit analysis (SCBA) has been conducted to evaluate and quantify the societal effects of introducing shared mopeds in the region of Schiedam. This SCBA values each effect over a discounted period of ten years, starting in year two and ending in year twelve. To show the uncertainty of the net societal benefit figure a sensitivity analysis has been performed from the perspective of an operator. This analysis has three scenarios: worst, nominal, and best.

For the SCBA, a total of ten different effects have been conceptualised (see Figure 4.1 for a conceptualisation of the effects) and each effect's magnitude and value were investigated. Seven conceptualised effects were valued quantitatively; operator setup cost, operator operating costs, operator revenue, accessibility, carbon emissions, noise emissions, and traffic safety. Three conceptualised effects were valued qualitatively; parking nuisance, public space freed, and the option value.

The magnitude of each effect is dependent on the modal shift and (latent) demand towards shared mopeds. Based on the nominal scenario, primarily users of public transport and biking choose to shift towards shared mopeds. A smaller percentage of the modal shift stems from walking and cars. This modal shift composition negatively impacts the net societal benefit as the highest positive effects occur when people switch from car usage towards shared moped usage. Depending on the region investigated, the composition of the modal shift could change, which is accounted for in the best and worst scenarios. In the best scenario, people mainly shift away from car usage, and there is little latent demand. In the worst scenario, most people shift from public transport towards shared mopeds and latent demand is larger. The valuation of each effect is based on existing key figures sourced from governmental reports, grey literature, scientific literature, and operator data.

Accessibility and safety are the most important positive and negative externalities that impact the net societal benefit. Safety results in a large negative externality as mopeds, including privately owned mopeds, have been proven to be much more dangerous compared to alternative modes. Furthermore, the societal costs of a severe accident or casualty are high, valued at € 0,4-1,2 million for a severe accident and € 4-11 million for a casualty. While the total safety change in the nominal scenario is an increase of 0,118 severe accidents and 0,0029 casualties per year, this results in a non-discounted welfare change of -€ 145.000 per year. The other externality which has a large impact on the net societal benefit is accessibility, which has a positive effect. This externality has been approximated by taking the value of time, ticket/fuel cost, and parking costs for various modes and comparing them to shared mopeds. This results in a welfare change valued at € 200.000 per year in the nominal scenario. In comparison, carbon and noise emissions combined are responsible for a welfare increase valued at € 3.500 per year in the same scenario. Because of the high value of safety and accessibility, over 80% of the net societal benefit can be attributed to these two externalities in each scenario. It shows that these effects are very important, but also risk 'drowning out' other effects. Stakeholders could value some effects differently and in such a case, they could choose to combine results from the different scenarios to get a more accurate image of their valuation.

In Table B.18 one can see an overview of the net societal benefit for each scenario and business model. The SCBA net societal benefit is positive, for the nominal scenario when an operator uses a free-floating model. The net societal benefit becomes negative in the nominal scenario when using a hub-based model. This shows that in the nominal scenario, the business model determines if the societal benefit is positive, and free-floating business models have a higher viability compared to hub-based models. The SCBA net societal benefit does not include unaccounted-for effects and qualitative effects. These qualitative effects include an increase in parking nuisance, shared mopeds freeing up public space (as fewer car parking facilities would be required), and the implicit value of having the option to take a shared moped.

In the worst scenario, the SCBA net present value is very negative, while in the best scenario, the net present value becomes very positive. This large range shows that there is a high amount of uncertainty in the SCBA result, which is caused by not all effects being included and safety and accessibility having a considerable influence on the overall societal benefit figure.

In the future, research should improve the current SCBA by quantifying more effects and increasing the validity of current results. Nevertheless, this research provides a framework to investigate shared moped operator viability and the societal impact in a (potential) region. Furthermore, it gives insight into that safety and accessibility effects should be prioritised when discussing the introduction of shared mopeds into a suburban region, but also which effects still need to be investigated further. Additionally, future research should identify the safety characteristics specifically for shared mopeds, instead of the entire moped population, as this externality has a large impact on the overall net societal benefit. Once this has been performed (and found to be positive), it is recommended to collaborate with governmental bodies to investigate the form, height, and (societal) effect of governmental support. This support was out of scope for this research, but could potentially make the business case for suburban shared mopeds viable while also increasing overall societal welfare.

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1 Introduction

The popularity of shared micromobility has grown over the past decade, allowing people to quickly and easily rent a vehicle for a short term, usually paid by the minute or hour. Out of all shared mobility types, moped sharing is the fastest growing in the Netherlands. Three firms in the Netherlands currently offer e-moped sharing services: Check, Go Sharing, and Felyx. All these firms offer their services predominantly in larger cities in the Netherlands, as shown in Figure 1.1 (Faber et al., 2020; M. Knoope & Kansen Maarten, 2021).

The average trip size in these cities is merely 2,3km with over half of the trips being less than 2km. This can be partially explained by the fact that these services require one to pay by the minute but more importantly, they have service zoning limited to urban areas. This last point is supported by the fact that in a survey of shared moped users, their primary annoyance was the limitation of the service area, disallowing trips to neighbouring suburban cities (Faber et al., 2020; M. Knoope & Kansen Maarten, 2021). This is confirmed by internal data of operator Check, which shows that larger service areas are the second most requested feature.

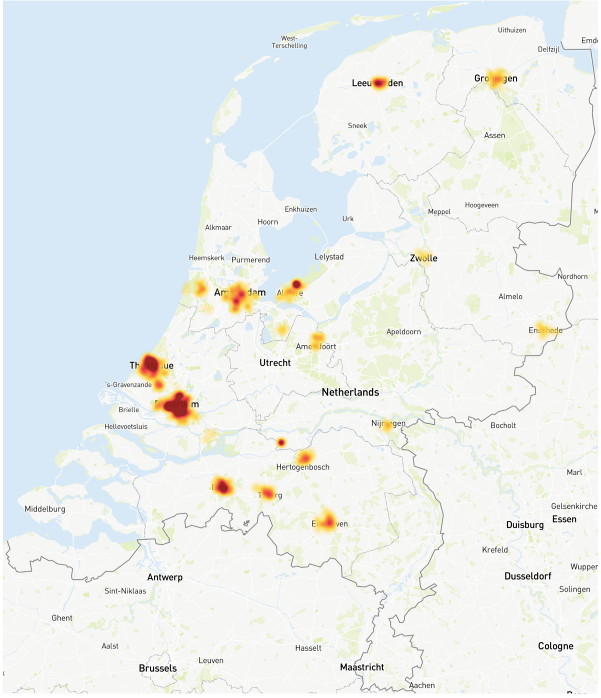

Figure 1.1: Heatmap of Shared mopeds in the Netherlands. Adapted from dashboarddeelmobiliteit.nl

1.1. Scientific Gap

Many challenges are associated with expanding a service zone to include suburban areas. Shared mobility works best when a user can reliably expect a vehicle nearby when they want to utilise the service, which only works with a dense network of vehicles. Additionally, shared mopeds need a high ridership to be financially viable. Data from shared moped operator Check shows that operating shared scooters in suburban areas is not financially feasible because of the low ridership and higher operational cost. Research is therefore needed into how business models impact financial performance, and if certain models improve viability in suburban areas.

From a societal perspective, there has been a change in the modal split between urban and suburban areas. While in Dutch urban areas, the number of people using cars has decreased over the last years from 38 to 30%, in suburban areas it remains high at 48% (Poorthuis & Zook, 2023). A report by Loos (2024), indicates that the energy transition in the Netherlands from fossil fuels towards green energy sources impacts the ability of 100-300 thousand people to transport themselves by car. This may give rise to transport poverty; people who can not afford cars can also not transport themselves easily and therefore experience social disadvantages (e.g. higher unemployment rates or lower income) (Allen & Farber, 2020). As this demographic resides mostly outside the large cities, there would be added value to enabling easy and cheap access from dense cities to their suburbs, reducing overall transport poverty.

At the same time, a public debate has been growing about the effectiveness of shared mopeds. Some municipalities argue for the introduction and expansion of shared mopeds as a way to reduce car usage in cities[1], while others have greatly reduced the number shared mopeds allowed due to the high number of resident complaints[2]. Despite the growing scientific and societal interest in shared micromobility, comprehensive studies investigating the effects of introducing shared mopeds into a (suburban) area remain limited, with the majority of existing literature concentrating on only one effect.

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[1] nos.nl/l/2483397

[2] nos.nl/l/2432155

If the combined effects of introducing shared mopeds to an area increase overall welfare, it could be interesting from a governmental perspective to subsidise the existence of shared mopeds. From an operator perspective, subsidies would enable operation in suburban regions, expanding their user base. Nevertheless, before such subsidisation can be investigated it is crucial to obtain a holistic overview of all the (societal) effects that occur when a municipality allows shared mopeds into their region. Existing scientific literature primarily investigates the trip dynamics, user demographics, and the environmental effects of shared micromobility within urban contexts. However, this body of research often overlooks the potential societal advantages and disadvantages of allowing shared micromobility in (sub)urban contexts. Furthermore, no literature provides a holistic overview of all effects that occur when introducing shared mopeds, and how this impacts societal welfare.

1.2. Research Questions

As previously discussed, the operation of shared mopeds by a private operator in suburban regions is not currently viable. One potential solution to enhance the viability of this business model is the introduction of governmental support. This support could help the operator internalise the external societal effects associated with the introduction of shared mopeds in suburban areas. However, such support would only be of interest to the government if these societal effects lead to an overall increase in welfare. To assess this, one can use a societal cost-benefit analysis (SCBA) to measure the impact on welfare resulting from the introduction of shared mopeds. Despite this, there is a notable lack of research on how different business models affect the financial viability of shared mopeds in suburban regions, as well as a holistic overview of the societal effects of shared mopeds in this context. This literature gap leads to the following research question:

How could the business case for shared mopeds in Dutch suburban areas become viable?

To be able to answer this research question, the following sub-questions are answered:

- What are possible shared moped business models for suburban areas?
  - This question answers what type of shared moped business models are suitable for Dutch suburban areas. Different types of business models could be free-floating (moped can be parked anywhere) versus hub (moped can only be parked in fixed areas). These characteristics could affect the direct profitability of an operator but also have different societal impacts.
- What are the operator revenues and costs associated with the different suburban shared moped business models?
  - The answer to this question maps the costs and revenues of operating suburban shared mopeds for an operator, which gives insight into the business case without any subsidies. If the business case is positive there might not be a need for subsidisation from the government. If negative, subsidisation could be necessary for an operator to expand to suburban regions. Nevertheless, understanding the societal effects could help policymakers make more founded decisions.
- What are the societal effects of allowing shared mopeds in suburban regions?
  - Before calculating a net societal benefit it is crucial to map the possible societal benefits and drawbacks associated with the introduction of shared mobility in Dutch suburban regions.
- What is the value of each societal effect that occurs when allowing shared mopeds in suburban regions?
  - To understand the importance of each societal effect, and create a net societal benefit, it is crucial to understand the total value of each effect.
- To what extent do suburban shared mopeds create a net societal benefit?
  - The answer to this question uses the effects found in the previous question to create a net societal benefit, utilising the Societal Cost Benefit Analysis approach. This net societal benefit substantiates the rationale for further investigation into subsidisation.

1.3. Thesis Outline

This research consists of a total of six chapters. In chapter 2, the methodology is elaborated upon, with an explanation of the usage of an SCBA, how the magnitude and value of each effect are found, and the reasoning behind choosing a case study and the focus region. Subsequently, in chapter 3, background context regarding shared micromobility, its business models, and rider demographics is given.

The largest chapter, chapter 4, consists of five main parts; conceptualisation, modal shift, magnitude effects, value effects, and the SCBA. First, a conceptualisation of all effects that can occur when introducing shared mopeds. Second, the modal shift from other modes towards shared mopeds is determined. Third, the conceptualisation and modal shift are used to determine the magnitude of each effect. Fourth, the cost of each effect is determined on a unit basis (euro per kilometre, trip, kilogram, etc.). Finally, the information described above is combined to form the zero alternative, societal cost-benefit analysis, and sensitivity analysis. For an overview of how this information is combined please refer to Figure 2.1 in the methodology.

Chapter 5 discusses the generalisability, unaccounted-for effects, limitations of an SCBA, and the scientific contribution of this research. Lastly, in chapter 6, an answer is provided to the main research question, and specific recommendations for various stakeholders are made.

2 Methodology

To answer the questions posed in section 1.2 a societal cost-benefit analysis (SCBA) is utilised. An SCBA is a standardised tool the Dutch government recommends using to support policy decisions. It is used to compare different policy alternatives and to get an objective idea of the policy's impact on society (Romijn & Renes, 2013). In an SCBA, direct and indirect effects are measured over x years (depending on how long the policy has an impact) and quantified in Euros where possible. In cases where this is not possible, a qualitative assessment is performed. Subsequently, the quantitative effects are discounted to the present day and the sum of the effects results in a net present value, which represents the net societal benefit. This net societal benefit is used as a tool to help determine if a project or policy should be enacted. For a more detailed explanation of an SCBA refer to Appendix A.1.

To the best of the author's knowledge, no SCBAs exist that investigate how the introduction of shared mopeds in suburban areas impacts societal welfare. A shared moped SCBA would give insight into whether shared mopeds create a net societal benefit. If the SCBA net societal benefit is positive, this would mean that the residents in this area experience a greater amount of welfare after the introduction of shared mopeds compared to before. Such an increase in welfare could make subsidisation interesting from a (local) government perspective, which would prompt an investigation into a shared moped subsidisation SCBA. For the operator, subsidisation would allow the expansion of service zones to suburban regions, which would be financially unviable otherwise. Such expansion could increase their market share and have cascading effects on other regions where they are active. Furthermore, from a scientific perspective, the SCBA gives a holistic overview of how shared mopeds impact society, and helps structure the debate on the effectiveness of shared micromobility. Additionally, the shared moped SCBA provides a framework for future SCBA studies. The following sections detail the methodology for obtaining the value of (societal) effects and the reasoning behind selecting a case study method in this research.

2.1. Magnitude and Value of Effects

One of the most crucial steps in the SCBA is determining the magnitude and value of the effects that occur when enacting a policy. This section details how the magnitude and value of each effect have been determined. In Figure 2.1 one can find an overview of the source type used for researching each effect, and how these effects relate. It can be observed that various source types are used; both scientific and grey (governmental, consultancy, operator data) sources. Sub-research questions 1 and 2 are answered using operator data. Sub-questions 3 and 4 and the main research question are answered using a mix of sources. Any calculations are performed in Microsoft Excel and visualisations are made using app.diagrams.net and the programming language R. Additionally, all cost figures are inflation-adjusted to 2023 using the Dutch Central Bureau of Statistics data[1].

Because little scientific literature is available for shared micromobility effects, grey literature has also been utilised. While the simplified overview in Figure 2.1 suggests little scientific literature has been used, where possible every effect has also been supported through scientific literature. In section 4.1 one can find a detailed explanation of the literature search process. Furthermore, the effects in chapter 4, are substantiated using the literature and corresponding calculations described in each effect section.

A large part of the valuation of various effects is based on governmental reports. Discovering governmental reports is performed through the Google search engine and is often provided on governmental websites such as rwseconomie.nl and rijksoverheid.nl. Governmental reports lie on the border between scientific and consultancy reports but are directly commissioned by a governmental body instead of emerging from the scientific community. Only reports based on scientific literature and held to high-quality standards were selected for this research.

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[1] cbs.nl/nl-nl/visualisaties/prijzen-toen-en-nu

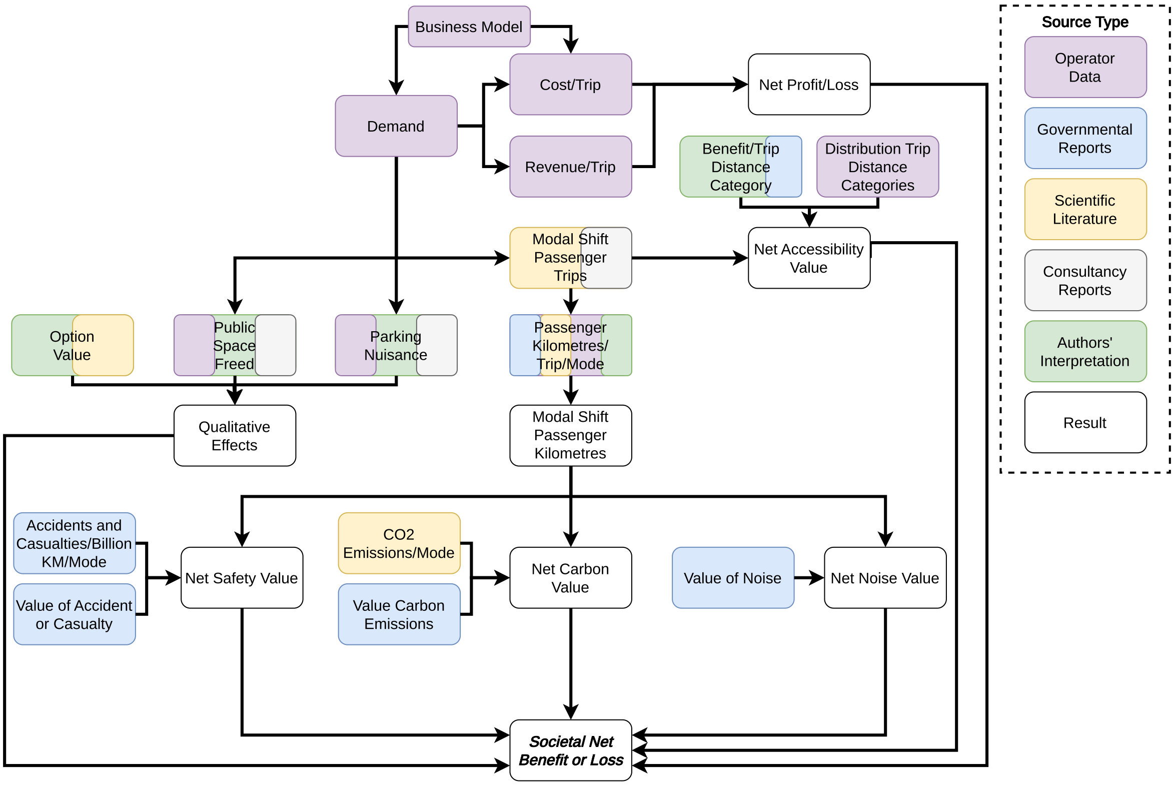


Figure 2.1: Overview of Methodology and Source Types

In the case where sources have contradicting findings, such as in modal shift and carbon emissions, an average and standard deviation is taken. The average is used in the nominal scenario. The standard deviation indicates the uncertainty of the figure between different findings and is used to show if a sensitivity analysis on this figure should be performed. Each effect has its sensitivity range described in its corresponding section.

Operator data is used to determine demand, costs and revenues for the shared mopeds in a suburban area. This data is obtained using SQL queries on the internal database and internal documentation. Existing data in a suburban region allows for an accurate image of demand in trips/moped/day. As the operator has switched from free-floating to hub-based business models, data is also available on the impact of the business model on demand and cost/trip. This data is used to determine the loss of a shared moped operator in a suburban region and, subsequently, the required amount of subsidy. Trip data and scientific sources are used to understand the average distance of a shared moped in the focus region. For how many kilometres people would have otherwise travelled using other modes, assumptions need to be made for the car and public transport modes, and governmental reports are used to determine how far people are willing to walk in a specific region. This results in a modal shift in passenger kilometres (pkt), which is required as many societal effects are expressed in effect/passenger kilometre.

The public space and parking nuisance effects are found using consultancy reports and confirmed using informal conversations with the operator. Option value has been based on scientific literature, and elaborated upon using the authors' knowledge.

One notable exception to the methodology to obtain the net value of an effect is the accessibility value. Because no existing stated or observed preference studies exist for the accessibility value of shared mopeds, and performing such an experiment is out of scope, a proxy was created. This proxy is described in subsection 4.4.2, and consists of the creation of five distance categories. These distance categories are based on existing operator trip data in the focus region.

For each category, a beginning and end address is determined as a proxy for that trip. Subsequently, the time it takes to travel between the beginning and end address is determined using Google Maps. This time is multiplied by the value of time found in governmental reports to obtain the cost of a trip. Ticket costs were determined using 9292.nl and operator data. Parking costs are based on the costs of the nearest parking place (found on garage or municipal websites). The largest delta between an alternative mode and a shared moped for each category is taken and used as an accessibility benefit for that distance category. The reasoning behind taking the largest delta can be found in subsection 4.4.2. To obtain a single figure, the category deltas are averaged using the relative frequency a trip category occurs. Finally, the rule-of-half (see subsection 4.4.2 for an explanation) figure is used to obtain the final accessibility benefit in euros per trip.

To conclude, various sources and methods are used to substantiate and quantify the effects that occur when introducing shared mopeds to suburban regions. The primary method used for quantification is to combine grey and scientific literature with operator data. The next section will detail the selected research approach and focus region.

2.2. Case Study: Schiedam

This research uses a single instrumental case study as its research method. A case study is ”a research approach that is used to generate an in-depth, multi-faceted understanding of a complex issue in its real-life context” (Crowe et al., 2011, p.1). An SCBA is usually performed on a future real-world policy decision that has an effect on society. Because the magnitude and type of effects can differ greatly between regions, it is crucial to select a specific suburban region to use as a case study. This helps to understand the effects of introducing shared mopeds into a suburban region in a real-life context and gives insight into the importance of each effect. Furthermore, to get a true understanding of demand patterns, existing operator data is needed which requires investigating a specific suburban region where an operator is, or has been, active. Shared micromobility operator permits are usually granted on a municipality level. Therefore the scale of each selected region will be the size of the municipality.

Considerable effort has gone into the selection of the focus region, which needs to adhere to various criteria. The full selection process can be read in Appendix A.3. The selected focus region for this research is the municipality of Schiedam, see Figure 2.2 for the region boundaries, as it is close to a large city (Rotterdam), has a train station nearby, has a high population density, a low number of cars per household, a similar average income to Rotterdam, a young population, and operator data is available. At the same time, the shared moped usage in Schiedam is much lower compared to the usage in Rotterdam. Because Schiedam has most attributes of a high-potential region, and demand is not extremely low, it is the most suitable region to function as a baseline. If the business case in this region is not viable, there is a high probability it is also not feasible in other regions with lower demand. Needless to say, it could be the case that some societal effects outweigh the extra operator costs in other regions. In such a case, this research could be used as a framework to investigate these regions.

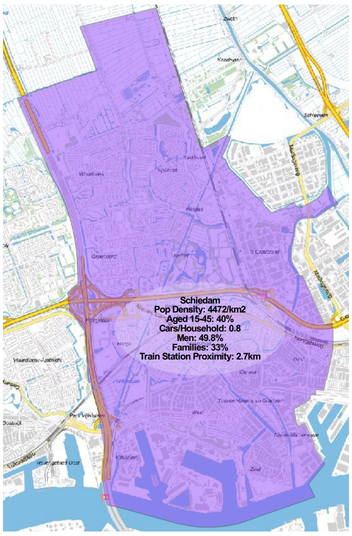


Figure 2.2: Map of Focus Region Schiedam

Crowe et al. (2011) mention that the lack of generalisability is a pitfall of case studies. To combat this, the SCBA guidelines are used and the research process has been made as transparent as possible. Nevertheless, this research is most applicable to the region of Schiedam and will need to be repeated for other regions. To this extent, generalisability is extensively discussed in section 5.2.

3 Shared Micromobility

This chapter discusses some key aspects related to shared micromobility, its business models, and its users. The definition of a business model is provided, the different existing business models for shared micromobility are explained, and the rider demographics are investigated. This information is used as context for the next chapters.

3.1. Definition Business Model

One of the key concepts required to answer the research questions is the definition of a business model. This model can be used to understand how shared mopeds are currently exploited in Dutch urban areas and to contrast this with possible models in suburban areas. Bagnoli et al. (2018) provides an overview of existing business model literature and shows that the definition of a business model differs widely between papers. While they attempt to give a comprehensive definition of a business model by incorporating four different dimensions (”the value dimension, the modelling principles dimension, the functional dimension, the strategy dimension” (p. 48)), this definition becomes unnecessarily complex for this research. Therefore, the definition by Teece (2010) is adopted: ”A business model articulates the logic and provides data and other evidence that demonstrates how a business creates and delivers value to customers. It also outlines the architecture of revenues, costs, and profits associated with the business enterprise delivering that value.” (p. 173). This definition encompasses all the necessary aspects that are needed for the definition of a business model to answer the research question.

3.2. Shared Micromobility Business Models

Research into shared mobility has uncovered six different categories of shared mobility: car sharing, bike sharing, on-demand ride services, micromobility, alternative transit services, and courier network services (Roukouni & Correia, 2020). This research focuses on shared micromobility, which encompasses the sharing of (e-)mopeds, (e-)bikes and (e-)scooters (most often via an app). More specifically, a focus is put on e-moped sharing. In the Netherlands, (e-)mopeds have a speed limit of 25 or 45km/h, require a driver’s license, can be ridden from 16 years of age (for shared mopeds it is usually from 18 years of age), and can carry a maximum of two passengers. For a more extensive definition of a moped refer to Appendix A.2.

