D1.6 IMPACT ASSESSMENT RESULTS

VOLUME 10: HAMBURG, GERMANY

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SOLUTIONSplus Impact Assessment Results

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EXECUTIVE SUMMARY

This report presents the work performed by the SOLUTIONSplus consortium for the impact assessment task of the Hamburg demonstration project. Only activities completed until April 2024 are reported here. The results of assessment of impacts on accessibility are missing. This information will be provided with an addendum to this report issued by the end of the project.

DEMONSTRATION ACTIVITY AND CONTEXT

In recent years, new mobility solutions have been introduced in cities around the world. In particular, electrification and digitalisation have facilitated the emergence of shared mobility services and shared vehicle schemes.

However, the proliferation of shared e-kick scooters has fuelled the debate on the drawbacks of micro-vehicles. The current operation areas of shared mobility solutions are mainly limited to inner cities, where a high level of public transport is already achieved. Dockless shared micro-vehicles have been criticised for obstructing pedestrian infrastructure and blocking access to buildings and public transport stations, especially for the visually and mobility impaired. Privately operated sharing systems are often poorly regulated, including the number of vehicles, the area of operation, or the parking of shared scooters and bicycles. Furthermore, the positive contribution of electric scooters to decarbonisation is questionable, as the production of the vehicles and the operation of the share scheme are carbon intensive. Finally, shared micro-vehicles are accused of mainly replacing low-carbon modes of transport rather than car trips, and thus actually increasing greenhouse gas emissions. This is mainly due to their limited operational range, with typical scooter trips covering distances of up to 2.5 km.

On the other hand, integrating micro-mobility with public transport has the potential to fill mobility gaps in the collective transport system, which remains the backbone of sustainable urban mobility. As a first and last mile link in intermodal journeys, shared e-scooters can facilitate combined trips and replace car travel, despite their limited range. For example, Hamburg's ITS strategy mentions the "linking of public mobility, sharing and on-demand services, [...] and the further expansion of mobility hubs as a means to reduce transport-related CO_2 emissions" (Freie und Hansestadt Hamburg 2021), and the European Mobility Framework states that "new mobility services are part of a multimodal, integrated approach to sustainable urban mobility. They can reinforce public transport and substitute car use".

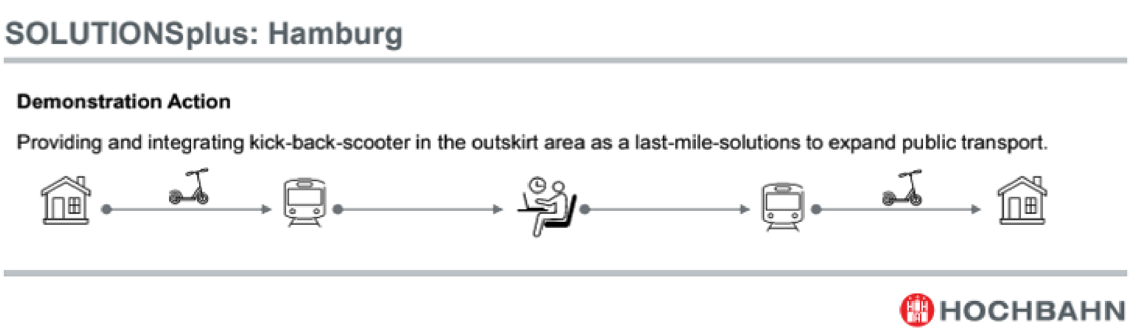


Figure 1: Outline of the Hamburg Demonstration Activity

In that sense, the Hamburg demonstration activity assessed the potential of free-floating shared e-scooters to complement public transport systems in suburban areas. The public transport operator, HAMBURGER HOCHBAHN, subcontracted a shared e-scooter operator and provided seed funding to introduce shared scooters in the demonstration areas in two Hamburg suburbs. Dedicated parking spaces were provided at four public transport stations in the demonstration areas. During the demonstration period, shared scooter schemes have been integrated into the public transport app.

STAKEHOLDERS AND KPIs

The selection of relevant key performance indicators (KPIs) for the assessment of the demonstration activity followed a structured approach, which was deployed in all SOLUTIONSplus demonstration activities. The quantitative weighting exercise was complemented with qualitative stakeholder interviews.

Main stakeholders, both from public authorities and the private sector rated the relevance of pre-defined KPIs for assessing the demonstration activity. Impacts on greenhouse gas emissions and on air and noise pollution were considered the by far most critical effects, followed by the contribution to urban strategies and targets. Impacts on society were considered as less relevant – with the exemption of the impact on travel time. The latter can be understood as an effect on the competitiveness compared to private car use. Financial aspects were not rated high, potentially because the shared vehicle scheme is operated by a private company and not continuously subsidised from public budgets.

Stakeholders did not consider the demonstration to have a macroeconomic impact on the wider economy.

DATA COLLECTION

As part of the sub-contracting between the SOLUTIONSplus partners and the service provider, an agreement was made to share relevant vehicle data. The vehicle data collected included the number of vehicles used during the demonstration period, the origins and destinations of trips, the total number of trips, trip distances and the proportion of journeys starting and/or ending at public transport stations. In addition, HAMBURGER HOCHBAHN conducted a survey of users of the shared e-kick scooters to obtain information on, among other things, the proportion of intermodal trips, the modes of transport substituted and the extent to which trips were induced, i.e. trips that would not have been made in the absence of the sharing scheme. All collected data was anonymised before use in the project context.

Other data had to be estimated or derived from literature reviews. In particular, the LCA-based greenhouse gas emissions per scooter-km varied substantially, from less than 40gCO2e per vehicle-km (vkm) to more than 130. The main reasons behind the vast range of estimates are diverging assumptions about the greenhouse gas intensity of vehicle production (e.g. depending on the use of secondary vs. raw materials), the expected lifetime of the vehicles (with very low assumptions for the first-generation e-scooters), and emissions related to service operations (diesel vans and collection of entire e-scooters for recharging vs. e-cargo bikes and vehicles with removable batteries). The vehicles deployed during the demonstration activity were recent models and expected to have a longer lifetime compared to the first-generation scooters. They have removable batteries and service was performed by electric vans. In consequence, the LCA-based emissions per vkm would tend to be at the lower end of estimates. In order to avoid overestimating the GHG reductions, however, a conservative approach has been taken and a value of 67g CO2e per vkm has been used. This value is the median of the studies reviewed and is at the upper end of more recent assessments. Moreover, we assumed that all deployed vehicles were additional and newly procured, and not redeployed from other areas of operation. Moreover, we assumed that no changes in private vehicle stocks or public transport vehicle-km result from the demonstration activity.

RESULTS OF THE DEMONSTRATION ACTIVITY AND UPSCALING

The results of the assessment have shown that shared e-scooters in the outskirts have the potential to contribute to mitigating transport-related carbon emissions. A mitigating effect on greenhouse gas emissions, however, is contingent on factors such as the number of additional e-scooters, assumptions about the indirect greenhouse gas emissions from scooters and operations, and the share of car trips replaced. SOLUTIONSplus data indicated that during the demonstration stage, approximately one third of all scooter trips were part of intermodal travel chains and that 26% of scooter trips replaced a car trip.

Based on our assumptions, the assessment found that the introduction of e-scooters had a mitigating effect on greenhouse gas emissions when only those scooter trips were considered that are part of intermodal travel chains (as approximation we assumed that trips that start or end at a public transport station are part of intermodal travel chains). When all e-scooter trips in the demonstration area were considered, however, the demonstration activity was found to cause additional emissions. This negative impact was mostly due to the number of deployed additional newly produced scooters (as the scooters remained in use after the demonstration period, a discounting factor could be used to cover the entire vehicle lifetime).

As assumptions about vehicle-related emissions are highly uncertain, we used scenarios to understand (a) how high GHG emissions per vkm could be and (b) which share of car trip replacements would be required to achieve a net-zero effect compared to the current situation.

Table 1: Compiled results of impacts on greenhouse gas emissions

	ONLY INTERMODAL TRIPS IN DEMO AREA	ALL E-SCOOTER TRIPS IN DEMO AREA	BREAK-EVEN CO2E PER SCOOTER -KM	BREAK-EVEN % OF CAR TRIPS REPLACED	
ADDITIONAL EMISSIONS					
SCOOTER-KM TO/ FROM PUBLIC TRANSPORT STATIONS	34.808,07	175.380,65	175.380,65	75.380,65	vkm
EMISSION FACTOR SCOOTER -VKM (LCA)	67	67	47,03	67	gCO2e / vkm

	ONLY INTERMODAL TRIPS IN DEMO AREA	ALL E-SCOOTER TRIPS IN DEMO AREA	BREAK-EVEN CO2E PER SCOOTER -KM	BREAK-EVEN % OF CAR TRIPS REPLACED	
ADDITIONAL EMISSIONS FROM E-SCOOTER TRIPS TO/FROM PUBLIC TRANSPORT (VKM*EMISSION FACTOR)	2.332.140	11.750.503	8.247.482	12.276.645	gCO2e
AVOIDED EMISSIONS					
NUMBER OF SCOOTER TRIPS TO PUBLIC TRANSPORT STATIONS	35.403	35.403	35.403	35.403	number
SHARE OF E-SCOOTER TRIPS THAT REPLACE CAR TRIPS	26	26	26	**38.7**	%
NUMBER OF REPLACED CAR TRIPS	9.205	9.205	9204,78	13.702	trips
AVERAGE DISTANCE OF CAR TRIP	5,60	5,60	5,60	5,60	vkm/trip
SHIFTED VKM FOM CAR TO INTERMODAL	51.547	51.547	51.547	76729	vkm
EMISSION FACTOR CAR-KM	160	160	160	160	gCO2eq / vkm
AVOIDED EMISSIONS	8.247.482	8.247.482	8.247.482	12.276.645	gCO2eq / vkm
NET AVOIDED EMISSIONS	**5.91,53**	**- 3.50,3**	**0**	**0**	**tCO2eq**

The scenarios found that, all other factors being kept constant, a positive mitigation impact would be achieved if:

a. LCA-based emissions per e-scooter-km would be below 47 gCO2e, which is within the lower range of recent LCA studies; or if

b. 38.7% of all scooter trips replaced car trips. This would require an increase by 12.7 per centage points compared to the survey results.

We assume that the demonstration activity has a mitigating impact on local air pollution and noise pollution, by reducing the use of cars with internal combustion engines. Quantifying the effect was not possible, however, since the routes of the replace car trips, along which the impact would occur, are not known.

In terms of accessibility, the solution complements the existing transport system in areas where public transport is less dense. However, it cannot be considered as a universal solution to improve the accessibility of public transport, as shared e-kick scooters exclude children, the elderly and people with disabilities; the vehicles are also not suitable for travel related to activities such as childcare or grocery shopping. Rather, the solution targets those groups that tend to use private cars for their purposes, mostly commuting and leisure, and increases the attractiveness of intermodal public transport services. Other new mobility services, such as ride-hailing, ride sharing and car-sharing services, sould be explored to address the shortcomings in terms of accessibility and to cover a wider range of use cases and user groups.

In the scaled-up scenario we assumed that shared vehicle services are provided in the entire city area, using a similar ratio of vehicles per inhabitant as in the demonstration area. Assumed that the required ca. 9,000 e-scooters would be newly built vehicles, greenhouse gas emissions would rise by ca. 9,500t CO2e. However, if the currently operative 20,000 e-scooters would be re-distributed across the city area, an emission reduction of 15,400 tCO2e could be achieved. Compared to a total of 3.435.000t CO2e, this would amount to ca. 0,4% of transport-related greenhouse gas emissions.

CONCLUSIONS AND RECOMMENDATIONS

The demonstration activity has indicated that shared micro-vehicles can support the decarbonisation of mobility, given that the number of new vehicles is limited and LCA-based emissions per scooter-km are at the lower end of the range of estimations. Tendering for concessions with attached provisions on vehicles and operations can encourage e-vehicle providers to become more sustainable. Low-carbon operations and extending vehicle lifetimes are crucial for achieving a positive climate impact of shared micro-vehicles. Achieving higher replacement rates for private car trips require push measures, including the removal of parking spaces in inner cities, the extension of parking management, or pedestrianisation of urban space.

CONTENTS

1 BACKGROUND AND CONTEXT

Hamburg is a major German harbour city connected to the North Sea by the River Elbe. With a population of over 1.8 million, Hamburg is the second largest city in Germany and the eighth largest in the European Union. More than five million people live in the city's metropolitan region. The 'Free and Hanseatic City of Hamburg', is one of the 16 federal states of Germany.