Little research has been performed on the business models of shared e-mopeds, but parallels can be drawn with the different business models of bike and car sharing. One important aspect of these business models is the method by which users can retrieve or return their vehicles. Three methods to manage the retrieving and returning of shared bikes and cars have been identified (Jorritsma et al., 2021):

- **Roundtrip (Station Based):** The vehicle has to be both retrieved and returned at the same station.
- **One-way/Hub (Station or GPS Based):** The vehicle has to be retrieved from a station but may be returned to many other stations. A station can be either a physical station or a GPS-based ’geofence’.
- **Free-floating (GPS Based):** The vehicle has to be retrieved and returned within a certain area. This is usually enforced by using GPS-based ’geofencing’.

Users of shared micromobility services usually pay by a fixed time interval (day, hour, or minute), with some operators also charging an ’unlocking’ fee or by distance. Currently, most Dutch shared moped operators mostly work with a free-floating model and payment by the minute with an unlocking fee. The challenge with one-way and free-floating models is that the distribution of vehicles may become unbalanced, resulting in users not being able to select a vehicle in the near vicinity. This forms a problem as many users will not utilise the service if the nearest vehicle is not very close by. Research by Boting (2023) suggests 225 meters is the maximum distance people are willing to walk for a shared e-moped. Solutions for this problem have been proposed by requiring either manual intervention by the operator (by moving the vehicles), or incentivising users to return their vehicles in an area with high demand (Caggiani et al., 2018).

Both of these re-balancing strategies can be costly as in manual intervention the operator must hire someone to manually move the vehicles, and incentivising users is usually done in the form of free ride minutes, which indirectly impacts revenue.

3.3. (Shared) Moped Rider Demographics

To fully comprehend why people are using shared mopeds, it is crucial to map rider demographics.

For Dutch private mopeds, most moped owners are male and aged between 50-70 years. Mopeds that can go 45km/h are predominantly used by people in the age bracket 50-60, and 25km/h mopeds are used by people in the age bracket 60-70. It has to be noted that owners were not the same as users, as some users might be children of which the parents legally own the moped (due to the cost of insurance) (M. Knoope & Kansen Maarten, 2021). Furthermore, M. Knoope and Kansen Maarten (2021) found that moped usage is dependent on the weather, with users making more use of them during spring and summer and less during autumn and winter. Interestingly, users who do not use shared mopeds perceive them as unreliable. In contrast, shared moped users view them as very reliable. This contradiction between users and non-users shows that there is a certain stigma towards shared mopeds in the Netherlands (M. Knoope & Kansen Maarten, 2021).

For Dutch shared mopeds, the age demographic is very different. Movares (2023) found that the primary users are between 18-35 years old (69%). The average shared moped user age is 28,6 years. An overview of the age distribution of shared moped users can be found in Figure 3.1. Why this age demographic differs from private mopeds is not scientifically proven. Still, it is hypothesised that shared mopeds attract younger users because they use an app to unlock and ride them. Additionally, shared mopeds are a new phenomenon and therefore will need time to diffuse throughout the market. Of the shared moped users, about 35% of users say they use them for work commutes (Movares, 2023).

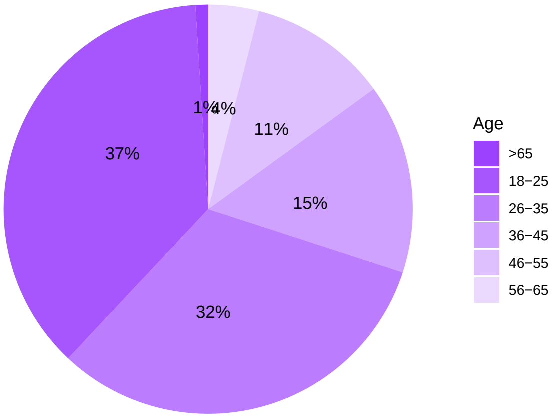


Figure 3.1: Age Distribution of Shared Moped Users.
Adapted from Movares (2023)

In the 18-36 age bracket, about 60% do not own a personal car. Most trips were unimodal (69%), 28% multimodal, and the remaining 3% were classified as other. Furthermore, 16% of trips started or ended near a train station, further enforcing that multimodal trips are less common compared to unimodal trips (Movares, 2023).

To summarise, the users of shared mopeds are primarily males aged between 15 and 36, who do not own a personal car, and use shared mopeds mainly for recreational purposes. Furthermore, the condition of the weather has a large impact on usage. Most trips were unimodal, with ~ 1/4th of trips being multimodal.

4 Results

The following sections present the steps taken and data collected to understand and create the societal cost-benefit analysis for the introduction of shared mopeds in suburban regions. The literature search process is explained, and the effects of introducing mopeds are conceptualised. Subsequent sections detail the modal shift, the magnitude of each conceptualised effect, the cost of each conceptualised effect, and the zero alternative. This data is used to create the societal cost-benefit analysis in section 4.7 and the sensitivity analysis in section 4.8.

4.1. Literature Used

This chapter makes extensive use of various forms of literature to support the figures and statements made. In this section, the search process and resulting literature are detailed.

In Table 4.1 one can see the search terms used in the Scopus search engine, the number of results, and the number of papers that were deemed relevant for this research. While shared AND mobility AND business_model resulted in 148 search results, most of them were focused on bike or car sharing, which resulted in only two papers that were deemed relevant. In total 42 papers were deemed relevant and therefore extensively read.

Table 4.1: Scopus Search Results

Search Term	Results (N)	Relevant (N)
last-mile AND micromobility	71	6
shared AND micromobility	241	18
shared AND mobility AND business_model	148	2
shared AND moped	46	15
subsidy AND micromobility	1	0
subsidy AND shared AND transport	37	1
suburban AND moped	2	0
Total Unique	**484**	**42**

An overview of the 42 papers and their category can be found in Appendix A.4. From these 42 papers, 12 are used in the following result sections. The twelve selected papers can be categorised into four different topics, with some papers spanning multiple topics. An overview of these topics and papers can be found in Table 4.2. A large portion of the scientific body is focused on (kick) e-scooters instead of e-mopeds. Nevertheless, it is assumed that both e-scooters and mopeds will exhibit similar characteristics. Interestingly, there has been a large focus on trip characteristics, rider characteristics, and the environmental impact of shared e-scooters and e-mopeds. Furthermore, almost all research focuses on urban areas.

Table 4.2: Used Papers Sorted by Topic

Author	Main Topic
Arias-Molinares et al. (2021), Caspi et al. (2020), Latinopoulos et al. (2021), Liao and Correia (2022), Mitropoulos et al. (2023), Oluwajana and Wang (2023), Reck et al. (2021), A. Shaheen and Cohen (2019), and Wortmann et al. (2021)	Trip Characteristics
Liao and Correia (2022), Mitropoulos et al. (2023), and A. Shaheen and Cohen (2019)	Rider Characteristics
de Bortoli and Christoforou (2020), Kazmaier et al. (2020), Schelte et al. (2021), and Wortmann et al. (2021)	Environmental Impact
Wortmann et al. (2021)	Operator Cost Estimation

Snowballing and searching the Google search engine for governmental reports resulted in 24 additional relevant reports. Furthermore, all data was complemented with trip data and commissioned reports from Check. An overview of snowballed, Googled, and Check obtained reports can be found in Table 4.3.

Table 4.3: Overview of Snowballed, Googled, and Check Obtained Reports

Author	Type	Main Topic
Hilster et al. (2022)	CE Delft for Felyx	Environmental Characteristics
Schroten et al. (2021)	CE Delft for Government	
Leestemaker et al. (2023)	CE Delft Research	
Grobben et al. (2023)	Check Commissioned Report	
de Bruyn et al. (2023)	CE Delft Research	
van Essen et al. (2019)	Governmental EC	
Walch and de la Court (2022)	Municipality Utrecht	
Aalbers et al. (2016)	Governmental CPB/PBL report	
Finke et al. (2022)	Research Paper	
Wijnen (2022)	Governmental KiM	Rider Safety
Oude Mulders et al. (2023)	Governmental SWOV	
SWOV (2021)	Governmental SWOV	
SWOV (2023a)	Governmental SWOV	
CBS (2023)	Governmental CBS	
Geurs et al. (2006)	Research Paper	Trip Characteristics
R. M. Knoope (2023)	Governmental KiM	
Groningen (2023)	Municipality Groningen	
ACM (2021)	Governmental ACM	Trip and Rider Characteristics
de Haas and Kolkowski (2023)	Governmental KiM	
M. Knoope and Kansen Maarten (2021)	Governmental KiM	
Kets et al. (2023)	Municipality Almere	
Movares and Amsterdam (2022)	Municipality Amsterdam	
Hofmann and Kaufmann (2013)	Research Paper	
Movares (2023)	Check Commissioned Report	Trip, Rider, and Environmental Characteristics

4.2. Conceptualisation of Effects

Based on the existing literature and the author's judgement, a conceptual model has been developed which can be seen in Figure 4.1. This model shows the hypothesised (societal) effects that occur when shared mopeds are introduced into suburban municipalities and is used as a thought framework throughout the rest of this research.

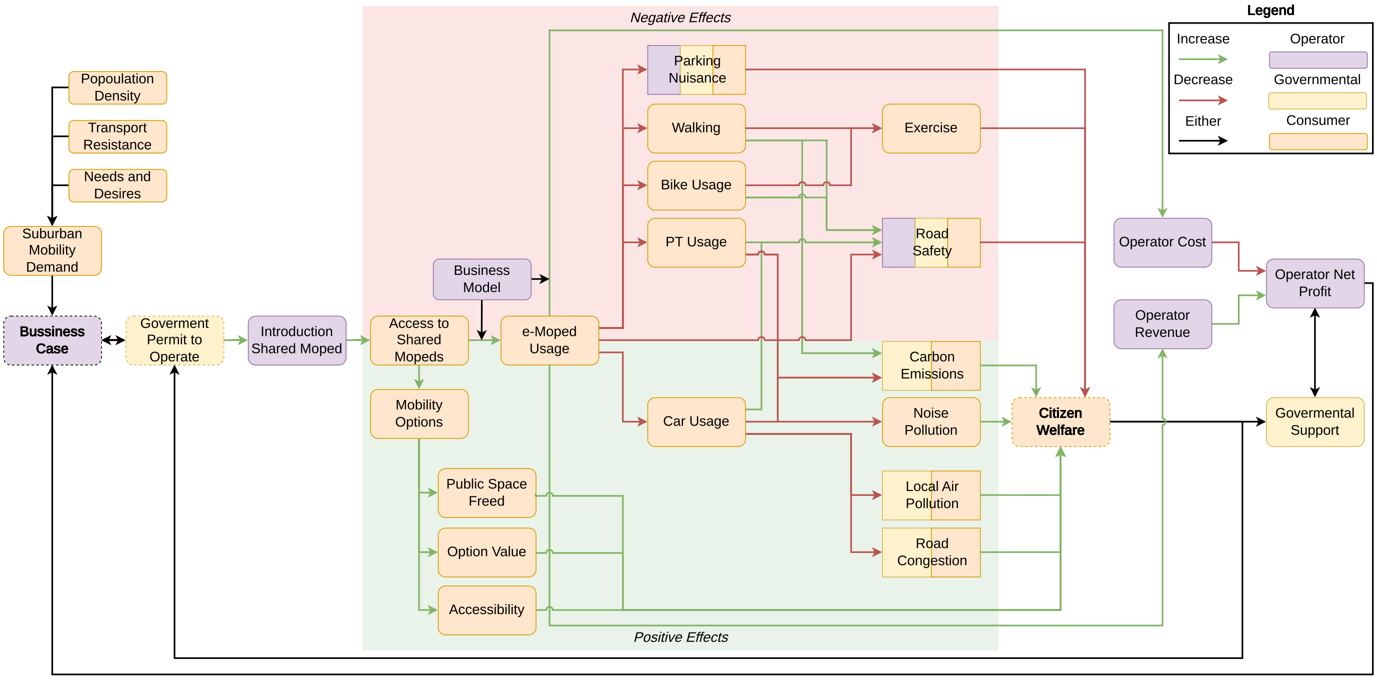


Figure 4.1: Conceptual Diagram of the Effects of Introducing Shared Mopeds to Suburban Regions

Linked to the main research question, the conceptualisation starts with the shared moped business case, which is impacted by suburban mobility demand, governmental permits, and operator net profit. In suburban areas, the market currently can not sustain private shared moped operators, which is why governmental support is modelled to impact operator net profit. Governmental support would be a way in which shared mopeds could be sustained in suburban areas. Both governmental support and the government permit to operate are contingent on the overall increase in citizen welfare when introducing shared mopeds into the respective governed region. This citizen welfare is the central key theme throughout this research. If this welfare increases with the introduction of shared mopeds, governmental support and permits are likely to be positive, which has a large impact on the business case. Citizen welfare is conceptualised to be impacted by ten main effects:

- **Road Safety:** The change from other modes towards shared e-mopeds, the modal shift, impacts road safety. Modes such as walking, biking, public transport and driving a car are safer compared to driving a moped. If people shift away from these modes towards mopeds, overall road safety goes down. This reduction in safety has a large negative impact on citizen welfare.
- **Accessibility:** Shared mopeds increase overall accessibility, be it by providing transport to places where public transport does not go, reducing direct consumer cost, or reducing transportation time. This effect encompasses the perceived consumer expense of shared scooters compared to other modes. The introduction of shared mopeds increases accessibility which greatly increases citizen welfare.
- **Carbon Emissions:** The modal shift from polluting modes, such as car usage and some forms of public transport, towards electric mopeds decreases carbon emissions. At the same time, shifts from non-emitting modes such as walking and biking towards electric mopeds increase carbon emissions. Overall, carbon emissions decrease when introducing shared mopeds to a region, which is beneficial as it helps reduce climate change and aligns with the EU goal to become climate neutral by 2050. This decrease in carbon emissions therefore increases citizen welfare.
- **Noise Pollution:** The shift from noisy modes such as cars and public transport towards quiet modes such as walking, biking, and electric (shared) mopeds, reduces overall noise pollution. Therefore, the introduction of shared mopeds increases citizen welfare.
- **Exercise:** When people shift away from active modes, such as walking and biking, towards passive modes, such as using public transport or driving a car/moped, they reduce their exercise. This reduction in exercise has negative health effects, which negatively impact citizen welfare.
- **Local Air Pollution:** This effect acts similarly to the carbon emission effect; the modal shift from car and public transport usage decreases air pollution while the modal shift from walking and biking increases air pollution. The difference is that it also encompasses chemicals other than carbon emissions and focuses on local air quality. This effect has not been researched extensively, but it is hypothesised that the introduction of shared mopeds decreases local air pollution. This decrease in air pollution increases citizen welfare.
- **Road Congestion:** When car users switch to shared mopeds, a reduction in car traffic occurs. This reduction results in less road congestion, which decreases road rage and transportation time for car users who do not have the option to switch to shared mopeds. This effect has not been researched extensively but is expected to be minor as the number of car passenger kilometres replaced is small compared to the total car passenger kilometres travelled. The small reduction in congestion would increase citizen welfare.
- **Parking Nuisance:** Shared mopeds have caused some parking nuisance when introduced in regions in the past. The percentage of parking complaints is low when comparing them to the total number of rides, but because residents see the same moped model wrongly parked they can feel like shared mopeds are parked incorrectly more often compared to private mopeds. This increase (or increased feeling of) in wrongly parked vehicles, increases parking nuisance, which decreases citizen welfare.

- **Public Space Freed:** When the introduction of shared mopeds motivates people to sell their cars, fewer parking spaces are needed within the city. This space can be redeveloped to facilitate other welfare-enhancing developments. This effect has been researched qualitatively and shared mopeds would increase free public space, which increases citizen welfare.
- **Option Value:** The introduction of shared mopeds provides an alternative option to existing modes. Having this option available has value, even when people do not actively use shared mopeds. For example, car drivers value public transport being available in the case when they are unable or willing to drive. This effect has been researched qualitatively, and the option of having shared mopeds increases citizen welfare.

These ten effects all impact citizen welfare, but accessibility and road safety have the largest impact because of their high valuation compared to other effects. The other effect that impacts the business case is the operator's net profit, which consists of operator cost and revenue. Both revenue and cost are contingent on the usage of the shared e-mopeds, with higher usage driving more marginal costs but also increasing revenue. The business model (free floating or hub) impacts usage but also changes the marginal operator costs. All the effects in Figure 4.1 come together to form the citizen welfare, which combined with operator net profit and the possibility of governmental support form the business case for suburban shared mopeds. It is important to note that this research does not investigate how and in which form this governmental support should be implemented but rather focuses on investigating the welfare change when introducing shared mopeds into suburban regions. There is a focus on suburban areas, as highly urbanised areas do not need governmental support for the business case to become viable because of their differing characteristics which impact demand. Furthermore, the magnitude and value of each effect may differ per region, which is why a single suburban region has been selected. In Table B.10 one can find a summary of the modal shift in passenger kilometres, in Table 4.10 one can find a summary of the magnitude of each investigated effect, and in Table 4.15 a summary of the cost per unit for each effect. These figures are used to create the societal cost-benefit analysis, found in section 4.7. The following sections are based on the conceptualisation in Figure 4.1 and detail the modal shift, effect magnitude, and cost per unit for each effect.

4.3. Modal Shift

As seen in Figure 4.1, the increase in e-moped usage affects the usage of other modes. When introducing shared mopeds into a region it is important to understand what users would have used as an alternative mode of transportation if the mopeds were not introduced. A net social benefit mainly occurs if people move from unhealthy and polluting modes of transportation towards healthier and cleaner modes. This section reviews literature addressing the modal split change when shared micromobility was introduced to understand how the modal split changes with the introduction of shared mopeds.

4.3.1. Modal Shift in Number of Trips

Various researchers have investigated how the introduction of micromobility changed modal use. This section first details the findings by numerous authors, which are subsequently used to create an overview of the modal shift in the number of trips.

A. Shaheen and Cohen (2019) researched bike and standing scooter sharing policy recommendations. They found that for scooter sharing, 71% of users used it for commuting, while the remaining 29% used it for recreational purposes. They suggest that ”public bike sharing may be more complementary to public transportation in small and medium metropolitan regions and more substitutive in larger metropolitan areas” (p.7). This points towards differing trip characteristics between urban and suburban areas. Interestingly, according to this study, six per cent of scooter users sold a vehicle and 16% were considering selling a vehicle because of the introduction of shared scooters.

Dibaj et al. (2021) performed a literature review on dockless shared e-scooters. One reviewed paper reported a 62% walking, 19% driving and 10% biking substitution for commuting trips. Another reviewed paper reported that in Austria, 35% of walking was replaced by e-scooters, with almost no car trips being replaced. Another extensive literature review by Liao and Correia (2022) compared electric cars, e-bikes, e-cargo bikes, and e-scooters. In this literature review e-bikes and mopeds are merged, but it is stated that e-bikes have the highest proliferation. E-bike trips substituted 4-17% of car trips, while e-scooter trips substituted 34% of car trips. At the same time, e-bike trips replaced 30% of public transport trips, with e-scooter trips replacing 11% of PT trips. Walking trips were replaced by e-bikes 27% of the time and 37-41% of the time for e-scooters. Finally, cycling was replaced 11% of the time by e-bikes and 5-7% of the time by e-scooters. Furthermore, the introduction of e-scooters induced demand by 7%.

Mitropoulos et al. (2023) made an extensive summary of 38 papers, focusing on e-scooters. Shifts from walking varied between 13,2-44%, but most literature found a modal walking shift of around 40%. Interestingly, while the substitution in the number of trips falls around 40%, the substitution in vehicle kilometres travelled was only 25%. This shows that walking trips were relatively short, but were replaced many times. Public transport was substituted between 10,5% (with only bus users), to 55.9% (with more multimodal transport such as metro + bus). The shift away from cars ranges between 7,3-53%, which is a large range, but the average substitution rate was 24%, with most papers finding a rate around this average. Reck et al. (2022) showed that 12% of trips were replaced by cars, but that only resulted in 15% of the vehicle kilometres travelled being replaced. This shows that the car trips that were replaced were mainly shorter. E-scooter trips replaced biking trips 4-25% of the time, with an average of 12.9%.

It has to be noted that a report by Movares (2023), commissioned by the three main Dutch shared moped operators, reported 62% would have otherwise biked, 61% would have used public transport, 23% the car, 38% would have walked, and 6% of demand was induced. As it was commissioned by the three large Dutch shared moped operators, the report might not be fully objective. Interestingly, the modal change from walking and driving is similar to other studies. Still, a significantly larger group of people switched away from public transport and biking compared to other studies/regions. As the Netherlands has a high number of people who bike actively, it follows logically that there is also a higher propensity for people to switch from biking to shared micromobility.

Interestingly, Hilster et al. (2022) reported just a 23% shift away from biking, which is much lower compared to the Movares or van Wechem studies. Their data comes from the Municipality of Rotterdam, making it unclear why there is such a large discrepancy. It has to be noted that the research by Movares (2023) and Hilster et al. (2022) was performed primarily in Dutch urban areas, which have better public transport and bikeable distances compared to suburban areas. Therefore the Dutch suburban modal shift might differ from the presented results.

The municipality of Groningen found that most people traded public transport and biking for shared mopeds. Interestingly, between the student and working population, a discrepancy exists between the modal shifts from public transport and cars. Students much more often switch away from public transport (34% vs 17% for working people), and working people much more often from the car (20% vs 3% for students) (Groningen, 2023). This can be explained by the purchasing power of the different groups and points towards a potential increased shift away from car usage in cities with a low student population. At the same time, as reported in section 3.3, there are more student-aged shared micromobility users compared to working-aged users, which could balance out the number of cars replaced by shared mopeds. The municipality of Almere found that users mostly replaced public transport with shared mopeds, but it has to be noted that there were merely 61 participants in this study, making the results insignificant (Kets et al., 2023).

In Table 4.4 one can find an overview of the existing literature, showing the modal split change when introducing shared micromobility. As some surveys allowed multiple answers, percentages can add up to more than 100. It can be observed that when taking the average, there are some differences between European and non-European modal changes. Europeans tend to substitute public transport and biking more while substituting cars less. When observing Dutch data only, it can be seen that mainly biking and public transport are being replaced by shared mopeds, while walking and driving are replaced less.

Table 4.4: Modal Change After Introducing Shared Micromobility

Author	Mode	Region	Trip Replacement (% of trips)			
Literature Review: Liao and Correia (2022)			**Walking**	**(e-)Bike**	**PT**	**Car**
Campbell et al. (2016)	e-Bike	Beijing, China	27	11	30	17
Munkácsy & Monzón (2017)	e-Bike	Madrid, Spain				5
Hollingsworth et al. (2019)	e-Scooters	Raleigh, USA	41	7	11	34
PBOT (2019)	e-Scooters	Portland, USA	37	5		34
Literature Review: Mitropoulos et al. (2023)						
Luo et al. (2021)	e-Scooters	Indiana, USA	44		27	
Abouelela et al. (2021)	e-Scooters	San Fransisco, USA				23
Yang et al. (2021)	e-Scooters	Illinois, USA		10,2		
Edel et al. (2021)	e-Scooters	Germany	42,1	25,5	51.6	28,4
Moreau et al. (2020)	e-Scooters	Belgium	26,1	15,7	29,2	26,7
Hollingsworth et al. (2019)	e-Scooters	North Carolina, USA	41,2	7,4	10,5	33,8
Latinopoulos et al. (2021)	e-Scooters	Paris, France	37	5	32	26
de Bortoli & Christoforou (2020)	e-Scooters	France	34,6	7,4	47	9,8
Weschke et al. (2022)	e-Scooters	Germany	42,8	14,2	19,06	15,1
Reck et al. (2022)	e-Scooters	Zurich, Switzerland	51	18	19	12
Literature review: Dibaj et al. (2021)						
Laa and Leth (2020)	e-Scooters	Vienna, Austria	35			
Sanders et al. (2020)	e-Scooters	Tempe, USA	57	8		25
Report: Faber et al. (2020)						
Kerst (2019), BSc Thesis	Mopeds	Netherlands		30	31	12
van Wechem (2020)[1]	Mopeds	Netherlands	50-70			20-30
Movares (2023)[1]	Mopeds	Netherlands	38	62	61	23
Hilster et al. (2022)[1]	Mopeds	Rotterdam, NL	10	23	27	30
Groningen (2023)	Mopeds	Groningen, NL	9,2	44,3	24,6	13,3
Kets et al. (2023)	Mopeds	Almere, NL	21,3	13,1	41,0	9,8
Mean			**35,1**	**18,0**	**31,4**	**21,1**
Standard Deviation			**12,5**	**15,4**	**15,4**	**9,1**
Mean Europe Only			**32,1**	**23,5**	**35,6**	**18,0**
Standard Deviation Europe Only			**13,0**	**16,9**	**15,1**	**8,4**
Mean Netherlands Only			**23,3**	**34,5**	**40,9**	**18,5**
Standard Deviation Netherlands Only			**14,2**	**19,1**	**16,5**	**8,0**

[1] Comissioned by Dutch Shared Moped Operators

Internal data from Check over 2023-2024 shows a modal shift from 28% from biking, 24% from driving, 17% of public transport, and 7,6% from walking. Interestingly, the figures for biking and driving are similar to the figures found in other papers, but the figures for public transport and walking differ greatly. This could be explained by possible sample bias for the Check data, as only a part of the users fill in the survey. Furthermore, survey users can only select one mode of substituted transport, which could lead to biking and driving being the most reported replaced method, compared to public transport and walking.

One other important shift is the shift from not making the trip to deciding to make the trip because of the introduction of shared mopeds. This induced demand does not substitute any other mode and therefore has a different impact on the societal effects compared to when they replace an existing mode. Mitropoulos et al. (2023) found that Weschke et al. (2022) reported a 7,9% induced demand and Hollingsworth et al. (2019) a 7,1% induced demand. Movares (2023) reports a 7% induced demand, Groningen (2023) reports a 5,2% induced demand, the municipality of Amsterdam reported a 4% induced demand (Movares & Amsterdam, 2022), and Hilster et al. (2022) reports a 3% induced demand. The mean of these reports results in a 5,7% induced demand, with a standard deviation of 1,9%. This report uses 5,7% as the figure for induced demand.

4.3.2. Average Distances per Mode

The size of the conceptualised effects in Figure 4.1 depends heavily on the number of trips and the distance of trips that are replaced. To better understand current shared micromobility usage, this section will detail existing research on peak usage times and the average distance travelled. The distances are also used to convert the modal shift in trips to the modal shift in kilometres, see subsection 4.3.3. This conversion is required to quantify various effects, as these are often expressed per (passenger) kilometre.

Shared Mopeds

This section investigates distances travelled, usage times, and other effects that impact the usage of shared mopeds.

Caspi et al. (2020) researched spatial movements of shared e-scooters in Austin, Texas. They found that peak usage occurred around 09:00, and between 12:00-18:00. Usage is highest in regions with commercial and industrial land use. Furthermore, bike lanes and bus stops increased usage in these areas. They suspect users mainly use the scooters for recreational purposes, as the usage during holidays and weekends is higher compared to during the week. Additionally, Oluwajana and Wang (2023) researched e-scooter trip data and found the average distance to be 4,7km and the peak usage to be between 18:00-00:00, while A. Shaheen and Cohen (2019) found a usage peak between 15:00-18:00 for commuters and 14:00-17:00 for recreational users.

Reck et al. (2021) modelled micromobility usage in Zurich, Switzerland. Their focus was on dockless e-scooters and docked and dockless (e-)bikes. They found that peak usage for e-scooters was between 21:00 and 05:00, and the off-peak hours were between rush hours (06:00-09:00, 16:00-19:00). This suggests that e-scooters were primarily used for trips other than commuting. The e-scooters were mainly chosen if the to-be-travelled distance was below 650 meters. Interestingly, between docked and dockless e-bikes, the docked version was chosen more often, with 64% of users choosing to ride a docked e-bike when available, compared to only 19% for dockless e-bikes. At the same time, vehicle density has a much larger impact on dockless solutions (lower density = lower usage) compared to docked solutions. This could point towards a preference for docked solutions compared to dockless solutions. Reck et al. (2021) hypothesise that this could be because users know the docks' fixed positions, enabling more habitual usage. The probability of choosing a free-floating e-scooter when available was around 25%. When battery charge gets below 40%, there is a decline in choice probability, pointing towards the importance of having fully charged vehicles. When raising prices of free-floating e-scooters by 1%, the choice probability went down by 0,94%, with people mostly shifting towards competitors and some towards other modes. This shows that people are price-sensitive when it comes to the use of shared micromobility.

Arias-Molinares et al. (2021) found that the average moped trip distance in Spain's larger cities is 3km. 72% of trips were made on workdays, while only 28% on weekends, suggesting that many trips are made for commuting purposes. Peaks occurred between 08:00-09:00, 13:00-14:00, and 18:00-20:00, with the biggest peak occurring in the evening. Furthermore, they show that these peaks correspond with commuting to work, with people travelling towards urban cores in the morning and back towards their place of residence in the evening, which is contrary to the findings by Reck et al. (2021). The users in the evening often leave the scooters at different places compared to the morning users (suggesting that they are a different user group), which results in the operator needing to move the moped to other places manually.

Liao and Correia (2022) summarises that the mean trip size is between 0.65-1.96km for e-scooters and 2km for e-bikes. Peak e-scooter usage during the week occurred between 15:00 and 18:00, with e-bike peaks occurring during the morning and evening work commutes. Mitropoulos et al. (2023) found an average e-scooter trip distance of 1.2-3.5km for US cities and 1,5-4,5km for European cities. Interestingly, between two studies performed in Paris, one reported an average distance of 1,85km, while the other reported 3,3km. This shows that within cities trip distances vary between reports.

Hilster et al. (2022) found an average travel distance of 3,1km for mopeds with a 25km/h speed limit and 3,8km for mopeds with a 45km/h speed limit. This shows that faster mopeds facilitate slightly longer trips.

M. Knoope and Kansen Maarten (2021) found that 45km/h mopeds were mainly used for work commutes (54% of commute purposes), while 25km/h mopeds were mainly used for recreation purposes (41% of commute purposes). This is also reflected in usage times, with 45km/h mopeds mainly used during rush hour (41% of total usage) and 25km/h mopeds primarily used during off-peak hours (46% of total usage).

Faber et al. (2020) found the average trip length to be 2,3km, based on Dutch operator data. Interestingly, they also provide the distribution of trip length, which shows that 8% of users travel more than 5km on the moped. This longer trip length could facilitate trips between cities. It has to be noted that mainly privately owned mopeds currently get used for larger distances (34% travel >5km), which shows a barrier related to the shared aspect of mopeds, limiting longer distances. Faber et al. (2020) claim that a service zone expansion and a possible reduction in consumer costs could facilitate longer trips. It has not been extensively researched if service zone size is the primary barrier to enabling longer trips, but it has been one of the primary wishes of users to have larger service zoning (M. Knoope & Kansen Maarten, 2021; Movares, 2023). Movares (2023) found an average distance of 3,6km in large municipalities and 3,3km in smaller municipalities. This is counterintuitive as one would expect trip distances in smaller municipalities to be longer as facilities are further apart/away. Additionally, it points towards the fact that people are not using shared mopeds to travel between municipalities but remain within their municipality (Movares, 2023). If the underlying cause is the limited service zoning, price, or demand has not been studied.

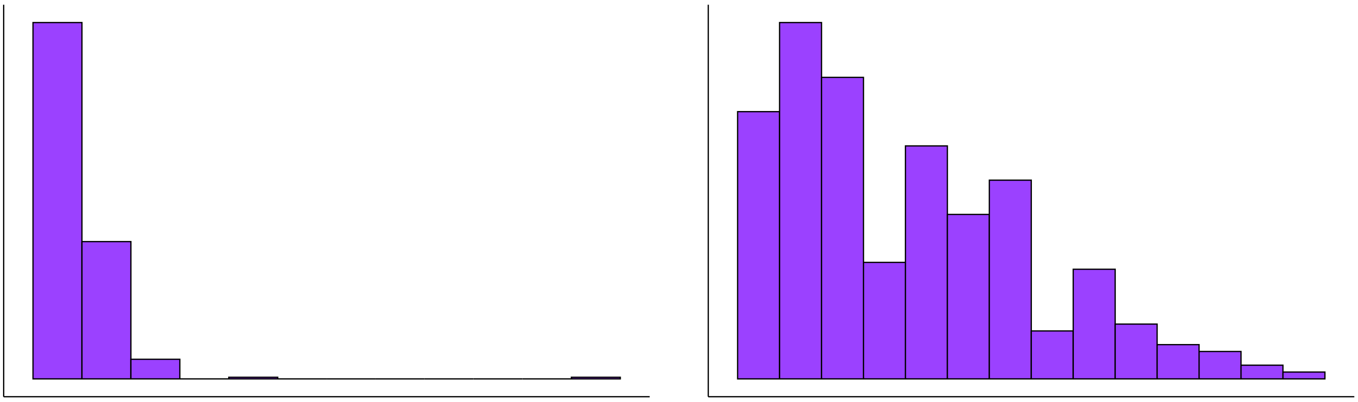
An overview of travel times and average distances can be found in Table 4.5. Most papers report peak usage in the afternoon, between 13:00-21:00. Some also reported peak usage during the morning rush hour, 07:00-11:00. This indicates that in the majority of cities shared micromobility is used for leisure or evening commutes. At the time of writing, it is not proven why people decide to use shared micromobility for their evening commute, but not for the morning commute. One theory is that people start their days at a public transport hub (e.g. travel into a city using the train), which has many connections towards their end destination, reducing the need for shared micromobility. When the workday ends, there are fewer connections from their place of work towards the public transport hub, increasing the need for shared micromobility. The average distance travelled per trip based on literature is 2,7km, showing that shared micromobility is used for shorter trips.

Table 4.5: Trip Distances and Peak Usage Times

Author	Mode	Region	Distance (km)	Peak Usage Time
Caspi et al. (2020)	e-Scooters	Austin, USA	0,97	09:00, 12:00-18:00
Arias-Molinares et al. (2021)	Mopeds	Spain	3	08:00-09:00, 13:00-14:00, 18:00-20:00
Oluwajana and Wang (2023)	e-Scooters	Windsor, USA	4,7	18:00-00:00
Literature Review: Liao and Correia (2022)				
PBOT (2019)	e-Scooters	Portland, USA	1,85	15:00-18:00
McKenzie (2019)	e-Scooters	Washington DC, USA	0,65	08:00, 12:00
Romanillos et al., (2018)	e-Bikes	Madrid, Spain	2	Morning commute, afternoon, and evening
Literature Review: Dibaj et al. (2021)				
Hosseinzadeh et al. (2021)	e-Scooters	Louisville, USA		13:00-17:00
Jijo et al. (2019)	e-Scooters	Indianapolis, USA		16:00-20:00
Jiao & Bai (2020)	e-Scooters	Austin, USA		13:00-17:00
Liu et al., (2020)	e-Scooters	Indianapolis, USA		18:00-21:00
Li & Axhausen	e-Scooters	Zurich, Switzerland		16:00-21:00
Literature Review: Mitropoulos et al. (2023)				
de Bortoli & Christoforou (2020)	e-Scooters	Paris, France	3,3	
Latinopoulos et al. (2021)	e-Scooters	Paris, France	1,85	
Wang et al. (2021)	e-Scooters	Sweden	1,64	
Ishaq et al. (2022)	e-Scooters	Turin, Italy	4,00	
Reck et al. (2022)	e-Scooters	Zurich, Switzerland	4,15	
Zagorskas & Burinskiene (2020)	e-Scooters	European Cities	2,75	
Haworth et al. (2021)	e-Scooters	Brisbane, AUS		07:00-11:00, 14:00-16:00
Movares (2023)[1]	Mopeds	Netherlands	3,5	
Hilster et al. (2022)[1]	Mopeds	Rotterdam, NL	3,1-3,8	12:00-17:00
Faber et al. (2020)	Mopeds	Netherlands	2,3	08:00, 12:00-18:00
Groningen (2023)	Mopeds	Groningen, NL	3,2	13:00-18:00
Mean			**2,7**	
Standard Deviation			**1,2**	

[1] Comissioned by Dutch Shared Moped Operators

Using operator trip data, the average moped distance in the Netherlands is found. In Schiedam, the average trip distance seems to be lower compared to the distance in the Netherlands, but this figure had a large standard deviation, pointing towards a skewed distribution. This distribution is confirmed by Figure 4.2a, which shows that many trips in the dataset were 0 meters, and few were longer than 20km. Filtering for trips between 20 meters and 20 kilometres results in the histogram in Figure 4.2b. The filtered Schiedam data has a larger average distance compared to the Dutch average, with a lower standard deviation.

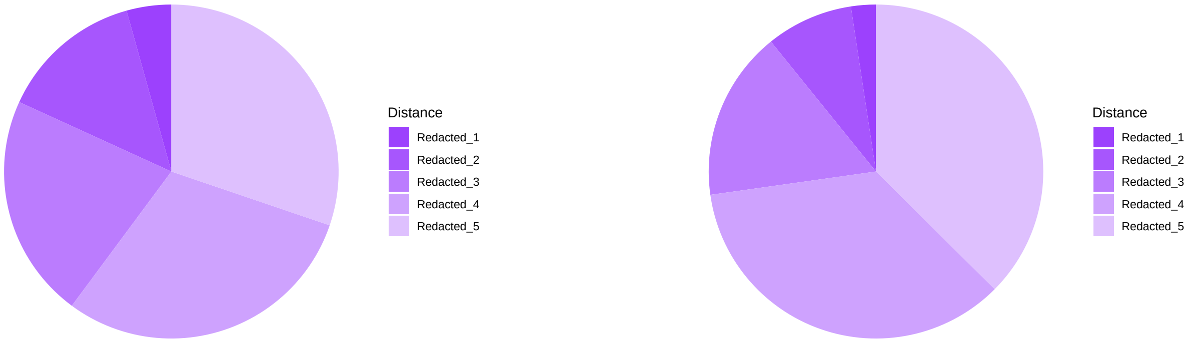


(a) Raw Data

(b) Filtered Between 20 Meters and 20 Kilometres.

Figure 4.2: Check Moped Distances in Schiedam 2023

Looking at the distribution of distances in Figure 4.3a, one can observe that most Schiedam trips (60%) are either between 5-10km or 1-2,5km. Furthermore, it shows that trips longer than 10km are not often made. In contrast, the nearby large urban city of Rotterdam has relatively more short (1-2,5km) and medium (2.5-5km) trips, see Figure 4.3b. It also has a lower average distance and a standard deviation compared to Schiedam. This shows that trip characteristics between highly urbanised cities such as Rotterdam, and less urbanised cities such as Schiedam differ, with suburban regions having more longer trips. In Table B.9 one can find the exact average distances.



(a) Schiedam

(b) Rotterdam

Figure 4.3: Check Moped Trip Distance Distribution 2023

As seen in Table 4.4, 4.5, and Check data, trip characteristics vary greatly between cities. This is also confirmed by Latinopoulos et al. (2021) which states ”peak usage and trip purposes vary across cities and this can be affected by several parameters such as the built environment, the recency of the scheme, the available infrastructure etc.” (p.17). This shows that it is important to take into account these parameters when creating and verifying Dutch-shared moped business models. An average moped travel distance of 4km is taken for trips in Schiedam, which is used in the societal cost-benefit analysis to calculate vehicle kilometres travelled.

Other Modes

While the average distance for moped trips is determined to be 4km, this does not mean that every trip they replaced was also 4km long. This section details how long the replaced distance is per mode. CBS (2023) found the average unimodal walking trip in the Netherlands to be 2,07km or about 20 min. Hoppesteyn (2023) researched the distances travelled in Metropolitan Region Rotterdam The Hague and found similar walking distances for both inside the city centre and outside the city centre. In fact, only a difference of 0,1km was found between inside and outside the city centre. Therefore, it is assumed that the average walking km substituted per trip is 2km.

Bike trips are found to be 4km on average (CBS, 2023), it is assumed people would travel the same distance on a moped as on a bike, and therefore the bike substituted km per trip is set to 4km.

An average car trip is 17km, while an average train trip is 50km (CBS, 2023). Shared mopeds will likely not replace longer trips, as they are used mainly for shorter distances. Bike paths often offer more direct routes compared to car roads, with about 0,5-1,5km shorter required travel distance by bike path compared to using the road. Therefore it is assumed that car trips would have taken 30% longer compared to moped trips, and consequently shared mopeds substitute a 5,2km car trip. Similarly, public transport often takes a more indirect route compared to driving a shared moped. Assuming the public transport route takes 30% longer compared to driving a shared moped, an average substitution of 5,2km for pt per trip is found.

4.3.3. Modal Shift in Kilometres

Most papers measure modal shift as a number of trips. To get the most accurate picture, it would be interesting to understand modal shift in terms of passenger kilometres. While each substituted mode has a different average trip distance, it is not realistic to assume that shared mopeds replace long (>10km) trips often. Because of this, the modal shift in the number of trips has been converted to a modal shift in passenger kilometres using the average distances described in subsection 4.3.2. The substitution rate in percentages can be seen in Table 4.6, and the substitution rate in kilometres in Table B.10.

Using the modal shift in trips, the number of passenger trips, and the average distance per trip one can obtain the total passenger kilometres substituted. In Table B.10, one can find a summary of the modal shift in passenger kilometres towards shared mopeds. The substitution rate has been normalised to add up to 100%.

Table 4.6: Mode Substitution for Shared Mopeds, Nominal Scenario

Mode	Subsitution Rate (% Trips) Normalised	KM/Trip Substituted	Subsitution Rate (% PKT)
Induced	4,6	4	4,4
Car	15,1	5,2	18,6
PT	33,3	5,2	41,2
Walk	19,0	2	9,0
Bike	28,1	4	26,7

To account for variances between different papers, and cities, two additional scenarios are created; worst and best case, see subsection 4.5.1 for a detailed explanation.

In the worst-case scenario, the number of induced and public transport kilometres increases while car, walking, and biking substitution decreases compared to the nominal scenario. This scenario would reflect a city where public transport usage and latent demand are high, while car, walk, and bike usage is low.

In the best-case scenario, the number of car-substituted kilometres increases greatly, while induced demand is low. Furthermore, public transport substitution decreases greatly. This scenario reflects a city where car usage is high, public transport usage is low, and there is little latent demand. In Table 4.7 and B.11 one can find an overview of the substitution rates in percentages and kilometres for the two scenarios. The conversion method from trip substitution towards kilometre substitution remains the same between the nominal, worst, and best scenarios.

Table 4.7: Scenarios for Mode Substitution for Shared Mopeds

Mode	Worst Case Substitution Rate (% PKT)	Best Case Substitution Rate (% PKT)
Induced	10,0	3,0
Car	13,0	44,9
PT	52,0	14,2
Walk	15,0	12,3
Bike	10,0	25,6

It has to be noted that a large part of the substitution data came from the introduction of shared e-scooters. While it is hypothesised that e-scooters have a similar impact compared to mopeds, they do have some differing characteristics. One can sit on mopeds, and many can reach speeds up to 45km/h, compared to just 25km/h for e-scooters. According to Faber et al. (2020), e-scooters and mopeds can not be compared. While this is probably true when discussing environmental impacts, when looking at trip characteristics they seem to attract similar users and have similar characteristics. Therefore for literature regarding modal shift, data from shared e-scooters is also included.

The higher speed and comfort of mopeds could facilitate longer trips compared to e-scooters, which could affect the modal split change. Reck et al. (2022) found that with larger travel distances, the walking shift lowered while the public transport and car shifts increased. Their study claimed that only public transport (75%) and cars (25%) were replaced when travelling >3km by e-scooter. As suburban distances are hypothesised to be longer, it could be that the introduction of shared heavy mopeds does not replace biking and walking by much but mainly public transport and cars. Additionally, most data comes from surveys, instead of more accurate field measurements. While this is the only data available, discrepancies are accounted for using the above-described scenarios.

4.4. Magnitude Effects

The following sections describe the magnitudes of each effect when introducing shared mopeds to a new suburban region, as conceptualised in Figure 4.1. For the costs of each effect please refer to section 4.5.

4.4.1. Traffic Safety

One of the expected negative effects, as shown in Figure 4.1, is the increase in accidents when the modal split shifts towards mopeds. The Institute for Road Safety Research (SWOV) performs extensive research into the safety of Dutch road users. They use the Maximum Abbreviated Injury Score (MAIS), which has a range of 1 (light injury) to 6 (maximally injured), to define injuries. After 2020, the SWOV defined ’severely injured’ as all injuries in the MAIS 3+ category. Examples of severe injuries are skull base fractures, broken hips, or the amputation of a wrist or ankle. Furthermore, they state that comparing injuries between countries is not possible as accident definitions differ, and data collection is not feasible in all countries (SWOV, 2023b). This section details the safety of mopeds and contrasts this to other modes.

Severe Accidents per Mode

In absolute numbers, most severe accidents happen by bike (70%), with mopeds coming in second at 11%. This is a misleading figure as it does not account for how many kilometres were travelled with each mode. When looking at accidents per billion kilometres, mopeds are the most dangerous with over 800 severe accidents per billion kilometres (SWOV, 2023b). It has to be noted that this figure includes both shared and privately owned mopeds. Most deathly collisions occurred between mopeds and cars, and mopeds and static objects (Oude Mulders et al., 2023). Bike riders experience 250 severe accidents per billion kilometres, pedestrians around 50 accidents, and car drivers exhibit the highest level of safety at less than 10 severe accidents per billion kilometres (SWOV, 2023b). An overview of severe accidents per mode can be found in Figure 4.4.

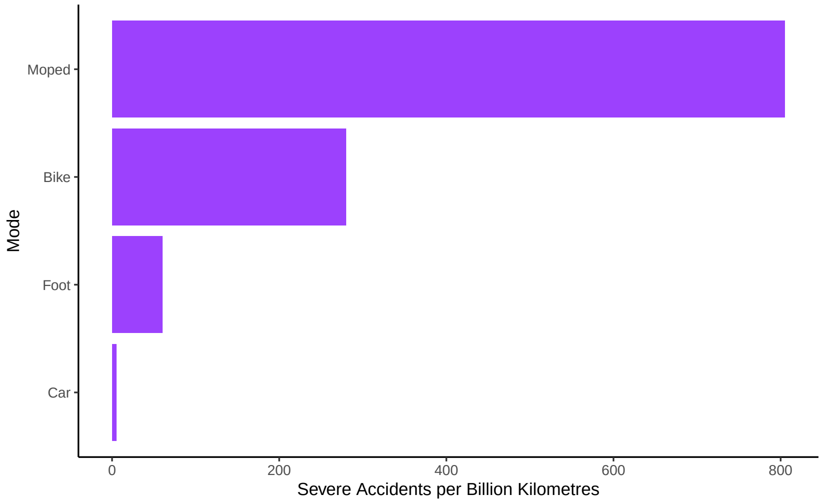


Figure 4.4: Number of Severe Accidents per Mode (Average 2020-2021).
Adapted from SWOV (2023b).

Interestingly, when delineating these figures on age, it can be seen that most severe accidents occur in the age bracket 60-80+ (58%), and only 15% in the age bracket 20-39 (SWOV, 2023b). The users of shared moped services are mainly male and between 18-35, see section 3.3. This could affect the number of severe moped accidents per billion kilometres as the shared moped age demographic has fewer severe accidents overall. The SWOV does not provide source data, which makes it not possible to uncover how many severe accidents occur per billion kilometres specifically for moped users between 18-35.

Accident data is not available for public transport passengers, but when looking at other modes, they have 20-80 times more accidents compared to casualties. Public transport casualty data is available and described in Figure 4.4.1. Using this data, between 0,5-2 accidents occur in public transport. For the societal cost-benefit analysis, 1,0 accident per billion kilometres is assumed for public transport.

To understand the safety characteristics of shared mopeds better, data from Movares (2023) is used. They found that shared moped riders had 12,515 reported accidents per billion kilometres. Furthermore, 1 in 22,875 trips led to an accident. They claim that real-world accidents may be higher as not all accidents are reported. Their definition of accidents may explain this high accident number, which likely includes minor and other accidents, while SWOV data includes major accidents. Based on data from Wijnen (2022), a distribution of accident types can be found: 0,2% of accidents resulted in death, 6,8% in severe accidents, 30,4% in light accidents, and 62,5% in other accidents. This includes all transportation modes, mopeds could have a different distribution. Using this distribution on the Movares data results in 25 casualties, 851 severe accidents, 3,805 light accidents, and 7,821 other accidents per billion kilometres. The number of severe accidents is in line with the data from SWOV (2023b), but is high when taking into account the age demographic of shared mopeds. It could also be the case that riders of shared mopeds drive more dangerously on average, or because electric mopeds are heavier and accelerate quickly they result in more severe accidents, but there is no scientific evidence for this.

What can be observed is that based on SWOV (2023b) data, riding a moped is 3 times as dangerous as biking, 16 times as dangerous as walking, and around 100 times more dangerous than driving a car when looking at severe accidents per billion kilometres. Please refer to subsection 4.5.3 for the value of a severe accident.

Casualties per Mode

SWOV (2023a) found that moped driving results in 52 deaths per billion kilometres. In contrast, biking resulted in 14 deaths, walking in 5, and driving in 2 deaths per billion kilometres. In 2020 and 2021 the number of moped deaths per billion kilometres was higher compared to the years 2014-2015 (40), 2016-2017 (42), and 2018-2019 (37), and similar to the years 2012-2013 (49). Why this is the case is not known, but when updating the societal cost-benefit analysis in the future this number should also be updated.

The CBS shows that of moped casualties between 2016-2022, 36,0% were between the age of 15-40. For bike riders, this age bracket represents 10,2% of deaths. For car drivers, 44,9% of deaths were between the ages 15 and 40, and for pedestrians the percentage of deaths between the age of 15 and 40 was 22,0.[1] Note that the minimum age to be able to drive shared mopeds is 16 for the operator 'Go' and 18 for 'Check' and 'Felyx', and not 15 years or older as in the CBS data. Normalising the casualty data to the age bracket 15-40 results in 18,7 moped, 1,4 bike, 1,1 walking, and 0,9 driving casualties per billion kilometres. In Figure 4.5 one can find an overview of deaths per billion kilometres per mode in the age bracket 15-45.