1.1 GEOGRAPHY, SOCIO-ECONOMIC, AND ADMINISTRATIVE CONTEXT

Location, topography, and climate

The city has a flat topography, with the urban area lying just above or below sea level. Its topography and proximity to the sea make Hamburg particularly vulnerable to the impacts of climate change and sea level rise.

Located in northern Germany, Hamburg has a maritime temperate climate that is influenced by its proximity to the North and Baltic Seas. The climate pattern closely follows an oceanic classification (Köppen-Geiger), with mild winters and relatively cool summers. During summer (June to August), the average temperature in Hamburg ranges between 20 and 25 degrees Celsius. Winter, which lasts from December to February, is colder, with temperatures ranging from 0 to 5 degrees Celsius. Snowfall is infrequent and generally light. Precipitation is relatively evenly distributed throughout the year, with the wettest months in summer.

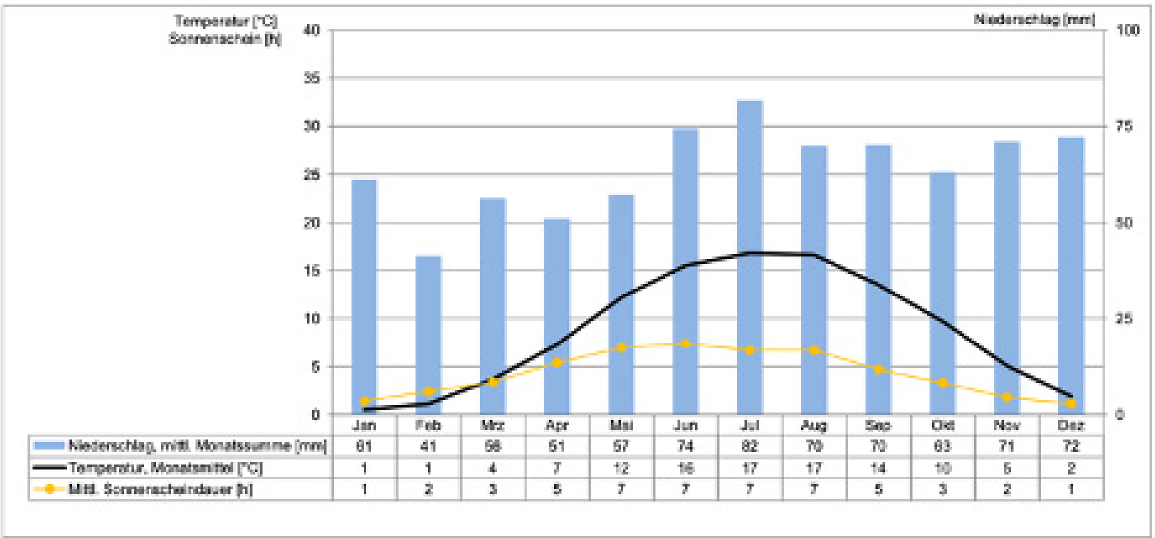


Figure 2: Climate Diagram Hamburg-Fuhlsbüttel Source: (Deutscher Wetterdienst n.d.)

The flat topography and its temperate climate make Hamburg generally conducive to the use of micro-vehicles. Hamburg is one node of several trans-European Network (TEN-T) corridors. The EU's TEN-T consists of railways, inland waterways, short sea shipping routes and roads and aims at providing a coherent, multimodal, and high-quality transport network across the EU member states.

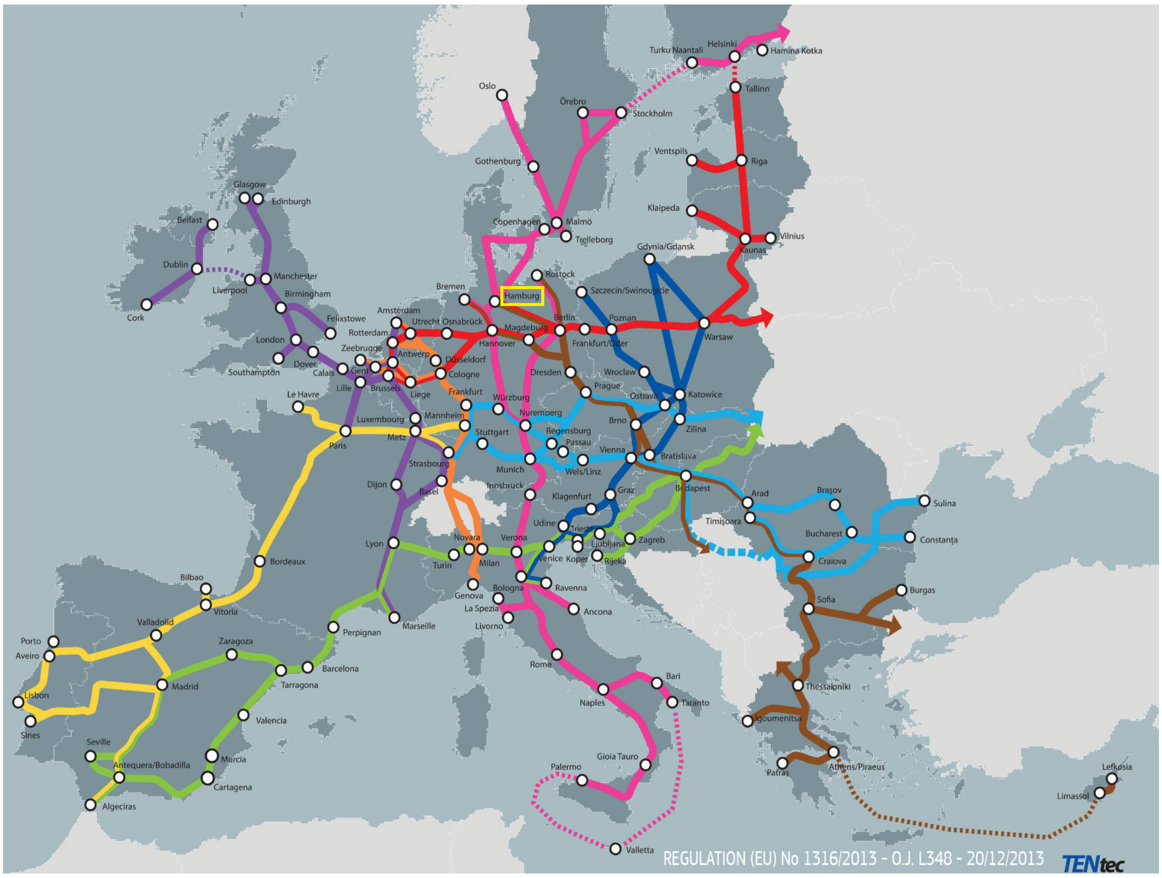


Figure 3: TEN-T Network. Emphasis on Hamburg added (European Commission, n.d.)

The European Commission's recent proposal for the revision of the TEN-T Directive (COM(2021) 812 final) aims, inter alia, to facilitate seamless and efficient transport in urban nodes of the network, promoting multimodality and interoperability between transport modes. It urges urban centres to develop Sustainable Urban Mobility Plans (SUMP) containing objectives, targets and indicators to measure the performance of the urban transport system, at least in terms of greenhouse gas emissions, congestion, accidents and injuries, modal share and access to mobility services. In addition, the proposal (Art.40) calls for urban TEN-T hubs to provide sustainable, seamless and safe connections between rail, road, air and active mobility by 2030; multimodal digital mobility services for passengers to access information, book, pay and retrieve their tickets; and the development of multimodal passenger hubs. Article 41 urges the promotion of efficient, low-noise and emission-free transport and mobility, including the greening of urban fleets and increasing the modal share of public transport and active modes in urban centres.

Administration

The 'Free and Hanseatic City of Hamburg' is administratively both a city and a German federal state. Internally, it consists of seven boroughs which are subdivided into 104 districts. The borough of Hamburg-Mitte covers most of the city's urban centre, while the SOLUTIONSplus demonstration areas were located in the borrows Hamburg-Nord (district Langenhorn) and Eimsbüttel (district Lokstedt).

Due to the multi-level administrative structure, responsibilities are divided between different authorities. As a federal state, Hamburg is responsible for the organisation of local and regional public transport, for general mobility planning and for the major road network, with the exception of motorways. The state of Hamburg has also adopted a climate law and a climate action plan (as mentioned in chapter 3.3). The planning and allocation of urban space and most secondary roads, including cycling infrastructure and low-speed zones, are the responsibility of the districts and boroughs. Road laws, vehicle and fuel taxations and subsidy programmes for e-mobility are determined on the national level. This also means that cities are not free to implement any instruments, but that potential actions, such as the introduction of a zero-emission zone or a 30 km/h speed limit in the urban area, are prohibited by legislation at national level.

Figure 4: Map of administrative districts of Hamburg. Source: TUBS, CC BY-SA 3.0, via Wikimedia Commons

Population and demography

With a population of over 1.8 million, Hamburg is the second largest city in Germany and the eighth largest in the European Union. The city's metropolitan region is home to more than five million people. With an average age of 42, Hamburg has the youngest population in the country. However, as in most industrialised countries, the proportion of the elderly population is expected to increase in the coming decades.

Data from the demonstration activity confirmed earlier assessments that claimed that the typical user of shared e-micro vehicles is between 18 and 65 years old. This age group is relatively well represented in Hamburg. It should also be noted that micro-vehicles in general and e-kick scooters in particular are neither suitable for all purposes, such as groceries or care activities, nor for all population groups, as they exclude children, elderly and disabled people. They can provide additional mobility options for a limited number of use-cases, but they cannot be considered as a universal solution to increase accessibility.

1.2 URBAN TRANSPORT

Modal split

Modal split is a commonly used indicator for urban mobility systems. It refers to the distribution of passenger or freight transport (based on the number of trips or of distance) across different transportation modes within a specific geographic area, such as a city or region.

Over the last decades, Hamburg has seen a rise in cycling from 13% of all trips in 2008 to 22% in 2022. In the same period, the share of walking declined from 29% to 22% and public transport went up from 19 to 24%. With 32% in 2022, private car use remained the most popular option, although with a strongly declining trend since 2008 (39%).

- Until 2039, the City of Hamburg aims at
- Increasing the share of active mobility to 50%,
- Increasing the share of public transport to 20%, and at

Reducing the share of motorised individual transport to 20%, from 32% in 2022. This would mean an average annual reduction by 5.7% between 2022 and 2030. The figure below indicates the development of Hamburg's modal split since 2017 and shows target values for 2030, as agreed in the climate plan and the mobility transition strategy.

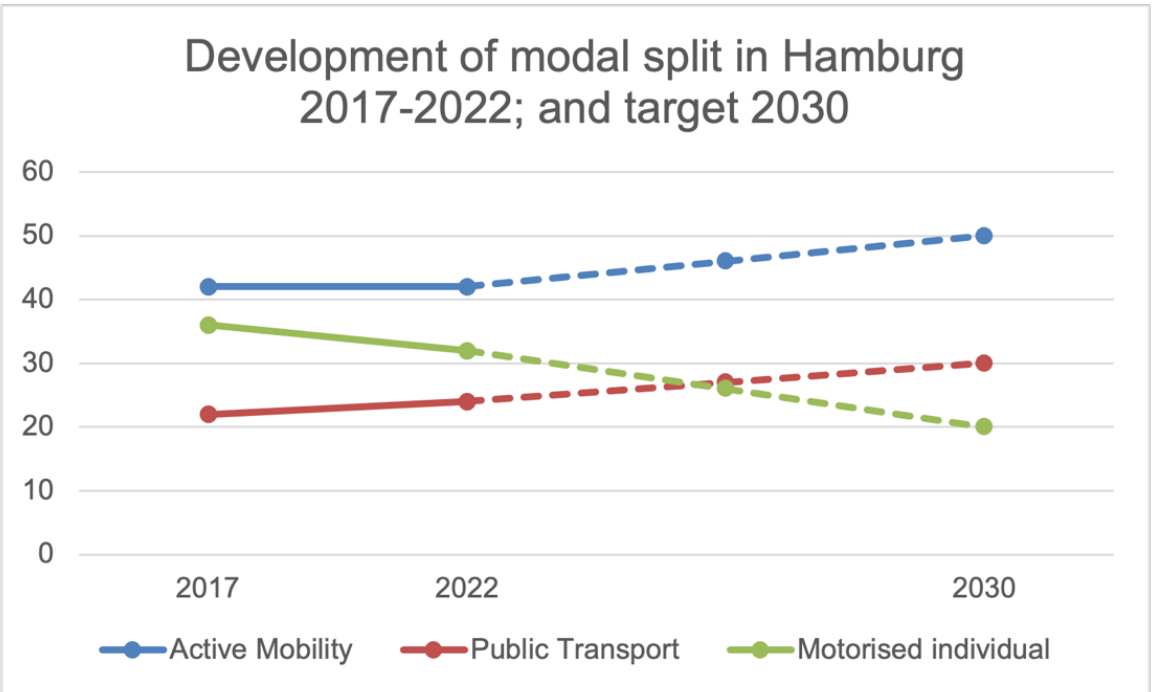


Figure 5: Development of modal split in Hamburg 2017-2030 and target for 2030, in %, by trip. (Data s(Source: Bürgerschaft der Freien und Hansestadt Hamburg, 2023a)

Public Transport

Hamburg's public transport network encompasses buses, the subway, light rail, regional trains, and ferries. Buses and the subway are operated through the publicly owned HOCHBAHN AG. Light rail (S-Bahn) and most regional trains are operated by Deutsche Bahn. The Hamburger Verkehrsverbund (hvv) is the transport association that covers the city of Hamburg and its surrounding area. Hvv coordinates the transport operators in the municipal area, provides a unified transport and fare system, and operates the integrated mobility app for the region. The network is complemented by two on-demand ride pooling operators (hvv hop and MOIA), that are integrated into the public transport system and operating in several parts of the city. To use the service, passengers need a public transport ticket and have to pay a surcharge. While hvv hop is operated by a public transport authority, MOIA is owned by Volkswagen AG. It deploys more than 300 fully electric mini vans and has a concession to operate up to 450 vehicles until 2025. The on-demand service uses ca. 15,000 virtual stations. Following an amendment of the national passenger transport act in 2021, on-demand services that do not follow pre-defined routes between two stations can be recognised as part of the public transport system.