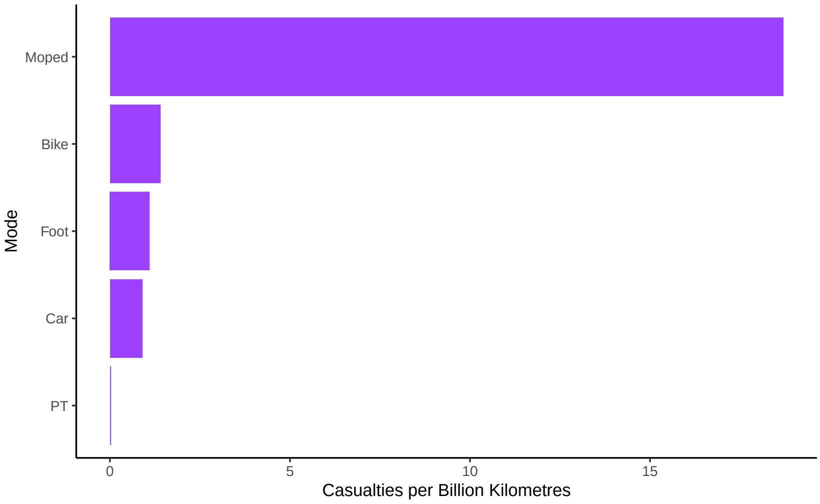


Figure 4.5: Number of Casualties per Mode in the Age Bracket 15-40 (Average 2020-2021).
Source: SWOV (2023a) and CBS Statline.

For public transport safety, less data is available, with the most recent data gathered between 2009-2017. SWOV (2021) found that busses resulted in 0,11 deaths per billion kilometres, and trains/trams resulted in 0,006 deaths per billion kilometres for passengers of all ages. On average, public transport causes 0,025 deaths per billion kilometres.

To summarise, mopeds are more dangerous, both in terms of casualties and severe accidents per billion kilometres, compared to biking, walking, or driving a car. The exact figures for shared mopeds are unavailable, but the available data suggests a similar risk profile as for private mopeds. Please refer to subsection 4.5.3 for the value of a casualty.

4.4.2. Accessibility

One expected positive effect conceptualised in Figure 4.1 is accessibility effects. These effects encompass the perceived consumer expense of shared scooters compared to other modes. To quantify these effects, it would be the most accurate to perform a stated or revealed choice experiment, but due to time constraints, this is not feasible. In order to still quantify accessibility effects, a proxy is created. This section will detail the creation of the proxy. In subsection 4.5.4 one can find the the accessibility gains in euros per trip.

It is assumed that the perceived value difference between different modes relates mostly to travel time saved and the direct cost of transport (fuel/ticket and parking). To this end, five different scenarios are created; very short distanced trips (<1,0km), short trips (1,0-2,5km), medium trips (2,5-5,0km), long trips (5,0-10,0km), and

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[1] opendata.cbs.nl/statline/#/CBS/nl/dataset/71936ned

very long trips (>10,0km). These distances are based on Check trip data from Schiedam and are represented by a real trip.

The shortest distance and corresponding time from point A to B in each scenario per mode is determined through Google Maps[2]. As Google Maps does not support (shared) mopeds, a shared moped is assumed to drive 1,75 times faster compared to a bike on average. Real-world trip data supports this assumption. Public transport cost was obtained using 9292.nl and the start and end stops were determined using Google Maps.

The largest delta between a shared moped and a different mode is taken for each scenario to account for various indirect effects that were not accounted for in the time and direct cost calculations. For example, while biking is oftentimes cheaper compared to other modes (and therefore one would expect another to take a bike instead of a shared moped), it requires effort to bike. Therefore, people might not choose to use this mode. Using a car requires a driver's license, and is unreliable in some scenarios. Both a bike and a car require ownership to be a viable alternative. If one does not own the vehicle, the cost of renting one often makes it unattractive compared to a shared moped. For public transport, reliability, hygiene, and transfer costs could have an impact, while for walking, health effects are not accounted for. Furthermore, the high reliability of a shared moped, comfort, and possible status are not accounted for in these calculations. Finally, the Value of Time is an average of leisure and business VoTs' and could be much higher for the shared moped user base. By taking the largest delta between a shared moped and the other modes per scenario, these indirect effects should (partially) be accounted for.

Because all shared moped users are new users in this research (as in the zero-alternative shared mopeds are not present in the city), the 'rule of half' will need to be applied. This states that new users in a (infrastructure) project only achieve half of the accessibility benefits compared to existing users. For example, some users will switch modes when the accessibility delta between their previous mode and a shared scooter is 10 eurocents, while other users will switch with an accessibility delta of 5 euros. Each new user switches at a different price point, but, on average, only half of the accessibility benefits are obtained compared to existing users. A visualisation of this effect can be seen in Figure 4.6.

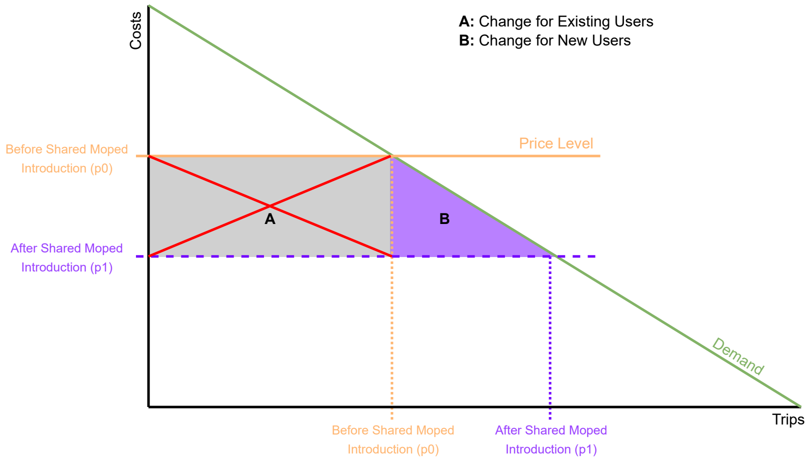

Figure 4.6: Visualisation of Rule-of-Half. Inspired by Romijn and Renes (2013, p.50).

4.4.3. Carbon Change

To explain the city air pollution and citizen health concepts in Figure 4.1, an understanding of CO2 equivalent emissions per passenger kilometre (CO2/pkt) is required. This section will detail existing literature on carbon emissions of shared mopeds compared to other modes.

Carbon Emissions Shared Mopeds

The emissions of shared micromobility greatly depend on the lifetime of the vehicle. For example, for e-scooters, Kazmaier et al. (2020) found emissions of 300 gCO2/pkt in the worst case scenario where a scooter

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[2] google.com/maps

only lasted 3 months, down to 82 gCO2/pkt in a scenario where a scooter lasts 15 months. In contrast, shared moped operator Check found that their mopeds have a much higher lifespan compared to previous studies. The details of this lifespan can be found in Table B.13.

de Bortoli and Christoforou (2020) found that for shared motor scooters (which are similar to mopeds but enable speeds up to 120km/h), vehicle production was the main contributor to CO2 emissions (71%), with infrastructure coming second at 21%. They did not consider servicing for shared motor scooters due to the lack of available data. It has to be noted that because the speed of shared motor scooters is higher, their CO2 impact can also differ.

Schelte et al. (2021) found a moped gCO2/pkt between 20-58. A large part of the emissions came from the need to swap the batteries (46% in the base case), followed by production (27%), and charging (22%). This shows that servicing has a large impact on emissions, questioning the outcome of de Bortoli and Christoforou (2020), which did not include servicing in their calculations. When using solar power for both moped battery charging and swapping vehicles, the best scenario of 20 gCO2/pkt is achieved. The worst-case scenario with gasoline-powered swapping vehicles and a relatively short moped lifespan (30k km instead of 50k km), results in a gCO2/pkt of 58.

Wortmann et al. (2021) found CO2 emissions of 18,7 gCO2/pkt in the best case scenario with renewable energy, up to 36,7 gCO2/pkt in the worst case scenario with non-renewables and 50.000 mopeds deployed. Main emission sources were usage (including servicing) at 70% of emissions, and production at 28% (for the base scenario).

Wortmann et al. (2021) also found 0,147-0,217 gSO2-Eq/pkt, 0,0152-0,0392 gP-Eq/pkt, and 0,058-0,081 gPM2.5 eq/pkt. While these polluting elements could influence total pollution, other sources do not report this data making it difficult to compare. Additionally, most studies measure CO2 as CO2 equivalent, including other pollution sources. Nevertheless, it is important to account for other emission factors aside from CO2, and in a societal cost-benefit analysis this is accounted for by correcting the gCO2/pkt to include other pollutants.

Hilster et al. (2022) found an average of 11-16 gCO2/pkt for Felyx shared mopeds in Rotterdam. This number is considerably lower compared to other studies, which can be explained by the fact that the vehicle production and infrastructure required are not considered in the calculation. Furthermore, the emission figures for comparative modes such as public transport are very high compared to other studies, most likely because of the low assumed occupation rates. Therefore this study is not taken into account when calculating the average emissions.

Finke et al. (2022) found a gCO2/pkt of 23,00 using e-cargo bikes as battery swapping vehicles and German non-renewable power. Utilising diesel vans to swap moped batteries increased emissions to 49 gCO2/pkt. Furthermore, they did not consider other operational emissions related to maintaining a head office, which could increase the average carbon emissions of a vehicle. Interestingly Finke et al. (2022) also researched if using battery swap stations, where users manually swap vehicle batteries, resulted in lower emissions. They found that, compared to using e-cargo bikes as battery-swapping vehicles, emissions were higher by 4,4 grams. This shows that battery swap stations do not decrease emissions compared to low-carbon battery swap vehicles.

OECD/ITF (2020) did extensive research on the emissions of various modes of transport. They found a gCO2/pkt of 79,17, assuming vehicles get recharged using ICE battery swapping vehicles. The biggest emission share was vehicle production (44%), followed by fuel (25%), servicing (17%), and infrastructure (14%). M. Knoope and Kansen Maarten (2021) used the same model to find an average of 63 gCO2/pkt specifically for the Dutch market.

Grobben et al. (2023) performed research, commissioned by Check, into all facets that affect the gCO2/pkt of shared mopeds. They found a gCO2/pkt of 28,3 for Check shared mopeds. The report has been externally audited by SpaakCS, and internal documents are available to the author to verify the data. Regarding the distribution of the emissions; 60% came from production, 22% from operations and maintenance, and 17% from charging.

Multiple factors explain the difference between the Grobben et al. (2023) results and the results from OECD/ITF (2020) and M. Knoope and Kansen Maarten (2021):

1. The use of grey energy was assumed by OECD/ITF (2020), while Check runs most of their scooters using 100% green energy contracts. This reduces carbon emissions by 19,74 gCO2/pkt. Some moped battery charging locations still use grey power, therefore the result from the updated OECD/ITF (2020) model should be corrected upwards.
2. Grobben et al. (2023) used a lifetime of 50.000 km, with 5.300km a year, resulting in a lifetime of 9,4 years without vandalism instead of 3,7 years. The 3,7 years was an assumption made by OECD/ITF (2020), using a degradation factor of 55% compared to privately owned mopeds. Changing the lifetime to reflect the 8,5 years or 45.000km due to vandalism (as discussed at the beginning of the section), reduces carbon emissions by 20,31 gCO2/pkt.
3. The average number of passengers was assumed to be 1,0, while Check found an average occupation rate of 1,3. This lowers carbon emissions by 8,42 gCO2/pkt. This number might be lower in countries where multiple people on a single moped are not allowed, such as Denmark.
4. OECD/ITF (2020) assumed mopeds use the same infrastructure as motorbikes, with the mopeds only being allowed on the road instead of the bike path. The bikes and e-scooters infrastructure parameter is a more suitable option as many Check mopeds are allowed on bike paths. This change lowers emissions by 1,30 gCO2/pkt.
5. Check has an almost fully electrified vehicle park and replaces batteries on the spot instead of loading the scooters onto a vehicle and charging them at a central location. One ICE van remains as the distances are too long for an EV. It is hypothesised the suburban distances are also longer, and therefore an ICE van might be needed. The model used by OECD/ITF (2020) also has support for electric vans instead of gasoline-powered vans. The difference between these two options is 5,61 gCO2/pkt.

When changing the five above-mentioned parameters in the OECD/ITF (2020) model, a gCO2/pkt of 23,79-29,40 (depending on the maintenance van used) is obtained, which is similar to the gCO2/pkt of 28,3 found by Grobben et al. (2023). This figure assumes a fully green energy mix and does not account for emissions produced by the head office. Therefore the real-world emission figures could end up being higher. An updated version of OECD/ITF (2020), using the above-mentioned changes to the parameters, can be found in Table 4.8 under the name ”OECD/ITF (2020) Check Modified”. As shown above, the figures by OECD/ITF (2020), and therefore M. Knoope and Kansen Maarten (2021), are not indicative of real-world emissions. Therefore, they are not considered in the final gCO2/pkt calculation.

In Table 4.8, an overview can be found regarding shared moped emissions. On average the gCO2/pkt was found to be between 24-34, with a standard deviation of 4-12. The exact gCO2/pkt depends on EV or ICE battery swapping and maintenance vehicles, whether the mopeds are charged using green or grey electricity, and emissions by a head office. Based on this, accounting for the research performed by an external party for Check, it is assumed that for Dutch operators of shared mopeds, the emissions per passenger kilometre is 30gCO2.

Carbon Emissions Alternative Modes

Some of the sources in Table 4.8 also provide emission figures for other modes of transport. These figures are used to compare emissions between mopeds and other modes. An overview of average emission figures can be found in Table 4.9. A list of all sources and their emission numbers is provided in Appendix A.3. For the modes that use electricity as a fuel, the Dutch energy mix was used for grey power (worst case), and all renewable for green power (best case). It can be observed that shared mopeds pollute less compared to

Table 4.8: CO2 emissions per passenger kilometre travelled for shared mopeds

Paper	Mode	gCO2e/pkt	Region
de Bortoli and Christoforou (2020)	Shared Motor Moped	27,69	Paris, FR
Hofmann and Kaufmann (2013)	Private e-Moped	32	Germany
Schelte et al. (2021)	Shared e-Moped	20-58	Germany
Wortmann et al. (2021)	Shared e-Moped	18,7-36,7	Berlin, DE
OECD/ITF (2020)	~~Shared e-Moped~~	~~79,17~~	~~Worldwide~~
M. Knoope and Kansen Maarten (2021)	~~Shared e-Moped~~	~~63~~	~~Netherlands~~
Finke et al. (2022)	Shared e-Moped	23	Bochum, DE
Hilster et al. (2022)[1]	~~Shared e-Moped~~	~~11-16~~	~~Rotterdam, NL~~
Grobben et al. (2023)[1]	Shared e-Moped	28,3	Netherlands
OECD/ITF (2020) Check Modified	Shared e-Moped	23,79-29,40	Netherlands
Mean gCO2/pkt best case		**24,74**	
Standard deviation gCO2/pkt best case		**4,74**	
Mean gCO2/pkt worst case		**33,54**	
Standard deviation gCO2/pkt worst case		**11,57**	

[1] Comissioned by Dutch Shared Moped Operators

cars and ICE buses. Other forms of transportation, such as walking, metro, train, (e-)bike, pollute less per passenger kilometre travelled compared to shared mopeds.

Table 4.9: Average CO2 emissions per passenger kilometre travelled for non-moped modes

	Mean best case	Standard deviation best case	Mean worst case	Standard deviation worst case
Walk	0,00		2,23	
Metro	9,86	2,84		
Train	8,40	0,56		
Tram	32,74	16,93		
ICE bus	111,98	29,55		
Electric bus	49,82	32,88	64,18	26,30
Private bike	12,05	5,00		
Private e-bike	26,96	6,16	31,72	5,95
Private ICE car	201,88	26,64		
Private hybrid car	119,14	18,58		
Private electric car	81,86	24,27	98,61	27,99
Taxi/ride-hailing	172,25	114,77	258,67	58,26

Bus carbon emissions heavily depend on the fuel type used; electric or diesel-powered. Rotteveel et al. (2023) found that the majority of buses in the Netherlands were powered by diesel. Furthermore, they found that bus gCO2/pkt lies between 17,8 and 202,77, depending on the region. Unfortunately, Rotteveel et al. (2023) did not consider vehicle production and infrastructure usage in their gCO2/pkt calculations. On average bus travel emitted 92 grams CO2/pkt. The region of South Holland (in which this research focus region lies) emitted 113 gCO2/pkt for bus travel in 2022. In the future, bus emissions will decrease with the introduction of electric buses (Rotteveel et al., 2023). OECD/ITF (2020) found that bus production adds 8-17 (depending on ICE or EV) gCO2/pkt and infrastructure adds 4 gCO2/pkt. Furthermore, Leestemaker et al. (2023) found a total gCO2/pkt of 112-132 for public buses. Assuming the South Holland bus emissions of 113 gCO2/pkt, and adding 12 gCO2/pkt for production and infrastructure, a total of 125 gCO2/pkt is assumed for bus usage.

A small percentage of trains in the Netherlands run on Diesel, and all trains in South Holland are electrified. Furthermore, all trains run on green electricity. Based on Table 4.9 a gCO2/pkt of 8,4 can be assumed, which is in line with results found by Schroten et al. (2021) (6-12 gCO2/pkt). It is higher than the emissions found by Leestemaker et al. (2023) (4,8 gCO2/pkt), but this number does not consider track infrastructure and train production emissions.

Leestemaker et al. (2023) found tram emissions to be 65 gCO2/pkt, and metro emissions to be 43 gCO2/pkt, assuming that grey energy is used. The trams and metros in Amsterdam and The Hague run on 100% clean energy, and in Rotterdam on biomass, resulting in their direct emissions being zero or low. Indirect emissions still result in some CO2 emitted for these modes. Leestemaker et al. (2023) found that energy infrastructure emissions accounted for 5,9gCO2/pkt for the tram, and 3,8 gCO2/pkt for the metro. Furthermore, the low Dutch emissions mean that the results in Table 4.9 for tram emissions are high and should be closer to the metro emissions. No data is available for the emissions of production, maintenance, and track infrastructure of trams and metros but it is assumed to be similar to that of the train. This means that total emissions for the tram and metro are assumed to be 10gCO2/pkt.

Most research on modal shift does not delineate the different modes of public transport but aggregates them into one single 'public transport' figure. To obtain this single figure, the yearly passenger kilometrage of different modes is used as a ratio. In 2019, a total of 25,06 billion passenger kilometres were travelled using public transport. Of these kilometres, 77,5% was travelled by train, 14,5% by bus, 3,2% by tram, and 4,8% by metro (ACM, 2021). Using a weighted average, the average CO2 emissions of public transport are found to be 25,4 gCO2/pkt. This figure is lower compared to the figure found in Leestemaker et al. (2023) (40,4 gCO2/pkt), which is likely because their assumed energy mix for all modes is mixed (grey and green) instead of green energy only.

One would expect that in regional areas, there could be a higher focus on bus usage instead of cleaner rail-based modes. As long as these buses do not run on (green) electricity, they will pollute considerably more compared to other modes. Surprisingly, in moderately urban areas (1000-1500 addresses per km2) between 2018-2022, 79,3% of passenger kilometres were performed by train and 20,7% by bus/tram/metro, which is similar to the data from ACM (2021). In low urban areas (500-1000 addresses per km2) the division between train and bus/tram/metro changes to 72,6% train and 27,4% bus/tram/metro passenger kilometres.[3] As only four municipalities in the Netherlands have trams or metros (Amsterdam, The Hague, Rotterdam, and Utrecht), most in dense urban areas, it is assumed that the public transport modal split in moderately and low urban areas is between trains and busses. Using this data as a weighted average, results in public transport emissions of 32,5 gCO2/pkt in moderately urban areas, and 40,4 gCO2/pkt in low urban areas.

Car emissions differ greatly between ICE and electric cars. Out of all vehicle kilometres driven in the Netherlands, 90,4% were from ICE/Hybrid vehicles, 5,4% from Fully Electric vehicles, 2,8% from Plug-in Hybrid vehicles, and the remaining fuel sources from LPG and CNG-powered cars. Taking the weighted average between ICE and fully electric vehicles of the data found in Table 4.9, a gCO2/pkt of 195,11 is obtained in the best case and 196,06 in the worst case. Leestemaker et al. (2023) found average car emissions to be 150,6 gCO2/pkt, excluding infrastructure needed. Schroten et al. (2021) found that external CO2 factors (production, infrastructure, etc.) added another 30-55 gCO2/pkt. In total a car therefore emits 180,6-205,5 gCO2/pkt. Only using the data from Leestemaker et al. (2023) results in a gCO2/pkt of 212 for gasoline cars and 60-125 for electric cars (depending on the source). Considering the above factors and the average emissions found in Table 4.9, a gCO2/pkt of 200 is assumed for private passenger cars.

Little information is available on the emissions of walking, which does require infrastructure to be created. de Bortoli and Christoforou (2020) found that walking emitted 2,2 gCO2/pkt, attributed to the infrastructure (sidewalks) required. This is the only available literature on walking emissions and is used as the primary source. Therefore, it is assumed that walking emits 2 gCO2/pkt.

For biking, it matters if it is performed on an e-bike or not. de Haas and Kolkowski (2023) found that e-bikes represent 37% of total kilometres biked. In the age group 18-39, around 22% of kilometres are biked on an e-bike. Outside the 'randstad' this figure is higher (de Haas & Kolkowski, 2023). Assuming that 25% of users are on an e-bike and 75% of users are on normal bikes, a weighted gCO2/pkt of 15,8 is found for biking. These emissions came mainly from production and infrastructure. This is higher than the numbers found by Leestemaker et al. (2023), which found 8-12 gCO2/pkt for biking. The standard deviation in Table 4.9 for

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[3] opendata.cbs.nl/statline/#/CBS/nl/dataset/84709NED

(e-)bikes is also relatively high, showing a great discrepancy between papers. As the data by Leestemaker et al. (2023) is solely focused on Dutch bikes it is hypothesised that their bike emission numbers are the most accurate. Taking both data points and e-bike usage into account, an average gCO2/pkt of 10 for biking is assumed.

Refer to subsection 4.5.5 for the cost of a kilogram of emitted CO2.

4.4.4. Noise Pollution

One of the expected negative effects, as shown in Figure 4.1, is a change in noise pollution. As shared mopeds are electric, they produce little to no noise. In contrast, combustion-powered vehicles tend to produce a significant amount of noise. In Figure 4.7 one can see a map of the noise caused by road and train traffic in Schiedam.

van Essen et al. (2019) performed extensive research into various factors related to external transport costs. One of these factors was noise pollution for various modes. They provide figures for both average and marginal costs. As this analysis constitutes a change in an existing traffic situation the marginal costs are utilised. The figures provided by van Essen et al. (2019) stem from 2016 and are therefore updated to 2023 by accounting for inflation.

Furthermore, a distinction is made between population density and noise during the day and night. As Schiedam is still relatively urbanised, traffic is assumed to occur equally during the day and night. Noise pollution is measured in eurocents per passenger kilometre, and the costs can be found in subsection 4.5.6.

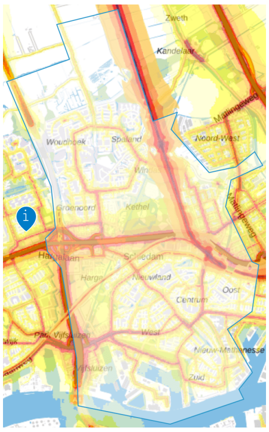

Figure 4.7: Noise Map of Traffic in Schiedam. Adapted from atlasleefomgeving.nl.

4.4.5. Business Model Impact

The business model has an impact on the usage and operating cost of shared mopeds, as conceptualised in Figure 4.1.

One main difference is how the scooters are parked; free-floating or hub. The hub model differs from docked models, as they do not require parking infrastructure (physical docks) to be maintained by the operator, but zone a certain parking area using GPS-based geofencing. Mopeds can be parked in this zone, and the user may only end the ride when a moped is parked in such a zone. In Free Floating models the zone encompasses a much larger region, which allows more flexibility for the user to park/take a moped near their destination/start location.

Check primarily employs a free-floating business model, which is particularly effective in highly urbanised areas. However, many cities are requiring the switch to a hub-based model, impacting the business case.

In the municipality of Groningen, Check was obliged to change from a free-floating to a hub-based model. This change sparked a decrease in overall trips but increased the average distance. For the exact changes refer to Table B.12. This distance increase was mainly attributed to people not being able to park everywhere, and needing to find a hub. It is expected that this increase in distance will fade as people get used to the new hubs.[4] Demand remains lower after switching from a free-floating to a hub-based model. In the SCBA this lower demand also lowers the magnitude of all other effects.

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[4] Check Internal Data

One would expect that as fixed hubs limit the number of possible parking places they result in fewer mopeds needed to facilitate a sufficient density. Trip data shows that this is not the case; hub-based models require the same or higher number of mopeds compared to free-floating models. This is because, in hub-based models, moped users can not drive to their final (high-demand) location directly, which causes them to park the moped in a non-ideal lower-demand location. Resultingly, more mopeds are needed so the high-demand locations have a sufficient number of mopeds to meet demand. Second, some hubs on the outskirts of the city incentivise users to park there, while in a free-floating model, a user would not have parked at that location. Because of low (return) demand at such locations, there is an accumulation of mopeds in such a hub. Finally, mopeds become more dispersed over multiple locations in a hub-based model, this requires a similar or higher number of mopeds to meet demand.