Shared micro-vehicles

Publicly owned and private-sector providers of shared micro-vehicles are operating in the city. StadtRAD is a station-based provider of ca. 3,700 shared bikes and ca. 50 e-cargo bikes. Highest density of the ca. 280 stations is in the city centre, but stations are also located in suburbs. The system is operated by Deutsche Bahn on behalf of the city of Hamburg. Moreover, several profit-oriented sharing operators, including TIER, LIME, VOI, Bird, and Bolt, are active in Hamburg. Their services are integrated with the local public transport app hvv switch, and can be paid via the app. While the service areas of most shared micro-vehicle services were limited to inner-city areas in 2020, providers subsequently extended their operation area to suburbs. Ca. 20,000 shared e-kick-scooters and 1,400 shared e-bikes are available in Hamburg (Bürgerschaft der Freien und Hansestadt Hamburg, 2023b). The provision of shared vehicles is mostly unregulated and relies on non-binding memorandums of understanding between providers and the city government.

Despite attempts to promote collective and active mobility, private vehicles continue to play a significant role in Hamburg's mobility system, and motorised private transport remains the most important mode of urban transport, with a share of 32% of all trips in 2022. In the surrounding area, however, the decline in car use has been slight: from over 60 per cent in 2008, now just below this mark (infas et al., 2020). In general, the average length of journeys made by car is increasing, while the proportion of such journeys is falling. In Hamburg, more than half of all passenger kilometres have been travelled by car in 2017.

Car ownership

In 2020, ca. 650,000 private cars had beeb registered in Hamburg, resulting in a car density of 341 per 1,000 inhabitants. Compared to the national car density of 439 cars per 1,000 inhabitants, Hamburg has the second lowest car density in Germany (destatis, 2023). However, car ownership varies widely between different parts of the city, ranging from ca. 282 cars per 1,000 inhabitants in the city centre up to more than 550 in some outlying areas in 2020 (Statistisches Amt für Hamburg und Schleswig-Holstein, 2020). This emphasises the importance of providing alternatives to car Identification of main problems

An analysis of the state of the mobility situation in Hamburg had been carried out as part of the preparation of the city's mobility plan. The following key issues related to the transport system were identified:

Congestion

According to the most recent mobility data, 32% of all trips in the city of Hamburg are made using private motorised vehicles, with a slightly decreasing modal share over the last years. Still, the rate of car ownership remained mostly stable at ca. 330-340 private cars per 1,000 inhabitants over the last years, while continuous population growth has led to an increase of the total number of registered vehicles by 10% since 2010 (infas et al., 2020).

The 2017 Climate Plan and the air quality plan (2nd update) assume that – despite a shift towards public transport and active mobility – total transport volumes and private motorised vehicle-kilometres will increase. This is mainly due to the growing population and an increasing share of elderly people (> 65 years). Consequently, the capacity of the street network is expected to reach its limits in some areas in the future (Planersozietät et al., 2020).

Air quality

Moreover, road transport is the main cause of air pollution in Hamburg, both for local peak concentrations of NOx and for the urban background air pollution (Behörde für Umwelt und Energie, 2017, p. 49). In 2017, four out of 15 air monitoring stations exceeded the European air quality limits for nitrogen dioxide concentrations. In order to comply with European legislation, the city adopted a set of measures to reduce transport-related air pollution in its 2017 air quality plan: Besides access restrictions for older diesel cars and trucks, the set of measures inter alia contains the provision and support of intermodal mobility options, including the integration of shared mobility and the provision of mobility hubs at public transport stations (Measure package 3: Intermodal offers & mobility management).

CO2 emissions

Accorgind to the revised Climate Protection Law which was passed in January 2024, Hamburg has committed to reducing total CO2 emissions by 70 per cent by 2030 and by 98 per cent by 2045 compared to 1990 levels.

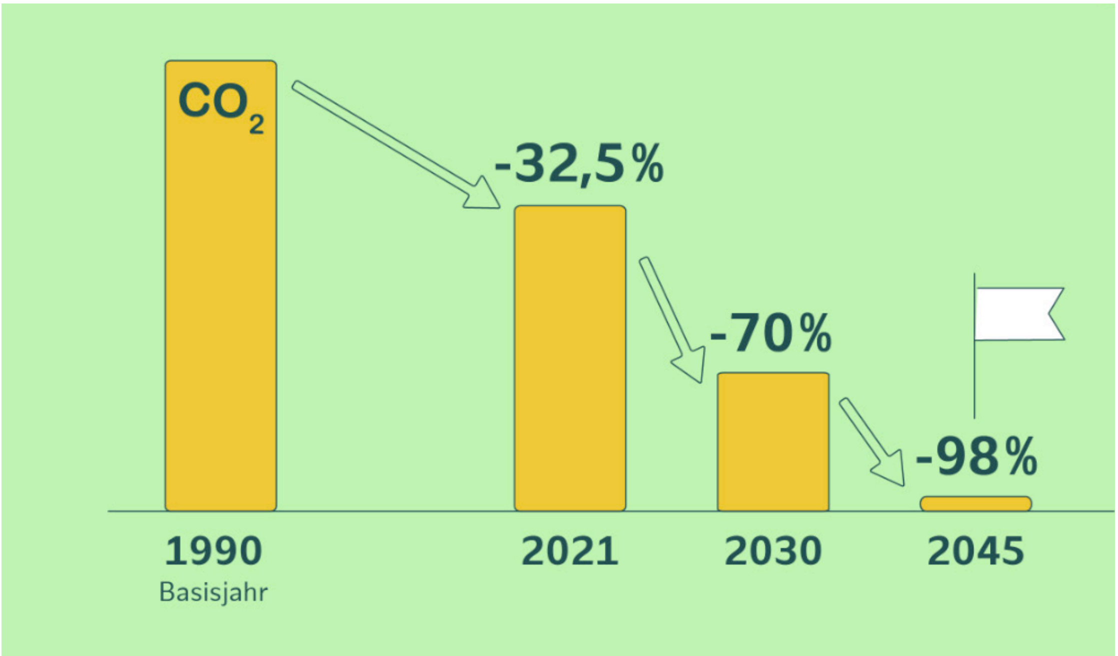


Figure 6: Hamburg's Climate Targets until 2045. (Source: City of Hamburg, 2024)

With regard to achieving sustainable and low-emission mobility, the law (§29) formulates, amongst others, the objective of expanding, improving and optimising cycling and walking infrastructure and local public transport services, which explicitly includes bike- and car-sharing, as well as on-demand services integrated with public transport.

To achieve emission reductions, the 2nd update of Haburg's climate plan (City of Hamburg, 2019) contains a 'measure programme: transformation pathway for the mobility transition'. At its centre is the extension of the public transport offer according to the so-called 'Hamburg Takt': each citizen should have an adequate public transport service within 5 minutes by 2030. This should be achieved through a significant expansion of public transport services and by linking on-demand services with the public transport system. An integration of mass transport with new mobility services and sharing services including micro-mobility should be achieved through the provision of physical mobility hubs at public transport stations and through an integration with the existing mobility app. As a result, the share of public transport should increase to 30% by 2030; and the total number of passengers should increase by 50% compared to 2017 numbers. Moreover, the deep integration of shared micro-mobility offers into the public transport platform (app) hvv switch is one indicator to assess the degree of interconnectedness of Hamburg's mobility system.

1.3 Description of demonstration project

The demonstration activity brought free-floating shared e-scooters to two suburbs of Hamburg where this service was not previously available. The micro-vehicles were intended to provide first and last mile connections to public transport services. The demonstration activity assumed that flexible shared micro-mobility offers can complement longer-distance and higher speed collective transport (subway, local trains) by offering door-to-door connectivity and thus can enhance competitiveness of public transport with private car use (Kager et al., 2016). To encourage the intermodal use of these vehicles, dedicated parking areas were created at major public transport stations. In addition, shared vehicle services had been integrated into the public transport app and incentive schemes had been tested.

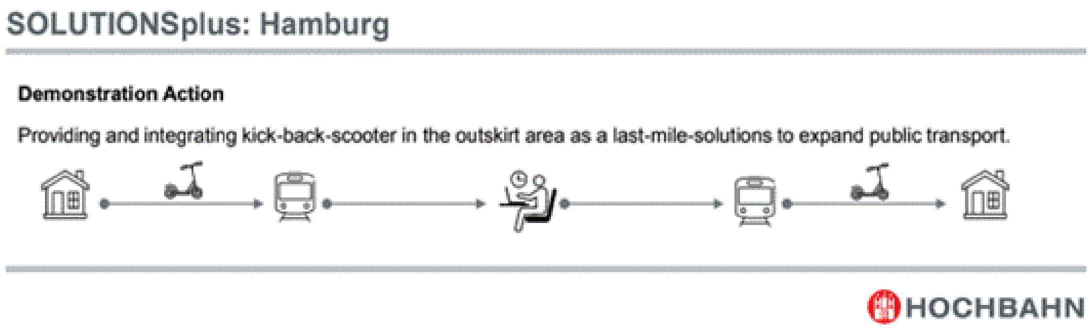


Figure 7: Outline of the Hamburg Demonstration Activity

This project tested the potential contribution of an e-kick-scooter sharing system as a complementary element to the existing public transport offer. The scooters should be used as a first- and last mile solution in two demonstration areas outside the city centre. With this demonstration project, the SOLUTIONSplus consortium aimed at a better understanding of the potential of shifting private car use towards a combination of sharing systems and public transport; and whether such integrated mobility offers can increase the attractiveness of the public transport system compared to private car use. The e-scooter is to be used primarily as a feeder service to the conventional public transport system.

The shared micro-vehicle scheme was integrated into the existing public transport application (hvv switch) and incentives, such as reimbursement of basic fees when the scooter is parked in a parking zone at a subway stop, are to promote intermodal use of scooters. The selection of the locations was based on criteria such as the availability of complementary mobility applications or the insufficient connection to the public transport network. These areas should also be outside the existing service area of e-scooter providers. Ultimately, two locations, one in the Lokstedt district and one in the Langenhorn district, were selected as demonstration sites. Both areas have an average population density, are located outside the city centre, and they have a combined population of 78,500 inhabitants.