This increase in dispersion, and resulting demand imbalance, has effects on operating costs. While differing per region (depending on a region's layout, hub densities, hub spread, user demand, and relocation efficiency) on average direct costs increase in hub-based models compared to free-floating models. Direct costs consist of three parts; battery swapping, relocating and maintenance costs. It is found that low-demand hubs/areas see an increase in parked mopeds when switching to a hub-based model. This results in more mopeds needing to be manually relocated, which increases relocation costs. Furthermore, the higher dispersion over multiple hubs results in increased travel distances and time required for battery swap vehicles. This results in an increased cost to swap the moped batteries. Maintenance costs do not change. Because of the increase in swapping and relocating costs, direct costs are found to increase when switching from a free-floating to a hub-based business model.

Promo costs could also increase slightly, to motivate people (with coins) to move a moped from a low-demand hub to somewhere else. No data is available to support this claim, but a small increase is assumed. Please refer to subsection 4.5.2 for the operating revenues and costs for a shared moped operator, and Table B.8 for the changes in percentages of each cost.

As shown, for the operator there is no benefit to switching to a hub-based model. Nevertheless, Check has found that municipalities often desire hub-based models because of the desire to reduce resident complaints, and wanting to anchor shared mobility in the streetscape. Therefore both free-floating and hub-based models are investigated.

4.4.6. Qualitative Effects

Effects that can not be quantified still need to be accounted for in a SCBA. This chapter details the remaining qualitative effects, and scores them on a scale between '- -' and '+ +'.

Parking Nuisance

One of the conceptualised effects in Figure 4.1, are wrongly parked vehicles.

In the Netherlands, a stigma exists that shared mopeds are often parked wrongly. Operator Check has multiple systems to reduce parking nuisance; a rating system where users can rate the previous users' parking, and a fine or block system for wrongly parked vehicles. In 2022 a total of 36,420 parking violations were reported throughout the Netherlands for all operators, which is 0,2% of the rides. It has to be noted that unreported parking nuisances could increase this figure (Movares, 2023). While this figure is low, it is hypothesised that because residents see the same-looking shared moped parked wrongly multiple times, they experience a greater welfare loss compared to when private mopeds are wrongly parked as each private moped is a different model. To the best of the authors' knowledge, no studies exist which quantify the societal cost of parking violations.

To combat parking nuisance, many municipalities have required operators to operate a hub-based model. In this model, users only have the option to park their vehicle in very specific GPS-fenced locations, instead of everywhere in the region as in a free-floating model. These hub-based models therefore result in a lower number of wrongly parked vehicle (complaints). Resultingly, in the SCBA the free-floating model is given a '--' score, while the hub-based model is assigned a '-' score.

Car Usage Public Space

As identified in section 4.3, about 20% of shared moped kilometres would have otherwise been performed by cars. Movares (2023) has found that around 5% of shared moped users have sold their car because of the introduction of shared mobility. Furthermore, travellers might choose to not use the car to reach their destination, but a combination of public transport and shared mopeds instead. This reduces the amount of car parking spots required in the city.

As a moped requires a factor of 5-6 less parking space compared to cars, the remaining public space could be used for other purposes. This does assume that one shared moped replaces one car, while most likely one car will be replaced by multiple shared mopeds to meet demand. Nevertheless, it is expected that on average more public space will be available because of the introduction of shared micromobility. In the SCBA, the free-floating business model is assigned a '+ +'. As hub-based models reduce demand they also reduce the number of cars replaced and therefore are assigned a '+' in the SCBA.

Option Value

The term option value is often used to determine the value of natural assets, such as nature parks, which offer possibilities for future consumption. People are indirectly willing to pay to 'have the option' to go to such a nature park. A similar effect exists for transport, where people value having the option to use a form of public transport, even when they are not actively using it regularly (Geurs et al., 2006). For example, people value the option to take public transport when their car breaks down. It is important for an option value to be publicly accessible, as otherwise, not all residents can exercise the option.

A similar option effect exists for shared mopeds; when a person's vehicle is non-functional (e.g. broken bike, car, or personal moped), they would be able to use a shared moped to reach their destination. While they will only make use of this option under unusual circumstances, it still has a certain value. This value differs greatly between regions, the option, and the type of users, and would require a local survey to be performed in order to better understand the option value for shared mopeds. This does not fit within the time frame of this thesis and therefore is assessed qualitatively. Both hub and free-floating models give users the option to take a moped. Free-floating models allow mopeds to be parked anywhere in the region and therefore provide access to more users compared to hub-based models. Nevertheless, hub-based models could increase the feeling of reliability, and thereby the option value, as people are aware of a nearby hub that provides shared mopeds. Therefore both business models are assigned a '+' for the option value.

4.4.7. Summary of Effect Magnitudes

Table 4.10 provides an overview of the magnitude of various effects that occur with the introduction of shared mopeds into a region. Please refer to subsection 4.3.3 for the worst and best-case scenarios for passenger kilometres substituted. The next section details the cost of each of these effects.

Table 4.10: Summary of Effects that Impact Shared Mopeds in the Nominal Scenario

Mode	Modal Shift/Induced (% PKT)	Subsituted Distance/Trip (KM)	Emissions (gCO2/PKT)	Severe Accidents (Per Billion PKT)	Casualties (Per Billion PKT)
Shared Moped	4,4	4	30	800	18,7
Car	18,6	5,2	200	10	0,9
Public Transport	41,2	5,2	50	1	0,025
Walking	9,0	2	2	50	1,1
(e-)Bike	26,7	4	15	250	1,4

4.5. Value of Each Effect Per Unit

This section details the value of each effect described in section 4.4 for three different scenarios. This section only presents the effect values on a per unit basis (e.g. euro/passenger kilometre, euro/vehicle kilometre, euro/kilogram), the aggregated value can be found in section 4.7. Each effect value is inflation adjusted to 2023 using the Dutch Central Bureau of Statistics data[5].

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[5] cbs.nl/nl-nl/visualisaties/prijzen-toen-en-nu

4.5.1. Scenarios Sensitivity Analysis

To account for and understand the error margins in the various figures, three scenarios are created; Best, Nominal, and Worst. Each scenario is viewed from the perspective of an operator. In the best scenario, optimistic figures are selected to generate the most positive societal benefits. In the nominal scenario, the average figures are selected, and in the worst-case scenario, the most pessimistic figures are selected to generate the most negative societal benefits. This indicates the error margins within this study. The sections below detail each cost item per unit and how it changes based on the scenario. If no scenario is mentioned the nominal scenario is discussed.

4.5.2. Business Models Revenue and Cost

This section details the revenue and cost items for a shared moped operator. It is used to show what has the largest impact on an item, and how this changes between business models.

Revenues

The main revenue source for Check is the operation of the mopeds. These mopeds have a 1 euro unlock fee (to disincentivise short trips) and a consumer cost of 33 euro cents per minute. Parking fees are 15 cents per minute. Furthermore, for every invoice Check sends, transaction fees of 1,25 euros are charged.

One important key performance indicator for revenue is trips per day per moped. In Table B.5 one can find the break-even of a moped without accounting for main office overhead and the number of trips per day per moped currently in Schiedam. The break-even number of trips is higher compared to the number of trips made in Schiedam. As Schiedam currently uses a free-floating model, it is assumed that this figure drops by the same percentage as the drop in the city of Groningen when switching to a hub-based model.

In Table B.14 one can find the average speed, trip length, and parking length of shared mopeds in Schiedam. Using the average ride and parking times, it is possible to obtain a revenue estimate per moped. To obtain yearly revenue numbers one multiplies the number of outstanding mopeds by the trips per moped per year and the average revenue per trip.

Other revenue sources come from any fines imposed on the user if they drive illegally, let someone else use the vehicle, require the moped to be relocated, lose a helmet, or damage the moped. It is assumed that these revenue sources exist to cover the costs of these offences, and not as a source of income.

To incentivise good parking, moped redistribution, and longer/more trips, Check uses a coin-based system. In this system, people who give feedback on previous users' parking, feedback to Check, ride 2 or more times a day, or make 20+ min trips get a coin for each action. Once a user has collected 10 coins they get a 50% discount on their next trip. Coins expire if a user does not use a Check for more than 7 days. The coin method could be used to give suburban users additional incentives such as driving between municipalities, usage during certain hours (stimulating morning traffic), or a municipality could subsidise coins to make it cheaper for users. While these effects are interesting from a research perspective, they are out of the scope of this research.

Recently, Check introduced a pro membership for 3,99 euros per month, which enables free unlocks and increases coin expiry to 21 days. However, Check Pro has not been available long enough to make conclusions about its effectiveness.

Costs

The business costs consist of three categories; fixed, variable, and setup costs. Fixed costs are made per day no matter if a moped is driven or not, variable costs are made per trip, and setup costs are all the costs associated with setting up mopeds in a new region.

Fixed costs consist of the following items:

- **Moped and Battery Lease:** See Table B.6.
- **Vandalism:** The cost of lost and damaged mopeds. This vandalism is external and encompasses damages such as third parties lighting the moped on fire, pushing it into the river, or any other damages caused by third parties. Because of its external nature, it is not possible to retrieve these costs using fines.
- **Connectivity:** The costs incurred for a mobile moped connection. Used to lock/unlock through the app as well as to track the moped.
- **City Costs:** See Table B.6.

In Figure 4.8, one can find the distribution of the fixed costs. In Appendix Table B.2 one can find a more detailed description of the fixed cost distribution.

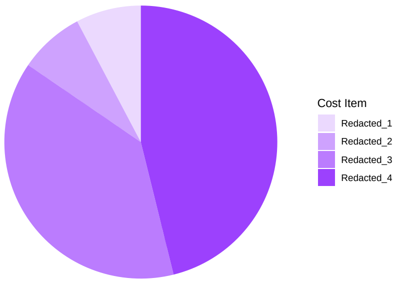


Figure 4.8: Distribution of Fixed Business Costs

Variable costs consist of the following items:

- **VAT:** Taxes to be paid on revenue. The per-minute pricing mentioned above included tax. As this tax is not revenue for the operator it is taken out of the revenue. The VAT rate in the Netherlands is 21%.
- **Promo Cost:** See Table B.6.
- **Direct Labour:** See Table B.6.
- **Transaction Fees:** Cost to process payments (costs of iDeal, MasterCard, Visa, etc.).
- **Support:** Cost to pay support staff to handle inquiries.
- **Spare Parts:** See Table B.6.
- **Insurance:** Cost of moped insurance for damages to other vehicles/people (WA insured).
- **Uncollectibles**: See Table B.6.
- **Other:** Cost of electricity and other marginal costs.

In Figure 4.9, one can find the distribution of the variable costs. Again, it can be observed that just a few cost items form the majority of variable costs. Additionally, while the energy used to drive mopeds greatly impacts carbon emissions, it has little impact on overall business costs. In Appendix B.2 one can find a more detailed description of the variable cost distribution.

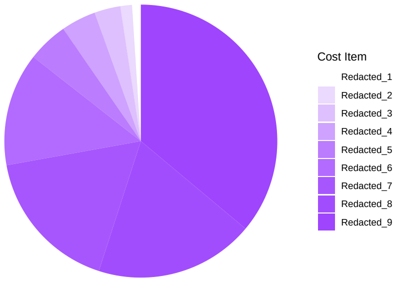


Figure 4.9: Distribution of Variable Business Costs

Setup costs for a new suburban region are negligible, with the only requirement being that it is close to a neighbouring large city where Check already operates, enabling the use of the existing infrastructure. As this research focuses on suburbs, this would most likely be the case. Researchers investigating expansion where no large city is nearby should account for setup costs.

In Appendix B.2 one can find an overview of the exact pricing of each revenue and cost item. The following sections detail the quantified cost of each (indirect) societal effect.

4.5.3. Traffic Safety Cost

The Dutch government uses research by Wijnen (2022) as the basis for the cost of accidents and casualties. According to Wijnen (2022), the societal cost for a severe accident is between 0,4-1,0 million Euros, with an average estimation of 700 thousand Euros.

The societal cost of a traffic casualty is between 3,6 and 9,2 million euros, with an average of 6,5 million. These costs include material costs (medical costs, and damage to vehicles), but also immaterial costs such as reduction in years lived or quality of life. Interestingly, immaterial costs account for 75% of total costs while medical costs only account for 2% of total costs. Lightly injured cost between 29-69 thousand euros, with an average of 51 thousand euros. The remaining injuries cost between 4-6 thousand, with an average of 5 thousand. Costs are mostly carried by individuals (90%), with the government only covering 1% of the costs (Wijnen, 2022).

The figures presented by Wijnen (2022) are based on the base year 2020 and are inflated by 17,3% to account for inflation between 2020 and 2023. These costs are combined with the magnitudes found in subsection 4.4.1 and the net safety change based on distances substituted to create an aggregate safety cost.

4.5.4. Accessibility Cost

For each of the scenarios described in subsection 4.4.2, the cost (in terms of time cost and direct costs) for each substituted mode (car, public transport, bike, walk) is determined. The Value of Time for different modes are taken from R. M. Knoope (2023) and can be found in Table 4.11. As the value of time for a moped driver has not been determined, it is set to the same value as for car drivers. To account for inflation between 2022 and 2023, the VoT figures are increased by 3,8%.

Table 4.11: Value of Time for Different Modes. Adapted from R. M. Knoope (2023).

Mode	Average Value of Time
Car (=Moped)	€10,82
Train	€10,46
BTM	€7,39
Bike	€10,78
Walk	€12,29

Car fuel costs are determined to be 2 euros/litre and a car drives 14km on a litre on average, resulting in a direct cost of 14 cents/km driven. Shared mopeds have a direct cost of 33 euro cents per minute, with a one euro unlock fee. Direct biking and walking costs are determined to be negligible. Other direct costs, such as parking and public transport tickets, are determined on a scenario-by-scenario basis. In Table 4.12 one can find an overview of the direct perceived transport costs.

Table 4.12: Direct Perceived Transport Costs

Mode	Fuel/Ticket Cost	Parking Cost
Car	€0,14/km	Scenario-by-scenario (€3,00-17,82)
Train	Scenario-by-scenario (€2,90-€2,90)	€0,00
Bus/Tram/Metro	Scenario-by-scenario (€1,21-1,99)	€0,00
Shared Moped	€1 + €0,33/min	€0,00
Bike	€0,00	€0,00
Walk	€0,00	€0,00

A perceived expense for each mode for each scenario was calculated using the above-described data and the data presented in subsection 4.4.2. Consequently, the delta between a moped trip and the most expensive mode was taken. Using these deltas, and the relative number of times a scenario occurs (see Figure 4.3a, scenarios have been rounded to the nearest 5%), a weighted average perceived expense (= accessibility gains) is obtained.

The resulting accessibility effect gains can be found in Table 4.13. The rule of half figure is used for the societal cost-benefit analysis. During the sensitivity analysis, this effect is 25% reduced and 25% increased. For detailed calculations please refer to the accompanying Excel file, sheet accessibility.

Table 4.13: Accessibility Gains

Scenario	% of Trips	Largest Delta in Scenario	Weighted Average/Passenger Trip	Rule of Half
Very Short (<1km)	15%	€ 3,43	€ 8,53	€ 4,26
Short (1-2,5km)	30%	€ 2,86		
Medium (2,5-5km)	20%	€ 6,43		
Long (5-10km)	30%	€ 16,68		
Very Long (>10km)	5%	€ 17,48		

4.5.5. Carbon Cost

For determining carbon costs, the Dutch government uses the figures presented in Aalbers et al. (2016). As these figures stem out of 2016, and many climate policies have changed since then, the Dutch government is currently in the process of updating the figures to 2024. In the meantime, de Bruyn et al. (2023) have updated the figures to 2021 by updating the 2016 figures to include inflation, carbon value increases, and tax. The same method is used to update the figures by Aalbers et al. (2016) to 2023. Multiple scenarios have been created, each with different emission goals or ways of measuring. An overview of the updated carbon cost figures can be found in Table 4.14.

Table 4.14: Carbon Cost Scenarios. Adapted from Aalbers et al. (2016) and Walch and de la Court (2022).

Scenario	CO2 Cost per KG
Low	€ 0,023
High	€ 0,091
2-Degree Low	€ 0,113
2-Degree High	€ 0,567
Utrecht Province	€ 0,875

This table excludes ETS prices, which are the prices companies currently have to pay to emit carbon dioxide. ETS prices are not used in societal cost-benefit analyses, but instead, an 'efficiency' price is used which also includes the (lowest) real cost to reduce carbon emissions.

The low scenario assumes a 45% carbon reduction goal by 2025, and the high scenario a 65% carbon reduction goal by 2025. In the two-degree scenario, global warming is limited to a maximum of two degrees by 2050. The costs of carbon emissions grow by 3,5% per year (Aalbers et al., 2016). Current European policy aims for a carbon reduction of 55% (compared to 1990) in 2030, and climate neutrality by 2050. Therefore it can be assumed that the high scenarios are more indicative of current carbon emission value compared to the low scenarios.

The province of Utrecht commissioned research into a carbon valuation that not only encompasses the cost of reducing carbon emissions but also includes the cost of damages caused by global warming. Based on data from the German government, equal welfare for all generations, and a risk premium of 25% for climate tipping points, a value of 875 euros per metric tonne of CO2 is suggested. This value increases by 0,4% each year. This value does not include the impact of climate change on developing countries and the 25% risk premium is said to be a conservative figure (Walch & de la Court, 2022). The all-encompassing carbon cost results in a value of 0,875 euros per kilogram of CO2.

In the societal cost-benefit analysis, the 2-degree high figure is used in the nominal scenario. For the sensitivity analysis, the Utrecht figure is used in the best scenario, and the High figure is used in the worst scenario.

4.5.6. Noise Pollution Cost

This section determines the cost of noise pollution, as described in subsection 4.4.4 and its magnitude is determined by the modal shift in passenger kilometres. For the nominal scenario, it was decided to use the urban population density and an equal noise reduction for both the day and night. Only car and public transport modes are assumed to generate noise pollution. A car emits 0,009 euros worth of noise pollution for each passenger kilometre. Assuming that most public transport noise pollution is caused by busses and trams inside Schiedam, a split of 75% bus and 25% train traffic is taken. Using this split a weighted cost of 0,008 euros worth of noise pollution is found for public transport per passenger kilometre (van Essen et al., 2019).

For the worst scenario, all suburban figures instead of urban figures are taken (van Essen et al., 2019). This results in a car noise value of 0,0005 euros per passenger kilometre, and a public transport noise value of 0,0007 euros per passenger kilometre.

For the best scenario, a thin traffic situation for the car and bus is assumed. Furthermore, instead of high-speed trains, conventional trains are used as a noise source. This results in a car noise value of 0,020 euros per passenger kilometre, and a public transport noise value of 0,019 euros per passenger kilometre.

4.5.7. Summary of Effect Costs Per Unit

In Table 4.15 one can find an overview of all the costs per unit described in previous sections. This data is combined with the modal shift data, as described in section 4.3, to obtain the societal effect gains/costs in the SCBA.

Table 4.15: Summary of Effect Costs for Each Scenario

Cost Item	Worst Scenario	Nominal Scenario	Best Scenario
Severe Accident	€ 1.173.000	€ 821.100	€ 469.200
Casualty	€ 10.791.600	€ 7.624.500	€ 4.222.800
Accessibility/Trip	€ 3,20	€ 4,26	€ 5,33
CO2/PKT	€ 0,091	€ 0,567	€ 0,875
Noise Car/PKT	€ 0,0004	€ 0,007	€ 0,016
Noise PT/PKT	€ 0,001	€ 0,006	€ 0,015

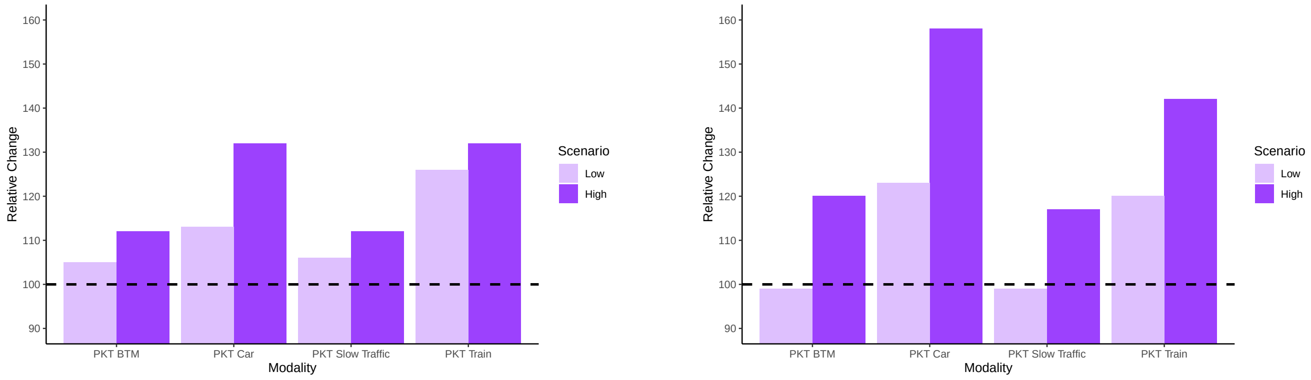
4.6. Zero Alternative

The zero alternative describes ”... the most likely development that will take place on all markets relevant to the SCBA in the event that the measure to be assessed is not implemented.” (Romijn & Renes, 2013, p.83, translated) While this is a very broad definition, for this case it consists of the (mobility) development if shared mopeds would not be placed in the region.

As shown in section 4.7, it is not financially viable for an operator to remain in Schiedam, at least not without subsidisation. Therefore, it is likely that in the zero alternative, no shared moped operator is present in the region of Schiedam. This results in no availability of shared mopeds in the region, and therefore all the effects described in the SCBA do not occur.

Baseline future scenarios are determined every decennial by the Dutch government in the ”Future Exploration of Prosperity and Living Environment” (in Dutch: WLO) report. The most recent report stems from 2015 and offers both low and high scenarios for various developments such as housing, regional developments, urbanisation, mobility, and climate and energy (Manders & Kool, 2015). These scenarios and developments can be used to get an insight into future developments with no policy changes. For this SCBA the urbanisation and mobility developments are relevant. There is no specific data available for Schiedam, therefore countrywide Dutch data is used.

In Figure 4.10 one can see that in the future, car usage will rise in all scenarios. The dashed line indicates the base WLO year of 2012. Without any precautions, this can lead to an increase in traffic jams, which increases the total loss in travel time and the number of required parking spaces in the city. In the Randstad (region between the four big Dutch cities), this growth is the largest, and results in there being twice as many traffic jams in 2050 compared to 2010 (Manders & Kool, 2015). These traffic jams increase travel times, reduce accessibility, and reduce traffic safety. Non-highway roads also experience a decrease in the ability for pedestrians to cross them and an increase in noise pollution for the residents (Ecorys, 2023). While there is an increase in the total vehicle kilometres travelled of cars, the total carbon emissions are reduced because of the greenification of vehicles. For other modes demand also increases, which will need to be met by increasing public transport and infrastructure (Manders & Kool, 2015).

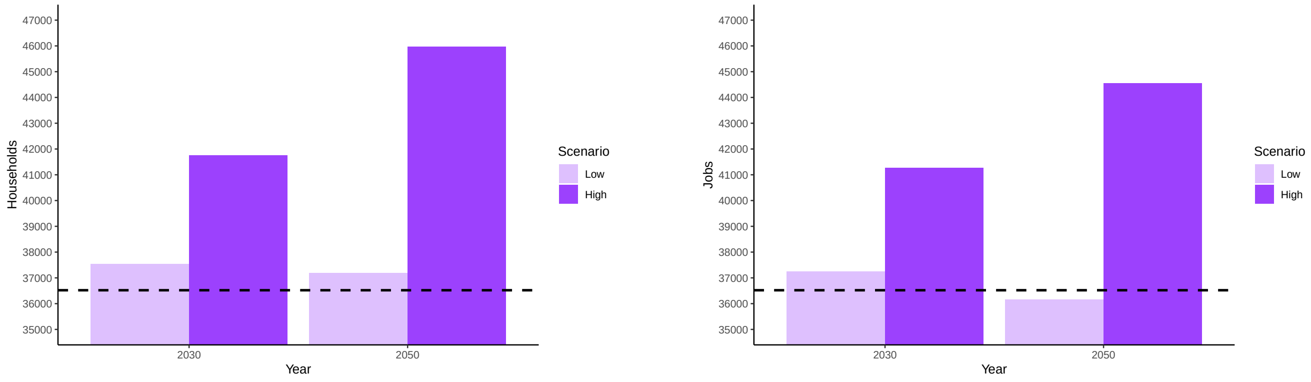


(a) 2030

(b) 2050

Figure 4.10: Future Mobility Development Scenarios. Data Adapted from Manders and Kool (2015).