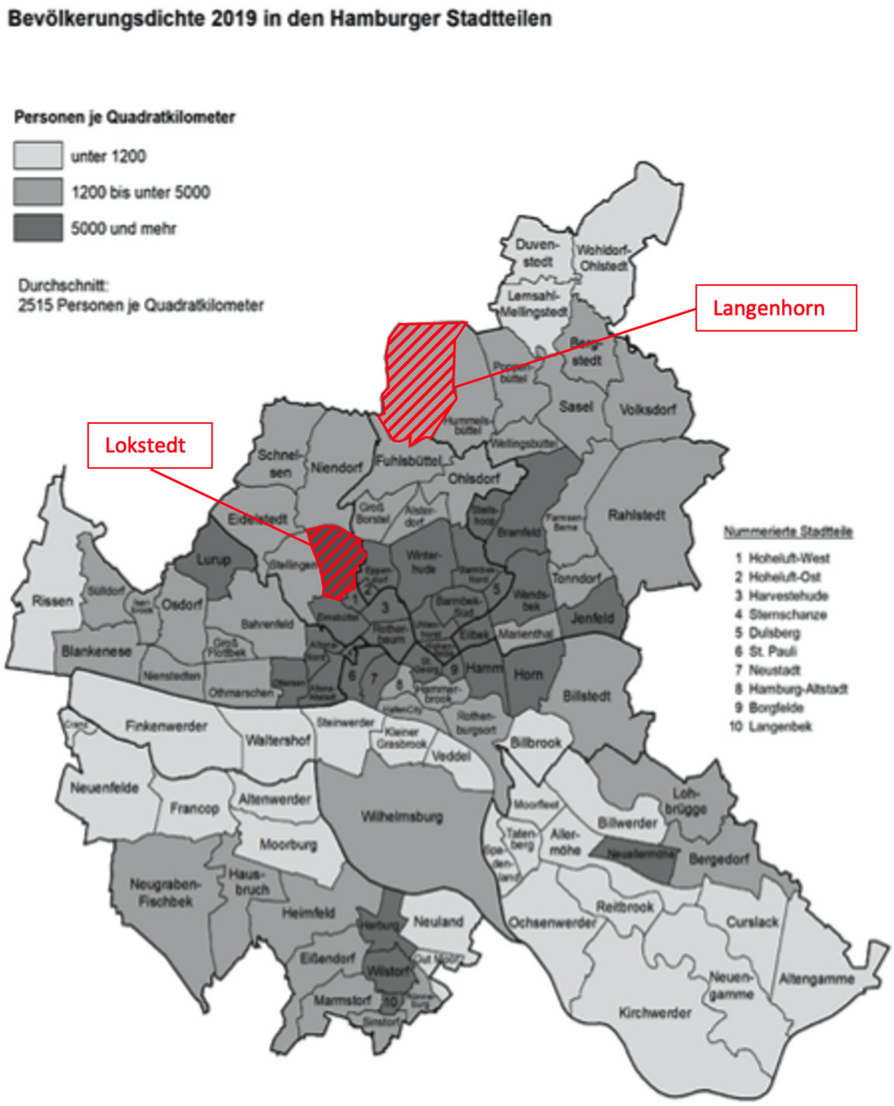


Figure 8: Population in Hamburg at 31.21.2019 by district. Highlighted in red: city districts in which the demonstration areas are located (Source: Statistisches Amt für Hamburg und Schleswig-Holstein, 2020) Markings of the districts were added.

1.4 Stakeholders and user needs

In order to better understand the mobility situation in Hamburg and expectations of key stakeholders, a set of interviews was conducted between November 2020 and January 2021 and a survey has been shared among key stakeholders. The list of interviewees comprised representatives of the municipal public transport operator (Department for Change and Innovation; ITS department); the city government (Department for Transport and Mobility Transition; Department for Economy and Innovation); a privately operated shared mobility provider, an e-mobility implementation agency, and a provider for charging solutions.

The common denominator of all interviews was a strong orientation towards testing innovative (e-)mobility solutions in Hamburg. Stakeholders were interested in understanding how e-scooters are used in areas outside the city centre; specifically, whether shared e-scooter systems can serve as a feeder for public transport, facilitate multimodal travel chains and ultimately substitute for private car trips. Survey participants expected that primary use cases for e-scooters are commuting, leisure activities, and job-related trips. Shopping and trips to school were less often expected as use cases. Moreover, all stakeholders understood e-scooters as a complementary mode to the existing mass transport system (Urban Rail and Subway), rather than a transport option on its own.

Key motivations of stakeholders were to push the urban mobility transition: on the one hand to contribute to Hamburg's image as a role model for future mobility and, on the other hand, to reduce air pollution, CO2 emissions and traffic related noise through e-mobility and multi-modal public transport, in line with the city's climate law and the climate action plan. The plan explicitly mentions measures such as 'linking the traditional public transport with sharing and on-demand services' and the provision of multimodal mobility offers in residential areas as contributions to achieve the city's climate targets. The high priority of environmental issues was validated with the high weighting of related KPIs.

An additional push factor for achieving a high public transport service level is the planned 'Hamburg Takt' which means that by 2030, all citizens should have access to a public transport service within 5 minutes in the entire urban area. Achieving this goal required also the use of new, flexible mobility services.

Public transport operators were interested in operational aspects, including whether the operation would be financially viable, how e-scooters can be integrated into a high quality and broadly accepted public multi-modality offer, and how potential users could be incentivized to use shared e-scooters as first- and last mile services. This also relates to the specification of the scheme, for example whether the system should be station-based or free-floating (with defined return-zones around public transport stops). Other stakeholders were interested in measuring impacts, i.e., whether the demo contributes to a shift from private car use to public transport, and understanding which means of transport are being replaced (car, walking, cycling, bus). Participants also indicated interest in the average length of trips and how many person-km are being replaced, also in relation to trip distances in the city centre, which are rather short.

Major concerns were related to the acceptance of the e-scooters, both from sides of the users and of the general public: shared e-scooters are often considered as 'urban pollution' – specifically if they block sidewalks – or as vehicles for tourists rather than as a genuine means of transport. Finally, some interviewees pointed to the logistics behind the sharing systems: relocation, charging, and servicing of the scooters in many cases was carried out with diesel vans, which might increase emissions of greenhouse gases, air pollutants and noise. Interviewees raised concerns that this might reduce public acceptance and compromise the environmental performance of the sharing system. Other environmental concerns were raised regarding the durability of e-scooters and the amount of natural resources required to replace broken vehicles.

Still, the general political environment was considered very supportive and was conceived as a facilitating factor for e-mobility projects, the extension of the public transport offer, and the pedestrianisation of inner-city areas. The relevant administrative departments and city districts were also considered to play a supportive role. The former Department for Economy, Transport and Innovation was split up and a new Department for Transport and Mobility Transition was founded in 2020. E-mobility and the development of public and private charging infrastructure remained under the responsibility of the Department for Economy and Innovation. Despite split competencies and partly diverging objectives (i.e., the reduction of private motorised mobility vs. electrification of public and private mobility), interviewees from both departments mentioned a high level of exchange on the operational level between the two entities.

Interviewees saw the most important implications for urban planning in the local impacts on the urban streetscape around mobility hubs: planners need to provide parking and charging infrastructure in densely populated districts with competition for scarce urban space. Experiences gained from demo projects (what works / what does not) could be used to design new urban developments in a way to discourage private car use. Successful examples from previous experiments that were replicated comprised the provision of car sharing stations in residential districts.

Due to the small scale of the demo project and the decentralised charging of e-scooter batteries, stakeholders did not expect a major impact on the energy grid. Still, most interviewees expected that a broader electrification of the mobility system, including private cars and public buses, will impact the electricity network in the long-term. A profound change of the fuel base – from oil to electricity – could lead to a 40% increase in peak loads and required the digitalisation grid connection points.

2 KEY PERFORMANCE INDICATORS (KPIS)

2.1 Prioritization of KPIs addressing the specific city needs

The priorities of the stakeholders are formally determined through the weights assigned to the selected key performance indicators (KPIs). The weighting activity in Hamburg took place in conjunction with the stakeholder interviews. As explained in Section 2.1.4, the priorities of the stakeholders are formally determined through the weights assigned to the selected attributes (KPIs). The attribute weighting activity in took place in conjunction with the stakeholder interviews organized in relation to the user needs analysis. The procedure was followed for all 13 stakeholders interviewed, representing eight stakeholder groups.

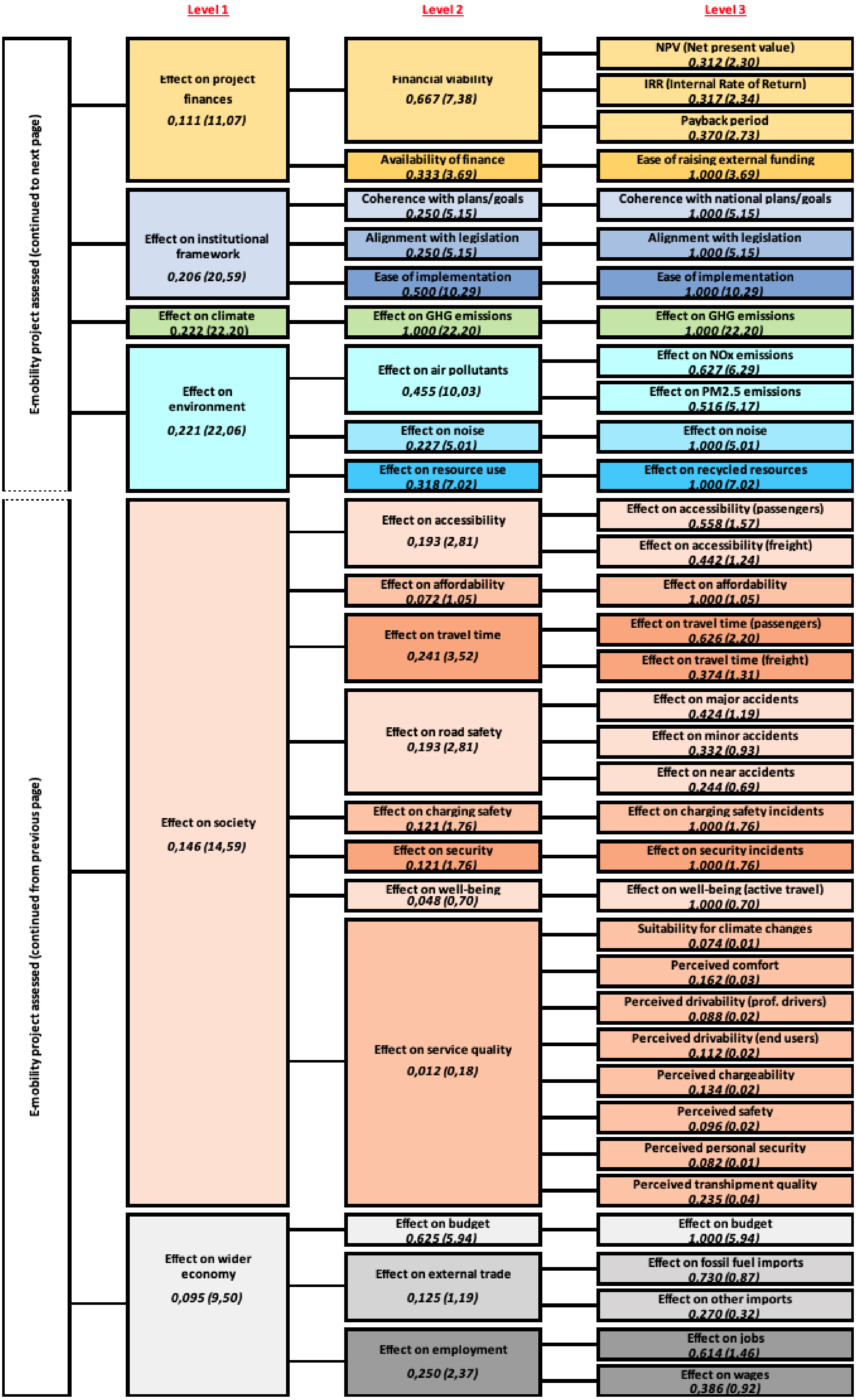


Figure 9: Stakeholder Attribute Rating of KPIs (previous page)

Figure 5.1 exhibits the mean values of the weights received from the stakeholders for all L1, L2 and L3 attributes. Both relative and cumulative (in brackets) weights are shown. Relative weights indicate stakeholder priorities within a family and sum to 1. Cumulative weights at each level are determined by applying the relative weights of that level to the cumulative weight of the parent attribute. To minimize potential mistakes, the sum of all cumulative weights at each level is set to 100. The cumulative weights of L1 are identical to the corresponding relative ones, only expressed at a different scale.

In line with the user needs assessment, stakeholders focused on environmental aspects (greenhouse gas emissions, air quality, and noise) and the compliance with existing regulatory framework, including city plans and EU legislation as most important KPIs (cumulative weight of 22.2 and 20.59). Social concerns were considered moderately important (14.59). Out of the 2nd level social indicators, the aspect of accessibility was perceived as the most important by far, whereas safety and security issues were of low relevance.

The impact on project finance (11.07) and the assumption whether the project should be financially viable differed, with private sector companies putting more emphasis on cost effectiveness. The weighting of microeconomic indicators at the individual project level varied greatly: The range was from 0 to 20, depending on the stakeholder. Macroeconomic impacts on public budgets, on imports and on employment were considered least important (9.5) to assess e-mobility solutions in Hamburg.

2.2 KPI estimation methods and data needs

Data requirements are determined by the KPIs selected for the impact assessment in conjunction with the methods to be deployed in their estimation. Table 1 briefly presents the Level 2 KPIs and the corresponding estimation methods and data needs. Note that a distinction is provided for the estimation method, depending on whether the assessment concerns the demonstration project/component or the corresponding scaled-up project. The absence of a demo entry in the estimation column signifies no expected effect at demonstration level.

Table 2: KPI estimation method and data needs

KEY PERFORMANCE INDICATORS		ESTIMATION METHOD	DATA NEEDS
LEVEL 1	LEVEL 2		
EFFECT ON PROJECT FINANCE	FINANCIAL VIABILITY	**Scaled-up:** The NPV, IRR, CER and payback indices will be calculated via specialized financial assessment tools calibrated for the specific applications. The total cost of ownership (TCO) calculations of the UNEP eMob model can also be used. **Demo:** No need to go beyond TCO estimates, as the purpose is to collect the data required for assessing the financial viability of the scaled-up project. Possible economies and diseconomies of scale effects need to be considered in applying demo figures on the scaled-up project.	Detailed capital, operating and maintenance costs on an annual basis for all project vehicles and for the duration of their expected lifespan One-time project preparation (if applicable) and residual values Cost structure of the corresponding baseline solutions (to be replaced by the proposed ones) Expected revenues of the executing agency Both costs and revenues are estimated based on the corresponding volume figures and unit prices

KEY PERFORMANCE INDICATORS – LEVEL 1	KEY PERFORMANCE INDICATORS – LEVEL 2	ESTIMATION METHOD	DATA NEEDS
EFFECT ON PROJECT FINANCE	AVAIL-ABILITY OF FINANCE	**Scaled-up:** Direct rating (Likert scale)	Available private, government and donor funds, credit lines, etc. to be used for the scaled-up project in case external funding is required
EFFECT ON INSTITU-TIONAL FRAME-WORK	COHER-ENCE WITH NATIONAL PLANS/ GOALS	**Scaled-up:** Direct rating (Likert scale)	National plans and development goals in relation to SDGs, climate change, energy policies, transport policies, environmental protection policies, etc. Similar plans and goals at regional/ city level
	ALIGN-MENT WITH LEG-ISLATION	**Scaled-up:** Direct rating (Likert scale)	National legislation concerning manufacturing, conversion, licensing, operation and decommissioning of urban transport vehicles with emphasis on EVs Similar regulations at regional/city level Technical standards for EV manufacturing and charging infrastructure
	EASE OF IMPLE-MENTA-TION	**Scaled-up:** Direct rating (Likert scale)	Implementation of existing legislation Enforcement mechanisms Administrative barriers
EFFECT ON CLIMATE	EFFECT ON GHG EMIS-SIONS	**Scaled-up:** Application of the UNEP eMob model or ad hoc calculations based on the demo results **Demo:** Calculation of the GHG emissions abated by comparing the EV carbon emissions (if any) to those of the do-nothing practice	Socio-economic data (population, regional GDP, expected GDP growth rate until target year) Composition of relevant fleets (existing vehicle stock, projected sales until target year, composition of sales by technology) Emission standards by year of introduction Fuel quality standards by year of introduction Existing and projected charging infrastructure Fuel economy of vehicles involved Operational characteristics (annual mileage, load factor, expected lifespan) The default emission figures provided by the UNEP eMob model for the vehicles involved might be sufficient for the demo components

KEY PERFORMANCE INDICATORS		ESTIMATION METHOD	DATA NEEDS
LEVEL 1	LEVEL 2		
EFFECT ON ENVIRONMENT	EFFECT ON AIR POLLUTANTS	**Scaled-up:** Application of the UNEP eMob model or ad hoc calculations based on the demo results **Demo:** Calculation of the NOx and PM2.5 emissions abated by comparing the EV corresponding emissions (if any) to those of the do-nothing practice	Ibid.
	EFFECT ON NOISE	**Scaled-up:** Expected reduction in noise due to the electric drive as reported in literature. **Demo:** On-site measurements & interviews	Speed-noise diagram for diesel vehicles Speed-noise diagram for EVs
	EFFECT ON RESOURCE USE	**Scaled up:** Quantification of mechanical parts and batteries recycled **Demo:** Ibid.	Weight of recycled parts (due to conversion) as a percentage of total weight Battery recycling infrastructure Volume of recycled batteries generated by project activities
EFFECT ON ENVIRONMENT	EFFECT ON ACCESSIBILITY	**Scaled-up:** No effect on accessibility is expected by the planned SOLUTIONSplus initiatives	N/A
	EFFECT ON AFFORDABILITY	**Scaled-up:** Effect is possible only in case of substantial cost savings due to conversion of diesel buses to e-buses	Pricing policy
	EFFECT ON TRAVEL TIME	**Scaled-up:** Possible effect due to improved reliability of e-buses in comparison to diesel ones	Delays due to malfunctions of diesel buses Technical reliability of e-buses vs. diesel buses
	EFFECT ON ROAD SAFETY	**Scaled-up:** Possible effect due to improved reliability of e-buses in comparison to diesel ones	Delays due to malfunctions of diesel buses Technical reliability of e-buses vs. diesel buses
	EFFECT ON CHARGING SAFETY	**Scaled-up:** Comparison of EVs with traditional vehicles with respect to charging safety incidents per thousand recharging/refuelling operations **Demo:** Monitoring of charging safety incidents during demo period & interviews	Official national/regional/city statistics on safety incidents during refuelling operations Official statistics on safety incidents during recharging operations of EVs (in Nepal or abroad)
	EFFECT ON SECURITY	**Scaled-up:** Comparison of EVs with traditional vehicles concerning security incidents per vkm **Demo:** Monitoring of security incidents during demo period & interviews	Official national/regional/city statistics on security incidents of traditional vehicles Official statistics on security incidents involving EVs (in Nepal or abroad)
	EFFECT ON WELLBEING	**Scaled-up:** No effect on accessibility is expected by the planned SOLUTIONSplus initiatives	N/A
	EFFECT ON SERVICE QUALITY	Scaled-up: Direct rating (Likert scale)	User perceptions on suitability for climate changes, comfort, drivability (by professional drivers), chargeability, safety, personal security, and transshipment quality

KEY PERFORMANCE INDICATORS LEVEL 1	KEY PERFORMANCE INDICATORS LEVEL 2	ESTIMATION METHOD	DATA NEEDS
EFFECT ON ENVIRON-MENT	EFFECT ON BUDGET	**Scaled-up:** Comparison of required investment to the annual budget of the executing agency	Annual budget of the executing agency
	EFFECT ON EXTERNAL TRADE	**Scaled-up:** Expected reduction in imported values due to lower fossil fuel quantities and the conversion activities	Reduction of fossil fuel consumption due to the introduction of EVs Reduction of import value due to converting existing buses
	EFFECT ON EMPLOY-MENT	**Scaled-up:** Expected effects on jobs and technical skills due to the introduced e-mobility activities based on published information & interviews	Effects on employment due to the introduction of e-mobility reported in Nepal and abroad Human resources required for the conversion activity Availability of necessary skills

2.3 Value functions

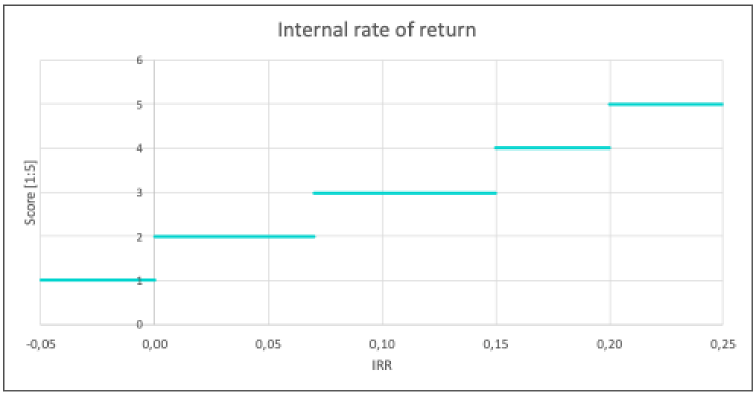
As explained in the methodology section of D1.6 – Vol.1 (Section 2.1.3.2), the KPI values estimated as described in Section 2.2 need to be transformed into star values to become compatible. This is done through value functions, as explained in the sections below. Those indicators comprise the financial KPIs, indicators related to the effect on the environment, indicators related to effects on society, and macroeconomic indicators.

Some KPIs use a 5-point scale for scoring through direct rating, in which case the KPI value is identical to the corresponding star-value. This includes indicators related to the three institutional/political indicators.

The following section outlines the valued functions for the relevant indicators to assess the Hamburg demonstration activity.

A1 – Financial viability

IRR, NPV and payback period are the indicators used for profit maximising operations, among which, the first two are considered more formal and are usually required by the financing institutions. Compared to NPV, IRR exhibits the advantage of being independent from the size of the investment. It was, thus, decided to construct a value function only for this indicator. The suggested function transforming the IRR (expressed in %) into a star value as required by the evaluation framework is shown in Figure 8. On the other hand, the cost effectiveness ratio (CER) is used for cost minimising operations. The difference of the CER value of the assessed solution from that of the old solution, denoted as ΔCER and expressed as a percentage of the old solution's CER value, is the attribute that needs to be transformed into a star value.

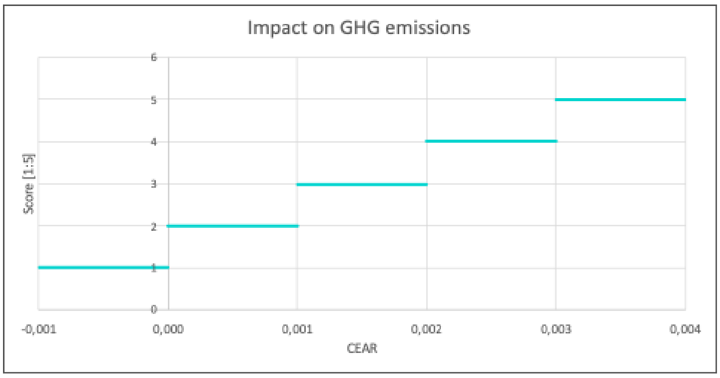


1 star	IRR ≤ 0%
2 stars	0% < IRR ≤ 7%
3 stars	7% < IRR ≤ 15%
4 stars	15% < IRR ≤ 20%
5 stars	IRR > 20%

Figure 10: Value function for the CER

C1 – Effect on GHG emissions

This KPI is defined as the percentage change in the absolute mass of GHG emissions resulting from the new e-mobility solution under consideration in comparison to the baseline scenario (defined by the type of services/vehicles relevant to the scaled-up project components). It concerns well-to-wheel CO_2 emissions accumulated over the entire assessment period (2019 to 2030). The value function needed to transform the percentage change of CO_2 emissions into a star value appears in Figure 10.



1 star	CEAR ≤ 0%
2 stars	0% < CEAR ≤ 0.1%
3 stars	0.1% < CEAR ≤ 0.2%
4 stars	0.2% < CEAR ≤ 0.3%
5 stars	CEAR > 0.3%

CEAR: Carbon Emissions Abatement Ratio

Figure 11: Value function for the effect on GHG emissions

The upscaled scenario assumes a realistically achievable greenhouse gas emission reduction of 0.4%, leading to a 5-star rating.

3 ASSESSMENT OF THE DEMONSTRATION PROJECT

3.1 Baseline scenario

The baseline scenario depicts trends in the environment of the demonstration project (on city level) and their likely development until 2025 and 2030.

Baseline values: Population

As a growth region in Germany, Hamburg expects an increase of population until 2030. The number of inhabitants is expected to grow from 1,841,000 in 2019 to 1,928,000 in 2030 (Statistisches Amt für Hamburg und Schleswig Holstein, 2019). We assume that the population dynamics in the target area follow this trend.