In Figure 4.11 one can find how households and jobs are expected to develop, the dashed line indicates the base year in Manders and Kool (2015), which is 2012. One can observe that in 2030, in all scenarios, the number of households and jobs will increase. Current projections from local governmental website maassluis-schiedam.incijfers.nl point towards a higher likelihood of the high scenario for households. The higher number of households suggests that either people will need to travel further within the municipality as new houses get built, or overall density will increase because of buildings being replaced by flats. The increase in jobs will most likely also increase mobility movements, as more people will need to travel to their work in Schiedam.



(a) Households

(b) Jobs

Figure 4.11: Future Living Development Scenarios.
Data Adapted from Manders and Kool (2015) and maassluis-schiedam.incijfers.nl.

The zero alternative shows that a solution will be needed to meet future mobility demand. A part of this solution could be the introduction/continuation of shared mopeds/mobility. The next sections detail the final SCBA outcome, which shows what effects occur when shared mopeds are introduced into a region.

4.7. Societal Cost Benefit Analysis

This section describes the societal cost-benefit outcome of the introduction of shared mopeds in the Schiedam region. The SCBA figures are based on the findings in previous sections of this chapter. As various assumptions and approximations were made in previous sections, each figure is rounded. The source for the calculations can be found in the accompanying Excel file.

The SCBA has a period of ten years. This time span was chosen as it is similar to the duration of a public transport concession and the lifespan of a shared moped. Public transport non-emergency concessions in the Netherlands last between 5-15 years (11,8 on average)[6]. A concession gives a public transport operator the sole right to exploit a certain route and oftentimes also determines the height/duration of a governmental subsidy. Taking into account the duration of a concession, the SCBA period is set to ten years. As obtaining a concession can take a considerable amount of time, it is assumed that the project will start in two years, which is the first year in the SCBA that the effects occur. The discount rate is determined to be 2,25% for the nominal case, as recommended by Werkgroep discontovoet (2020). For the worst and best case scenarios, the discount rate is changed to WLO scenario Low; 1,85%.

All valuations presented in the SCBA tables are the net present values over ten years, starting in year two and ending in year twelve. Each table contains an effect/cost ratio (NPV effects/NPV costs). If this ratio is above 1,0, the introduction of shared mopeds is socially feasible. If the effect/cost ratio is below 1,0, the introduction is not socially feasible. It has to be noted that qualitative effects should be considered as strongly as quantitative effects, and therefore the effect/cost ratio is not the only figure one should consider. In Table 4.16 one can find the societal cost-benefit analysis for the nominal scenario, and in Table B.15 the full SCBA including redacted information.

Table 4.16: Societal Cost Benefit Analysis Results for Nominal Scenario, Redacted

Costs	**Free Floating**	**Hub**
Setup Costs	€ 0	€ 0
Direct Effects		
Accessibility	€ 1.900.000	€ 1.620.000
External Effects		
Carbon Emissions	€ 31.700	€ 27.000
Noise	€ 9.000	€ 7.600
Traffic Safety	-€ 1.370.000	-€ 1.170.000
Parking Nuisance	- -	-
Public Space Freed	+ +	+
Option Value	+	+
Effect/Cost Ratio	**1,10**	**0,94**

In Table B.15 it can be observed that the net present value (NPV) for the free-floating is positive, with an effect/cost ratio of 1,1. Because of the lower demand and higher operating costs of hub-based models, the NPV of a hub-based model is negative, with an effect/cost ratio of 0,94. Nevertheless, depending on the value given to parking nuisance and public space freed, a hub-based model could prove a viable alternative.

One interesting thing to note is that in the case of Schiedam, the required operator subsidy for a free-floating model is in line with public bus subsidisation, which lay at 18 eurocents per passenger kilometre on average in 2019 (before covid), and 27 eurocents per passenger kilometre in 2022 (at the end of covid). The concession for the bus in Schiedam is included in the concession for Rotterdam (also includes Albrandswaard, Capelle aan den IJssel, and Rotterdam), and required 38 eurocents per passenger kilometre in 2022[7], which is higher than average.

It has to be noted that the promotion of shared mopeds could shift some people from the bus towards the

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[6] wiki.ovinnederland.nl/wiki/Concessietabel

[7] ovdashboard.databank.nl

shared moped, which would increase the required subsidy per passenger kilometre for the bus. For hub-based models the required subsidy increases. Only a minority of public bus concessions also require this amount of subsidisation, making subsidisation of a hub-based model a less attractive option in this case. While this research has not investigated in what form subsidy would be most suited, these findings do show that the height of the subsidy would be comparable to current public transport subsidies.

In Figure B.2 the impact of each quantified effect (both negative and positive) is shown. It can be observed that accessibility and traffic safety have a large impact on the SCBA, accounting for over 80% of total value. In contrast, carbon and noise pollution have an almost negligible impact on the overall SCBA, most likely because of their low value assigned by SCBA literature. In the hub scenario, company loss has a higher impact on the overall SCBA, with accessibility and safety still accounting for over 80% of the SCBA value. In the next sections, a sensitivity analysis is performed to better understand the impact of the various effects.

4.8. Sensitivity Analysis

Two scenarios are created, as described in subsection 4.5.1, to better understand the range of the net present value when changing the value or magnitude of various effects. The variables changed can be found in Table 4.7 and 4.15. Both scenarios make use of the lowered discount rate of 1,85%, which explains the change in company revenue and costs. No other changes are made to the business models.

4.8.1. Worst Scenario

The results for the worst-case scenario can be found in Table B.17, and in Table B.17 the full SCBA including redacted information. It can be observed that the NPV became significantly more negative compared to the nominal scenario. This can be explained by the fact that the modal shift changed, accessibility became less valuable, and traffic safety increased in value. It reflects a scenario where most trips being replaced are public transport and walking trips, and there is a large amount of latent demand. Furthermore, accessibility is valued less, while traffic safety is highly valued. Additionally, noise and carbon pollution are valued significantly less compared to the nominal scenario.

This scenario results in an effect/cost ratio of 0,53 for the free-floating model and 0,45 in the hub model. If one would put great value on freeing public space, and the option to take a shared moped, the NPV could become more positive. Nevertheless, in this scenario, it would most likely not be recommended to allow shared mopeds in a region.

Table 4.17: Societal Cost Benefit Analysis Results for Worst Scenario, Redacted

Costs	**Free Floating**	**Hub**
Setup Costs	€ 0	€ 0
Direct Effects		
Accessibility	€ 1.470.000	€ 1.250.000
External Effects		
Carbon Emissions	€ 3.000	€ 2.600
Noise	€ 800	€ 700
Traffic Safety	-€ 2.010.000	-€ 1.710.000
Parking Nuisance	- -	-
Public Space Freed	+ +	+
Option Value	+	+
Effect/Cost Ratio	**0,53**	**0,45**

In Figure B.3 one can observe how the quantitative effects have an impact on the SCBA in the worst scenario. Switching to a hub-based model still increases company loss impact by the same amount as in the other scenarios. It can be observed that in this scenario, traffic safety has the largest impact on the net present value, while accessibility has the second largest impact. Nevertheless, they are still responsible for over 80% of the SCBA net present value. Noise and carbon pollution impact have become negligible in this scenario, accounting for just 0,1% of the total impact.

4.8.2. Best Scenario

The SCBA results for the best scenario can be found in Table 4.18, and in Table B.16 the full SCBA including redacted information. The NPV for both the free-floating and the hub-based model is significantly more positive compared to the nominal scenario. This can be explained by the fact that the value for accessibility, carbon emissions, and noise have risen significantly, while the value for traffic safety has decreased. It reflects a region where car usage is high and gets substituted often, while latent demand is low. Furthermore, a high value is put on accessibility and carbon emissions, and a lower value on traffic-related accidents. The quantitative effects result in an effect/cost ratio of 1,71 in the free-floating model and 1,47 in the hub-based model. While in both cases the effect/cost ratio is positive, it becomes more positive in a free-floating model. Depending on the value assigned to parking nuisance, freed public space, and the option value the NPV and effect/cost ratio could change. In this scenario, it would be recommended to allow shared mopeds in a region.

Table 4.18: Societal Cost Benefit Analysis Results for Best Scenario, Redacted

Costs	**Free Floating**	**Hub**
Setup Costs	€ 0	€ 0
Direct Effects		
Accessibility	€ 2.440.000	€ 2.080.000
External Effects		
Carbon Emissions	€ 112.400	€ 95.500
Noise	€ 21.900	€ 18.600
Traffic Safety	-€ 770.000	-€ 660.000
Parking Nuisance	- -	-
Public Space Freed	+ +	+
Option Value	+	+
Effect/Cost Ratio	**1,71**	**1,47**

In Figure B.4 one can find how each effect impacts the SCBA for the best-case scenario. Switching to a hub-based model still increases company loss impact by the same amount as in the other scenarios. It can be observed that accessibility accounts for the majority of the effect impacts. At the same time, traffic safety impact has been greatly reduced compared to the nominal scenario. Nevertheless, accessibility and traffic safety effects combined still account for over 85% of the SCBA net present value. Carbon emissions have a significantly larger, albeit still small, impact compared to the nominal scenario. The impact of noise pollution remains very small.

As shown above, the net present value of the SCBA differs greatly between scenarios. This can be mainly attributed to the value uncertainty of safety and accessibility effects. Aspects that could be improved for future studies, to obtain a more accurate number with a smaller sensitivity range, are addressed in the next chapter.

5 Discussion

5.1. Scientific Contribution

This research has shown that little literature exists which investigates the effects of shared mopeds in suburban areas. Various sources argue for or against the introduction of shared mobility, discussing the modal shift away from cars, the impact on emissions, the nuisance they can cause and various other factors. At the same time, literature that provides a holistic overview of the (societal) effects of shared mopeds in a suburban setting, is currently unavailable.

To fill this gap, this research combined various scientific and grey literature sources to provide a holistic overview of the (importance of certain) societal effects when introducing shared mopeds into a suburban region. This effect overview helps structure the debate on shared micromobility but also shows where scientific gaps lie which still need to be investigated to obtain a full holistic overview of the effects of introducing shared micromobility into an area. Additionally, this research provides a framework to measure the societal impact of introducing a new shared mode into a certain region. This framework can be used, and extended, to investigate the introduction effects in different areas and of various shared modes. This allows for reproducible comparisons between areas and shared modes, which can help structure the debate on the effectiveness of shared mobility.

5.2. Generalisability

This research has focused on shared micromobility in the Netherlands, specifically on Schiedam. This has an impact on the generalisability of the results. This section discusses these impacts and what they mean for future research.

The modal shift has been based on shifts in the Netherlands, where biking is much more popular compared to other countries. A different modal shift could be observed in regions where other modes, such as driving a car or using public transport, are more popular. The various modal shift compositions can both positively and negatively impact the SCBA. This can already be observed in the different scenarios; while in the worst-case scenario, mainly public transport is replaced, in the best-case scenario cars are mainly replaced. Furthermore, demand in trips/vehicle/day changes per region based on various factors such as the distance between points of interest, built environment, demographics, the recency of the scheme, and the available infrastructure. Depending on this demand, the required operator subsidy and the magnitude of the effects can change greatly. Therefore it is crucial to determine (expected) demand in a region before performing the SCBA in a new region. Additionally, it has to be noted that this SCBA assumed a nearby (large) city where an operator is already active, allowing the use of existing facilities for the repair and maintenance of mopeds, storage of swapping vehicles, and the charging of batteries. Without such a facility nearby, set-up and fixed costs would increase, which would decrease the NPV of the SCBA.

As SWOV safety statistics were obtained for the entirety of the Netherlands, including highways, it could be that accidents/casualties per billion kilometres for public transport or cars are higher in regional areas. Cars make most of their kilometres on highways, while 55% of car accidents occur on municipally maintained roads and 27% on roads with a speed limit of 50km/h (SWOV, 2023a). This shows that car accidents/casualties per billion kilometres could be higher for specific suburban regions such as Schiedam. Because mopeds, bikes, and walking get used for shorter distances in cities, their accident rate would most likely not change significantly when analysing more suburban-specific data (e.g. excluding highways). Furthermore, the safety data used for shared mopeds was the same as for private mopeds. Shared moped safety statistics from the SWOV are not available and shared moped insurance data[1] shows no severe accidents or casualties between 01-12-2023 and 15-05-2024. Insurance data does show that some minor accidents have occurred in this period, but the MAIS score of these accidents is unclear. Minor accidents have not been accounted for in the SCBA as the SWOV does not register them for other modes, and they have a relatively low value. Therefore, it is currently unclear if shared mopeds are safer (because of good maintenance, enforced maximum speeds,

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[1] Internal Data from Insurer Check

and modern models) or dangerous (because of driver characteristics) compared to privately owned mopeds. Additionally, age has an impact on accident and casualty rates, with the elderly experiencing higher rates. As the shared moped user base has a younger demographic (aged 20-35), the shared moped might have a lower accident rate. The SWOV was unable to provide more specific data for Schiedam or shared mopeds, making it unfeasible to use Schiedam-specific data in this case. As safety has a large impact on the SCBA, these limitations could greatly impact the societal net benefit or cost. For example, when assuming that shared mopeds are twice as safe compared to the general moped population, the value of safety in the nominal free-floating scenario decreases from -€ 1.370.000 to -€ 620.000. This change makes the total NPV positive in all scenarios, except for the worst case with hub business model scenario. Similarly, when assuming that shared mopeds are 50% more dangerous compared to the general moped population, the value of safety in the nominal free-floating scenario increases from -€ 1.370.000 to -€ 2.120.000. This change would result in the NPV for the nominal and worst-case scenario becoming negative while decreasing the NPV for the best scenario greatly. This great impact shows the importance of investigating more accurate safety figures for shared mopeds, as they could make or break the business case. Future research should closely investigate the safety characteristics of their region and shared mopeds to get a more accurate picture of the safety impact of introducing shared mopeds.

Accessibility gains were estimated using moped trips in Schiedam, and their corresponding cost for alternative modes. As the distribution of trip length and the cost of alternative modes differ per region, the accessibility gains will need to be re-determined when performing an SCBA for a different region. While utmost care has gone into the development of the accessibility value, preferably one would perform a stated or observed preference experiment in the target region to get the most accurate picture of the willingness to pay for shared mopeds and their associated accessibility benefits. This would also allow the delineation of effort, health, reliability, transfers, and other accessibility benefits/costs of shared mopeds. Such an extensive look into the accessibility value of shared mopeds was not feasible in the time frame of this research. As accessibility has a large impact on the SCBA result, it is recommended to further study the value of accessibility for shared mopeds.

The carbon emissions of each mode also depend on the context they are used. For electric vehicles, the electricity mix used to charge them has a large impact on overall carbon emissions. The type of road/track infrastructure used, and the method of building such infrastructure also have an impact on carbon emissions. For example in mountainous areas where much more land needs to be flattened, carbon emissions are higher compared to flat land areas. Within the Netherlands, the way infrastructure is built would not change much, but for other regions, this infrastructure might have a lower or higher impact on carbon emissions. Furthermore, other impacts include the emissions during the production and operation (swapping batteries and maintenance) of shared mopeds. As all the above-mentioned factors differ per region, this could also impact the carbon emissions saved, and future research should account for this. Additionally, it has to be noted that as various modes (cars, buses) move from combustion-based energy sources to electric energy sources, their emissions will drastically change in the future. Furthermore, the carbon emission gains from public transport are mainly obtained when the transport line is able to scale down after the introduction of shared mopeds. Otherwise, the same amount of pollution will occur, but spread over fewer passengers, increasing the CO2/pkt for public transport. Future research should investigate if scaling down public transport because of the introduction of shared mopeds is viable. Because the current value of CO2 is low, it has little impact on the SCBA net present value. Therefore, when investigating other regions, one should first focus on obtaining more accurate numbers for accessibility and safety before further investigating carbon emissions per mode.

The value of noise pollution is dependent on factors such as day/night traffic, modal composition, and the amount of urbanisation. This should be accounted for when investigating a different region. Furthermore, the value of car and public transport noise will likely become lower in the future as they move from combustion-powered towards electric-powered. Additionally, the mix of public transport (train, bus, tram) in a focus region also impacts the amount of noise pollution that affects residents. Public transport could remain operational regardless of the lower occupation rate because of the introduction of shared mopeds and is responsible for

2/3 of the value in the nominal scenario. Therefore future research should investigate if public transport could be scaled down when introducing shared mopeds, saving both noise and carbon emissions. If this is not the case, the figures for public transport should be updated to reflect the low impact of shared mopeds on public transport deployment. As noise has a minor impact on the SCBA net present value, it is recommended to update the noise figure once all other figures have been updated.

The value of parking nuisance and public space freed depend on the value assigned by a municipality. Some municipalities might have a higher desire to have few parking complaints or to get cars out of their region, which impacts the value of these effects. There has been no research into the numerical value of these effects, but if future research wants to determine this value it should be noted that it differs per municipality/jurisdiction. For now, it is only known that there is a difference in the magnitude of these effects between free-floating and hub-based business models.

In conclusion, the magnitude and distribution of effects vary wildly per region. Therefore, when applying this research to other regions, one should closely monitor if all figures used are transferable for this region. Most effects, aside from demand, should be transferable when investigating regions within the Netherlands without losing much accuracy. As both the magnitude and value of effects can vary greatly in regions outside the Netherlands, it is recommended to re-evaluate these effects when transferring this research outside the Netherlands. Nevertheless, this research provides a, starting, framework for shared moped SCBAs, which can be expanded upon to make it more specific or generalisable in future research.

5.3. Unaccounted Effects

While utmost care has gone into determining the effects of introducing shared micromobility into suburban regions, some effects are not included, due to time constraints or limited information available, but are (hypothesised) to exist. This section details these expected effects.

First, it has to be noted that the qualitative effects, described in subsection 4.4.6, could have a large influence on the SCBA. To the best of the authors' knowledge, no research has tried to quantify these effects for (shared) mopeds. As the impact of parking nuisance could negatively impact the societal benefit, while public space freed and option value could positively impact the societal benefit, it would be interesting to quantify the impact (in euros) in future research. Due to time constraints, they are only discussed qualitatively in this research.

Additionally, some effects have not been discussed in this research but could have a (minor) impact on the SCBA. Air pollution is one of these effects. While extensive research has gone into CO2 air pollution, see subsection 4.4.3, other forms of air pollution such as PM2.5, NOx, SO2, and NH3 have not been discussed while they could affect societal welfare. These forms of pollution could occur for the various modes discussed and could change when moving towards shared mopeds. A quick analysis, using the data from van Essen et al. (2019), shows that the reduction in car and public transport usage has a positive effect of ~ 1000 euros per year. Due to the small effect, lack of data for e-mopeds, and time constraints, air pollution has not been discussed further. For the same reason, the modal shift away from old (polluting) mopeds towards shared e-mopeds has also not been considered.

Furthermore, the exercise health benefits from biking and walking have not been included in this research. When people move from modes that require exercise, such as biking and walking, towards mopeds, they experience an indirect health decrease. One study by Ommeren van et al. (2017) has quantified this effect for biking at 17 cents per vehicle kilometre. No data has been found for walking. By performing a quick analysis, there is a reduction of ~ 9000 euros per year in health after the introduction of shared mopeds because people moved away from bikes. Due to time constraints and no data available for walking health benefits, it was decided not to investigate health benefits further. Nevertheless, as the impact of health on the SCBA is relatively high it would be worthwhile to further explore exercise health effects in future research.

Romijn and Renes (2013, p.120) describes agglomeration effects as one of the possible indirect effects in public space or infrastructure developments. These effects occur because of an increase in economic density or proximity. For example, when shared mopeds allow for faster travel, they allow people to work at places which they could not have reached before. This increases worker competition, but also employer-employee match, increasing labour productivity (Romijn & Renes, 2013). Much discussion has gone into the magnitude of this effect, but an infrastructure SCBA by Ecorys (2023) added 15-30% of the obtained accessibility effects as agglomeration effects. Because accessibility effects already accounted for a large part of the SCBA, were approximated, and the agglomeration effect of shared mopeds can be put up for discussion, it was decided to not include this effect in the SCBA. Future research could investigate if agglomeration effects occur and what the magnitude of these effects would be.

Frits Bos et al. (2022) recommended extending the SCBA guideline by Romijn and Renes (2013) to include broad prosperity. This broad prosperity not only includes health, safety, and habitat effects, but also includes prosperity for future generations, the distribution of prosperity, and prosperity in other countries (for example, if a company moves their factory from the Netherlands to a country without regulations, one is only moving the emissions). Future generations will most likely have to deal with recycling the mopeds once they have reached their end-of-life and any pollution from people throwing helmets/accessories into nature. Prosperity in other countries should already be partially included, as moped production (which happens outside the Netherlands) emissions have been included in the CO2 figures. In the case end-of-life mopeds do not get recycled but shipped to another country, there is an impact on the prosperity of this country in the future. Nevertheless, waste pollution also occurs for most alternative modes, and might be lower for mopeds. As the introduction of shared mopeds is very localised, the societal impact on future generations and other countries is limited.

On the contrary, the prosperity distribution of shared should be investigated further. As the age demographic 20-35 is most actively using shared mopeds, not everyone benefits equally from their introduction. Furthermore, it is hypothesised that medium- and high-income individuals benefit more from introducing shared mopeds (as they can afford to ride them) compared to low-income individuals. In such a case, low-income individuals could be subsidised to make shared mopeds more accessible for this group. At the same time, shared mopeds do not require individuals to purchase a moped upfront and all look the same, reducing the status effect some individuals experience when owning a specific moped. Future research should investigate how the societal benefits and drawbacks are distributed over various demographics.

One possible effect could be the reduction of congestion because of the modal shift away from cars towards mopeds. This could result in time saved for non-moped users as well, thereby increasing the SCBA net present value. A quick calculation shows that the cars in Schiedam have travelled ~ 377 million passenger kilometres (29.000 cars * 10.000km/year * 1,3 car occupation rate). If only 5% of this distance was made in Schiedam, 18,9 million passenger kilometres have been travelled by car in Schiedam. Car-to-moped substitution is significantly lower compared to overall passenger kilometres travelled by car. While this calculation has a considerable amount of assumptions, and congestion grows exponentially, it shows that the overall impact of shared mopeds towards congestion is low, at least in Schiedam. This could change with an increase in overall shared moped usage, depending on the size and popularity of a shared moped in a certain region. Because of this, and time constraints, no further research has gone into congestion effects. Future research could focus on identifying the value of congestion relief effects when introducing shared mopeds to a region.

This research also has not identified subsidisation effects and which form of subsidisation would be best suited for shared mopeds. For example, further subsidising than necessary to break even with the current operator price scheme, thereby lowering the price/min an operator has to ask, could result in more shared moped users, which increases the magnitude of all effects. This depends on the price sensitivity of shared moped users (how many more people use a shared moped when the price drops by x%), which can be investigated in future research. Alternatively, subsidising marketing and awareness of shared mopeds could also prove more beneficial if this increases shared moped usage to the required level and is cheaper than direct operator subsidisation. Furthermore, it is also not clear if/how shared moped governmental subsidies are legally possible. One subsidisation form could be through a direct governmental concession with an operator, where terms are made that specify how many shared mopeds should be available in which regions at all times. Usually, transport concessions in the Netherlands are done on a transport region level (often province-wide, except for in large population centres). Giving out a concession on a transport region level would simplify the application process for an operator, but also requires significant effort from local governments to transfer the rights from the local to the transport region. Another subsidisation form could be a government contract, which differs from the concession as concessions are already established in law while a governmental contract would be a direct government contract. This option would be unprecedented and would therefore take a long time to research and implement.[2] Any shared moped concessions would need to comply with the Dutch ”PSO-verordening” or otherwise risk being marked as state aid. State aid is mostly forbidden in the European Union and is only allowed under very specific conditions[3]. Therefore, the legal landscape of subsidising shared mopeds should be investigated further. If concessions would prove to be illegal, an operator could look at becoming a subcontractor for an existing public transport company with a concession. This would require the public transport company to be willing to collaborate, or it would need to be required in their concession to provide shared mobility. Future research should investigate Which form of subsidisation or promotion is best suited for shared mopeds, as there are many ways to create governmental support for shared mobility.

It also has to be noted that company profit/loss is dependent on the operator’s efficiency. While the current operator in this research paper is Check, other shared mobility operators could have different levels of operational efficiency. This efficiency would impact the required ridership, and therefore impact the SCBA. Additionally, the discount rate for operator revenue and costs has been set to the same level as the rate for other effects (1,85-2,25%), while in the real world, the discount rate a company uses is most likely higher. Additionally, the scenarios did not allow for an investigation of the 2,65% discount rate, as recommended by Werkgroep discontovoet (2020). Future researchers should take into account operator efficiency (especially when assessing a different operator) and the most appropriate discount rate for each effect. Furthermore, the value of safety has also been discounted, and one can argue that discounting the future value of a casualty or severe accident is not correct. Not discounting safety increases (making it more negative) its NPV by 14% in the nominal scenario and 17% in the worst and best scenarios. This increase results in the NPV of the Nominal Free-Floating scenario becoming negative. Subsequently, it is recommended to investigate the appropriate discount rate, or if one should be applied at all, for the safety effects.

Finally, it has to be noted that to obtain a full SCBA picture of all alternatives, other shared modes such as (e-)bikes, kick-scooters (once legal in the Netherlands), and cars should also be considered. Such an overview could show if shared mopeds have the highest net societal benefit, or if other shared modes result in a higher net societal benefit. Other modes were out of scope for this research, both due to time constraints and the lack of (demand) data. Future research should focus on identifying the societal value of introducing alternative shared modes, and their business models, to a suburban region.