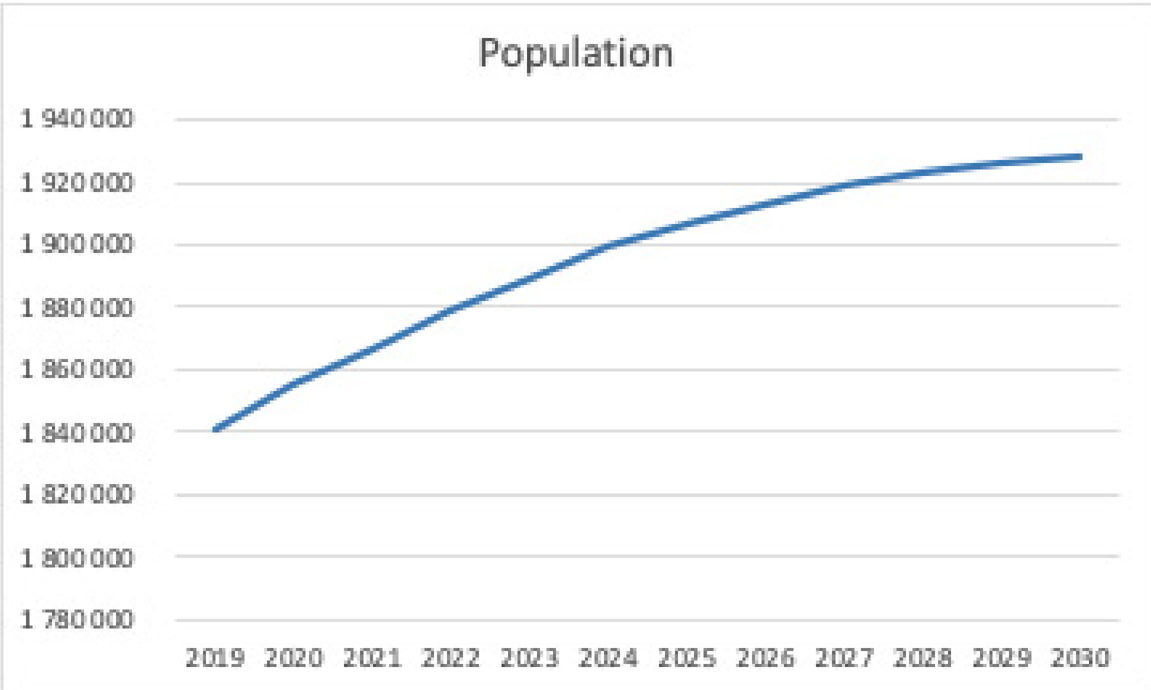


Figure 12: Population development for Hamburg until 2030. Based on (Statistisches Amt für Hamburg und Schleswig Holstein, 2019).

Size of the target population in the demonstration areas

The figures for the total population (78,500 people) were derived from predefined 'statistical units' („Verkehrszellen") that cover the broader demonstration area. Those units contain population data which is used for modelling transport trips on s neighbourhood scale. The target population is defined as the share of the total population in the demonstration area, which can potentially use the e-kick scooters. As a proxy indicator, we used the age structure: users need to be at least 18years, and usually are not older than 65 years. A study from Portland suggests that more than 95% of e-kick-scooter users are in this age group (Table 3, Portland Bureau of Transportation, 2018). This number has been validated during the demo project via the user survey (Figure 13).

Table 3: Age structure of e-scooter users in Portland. Source: (Portland Bureau of Transportation, 2018

How old are you?	Percent of respondents
16-20	3.77%
20-29	31.13%
30-39	37.62%
40-49	17.52%
50-59	7.88%
60-69	1.88%
70-79	0.15%
90-99	0.04%
Grand Total	**100.00%**

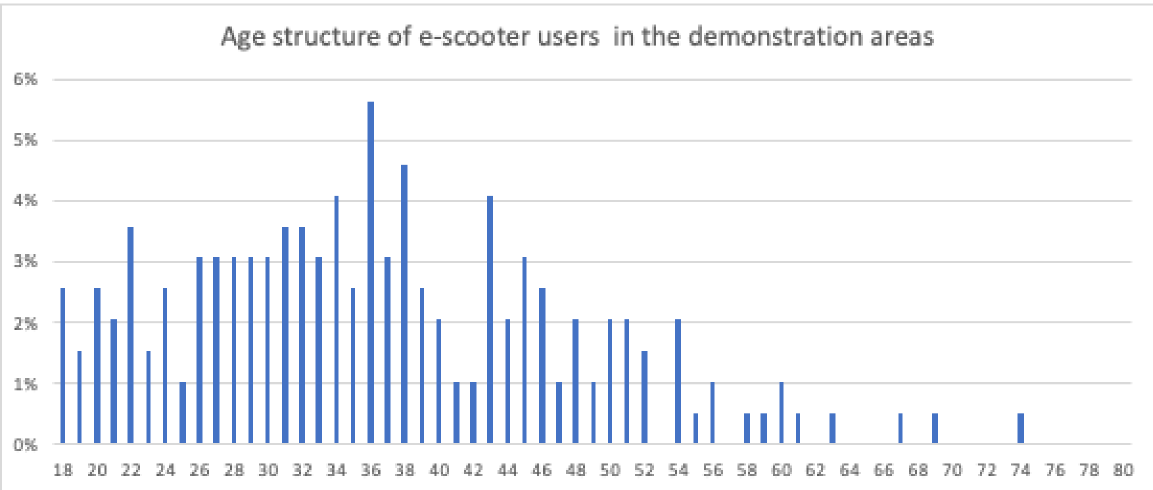


Figure 13: Age structure of e-scooter users in the demonstration area.

To derive the target population, we used the average share of the respective age group (between 18 and 65 years) in the total population of Hamburg (64,96%), which is derived from the official population statistics (Statistisches Amt für Hamburg und Schleswig-Holstein, 2020). Combining those numbers, we assumed the target population that potentially uses the e-kick-scooters in the demonstration amounts to 50.995 people.

The 2017 regional mobility assessment for Hamburg shows that the share of persons that "never use public transport", and that have a very low likelihood to use intermodal transport chains, is very low with 5% max. of the population in the target group (infas et al., 2020, p. 28).

Mobility data

The assessment relied on data collected during the demonstration activity (vehicle data, user survey) and external data. Wherever possible, the assessment uses data from official statistical sources. Mobility data was sourced from the study 'Mobilität in Deutschland 2017' and the regional report for Hamburg. The report contains a wealth of information on mobility-related indicators, including typical trip distances by purpose, or modal share data for city districts. The report was partially updated with 2022 data, and those data was used wherever possible. Data on vehicle fleets and average CO2 emissions came from the German office for motor vehicles (Kraftfahrtbundesamt).

Data on the CO2 intensity of e-scooters ('embedded emissions') over their lifetime was sourced from a review of life cycle assessments on micro-vehicles.

Energy intensity of the German electricity production

Assumptions about the electricity production are needed in order to assess the ghg emissions from e-scooter rides and related to operations of the sharing system (servicing, relocation, charging). Values for the ghg intensity of electricity production in 2020 are derived from the German Environmental Agency (UBA) and amount to 432 gCO2eq per kWh (Umweltbundesamt, 2023a). Assumptions for 2025 and 2030 stem from the German Environmental Agency's Projection report 2023 (No additional mesaures scenario, Umweltbundesamt, 2023b). According to the report, CO2eq emissions are expected to decrease to 362 g per kWh in 2025 and to 92 g in 2030.

The following table provides an overview of data needs, data sources and suggested default values for the excel calculation tool. A more detailed version is provided in SOLUTIONSplus Deliverable 4.1.

Table 4: Key data, values and assumptions, and data sources

POPULATION & TARGET GROUP	VALUE	UNIT	DATA SOURCES & ASSUMPTIONS
Total population of demo area: population within a 200m distance around the demo public transport stations	78,500	inhabitants	Determined via Statistische Gebiete / Verkehrszellen
Total Population of Hamburg	1,847,253	inhabitants	Official statistics (Statistisches Amt für Hamburg und Schleswig-Holstein, 2020)
Target group: Typical user of shared e-scooters (defined by age)	18-65	years	Portland Bureau of Transportation, 2018, validated via project survey
Share of target group in total number of inhabitants (for Hamburg)	64.96	% of inhabitants 18-65 y.	infas et al., 2020
MOBILITY DATA			
Total distance of car trips per day in Hamburg	38,300,000	vkm / day	infas et al., 2020
Average distance per car trip	5.6	vkm	infas et al., 2020, p.31 (for Hamburg)
share of e-scooter trips that replace car trips	26	%	SOL+ Survey data

POPULATION & TARGET GROUP	VALUE	UNIT	DATA SOURCES & ASSUMPTIONS
Additional public transport km	0	vkm	Assumption: no new public transport v-km are induced
Total number of e-scooter trips in demo areas during demonstration	151,055	Number of trips	TIER vehicle data
Nuber of e-scooter trips in demo areas during demonstration, starting and/or ending at a public transport station	35,403	Number of trips	TIER vehicle data
Share of e-scooter trips in demo areas during demonstration, starting and/or ending at a public transport station (of total number of trips)	23	%	TIER vehicle data
Share of e-scooter trips in demonstration area that are intermodal	30	%	SOL+ survey data
Total e-scooter vkm in demo areas during demonstration activity	175,380.65	vkm	TIER vehicle data
COST & REVENUES			
Cost of scooter trips per min	0.19	€/min	TIER app
Basic fee for scooter trips	1	€/trip	TIER app
Number of induced scooter trips	2% of all e-scooter trips	%	SOL+ Survey data
Cost of a single ticket	3.4	€/trip	HOCHBAHN, switch app
Cost of monthly subscription	57.7	€ / month	HOCHBAHN, switch app
Cost of vehicle procurement	600	€ / vehicle	Estimation
Servicing of vehicles per day	---	€ / day	TIER
Service-km per scooter-km (incl. relocation, repair, charging)	0.2	vkm	Based on literature review
Additional Hochbahn staff cost	---	€	HOCHBAHN
VEHICLE DATA AND EMISSIONS			
Emission factor vehicle-km	160	gCO2eq / km	Assumption, based on (Deutsche Energie-Agentur, n.d.; ICCT, 2024)
Total number of e-scooters in demo area	400	number of vehicles	TIER
Typical lifetime of e-scooters	720	days	TIER
Energy use per scooter km	0,0146	kwh / vkm	(Weiss et al., 2020)
Total CO2e emissions per e-scooter-km (Life Cycle Assessment)	35-123	gCO2eq/vkm	Range, based on literature reserach
Total CO2e emissions per e-scooter-km (Life Cycle Assessment). Median	67.38	gCO2eq/vkm	Median, based on desktop reserach
Emission factor for service-km (diesel van)	164	gCO2eq / vkm	Assumption, based on (infas, 2020)
Emission factor for service-km (e-van)	70	gCO2eq / vkm	Assumption, based on (infas, 2020)

POPULATION & TARGET GROUP	VALUE	UNIT	DATA SOURCES & ASSUMPTIONS
VEHICLE DATA AND EMISSIONS			
Avoidance cost per unit CO2eq	100	€ / t CO2eq	The EU Handbook provides three values for avoidance costs of 1t CO-2eq up to 2030: 60€ - 100€ -189€
Emission factor for energy mix (Germany, 2020)	400	gCO2eq/kwh	(Agora Energiewende, 2022)

3.2 KPIs for assessing the demonstration project

The demonstration activity created an additional mobility option that can be used as a first and last mile connection to public transport. SOLUTIONSplus tendered seed funding to a provider of shared e-scooters to introduce the service in an area where it was not previously available. The e-scooters are provided, owned and operated by a private company. Besides the initial seed funding, no further compensations were rewarded. HOCHBAHN converted public spaces (mostly car parks) at four metro stations into parking lots for shared micro-vehicles.

Indicators related to 'effect on project finances'

As costs for public entities were minor, mostly for re-purposing public space, financial viability was assessed for the tendered provider of e-scooters. Financial information on internal operations of the e-scooter company, however, was kept confidential, so that the assessment had to rely on estimations. Since no external funding beyond the initial funding was required, the indicator "availability of finance" is not relevant for the project.

Indicators related to 'effect on institutional framework'

The coherence with national plans and goals, the alignment with legislation, and the ease of implementation were assessed.

Indicators related to 'effect on climate'

Stakeholders rated the impact of the demonstration activity on GHG emissions as highly relevant. As the proposed UNEP eMob tool was not adequate to calculate the impact of modal shift from car use to intermodal mobility, an additional, excel-based tool was developed in SOLUTIONSplus.

The tool also takes into account the 'embedded' energy used for the production and transport of e-scooters, and allows factors such as average vehicle lifetime, use intensity, carbon intensity of the energy mix or maintenance of shared vehicles to be varied. This is important because the production phase and servicing of shared micro-vehicles account for by far the largest share of energy use and GHG emissions over the life of the micro-vehicle. Both the carbon intensity of vehicles and the evolution of the carbon intensity of the electricity mix are highly dynamic and future developments are difficult to predict.

Indicators related to 'effect on environment'

Due to the complexity of the impact assessment, effects on noise and air pollution have not been analysed. Unlike greenhouse gas emissions, air and noise pollution refer to the specific situation in a given area - such as a section of a route. Potential reductions in noise and air pollution would occur along the former routes of the replaced car trips. These routes are different from those of the additional intermodal trips. Consequently, it is not known at which geographical point the reduction in noise and air pollutants should be measured, how the causal effects of the demonstration activity would be inferred, and how other intervening factors would be excluded at a given point along the car route. Calculating the impact on such localised indicators requires more information on the routes that car users would have taken, which is not available.

Indicators related to 'effect on wider economy'

As no broader impacts on the wider economy were expected, no indicators from this group were considered.

3.3 Grouped indicators

This section presents in tabular form the rating against the parameters that enter the definition of the respective KPIs, as well as the corresponding final score. Relevant indicators are: the availability of financial resources; the coherence with national plans and goals; the alignment with legislation; and the ease of implementation.

The justification of each rating is provided through the explanatory notes shown in the lower part of each table. The links to supporting documents are also provided.

Availability of financial resources

Of this group of indicators, only indicator A is relevant. As the shared vehicle service is provided by a private company on its own account (except for the initial seed funding), there are no substantial costs for the public authorities. The remaining cost factors are mostly related to the use of public land, which may require cross-payments between public bodies, including HOCHBAHN, the districts or the city level.

Table 5: Assessment of KPI: Availability of financial resources

A.2 AVAILABILITY OF FINANCIAL RESOURCES			
EVALUATION PARAMETERS		ANSWER	JUSTIFICATION
A	Availability of government/regional/city finds for supporting the project	Yes	[1]
B	Intention of international donors to get involved in funding e-mobility projects of the suggested nature	N.A.	[1]
C	Preparedness of commercial banks to support projects concerning e-mobility in the project city through preferential interest rates	N.A.	[1]
SCORE		5	
NOTES			
[1]	Hamburg's budget plan for mobility 2023/2024 acknowledges and takes into account the need to increase the number of mobility hubs ('switch-points') at public transport stations link.		

Coherence with national plans and development goals

B.2 COHERENCE WITH NATIONAL PLANS AND DEVELOPMENT GOALS			
EVALUATION PARAMETERS		ANSWER	JUSTIFICATION
A	Alignment with transport policy at national or city level	Yes	[1] [2] [3][7]
B	Alignment with energy policy at national level	Yes	[6][8]
C	Alignment with environmental policy at national level	Yes	
D	Alignment with overarching policies at national level (e.g. NDCs, Climate Action Plans, National Development Plans)	Yes	[4][5]
SCORE		5	

NOTES	
[1]	Hamburg's mobility strategy explicitly mentions shared micro-vehicles and their potential role as first- and last mile connection to pubic transport.
[2]	The European Sustainable and Smart Mobility Strategy (SSMS, COM(2020) 789 final) maintains that mobility in Europe should be based on an efficient and interconnected multimodal transport system with cleaner and more active mobility in greener cities that contribute to the good health and wellbeing of their citizens.
[3]	The European Commission's recent proposal for the revision of the TEN-T Directive (COM(2021) 812 final) aims, inter alia, to facilitate seamless and efficient transport in urban nodes of the network, promoting multimodality and interoperability between transport modes.
[4]	Hamburg's updated Climate Law also aims to gradually increase the proportion of locally emission-free motor vehicles and to reduce negative effects of transport on the climate, the environment and health, and appropriate traffic-calming and traffic-reducing measures (§29).
[5]	The German Climate Change Act of 2021 outlines targets to reduce CO2eq emissions by 65% by 2030 (compared to 1990 levels) and achieve greenhouse gas neutrality by 2045. The Act also establishes sector-specific targets and mitigation pathways. The transport sector is supposed to reduce its annual CO2eq emissions from 150 million tonnes in 2020 to 85 million tonnes in 2030, a reduction of 43%.
[6]	According to the amended German Renewable Energy Act of 2023, at least 80% of the electricity consumed in Germany should come from renewable sources by 2030. Once the coal phase-out is complete, Germany's electricity supply is expected to be greenhouse gas neutral. A low-carbon electricity mix is crucial to avoid emissions from e-vehicles.
[7]	The Ordinance on Electric Micro-Vehicles (Elektrokleinstfahrzeuge-Verordnung) sets out the framework for the legal use of micro electric vehicles (micro-EVs) on the road. It states that the maximum speed of micro-EVs is 20 km/h, that they must be insured, that they can only be used by one person at a time, and that they are permitted on cycle paths and roads, but not on sidewalks or in pedestrian areas. Defining how micro-EV may be used is a prerequisite for efficient urban planning, e.g. for locating parking facilities or connecting them to the road or cycling infrastructure. Unclear legal requirements have led to inconsistencies in route planning or delays in the allocation of urban space for parking shared micro-vehicles in cities.
[8]	The recast of the European Renewable Energy Directive (RED II) aims to increase the share of renewable energy in consumption sectors, including transport. Member States must oblige fuel suppliers to provide at least 14% of the energy used in road and rail transport from renewable sources by 2030. The use of electricity in transport is one option to meet this requirement

Alignment with supra-national/national/city legislation & regulations

Table 6: Assessment of KPI: Coherence with national plans and development goals

B.2 COHERENCE WITH NATIONAL PLANS AND DEVELOPMENT GOALS			
EVALUATION PARAMETERS		ANSWER	JUSTIFICATION
A	Alignment with transport policy at national or city level	Yes	[1] [2] [3][7]
B	Alignment with energy policy at national level	Yes	[6][8]

C	Alignment with environmental policy at national level	Yes	
D	Alignment with overarching policies at national level (e.g. NDCs, Climate Action Plans, National Development Plans)	Yes	[4][5]
	SCORE	5	

NOTES	
[1]	Hamburg's mobility strategy explicitly mentions shared micro-vehicles and their potential role as first- and last mile connection to pubic transport.
[2]	The European Sustainable and Smart Mobility Strategy (SSMS, COM(2020) 789 final) maintains that mobility in Europe should be based on an efficient and interconnected multimodal transport system with cleaner and more active mobility in greener cities that contribute to the good health and wellbeing of their citizens.
[3]	The European Commission's recent proposal for the revision of the TEN-T Directive (COM(2021) 812 final) aims, inter alia, to facilitate seamless and efficient transport in urban nodes of the network, promoting multimodality and interoperability between transport modes.
[4]	Hamburg's updated Climate Law also aims to gradually increase the proportion of locally emission-free motor vehicles and to reduce negative effects of transport on the climate, the environment and health, and appropriate traffic-calming and traffic-reducing measures (§29).
[5]	The German Climate Change Act of 2021 outlines targets to reduce CO2eq emissions by 65% by 2030 (compared to 1990 levels) and achieve greenhouse gas neutrality by 2045. The Act also establishes sector-specific targets and mitigation pathways. The transport sector is supposed to reduce its annual CO2eq emissions from 150 million tonnes in 2020 to 85 million tonnes in 2030, a reduction of 43%.
[6]	According to the amended German Renewable Energy Act of 2023, at least 80% of the electricity consumed in Germany should come from renewable sources by 2030. Once the coal phase-out is complete, Germany's electricity supply is expected to be greenhouse gas neutral. A low-carbon electricity mix is crucial to avoid emissions from e-vehicles.
[7]	The Ordinance on Electric Micro-Vehicles (Elektrokleinstfahrzeuge-Verordnung) sets out the framework for the legal use of micro electric vehicles (micro-EVs) on the road. It states that the maximum speed of micro-EVs is 20 km/h, that they must be insured, that they can only be used by one person at a time, and that they are permitted on cycle paths and roads, but not on sidewalks or in pedestrian areas. Defining how micro-EV may be used is a prerequisite for efficient urban planning, e.g. for locating parking facilities or connecting them to the road or cycling infrastructure. Unclear legal requirements have led to inconsistencies in route planning or delays in the allocation of urban space for parking shared micro-vehicles in cities.
[8]	The recast of the European Renewable Energy Directive (RED II) aims to increase the share of renewable energy in consumption sectors, including transport. Member States must oblige fuel suppliers to provide at least 14% of the energy used in road and rail transport from renewable sources by 2030. The use of electricity in transport is one option to meet this requirement

Ease of implementation (in terms of administrative barriers)

Table 7: Assessment of KPI: Ease of implementation

B.3 EASE OF IMPLEMENTATION			
	EVALUATION PARAMETERS	ANSWER	JUSTIFICATION
A	The project requires administrative intervention of limited scope from the relevant political and institutional bodies, e.g. activities for passing a new law that will make the uptake of an e-mobility solution possible	No	[1] [2]
B	The political and institutional bodies needed for supporting the implementation are in place.	Yes	[1] [2]
C	The existing national / city-level political and institutional bodies are likely to be supportive of the necessary action required for the project implementation.	Yes	[3] [4]

SCORE	5

NOTES	
[1]	No activity needed. The Ordinance on Electric Micro-Vehicles sets out the framework for the legal use of micro electric vehicles (micro-EVs) on the road.
[2]	No activity needed. Micro-vehicle sharing is a legal and recognised business model in Germany and the EU.
[3]	Hamburg's mobility strategy explicitly mentions shared micro-vehicles and their potential role as first- and last mile connection to public transport.
[4]	The European Sustainable and Smart Mobility Strategy (SSMS, COM(2020) 789 final) maintains that mobility in Europe should be based on an efficient and interconnected multimodal transport system with cleaner and more active mobility in greener cities that contribute to the good health and wellbeing of their citizens.

3.4 Impact on greenhouse gas emissions

The effect on GHG emissions is expected from a shift of private car trips to a combination of public transport and e-kick-scooters for the first- and last-mile segment. To account for this impact, it is important to consider the following factors:

- Number of shifted private car-km and avoided greenhouse gas emissions (CO2 equivalents)
- Number of additional e-scooter km in the demonstration areas, direct energy consumption of e-scooters and resulting greenhouse gas emissions
- Embedded greenhouse gas emissions from the production, transport, and disposal of e-scooters required
- Greenhouse gas emissions from operating the shared e-scooter system (maintenance, charging, re-location)
- Emission factors per shifted car-km.

The assessment results heavily depend on the emission factor used for the carbon intensity of e-scooters. Over the last year, a wealth of assessments has been produced, showing a high volatility in the respective results, depending on authorship and publication year:

Table 8: Overview of studies on CO2eq emissions per e-scooter-km (LCA)

MED.	LOW	HIGH	SEVERENGIZ ET AL.2020			HOLL-INGS-WORTH	ITF 2020	EY / VOI 2020	CENEX 2020		NCSU	SCHÜNEMANN ET AL. 2022		DENA	
			BASE	SCE-NARIO E-VAN	SCE-NARIO E-CAR-GO BIKE				LOW	HIGH		LOW	HIGH	2020	2021
67	35	105	77	68	46	88	105	35	105	35	105	105	105	105	105

The derived data were validated in a first round with internal experts and used as default values in the excel tool. Still, it needs to be noted that the evidence base and reliability of assumptions and default values vary to a high degree. Some data are based on a sound evidence base, but for others we had to rely on informed guesses, for instance those related to operations of the scooter operator. For other data, such as total emissions per e-scooter kilometre (based on the entire Life Cycle), studies displayed a high variance, ranging from 35g CO2e to more than 120g CO2e. In those cases, median values of were deployed.

The tool takes a conservative and cautious approach: It assesses all CO2e emissions associated with the production, use and operation (maintenance, relocation) of the required number e-scooters throughout their life cycle, based on a broad review of LCA studies. It considers the emissions from all e-scooter trips in the demonstration area - not just those that replace car trips - to account for trips that have replaced active mobility and public transport, as well as trips that would not have taken place without the introduction of e-scooters in the area (induced trips). Greenhouse gas savings were determined by deducting all additional e-scooter-km (LCA) from the avoided GHG emissions from car trips shifted to intermodal trips. As means of caution, we do not assume that the provision of an alternative mobility option leads to lower car ownership rates. Consequently, the impact on emissions from private car trips only considers direct emissions of car use.

To understand the impact of the demonstration activity, we used an emission factor of 70g CO2e per vehicle kilometre (CO2e /vkm, slightly above the median), assuming that all 400 e-scooters were newly purchased.

Based on the results of the user survey conducted during the demonstration phase, we assumed that 26% of e-scooter trips would replace a car trip. The average distance per car trip was assumed to be 5.6 km, with an emission factor for cars of 160 g CO2e/ vkm.