To conclude, while utmost care has gone into identifying and quantifying as many effects of the introduction of shared mopeds as possible, the investigated effects are not exhaustive. Various effects and other shared modes exist that could increase the accuracy of the SCBA, and future research should try to quantify these effects as well.

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[2] Internal documentation: Onderzoek regionale aanpak deelmobiliteit by Vervoerregio Amsterdam

[3] europadecentraal.nl/praktijkvraag/hoe-zit-het-met-staatssteun-en-openbaarvervoermarketing/

5.4. SCBA for Decision Making

The SCBA results, as presented in section 4.7 and 4.8, suggest subsidising it or not subsidising it based on the scenario one uses. It is important to note that one should not base their policy decision to subsidise shared mopeds solely on the SCBA. It is almost impossible to create an accurate SCBA that encompasses all effects, as discussed in section 5.2 and 5.3 (Romijn & Renes, 2013). This is also reflected in the significant difference between the worst and best-case scenario net present values. The SCBA does show which effects still require further research to be quantified, which effects are currently important, how different business models impact the net present value, and to enable a more business-like discussion. The conclusions made in this report are based on the SCBA, but further research should be performed into unexplored and undiscussed effects. The SCBA is therefore mostly an informative tool, that should be complemented with other tools and discussions to reach a final decision.

6 Conclusion

This research has shown that the operation of shared mopeds in a suburban region is not viable for a private operator. The societal impact of shared mopeds primarily revolves around accessibility and safety, which have an uncertain valuation. Nevertheless, based on the scenario selected, the introduction of shared mopeds can increase overall welfare under certain circumstances. Governmental support could help a private operator to internalise the external societal effects in scenarios where overall welfare increases with the introduction of shared mopeds.

In order to come to these conclusions this research has investigated how the business case for shared mopeds in Dutch suburban areas could be made viable, with a focus on the city of Schiedam, the Netherlands. To that extent, two business models have been investigated; a free-floating and a hub-based model. Operator data showed that shared mopeds are not long-term financially viable in this region, no matter the business model, as the required ridership is not available. Operating shared mopeds in the suburban region of Schiedam results in a large (discounted) shared moped operator loss for free-floating business models and an even larger loss for hub-based models over ten years, refer to Table B.4 for the exact loss figures. This difference between business models is attributed to the lower usage and higher costs in hub-based models. The lower usage in hub models can be attributed to the lower moped visibility and higher walking distances to the nearest shared moped. This research shows that the private operation of shared mopeds in suburban regions is not viable.

One of the possible ways to make the business model viable would be through governmental support. However, before exploring the effects of various support forms, it is essential to assess the societal impact. To this end, a societal cost-benefit analysis (SCBA) was conducted to evaluate the societal effects of introducing shared mopeds in the region of Schiedam. Ten different effects have been identified and their impact has been further investigated. Three SCBA scenarios have been created from the operator's perspective to account for effect uncertainty: worst, nominal, and best.

In the nominal scenario, the free-floating model results in a positive net societal benefit while a hub-based model results in a negative net societal benefit, resulting from the higher operator costs and lower effect magnitudes. Based on these results, it is recommended that free-floating business models be utilised to improve the business case for shared mopeds. Additionally, free-floating business models provide a higher magnitude of effects compared to hub-based business models.

However, a large difference in net societal benefits exists between the worst, nominal, and best scenarios. When safety is deemed of the utmost importance, and accessibility is deemed less important, the net societal benefit for both business models becomes greatly negative. The opposite is also true, when safety is deemed less important, but accessibility is deemed very important, the net societal benefit for both business models becomes greatly positive. Although other effects play a role in the wide range of outcomes, the significant impact of these two effects, constituting 80% of the net societal value, dominates the scenarios. This can be attributed to the high value of safety and accessibility compared to other quantified effects. The large range between scenarios shows that there is still uncertainty in the net societal benefit figure, which will need to be investigated further. Based on current results, it depends on the scenario used if allowing shared mopeds in Schiedam results in a net societal benefit. In a region where usage of public transport usage is already high, and there is a significant amount of induced demand (such as in the worst scenario), the introduction of shared moped has a propensity to reduce overall welfare. Especially when safety is deemed extremely important, and is assigned a high value, the introduction of shared mopeds results in a negative net societal benefit. At the other end of the spectrum, when current car usage is high and latent demand low, the introduction of shared mopeds has a propensity to increase overall welfare. This is reinforced when traffic safety is deemed less crucial while the increased accessibility is highly valued. In summary, the introduction of suburban shared mopeds skews towards a positive net societal benefit, contingent upon specific circumstances and the chosen business model.

Moreover, this research provides a framework to investigate shared moped operator viability and the societal benefits in other (potential) regions. Furthermore, it gives insight into what effects should be prioritised when discussing the societal benefit of shared mopeds, and which effects still need to be investigated further. Future research could provide a more holistic and valid picture of the societal effects that occur when introducing shared mopeds into a region. Afterwards, a subsidisation SCBA should be performed to better understand if, in what form, and what magnitude subsidisation could improve the business case for shared mopeds. The next sections discuss specific recommendations for operators, municipalities and future research.

6.1. Recommendations for Operators

To improve the net societal benefit, the operator can investigate various measures. As the current results point towards a positive welfare increase when introducing shared mopeds to a suburban region, it can be worthwhile to investigate these measures to obtain a more accurate (and possibly more positive) welfare change estimate.

Firstly, it would be interesting to find specific shared moped safety figures to better understand how they relate to the safety of the general moped population. As safety has a large impact on the SCBA, finding a more accurate accident and casualty/billion kilometres figure could greatly impact the net societal benefit. For example, if shared mopeds are found to be twice as safe as the general moped population, all scenarios except the worst scenario with a hub-based business model increase overall welfare. Nevertheless, it is recommended to make users more aware of safe riding practices through the app, try out/test drive days, and possibly punish bad driving behaviour (using the GPS data/sensors on the vehicle).

Once the safety figures for shared mopeds have been obtained, it is recommended to discuss the findings with local governmental bodies. This could be either the municipality or the local regional transport authority. These discussions could uncover further uncertainties and barriers that these authorities experience with the introduction and support of shared mopeds in their region, but can also lead to governmental support which would make the business case viable. Depending on the outcome of these discussions, the operator could further investigate certain effects to better understand the effects of shared mopeds, possibly taking away the concerns of some governmental bodies.

One possible investigation is to shift their marketing towards existing car users and try to place mopeds in areas with high car usage. This could result in a higher modal shift away from cars, which increases the value of noise and carbon emissions further. Furthermore, it would increase the qualitative valuation of freed public space. These efforts could improve the value of the net societal benefit.

Another possibility is to investigate the (cross) price sensitivity of shared mopeds. This would give insight into how many users would take the shared moped if the price/min would change. Using this price sensitivity, the optimal price which maximises the net present value could be obtained. This could either minimise the loss for the operator or maximise other effects which would allow for a higher subsidisation amount.

Alternatively, it could be the case that expanding to suburban regions increases demand in the nearby large city. Depending on this increase in demand, it could still be viable to expand to suburban areas, even without governmental support. It should be investigated if and how much the expansion into suburban areas increases demand in urban areas.

6.2. Recommendations for Municipalities

To make the best use of the SCBA, it is crucial to clarify what a municipality wants to achieve by allowing shared mopeds into its governed region. Derived from this goal, different importance values could be given to each effect by selecting one of three scenarios. For example, when the main goal of a municipality is to increase accessibility, they could select the best (= high value) scenario figure for accessibility. At the same time, they could value safety less, and based on this select the nominal scenario figure for safety. Alternatively, If their primary goal is reducing carbon emissions, they can compare the emissions saved by introducing shared mopeds to the total carbon emissions in their region. This comparison will help them understand the overall impact on emissions. Based on the results, they can decide if shared mopeds contribute enough to their emission reduction plans to support and allow them, while also considering the other effects of introducing shared mopeds to suburban regions.

Once municipalities understand their primary achievement with allowing shared mopeds and adapting the SCBA, they should discuss with operators how to best achieve this goal. The SCBA can be used here as a way to show the magnitude of each effect, and which effects operators and municipalities should focus on. If under no circumstances the net societal benefit is positive and the qualitative effects are also negative, the municipality could consider not allowing shared mopeds in their region. If societal welfare is expected to increase, they can collaborate with the operator to maximise this benefit. For example, they can enforce safety measures or strategically place mopeds in regions to enhance accessibility. As the private operator can not internalise the external effects, governmental support can be considered the case where overall welfare increases. Given the unclear regulatory landscape, the municipality should investigate the legal possibilities for supporting shared mobility and determine the best form of support, such as direct subsidisation, concessions, marketing, or other methods.

It has to be noted that other shared modes, such as (e-)bikes and kick-scooters, have not been investigated but could have a very different net societal benefit, which should be investigated using the same framework to allow for comparisons between modes. Based on the outcome of these SCBAs, the region could permit not only shared mopeds but also other shared transportation modes. This combination may enhance overall social welfare further compared to allowing only shared mopeds.

To summarise, using the SCBA framework allows municipalities to evaluate the impact of shared mopeds more effectively. By aligning these assessments with their primary goals, municipalities can maximise overall societal welfare. Nevertheless, collaboration with operators and appropriate regulatory support are key to achieving these benefits.

6.3. Recommendations for Future Research

In chapter 5 many future research suggestions have been made that improve and extend the current findings. The most crucial suggestion is to improve the accuracy of the identified effects, thereby narrowing the gap between the worst and best scenarios. The current large range can result in differing interpretations between stakeholders, sparking discussions about the net societal benefit of shared mopeds. The reduction of the range would provide a clearer answer regarding whether shared mopeds generate a positive societal impact. In turn, this would help prevent prolonged discussions among stakeholders about the societal implications of shared mopeds.

Furthermore, current qualitative effects should be quantified and unexplored effects should be researched to better understand their importance. The increased valuation accuracy of existing effects and the value of unaccounted-for effects could be found through stated or revealed preference surveys, as these provide a higher (and more localised) accuracy compared to the currently used key figures. Once the valuation of these effects has been found, increasing the accuracy of the framework, the framework can be used to extend the research to other regions. This could provide insight into how much the focus location impacts the net societal benefit, and which region-specific characteristics impact the viability of shared mopeds. Moreover, alternative shared modes (such as e-bikes, cars, and e-scooters) should be investigated using this framework to give a holistic overview of the benefits and drawbacks of these modes. This allows policymakers to weigh the effects and obtain a better insight into which shared mode is most suited to their region.

References

Aalbers, R., Renes, G., & Romijn, G. (2016, November). *WLO-klimaatscenarios en de waardering van CO2 uitstoot in MKBAs* (tech. rep.).

ACM. (2021, January). *Vervoersmonitor 2019* (tech. rep.). ACM/19/035445.

Aguilera-García, Á., Gomez, J., Rangel, T., Baeza, M. d. l. Á., & Vassallo, J. M. (2024). Which factors influence the use of shared and privately-owned e-scooters in the city of Madrid? Implications for urban mobility. *Cities*, *147*. https://doi.org/10.1016/j.cities.2023.104785

Aguilera-García, Á., Gomez, J., & Sobrino, N. (2020). Exploring the adoption of moped scooter-sharing systems in Spanish urban areas. *Cities*, *96*. https://doi.org/10.1016/j.cities.2019.102424

Aguilera-García, Á., Gomez, J., Sobrino, N., & Díaz, J. J. V. (2021). Moped scooter sharing: Citizens' perceptions, users' behavior, and implications for urban mobility. *Sustainability (Switzerland)*, *13*(12). https://doi.org/10.3390/su13126886

Allen, J., & Farber, S. (2020). Suburbanization of Transport Poverty. *Annals of the American Association of Geographers*, *111*(6), 1833–1850. https://doi.org/10.1080/24694452.2020.1859981

Arbeláez Vélez, A. M. (2023). Environmental impacts of shared mobility: a systematic literature review of life-cycle assessments focusing on car sharing, carpooling, bikesharing, scooters and moped sharing. *Transport Reviews*. https://doi.org/10.1080/01441647.2023.2259104

Arias-Molinares, D., Romanillos, G., García-Palomares, J. C., & Gutiérrez, J. (2021). Exploring the spatio-temporal dynamics of moped-style scooter sharing services in urban areas. *Journal of Transport Geography*, *96*. https://doi.org/10.1016/j.jtrangeo.2021.103193

Bach, X., Marquet, O., & Miralles-Guasch, C. (2023). Assessing social and spatial access equity in regulatory frameworks for moped-style scooter sharing services. *Transport Policy*, *132*, 154–162. https://doi.org/10.1016/j.tranpol.2023.01.002

Bagnoli, C., Massaro, M., Dal Mas, F., & Demartini, M. (2018). Defining The Concept Of Business Model: Searching For A Business Model Framework. *International Journal of Knowledge and Systems Science*, *9*(3), 52–60. https://www.igi-global.com/article/defining-the-concept-of-business-model/224959

Bieliński, T., & Ważna, A. (2020). Electric scooter sharing and bike sharing user behaviour and characteristics. *Sustainability (Switzerland)*, *12*(22), 1–13. https://doi.org/10.3390/su12229640

Boting, R. (2023, December). *Unleashing Suburban Shared Micromobility A Comprehensive Framework with Guidelines for Implementing Suburban Shared (E-)Bike and Moped Services, the Netherlands* (tech. rep.). Technical University Delft. Delft. https://repository.tudelft.nl/islandora/object/uuid%3Af00389e5-26eb-4cbe-abdf-2b88eaf0aa70

Caggiani, L., Camporeale, R., Ottomanelli, M., & Szeto, W. Y. (2018). A modeling framework for the dynamic management of free-floating bike-sharing systems. *Transportation Research Part C: Emerging Technologies*, *87*, 159–182. https://doi.org/10.1016/j.trc.2018.01.001

Caspi, O., Smart, M. J., & Noland, R. B. (2020). Spatial associations of dockless shared e-scooter usage. *Transportation Research Part D: Transport and Environment*, *86*. https://doi.org/10.1016/j.trd.2020.102396

CBS. (2023, July). *Onderweg in Nederland (ODiN) 2022* (tech. rep.). https://www.cbs.nl/nl-nl/longread/rapportages/2023/onderweg-in-nederland--odin---2022-onderzoeksbeschrijving?onepage=true#c-Bijlage-D-Kerntabellen

Crowe, S., Cresswell, K., Robertson, A., Huby, G., Avery, A., & Sheikh, A. (2011). The case study approach. *BMC Medical Research Methodology*, *11*. https://doi.org/10.1186/1471-2288-11-100

Damen, I. (2020). *Deelfietsen in niet-stedelijke gebieden* (tech. rep.). Hasselt University. https://documentserver.uhasselt.be/handle/1942/32377

Davidse, R. J., van Duijvenvoorde, K., Boele-Vos, M. J., Louwerse, W. J., Stelling-Konczak, A., Duivenvoorden, C. W., & Algera, A. J. (2019). Scenarios of crashes involving light mopeds on urban bicycle paths. *Accident Analysis and Prevention*, *129*, 334–341. https://doi.org/10.1016/j.aap.2019.05.016

de Bortoli, A. (2021). Environmental performance of shared micromobility and personal alternatives using integrated modal LCA. *Transportation Research Part D: Transport and Environment*, *93*. https://doi.org/10.1016/j.trd.2021.102743

de Bortoli, A., & Christoforou, Z. (2020). Consequential LCA for territorial and multimodal transportation policies: method and application to the free-floating e-scooter disruption in Paris. *Journal of Cleaner Production*, *273*. https://doi.org/10.1016/j.jclepro.2020.122898

de Bruyn, S., de Vries, J., Juijn, D., Bijleveld, M., van der Giesen, C., Korteland, M., van Santen, W., & Pápai, S. (2023, February). *Handboek Milieuprijzen 2023* (tech. rep.). CE Delft. Delft.

de Haas, M., & Kolkowski, L. (2023, November). *Fietsfeiten 2023 Brochure* (tech. rep.). Kennisinstituut voor Mobiliteitsbeleid. Den Haag.

Dekker, H. J. (2021). An accident of history? How mopeds boosted Dutch cycling infrastructure (1950–1970). *Journal of Transport History*, *42*(3), 420–443. https://doi.org/10.1177/00225266211011935

Dibaj, S., Hosseinzadeh, A., Mladenović, M. N., & Kluger, R. (2021, November). Where have shared e-scooters taken us so far? A review of mobility patterns, usage frequency, and personas. https://doi.org/10.3390/su132111792

Ecorys. (2023, December). *MKBA Alternatief Ring A27 Utrecht* (tech. rep.). Gemeente Utrecht. Rotterdam.

Estrada, M., Salanova, J. M., Medina-Tapia, M., & Robusté, F. (2021). Operational cost and user performance analysis of on-demand bus and taxi systems. *Transportation Letters*, *13*(3), 229–242. https://doi.org/10.1080/19427867.2020.1861507

Faber, R., Durand, A., & Zijlstra, T. (2020, December). *Kansrijke verplaatsingen met Mobility-as-a-Service* (tech. rep.). Kennisinstituut voor Mobiliteitsbeleid. https://www.kimnet.nl/publicaties/rapporten/2020/12/17/kansrijke-verplaatsingen-met-mobility-as-a-service

Felipe-Falgas, P., Madrid-Lopez, C., & Marquet, O. (2022). Assessing Environmental Performance of Micromobility Using LCA and Self-Reported Modal Change: The Case of Shared E-Bikes, E-Scooters, and E-Mopeds in Barcelona. *Sustainability (Switzerland)*, *14*(7). https://doi.org/10.3390/su14074139

Finke, S., Schelte, N., Severengiz, S., Fortkort, M., & Kähler, F. (2022). Can battery swapping stations make micromobility more environmentally sustainable? *E3S Web of Conferences*, *349*. https://doi.org/10.1051/e3sconf/202234902007

Forsyth, A. (2012). Defining Suburbs. *Journal of Planning Literature*, *27*(3), 270–281. https://doi.org/10.1177/0885412212448101

Frits Bos, Bert Hof, & Joep Tijm. (2022, June). *Maatschappelijke kosten-batenanalyse en brede welvaart; een aanvulling op de Algemene MKBA-Leidraad* (tech. rep.). CPB/PBL.

Geurs, K., Haaijer, R., & Van Wee, B. (2006). Option value of public transport: Methodology for measurement and case study for regional rail links in the Netherlands. *Transport Reviews*, *26*(5), 613–643. https://doi.org/10.1080/01441640600655763

Ghaffar, A., Hyland, M., & Saphores, J. D. (2023). Meta-analysis of shared micromobility ridership determinants. *Transportation Research Part D: Transport and Environment*, *121*. https://doi.org/10.1016/j.trd.2023.103847

Grobben, I., Kimppa, E., & Link, J. (2023, October). *Nulmeting Check* (tech. rep.). New Economy.

Groningen, G. (2023). Rapportage gebruik deelscooters 2022.

Hilster, D., Tol, E., & Van Den Berg, R. (2022). *Effect of shared electric mopeds on CO2 emissions* (tech. rep.). www.cedelft.eu

Hofmann, H., & Kaufmann, R. (2013). *E-Scooter-Sozial-und naturwissenschaft-liche Beiträge zur Förderung leichter Elektro-fahrzeuge in der Schweiz* (tech. rep.). www.ikaoe.unibe.ch/forschung/e-scooters/index.html

Hoobroeckx, T., Cats, O., Shelat, S., & Molin, E. (2023). Travel choices in (e-)moped sharing systems: Estimating explanatory variables and the value of ride fee savings. *Research in Transportation Business and Management*, *50*. https://doi.org/10.1016/j.rtbm.2023.101021

Hoppesteyn, M. (2023, July). *Onderweg in de Metropoolregio 2018 - 2022* (tech. rep.). Gemeente Rotterdam, Afdeling Onderzoek en Business Intelligence (OBI).

Hosseinzadeh, A., Algomaiah, M., Kluger, R., & Li, Z. (2021). E-scooters and sustainability: Investigating the relationship between the density of E-scooter trips and characteristics of sustainable urban development. *Sustainable Cities and Society*, *66*. https://doi.org/10.1016/j.scs.2020.102624

Huang, E., Yin, Z., Broaddus, A., & Yan, X. (2024). Shared e-scooters as a last-mile transit solution? Travel behavior insights from Los Angeles and Washington D.C. *Travel Behaviour and Society*, *34*. https://doi.org/10.1016/j.tbs.2023.100663

Jorritsma, P., Witte, J.-J., Alonso González, M. J., & Hamersma, M. (2021, October). *Deelauto- en deelfietsmobiliteit in Nederland* (tech. rep.). Kennisinstituut voor Mobiliteitsbeleid. https://www.kimnet.nl/publicaties/rapporten/2021/10/05/deelauto--en-deelfietsmobiliteit-in-nederland-ontwikkelingen-effecten-en-potentie

Ju, M., Martin, E., & Shaheen, S. (2024). What Is the Connection? Understanding Shared Micromobility Links to Rail Public Transit Systems in Major California Cities. *Sustainability (Switzerland)*, *16*(2). https://doi.org/10.3390/su16020555

Kazmaier, M., Taefi, T., & Hettesheimer, T. (2020). Techno-economical and ecological potential of electrical scooters: A life cycle analysis. *European Journal of Transport and Infrastructure Research*, *20*(4), 233–251. https://doi.org/10.18757/ejtir.2020.20.4.4912

Kets, A., Gökce. Hanifi, & van der Geest, L. (2023, June). *Deelmobiliteit- Uitkomsten van een peiling door middel van drie vragenlijsten* (tech. rep.). Gemeente Almere. Almere.

Kim, M., Puczkowskyj, N., MacArthur, J., & Dill, J. (2023). Perspectives on e-scooters use: A multi-year cross-sectional approach to understanding e-scooter travel behavior in Portland, Oregon. *Transportation Research Part A: Policy and Practice*, *178*. https://doi.org/10.1016/j.tra.2023.103866

Knoope, M., & Kansen Maarten. (2021, July). *De rol van lichte elektrische voertuigen in het mobiliteitssysteem* (tech. rep.). Kennisinstituut voor Mobiliteitsbeleid. https://www.kimnet.nl/publicaties/publicaties/2021/07/09/op-weg-met-lev-de-rol-van-lichte-elektrische-voertuigen-in-het-mobiliteitssysteem

Knoope, R. M. (2023). *Nieuwe waarderingskengetallen voor reistijd, betrouwbaarheid en comfort Kennisinstituut voor Mobiliteitsbeleid | KiM* (tech. rep.).

Latinopoulos, C., Patrier, A., & Sivakumar, A. (2021). Planning for e-scooter use in metropolitan cities: A case study for Paris. *Transportation Research Part D: Transport and Environment*, *100*. https://doi.org/10.1016/j.trd.2021.103037

Leestemaker, L., Otten, M., Scholten, P., Hilster, D., Meijer, C., Király, J., van den Berg, R., & Bruinsma, M. (2023, February). *STREAM Personenvervoer Emissiekentallen modaliteiten 2022* (tech. rep.). www.ce.nl

Liao, F., & Correia, G. (2022). Electric carsharing and micromobility: A literature review on their usage pattern, demand, and potential impacts. *International Journal of Sustainable Transportation*, *16*(3), 269–286. https://doi.org/10.1080/15568318.2020.1861394

Loos, M. (2024). *Vervoersarmoede en de energietransitie* (tech. rep.). www.tno.nl

Loudon, E., Geržinič, N., Molin, E., & Cats, O. (2023). Determinants of shared moped mode choice. *Journal of Urban Mobility*, *3*. https://doi.org/10.1016/j.urbmob.2023.100053

Manders, T., & Kool, C. (2015). *Nederland in 2030 en 2050: twee referentiescenario's-WLO* (tech. rep.). CPB, PBL. Den Haag.

Meng, L., Somenahalli, S., & Berry, S. (2020). Policy implementation of multi-modal (shared) mobility: review of a supply-demand value proposition canvas. *Transport Reviews*, *40*(5), 670–684. https://doi.org/10.1080/01441647.2020.1758237

micro consult. (2023, March). *Landelijk Reizigersonderzoek 2022* (tech. rep.). Ministerie van Infrastructuur en Waterstaat. Amersfoort.

Mitropoulos, L., Stavropoulou, E., Tzouras, P., Karolemeas, C., & Kepaptsoglou, K. (2023, September). E-scooter micromobility systems: Review of attributes and impacts. https://doi.org/10.1016/j.trip.2023.100888

Movares. (2023, March). *Synthese deelscooters* (tech. rep.). Movares. https://movares.nl/wp-content/uploads/2023/07/Synthese-deelscooters-eindrapportage-Movares.pdf

Movares & Amsterdam, G. (2022, October). *Deelvervoer in Amsterdam: deelfiets, deelbakfiets, deelscooter en deelauto* (tech. rep.).

Nikiforiadis, A., Paschalidis, E., Stamatiadis, N., Raptopoulou, A., Kostareli, A., & Basbas, S. (2021). Analysis of attitudes and engagement of shared e-scooter users. *Transportation Research Part D: Transport and Environment*, *94*. https://doi.org/10.1016/j.trd.2021.102790

OECD/ITF. (2020, September). *Good to Go? Assessing the Environmental Performance of New Mobility* (tech. rep.). International Transport Forum.

Oluwajana, S. D., & Wang, C. M. (2023). Rationale for governance and effective guidelines towards attainment of shared e-scooter micromobility benefits in Windsor, Ontario. *Case Studies on Transport Policy*, *13*. https://doi.org/10.1016/j.cstp.2023.101051

Ommeren van, K., Lelieveld, M., de Pater, M., Ruffino, P., van der West, R., & Goedhart, W. (2017, December). *Waarderingskengetallen MKBA Fiets: state-of-the-art* (tech. rep.). Ministerie Van Infrastructuur En Waterstaat.

Oude Mulders, J., Aarts, L., Decae, R., Bos, N., Goldenbeld, C., Schermers, G., Mons, C., Hoekstra, T., & Bijleveld, F. (2023). *De Staat van de Verkeersveiligheid 2023 Sterke stijging in aantallen doden en gewonden* (tech. rep.). SWOV – Instituut voor Wetenschappelijk Onderzoek Verkeersveiligheid. Den Haag.

Pérez-Fernández, O., & García-Palomares, J. C. (2021). Parking places to moped-style scooter sharing services using GIS location-allocation models and GPS data. *ISPRS International Journal of Geo-Information*, *10*(4). https://doi.org/10.3390/ijgi10040230

Poorthuis, A., & Zook, M. (2023). Moving the 15-minute city beyond the urban core: The role of accessibility and public transport in the Netherlands. *Journal of Transport Geography*, *110*. https://doi.org/10.1016/j.jtrangeo.2023.103629

Reck, D. J., Haitao, H., Guidon, S., & Axhausen, K. W. (2021). Explaining shared micromobility usage, competition and mode choice by modelling empirical data from Zurich, Switzerland. *Transportation Research Part C: Emerging Technologies*, *124*. https://doi.org/10.1016/j.trc.2020.102947

Reck, D. J., Martin, H., & Axhausen, K. W. (2022). Mode choice, substitution patterns and environmental impacts of shared and personal micro-mobility. *Transportation Research Part D: Transport and Environment*, *102*. https://doi.org/10.1016/j.trd.2021.103134

Romijn, G., & Renes, G. ((2013). *Algemene leidraad voor maatschappelijke kosten-batenanalyse*.

Rotteveel, M., Sloot, M., Eradus, P., de Vries, B., & ter Haar, J. (2023, December). *Staat van het openbaar vervoer 2022* (tech. rep.). CROW-KpVV. Ede. https://www-crow-nl.tudelft.idm.oclc.org/kennis/bibliotheek-verkeer-en-vervoer/kennisdocumenten/staat-van-het-openbaar-vervoer-2022

Roukouni, A., & Correia, G. H. d. A. (2020). Evaluation methods for the impacts of shared mobility: Classification and critical review. *Sustainability (Switzerland)*, *12*(24), 1–22. https://doi.org/10.3390/su122410504

Schelte, N., Severengiz, S., Schünemann, J., Finke, S., Bauer, O., & Metzen, M. (2021). Life cycle assessment on electric moped scooter sharing. *Sustainability (Switzerland)*, *13*(15). https://doi.org/10.3390/su13158297

Schroten, A., Hilster, D., Scholten, P., & Kiraly, J. (2021, May). *Externe kosten van ketenemissies van transport Een verkennende analyse* (tech. rep.). CE Delft. Delft. www.ce.nl

Shah, N. R., Ziedan, A., Brakewood, C., & Cherry, C. R. (2023). Shared e-scooter service providers with large fleet size have a competitive advantage: Findings from e-scooter demand and supply analysis of Nashville, Tennessee. *Transportation Research Part A: Policy and Practice*, *178*. https://doi.org/10.1016/j.tra.2023.103878

Shaheen, A., & Cohen, A. (2019). Shared Micromoblity Policy Toolkit: Docked and Dockless Bike and Scooter Sharing. https://doi.org/10.7922/G2TH8JW7

Shaheen, S., Guzman, S., & Zhang, H. (2010). Bikesharing in Europe, the Americas, and Asia. *Transportation Research Record*, (2143), 159–167. https://doi.org/10.3141/2143-20

Su, L., Yan, X., & Zhao, X. (2024). Spatial equity of micromobility systems: A comparison of shared E-scooters and docked bikeshare in Washington DC. *Transport Policy*, *145*, 25–36. https://doi.org/10.1016/j.tranpol.2023.10.008

SWOV. (2021, February). *Openbaar vervoer en spoorwegovergangen* (tech. rep.). SWOV. Den Haag.

SWOV. (2023a, September). *Verkeersdoden in Nederland* (tech. rep.). Den Haag. https://swov.nl/factsheet/verkeersdoden-nederland

SWOV. (2023b, December). *Ernstig verkeersgewonden in Nederland* (tech. rep.). SWOV. Den Haag. https://swov.nl/nl/factsheet/ernstig-verkeersgewonden-nederland

Teece, D. J. (2010). Business models, business strategy and innovation. *Long Range Planning*, *43*(2-3), 172–194. https://doi.org/10.1016/j.lrp.2009.07.003

Thissen, M., & Content, J. (2022, February). *Brede welvaart in Nederlandse gemeenten: het belang van regionale samenhang* (tech. rep.). Planbureau voor de Leefomgeving. https://www.pbl.nl/publicaties/brede-welvaart-in-nederlandse-gemeenten-het-belang-van-regionale-samenhang

van Essen, H., van Wijngaarden, L., Schroten, A., Sutter, D., Bieler, C., Maffii, S., Brambilla, M., Fiorello, D., Fermi, F., Parolin, R., & El Beyrouty, K. (2019, January). *Handbook on the external costs of transport* (tech. rep.). CE Delft. https://doi.org/10.2832/51388

van Kuijk, R. J., de Almeida Correia, G. H., van Oort, N., & van Arem, B. (2022). Preferences for first and last mile shared mobility between stops and activity locations: A case study of local public transport users in Utrecht, the Netherlands. *Transportation Research Part A: Policy and Practice*, *166*, 285–306. https://doi.org/10.1016/j.tra.2022.10.008

Vega-Gonzalo, M., Aguilera-García, Á., Gomez, J., & Vassallo, J. M. (2024). Analysing individuals' use of moped-sharing and their perception about future private car dependency. *Cities*, *146*. https://doi.org/10.1016/j.cities.2023.104741

Walch, D., & de la Court, T. (2022, October). *Rekening houden met de Toekomst Afwegingskader voor CO2 in provinciaal beleid* (tech. rep.). Provincie Utrecht. Rotterdam.

Werkgroep discontovoet. (2020, October). *Rapport Werkgroep discontovoet* (tech. rep.). Ministerie van Financiën.

Wijnen, W. (2022, November). *Maatschappelijke kosten van verkeersongevallen in Nederland: actualisatie 2020* (tech. rep.). Kennisinstituut voor Mobiliteitsbeleid.

Wortmann, C., Syré, A. M., Grahle, A., & Göhlich, D. (2021). Analysis of electric moped scooter sharing in berlin: A technical, economic and environmental perspective. *World Electric Vehicle Journal*, *12*(3). https://doi.org/10.3390/wevj12030096

Xanthopoulos, S., van der Tuin, M., Sharif Azadeh, S., Correia, G. H. d. A., van Oort, N., & Snelder, M. (2024). Optimization of the location and capacity of shared multimodal mobility hubs to maximize travel utility in urban areas. *Transportation Research Part A: Policy and Practice*, *179*, 103934. https://doi.org/10.1016/j.tra.2023.103934

Yin, Z., Rybarczyk, G., Zheng, A., Su, L., Sun, B., & Yan, X. (2024). Shared micromobility as a first- and last-mile transit solution? Spatiotemporal insights from a novel dataset. *Journal of Transport Geography*, *114*. https://doi.org/10.1016/j.jtrangeo.2023.103778

Zakhem, M., & Smith-Colin, J. (2024). An E-scooter route assignment framework to improve user safety, comfort and compliance with city rules and regulations. *Transportation Research Part A: Policy and Practice*, *179*. https://doi.org/10.1016/j.tra.2023.103930

A Public Appendix

A.1. Societal Cost Benefit Analyses

An extensive SCBA guideline has been written by Romijn and Renes (2013), with later additions made by Frits Bos et al. (2022). To get a full comprehension of how to perform a (Dutch) SCBA, it is recommended to consult these sources. This section will briefly touch upon some key SCBA points.

A policy change results in many different effects, each with a different unit. Think of carbon emissions in tonnes, safety in the number of accidents or even effects such as social cohesion. In a societal cost-benefit analysis, one tries to quantify these effects by translating each unit into euros.

By valuing as many of the effects in euros one can obtain an overview of all benefits and costs. The effects are determined for each year, and for the duration the policy change has an impact. They are discounted to obtain a net present value (NPV), which shows if the societal benefits outweigh the societal costs.

It is important to note that the outcome of an SCBA should be used as a guidance tool, and not as a final decision tool. Not all effects can be accounted for or quantified in euros in a SCBA. Nevertheless, the SCBA is a useful tool as it allows exploration and a better understanding of the effects, as well as helping to structure the decision-making process (Romijn & Renes, 2013).

The SCBA consists of eight different steps (Romijn & Renes, 2013), these steps are detailed below:

1. **Problem Analysis:** What is the issue and what opportunities are currently available?
2. **Determine zero alternative:** What will happen if no subsidies are given to operate suburban shared scooters?
3. **Define policy alternatives:** While usually this step would compare alternatives (such as shared (e-)bikes, or public transport), this research will only focus on the differences between the possible suburban shared moped business models. Using the answer to the first sub-question the different business models will be delineated and offered as policy alternatives.
4. **Determine effects and benefits:** The (indirect) effects and benefits of the policy should be determined. These benefits may include a reduction in travel time or an increase in accessibility. It is deemed not feasible to perform such a stated or revealed preference study within this study. Therefore the benefits or drawbacks may be valued using known key figures.
5. **Determine [subsidy] cost:** This is the amount of subsidy that is required, both to set up the shared moped service but also to maintain it. This number may be obtained from the answer to sub-question two.
6. **Variant and risk analysis:** As the methods deployed in the previous stages have an inherent form of uncertainty, it is crucial to map these uncertainties. To account for these uncertainties, a sensitivity analysis is performed, with the ranges based on the literature.
7. **Draw up an overview of costs and benefits:** Using the previous steps an overview of (societal) costs and benefits can be made. It is important to discount all the benefits and costs to the present day. This would result in a net loss or profit for society, which can be discussed as some factors could have a large impact on the cost but may be less important for certain stakeholders.
8. **Present Results:** This step outlines the guidelines for how the SCBA should be presented.

A.2. Definition Moped

Worldwide the definition of a moped differs, which is why in this section the definition of moped that is used throughout this report is clarified.

The moped originated in the 1950s as a bicycle with an engine attached to the front wheel. It was focused on providing transport to low and middle-class citizens. Over the years, it transformed into its own vehicle class, without pedals, and its own set of legislation (Dekker, 2021). The current definition of a moped in the Netherlands is a two-wheeled vehicle with a maximum cylinder capacity of 50cc, or 4kw of power. It has a saddle so riders can sit on it like a bicycle or with their feet between the seat and the steering column. They can not be longer than 4 meters, wider than 1 meter, and higher than 2,5 meters. Furthermore, they must ride on air tyres, have at least one rear-view mirror mounted on the left side, a vehicle identification number, and a horn. Additionally, it needs at least one headlight, one backlight, one red reflector on the back side, a brake light, and one orange reflector on the side. To be allowed to drive a moped in the Netherlands, one must be at least 16 years old and be in possession of an AM driver's license. This license will be automatically granted when obtaining a car license (B), a motorcycle license (A), or separately. A maximum of two people can occupy a moped in the Netherlands. [1]

Two types of mopeds are classified, light and heavy mopeds. Light mopeds have a maximum speed of 25km/h, a blue license plate, and require users to wear a speed-pedelec or motorcycle helmet. Heavy mopeds have a maximum speed of 45km/h, a yellow license plate, and require users to wear a motorcycle helmet. In this report, no distinction is made between light and heavy mopeds. Shared moped operator Check utilises both light and heavy mopeds in its fleet. Additionally, all mopeds in the fleet of Check are powered by electricity and are therefore classified as e-mopeds. There is no regulatory difference between regular and e-mopeds in the Netherlands, but as they are electric they emit little local pollution and are much quieter compared to gasoline-powered mopeds.

Figure A.1: Example of Moped. Created by Microsoft Designer.

Special mopeds also exist which have more than two wheels and have to abide by different rules, but these are not the focus of this report. Furthermore, mopeds should not be confused with scooters; a scooter usually has smaller wheels and the driver needs to stand. Scooters are popular forms of shared mobility in non-Dutch countries but have not been road-legal in the Netherlands until recently. At the time of writing only five scooter models are allowed on the public road. Because moped-style shared micromobility is the most popular in the Netherlands, it is selected as the focus vehicle. In Figure A.1 an example of a moped can be found.

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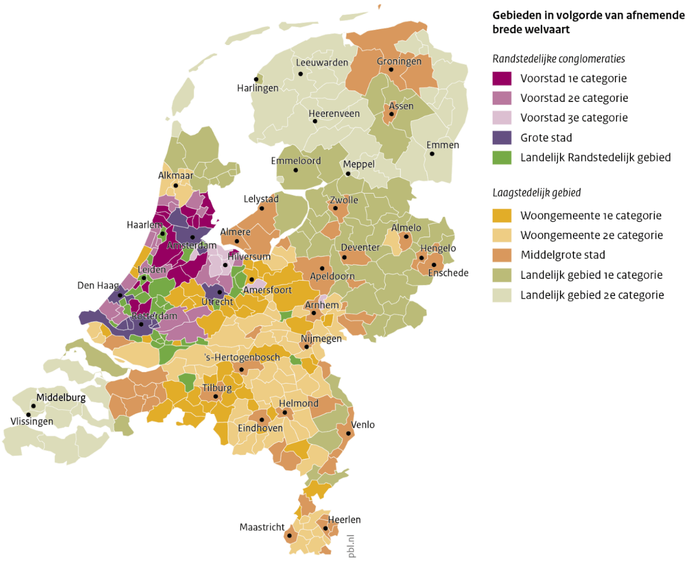
[1] https://wetten.overheid.nl/BWBR0025798/2024-01-01

A.3. Context Focus Region Selection

It is hypothesised that the business case, required subsidy amount, and the social benefit differ per municipality because of differing characteristics (e.g. demographic, population density, proximity to a large city). This leads to the need to select a specific municipality.

In the English language, the word suburb encompasses many different types of regions where people reside around a city centre. This results in there not being a consensus in the literature on what constitutes a suburb. Forsyth (2012) describes that a simplified way to define suburbs is: "... parts of an urban or metropolitan area outside the core or historical city area." (p. 279). While this definition encompasses the idea of what a suburban area is, many terms are undefined; how far is 'outside the core' and when is an area 'historical'? In the Dutch language, there is a more gradual distinction between different types of suburbs; with 'voorsteden' and 'buitenwijken' both being at the edge of a large city but 'voorsteden' have their own municipality while 'buitenwijken' are part of the municipality of a large city. This research will focus on 'voorsteden' with their own municipality.

Thissen and Content (2022) have categorised 'voorsteden' into three categories based on prosperity: 1. 'Voorsteden' that can easily make use of the recreation and creative facilities in one of the four big Dutch cities (Amsterdam, Rotterdam, Utrecht, The Hague) because of their proximity, 2. 'Voorsteden' that are further away from the big cities making the use of facilities in the big cities more challenging, and 3. 'Voorsteden' which need to borrow employment opportunities from other municipalities. In Figure A.2 one can find an overview of the different categories of suburbs based on prosperity in the Netherlands. The category of interest here is the 'Voorstad 2e categorie' cities. This category of suburban areas has challenges with using the facilities in the big cities because of their distance to these cities, and shared mopeds may bring this suburban region closer to the city by offering an easy, widely available, and affordable way to transport people between suburbs and cities.



Bron: PBL, gebaseerd op data uit 2019

Figure A.2: Topologies of Dutch Municipalities based on Prosperity. Adapted from Thissen and Content (2022)

As described in section 3.3, users of shared mopeds are primarily males in the age bracket 18-36. Additionally, the majority of users do not own cars. Furthermore, micro consult (2023) found that South Holland has the highest share of people who use shared mopeds of all provinces at 7%. This can also be explained by the fact that most supply is concentrated in South Holland (Rotterdam and the Hague). Nevertheless, South Holland is chosen as the focus province because of the data availability from the operator. The Central Bureau of Statistics defines five types of urbanisation, from non-urban (<500 addresses/km2) to very strongly urban (>2500 addresses/km2).[2]

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[2] cbs.nl/nl-nl/onze-diensten/methoden/begrippen/stedelijkheid–van-een-gebied–

Using QGIS, one can filter for municipalities which have a population density between 1000-2500 (moderately - strongly urbanised), more than 35% between the ages 15-45, and car possession lower than 1,2 per household. This results in the map in Figure A.3, and shows suburban municipalities where shared mopeds have financial potential. The reasoning behind this is to select a focus municipality where the least amount of subsidy is required. Nevertheless, it has to be noted that in high car possession municipalities, there might be a higher municipal demand for shared micromobility to reduce car usage. At the same time, the subsidy costs are hypothesised to be higher in these municipalities as demand will be lower.

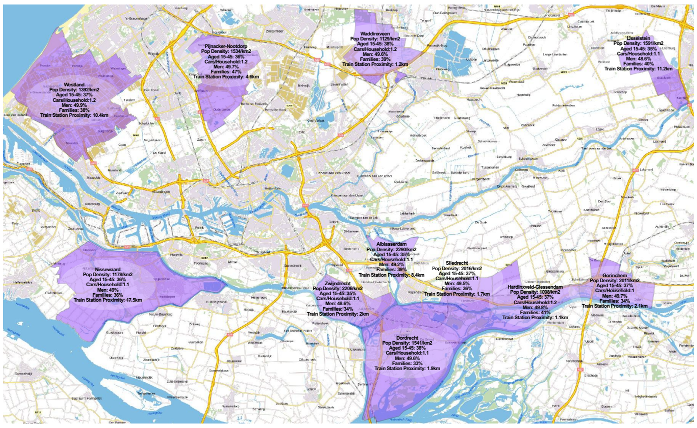

Figure A.3: Map of South Holland Municipalities Filtered on Population Density, Age, and Car Possession. Based on 2022 CBS data.

Comparing Figure A.3 and A.2, only one second category suburban area overlaps; Westland. This area has the population density of a moderately urbanised city, many young individuals, and an average of 1,2 cars per household. The nearest strongly urbanised cities are the Hague at 12km and Delft at 14km from Westland. Interestingly, it also has an average proximity to the closest train station of 10,4km, which shows that many public transport trips will need to be performed by bus. As the average travel distance of shared moped users is much lower than 10-14km, it could be the case that this region is not the most ideal for in-between-city trips. The municipality of Pijnacker-Nootdorp, a suburban first category municipality, has a higher population density of 1534/km2, and is closer to strongly urbanised areas such as Delft (6km) and similarly distanced from the Hague (14km). Additionally, it is much closer to a train station, at 4,6km on average. Other regions that were filtered are classified as rural suburban in Figure A.2, and were therefore not considered.

In Appendix B.1 one can find the final selected region.

A.4. Literature Categorisation

Table A.1: Relevant Papers Sorted by Topic

Author	**Main Topic**
Arias-Molinares et al. (2021), Caspi et al. (2020), Hosseinzadeh et al. (2021), Kim et al. (2023), Latinopoulos et al. (2021), Liao and Correia (2022), Mitropoulos et al. (2023), Oluwajana and Wang (2023), Reck et al. (2021), A. Shaheen and Cohen (2019), and Wortmann et al. (2021)	Trip Characteristics
Aguilera-García et al. (2020, 2021, 2024), Bieliński and Ważna (2020), Liao and Correia (2022), Loudon et al. (2023), Mitropoulos et al. (2023), Nikiforiadis et al. (2021), A. Shaheen and Cohen (2019), and Vega-Gonzalo et al. (2024)	Rider Characteristics
Arbeláez Vélez (2023), de Bortoli (2021), de Bortoli and Christoforou (2020), Felipe-Falgas et al. (2022), Kazmaier et al. (2020), Mitropoulos et al. (2023), Schelte et al. (2021), S. Shaheen et al. (2010), and Wortmann et al. (2021)	Environmental Impact
Huang et al. (2024), Ju et al. (2024), Mitropoulos et al. (2023), van Kuijk et al. (2022), and Yin et al. (2024)	Public Transport Interaction
Ghaffar et al. (2023), Hoobroeckx et al. (2023), and Shah et al. (2023)	Elasticity
Pérez-Fernández and García-Palomares (2021) and Xanthopoulos et al. (2024)	Distribution Optimisation
Bach et al. (2023) and Su et al. (2024)	Equity
Davidse et al. (2019) and Zakhem and Smith-Colin (2024)	Safety for Rider
Estrada et al. (2021) and Wortmann et al. (2021)	Operator Cost Estimation
Meng et al. (2020) and S. Shaheen et al. (2010)	Business Models

Table A.2: The author, urban type, and region for literature used

Author	Urban Type	Region
Latinopoulos et al. (2021)	Urban	Paris
Kim et al. (2023)	Urban	Portland
Oluwajana and Wang (2023)	Urban	Windsor
Caspi et al. (2020)	Urban	Austin
Reck et al. (2021)	Urban	Zurich
Hosseinzadeh et al. (2021)	Urban	Louisville
Arias-Molinares et al. (2021)	Urban	Spain
Zakhem and Smith-Colin (2024)	Urban	Dallas
Davidse et al. (2019)	Urban	Netherlands
Mitropoulos et al. (2023)	N/A	N/A
A. Shaheen and Cohen (2019)	Urban	USA
Liao and Correia (2022)	N/A	N/A
Bieliński and Ważna (2020)	Urban	Tricity
Aguilera-García et al. (2020)	Urban	Spain
Aguilera-García et al. (2024)	Urban	Madrid
Nikiforiadis et al. (2021)	Urban	Thessaloniki
Aguilera-García et al. (2021)	Urban	Spain
Loudon et al. (2023)	Urban	Netherlands
Vega-Gonzalo et al. (2024)	Urban	Four main cities in Spain
van Kuijk et al. (2022)	Urban/Suburban	Utrecht
Ju et al. (2024)	Urban	Four Californian Cities
Yin et al. (2024)	Urban	Washington DC
Huang et al. (2024)	Urban	Washington DC and Los Angeles
Su et al. (2024)	Urban/Suburban	Washington DC
Bach et al. (2023)	Urban	Europe
Wortmann et al. (2021)	Urban	Berlin
Felipe-Falgas et al. (2022)	Urban	Barcelona
Kazmaier et al. (2020)	Urban	Germany
de Bortoli and Christoforou (2020)	Urban	Paris
de Bortoli (2021)	Urban	Paris
Schelte et al. (2021)	Urban	Germany
Arbeláez Vélez (2023)	N/A	N/A
Shah et al. (2023)	Urban	Nashville
Ghaffar et al. (2023)	Urban	Various
Hoobroeckx et al. (2023)	N/A	Netherlands
Pérez-Fernández and García-Palomares (2021)	Urban	Madrid
Xanthopoulos et al. (2024)	Urban	Netherlands
Estrada et al. (2021)	N/A	N/A
Meng et al. (2020)	N/A	N/A
S. Shaheen et al. (2010)	N/A	Europe, America, Asia
Damen (2020)	Suburban	Belgium
Boting (2023)	Suburban	Netherlands

A.5. CO2 per passenger kilometre travelled for non-moped modes

In Table A.3, an overview can be found of the various sources used for the carbon emissions of alternative modes of transport. As Hilster et al. (2022) used low occupation rates for public transport modes, they have not been considered. Furthermore, OECD/ITF (2020) used grey energy for the metro, while the Dutch metro runs on green energy, and was therefore not considered.

Table A.3: CO2 per passenger kilometre travelled for non-moped modes

	de Bortoli and Christoforou (2020)	**Schelte et al. (2021)**	**Hofmann and Kaufmann (2013)**	**OECD/ITF (2020)**	**Hilster et al. (2022)[1]**	**M. Knoope and Kansen Maarten (2021)**	**OECD/ITF (2020) Check Modified**
Region	Paris, France	Germany	Germany	Worldwide	Rotterdam, NL	Netherlands	Netherlands
Walk	2,23						
Metro	7,55		9	~~65,61~~		~~42~~	13,03
Train	8,79		8		~~37~~		
Tram	20,21	52	26		~~82~~		
ICE bus	133,45	80	104	91,43	~~151~~		91,43
Electric bus		27-52	25	68,28	~~103~~	58	17,66-82,12
Private bike	15,24	10		16,94	6		16,94
Private e-bike	25			33,86			22,02-36,31
Private ICE car	209,43	225	189	161,97	224		189
Private hybrid car			106	132,28			132,28
Private electric car	76,06		74	125,38	80	96	53,85-140,23
Taxi/ride-hailing	299,30			239,42	74-185		76,28-310,96

[1] Commissioned by Dutch Shared Moped Operators