The user survey confirmed the findings of other reports (International Transport Forum 2021; Moreau et al. 2020) that shared e-scooter rides most often substitute active mobility and public transport. Still, 26% of respondents indicated that e-scooter trips also replaced private motorised mobility (several answers to the question were possible).

In a first step, the assessment only considered the GHG impacts of those e-scooter trips that started and/or ended at public transport stations in the demonstration area. Trip data was collected from the e-scooters during the demonstration period. The following table shows a positive impact on greenhouse gas emissions, with approximately 591t CO2e avoided during the demonstration period.

Table 9: Assessment of greenhouse gas emissions: intermodal e-scooter trips to/from demonstration area

Only trips that start/end at public transport stations

ADDITIONAL EMISSIONS		
Scooter-km to/from public transport stations	34.808,07	vkm
Emission factor scooter-vkm (LCA)	67	gCO2e / vkm
ADDITIONAL EMISSIONS FROM E-SCOOTER TRIPS TO/FROM PUBLIC TRANSPORT (VKM*EMISSION FACTOR LCA)	2.332.140,69	gCO2e
AVOIDED EMISSIONS		
Number of scooter trips to public transport stations	34.808,07	vkm
Share of e-scooter trips that replace car trips	26	%
Number of replaced car trips	9.205	trips
Average distance of car trip	5,60	vkm/trip

Shifted vkm fom car to intermodal	34.808,07	vkm
Emission factor car-km	160	gCO2e / vkm
AVOIDED EMISSIONS	8.247.482,88	gCO2e / vkm
NET AVOIDED EMISSIONS	591,53	t CO2e

However, the positive impact on greenhouse gas mitigation turns negative when all e-scooter trips in the demonstration area are considered. As approximately three quarters of the e-scooter trips replace active mobility (walking/cycling), public transport (assuming no change in vkm) or would not have taken place (induced trips), the emissions associated with these trips must also be taken into account. The following table shows a negative impact on greenhouse gas emissions, resulting in an additional 350t CO2e over the demonstration period.

Table 10: Assessment of greenhouse gas emissions: all e-scooter trips in demonstration area

All trips in demo Area

ADDITIONAL EMISSIONS		
Scooter-km in demonstration area	175.380,65	vkm
Emission factor scooter-vkm (LCA)	67	gCO2e / vkm
COMBINED ADDITIONAL EMISSIONS FROM E-SCOOTERS IN DEMO AREA (VKM*EMISSION FACTOR LCA)	11.750.503,55	gCO2e
AVOIDED EMISSIONS		
Number of scooter trips to public transport stations	35.403	number
Share of e-scooter trips that replace car trips	26	%
Number of replaced car trips	9.205	trips
Average distance of car trip	5,60	vkm/trip
Shifted vkm fom car to intermodal	34.808,07	vkm
Emission factor car-km	160	gCO2e / vkm
AVOIDED EMISSIONS	8.247.482,88	gCO2e / vkm
NET AVOIDED EMISSIONS	**- 350,30**	t CO2e

The actual use of e-kick-scooters is very energy efficient compared to cars, and the main reason behind the negative impacts on greenhouse gas emissions relate to emissions from production, transport and disposal of e-scooters, and from operations.

As the assumptions about emission factors per e-scooter-km differ highly (as indicated in Table 3), we calculated the maximal LCA-based emissions per e-scooter-vkm to 47,03 gCO2e/vkm would avoid additional greenhouse gas emissions from the operation of shared e-scooters. This value is within the lower range of assessments. Most important factors to achieve this are an extension of vehicle life-time, and using e-vehicles for maintenance, charging, and relocation. Some cities have implemented respective regulations in concessions with e-scooter providers.

Table 11: Assessment of greenhouse gas emissions: all e-scooter trips in demonstration area. Break-even CO2e emissions per vkm

All trips in demo Area - climate neutral

ADDITIONAL EMISSIONS		
Scooter-km in demonstration area	175.380,65	vkm
Emission factor scooter-vkm (LCA)	**47,03**	gCO2e / vkm
COMBINED ADDITIONAL EMISSIONS FROM E-SCOOTERS IN DEMO AREA (VKM*EMISSION FACTOR LCA)	8.247.482,88	gCO2e
AVOIDED EMISSIONS		
Number of scooter trips to public transport stations	35.403	number
Share of e-scooter trips that replace car trips	26	%
Number of replaced car trips	9.205	trips
Average distance of car trip	5,60	vkm/trip
Shifted vkm fom car to intermodal	51.546,77	vkm
Emission factor car-km	160	gCO2e / vkm
AVOIDED EMISSIONS	8.247.482,88	gCO2e / vkm
NET AVOIDED EMISSIONS	0	gCO2e

A final calculation indicated that if 38.7% of e-scooter rides would be intermodal and replace car trips, no additional greenhouse gases would be emitted.

Table 12: Assessment of greenhouse gas emissions: all e-scooter trips in demonstration area. Break-even share of e-scooter trips that replace car trips

All trips in demo Area

ADDITIONAL EMISSIONS		
Scooter-km in demonstration area	175.380,65	vkm
Emission factor scooter-vkm (LCA)	67	gCO2e / vkm
COMBINED ADDITIONAL EMISSIONS FROM E-SCOOTERS IN DEMO AREA (VKM*EMISSION FACTOR LCA)	12.276.645,50	gCO2e
AVOIDED EMISSIONS		
Number of scooter trips to public transport stations	35.403	number
Share of e-scooter trips that replace car trips	38,70	%
Number of replaced car trips	13.702	trips
Average distance of car trip	5,60	vkm/trip
Shifted vkm fom car to intermodal	76.729,03	vkm
Emission factor car-km	160	gCO2e / vkm
AVOIDED EMISSIONS	12.276.645,50	gCO2e / vkm
NET AVOIDED EMISSIONS	0	gCO2e

Impact on Air pollution: Effect on NOx emissions and PM2.5 emissions and effect on noise:

Air and noise pollution are determined through factors such as traffic loads and the characteristics of vehicles and driving behaviour. They refer to the situation (NOx, PM, db levels) in local contexts, for example in a specific segment of a street. While we assume that reductions of transport related ghg emissions coincide with reduced levels of transport related noise and air pollution, an assessment of how this will materialise in more specific, local circumstances goes beyond the scope of this assessment. As the routes of avoided car trips and intermodal trips differ, deriving assumptions on the impacts of traffic loads on individual streets with high levels of air and noise pollution would require an integration with transport models.

Financial and socio-economic profitability

In the financial and socio-economic profitability section, a new approach was adopted compared to the ex-ante assessment. This approach aligns with the calculation principles outlined by the solution plus project team for KPI regulations. With access to financial data from TIER, the Hamburg city team opted to focus on the financial costs and revenues for the e-scooter provider, aiming to adapt the assessment accordingly. Hence, the subsequent section addresses the computation and interpretation of the three financial KPIs employed in the Solutions Plus projects.

Financial viability

Financial viability entails examining the monetary aspects of the projects, primarily focusing on their sustainability for future utilization without project funding. While much of the data for computing the financial KPIs could be obtained from TIER and Hochbahn, certain assumptions had to be formulated based on a literature review. To ensure a comprehensive understanding of the project's financial viability, three widely recognized economic indicators are computed: Net Present Value (NPV), Internal Rate of Return (IRR), and the Payback Period. The cash flows for the project period were derived from various sources, including TIER, the mobility-data analysis, Hochbahn, and relevant literature.

Table 13: Data Input for Financial KPI Calculation

NAME	VALUE	SOURCES
Price per Scooter	600 €	Assumption, based on TIER, Busgeldkatalog1
# of new Scooters	400	Assumption / based on Data Analysis
Battery Capacity of scooters	0,25 kWh	Verivox2
Energy Price / kWh	0,32 €	CO2 Online3
Battery Range	30 km	Mi Global Home4
Average Speed	10,5 km/h	Data Analysis

Utilizing the data supplied by TIER and the results of our data analysis, we were able to compute the monthly cash flows. This involved calculating the monthly revenues, which were provided with the data from TIER, and the monthly costs encompassing investment, operational expenses, and energy consumption. While it was feasible to calculate overhead costs, we assumed that the initial funding was allocated to cover infrastructure and overhead expenses (amounting to 41,000€).

A more anecdotical evidence for the project's viability is that soon after the start of the demonstration activity, other providers of shared e-kick-scooters extended their operation areas and started offering their service in the demonstration areas. Moreover, the initially selected provider decided to continue its service in the Lokstedt and Langenhorn also beyond the demonstration period.

Net present value (NPV)

The NPV of an investment is the present value of its future cash inflows minus the present value of the cash outflows. It is used to determine the profitability you derive from a project. To compute the net present value of the pilot project, we needed to determine TIER's discount rate. Since this information wasn't provided, the project team opted to use a conservative estimate of 6% for initial calculations. This figure reflects the potential return from an alternative investment for the company. While 6% might appear high for alternative investment profit, it serves as a prudent measure to assess the profitability of the pilot project in Hamburg based on the computed monthly cash flows.

As TIER didn't furnish specific values for the number of scooters purchased, the Hamburg team made an assumption regarding the initial investment sum. It was decided that initially, 50% of the average scooters would be new investments, while the remaining 50% would be relocated from other areas within Hamburg or Germany. This led to an initial investment sum of 120,000€.

The computed NPV for the project amounted to 15,700€ over a period of 14 months, considering an initial investment of 120,000€. The positive NPV indicates that the project is financially viable and potentially lucrative, as it is yielding returns greater than the initial investment. However, it's essential to consider other factors such as market conditions, competition, and regulatory changes for a comprehensive evaluation of the project's profitability and sustainability. Further analysis of the data reveals a noticeable decrease in both revenues and costs during the winter months in Hamburg, followed by a gradual increase throughout the spring, peaking in the summer months.

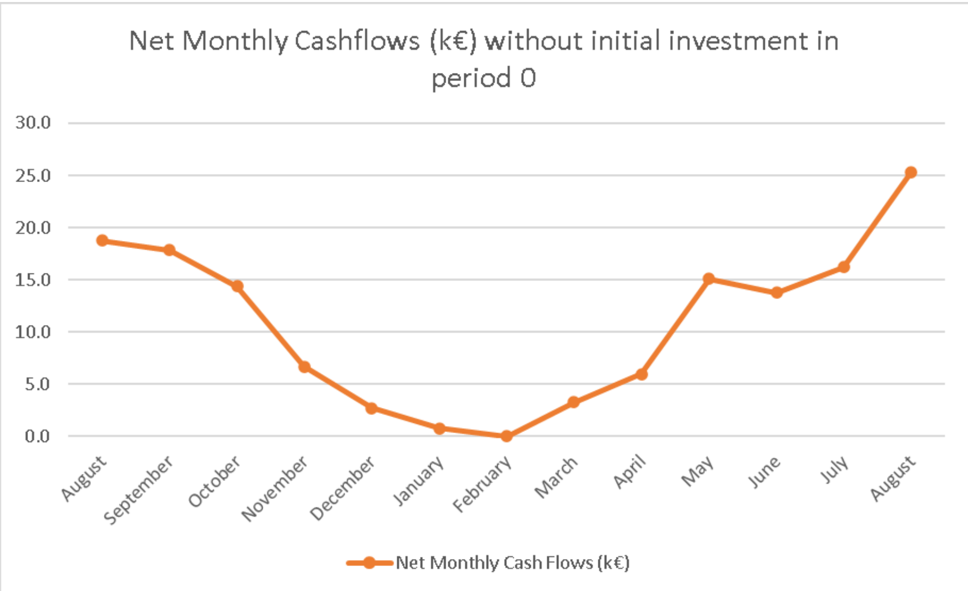


Figure 14: Net monthly CF

Internal rate of return (IRR)

The internal rate of return (IRR), often referred to as the discounted cash flow rate of return, is a crucial metric for assessing the profitability of an investment. It represents the discount rate at which the net present value (NPV) of future cash flows becomes zero. In the context of the pilot project in Hamburg, the computed cash flows resulted in an IRR of 2.3% for the entire project duration, considering the initial investment. This indicates that the project is expected to yield a return of 2.3% over its lifespan, considering the timing and magnitude of cash inflows and outflows. While the IRR provides insight into the project's potential profitability, it's important to compare it with the project's cost of capital and other investment opportunities to make informed decisions about resource allocation.

Payback period (PP)

The Payback Period calculates how long it takes for the project to get back the funds it originally invested in a project. It is basically used to determine the time needed for an investment to break-even.

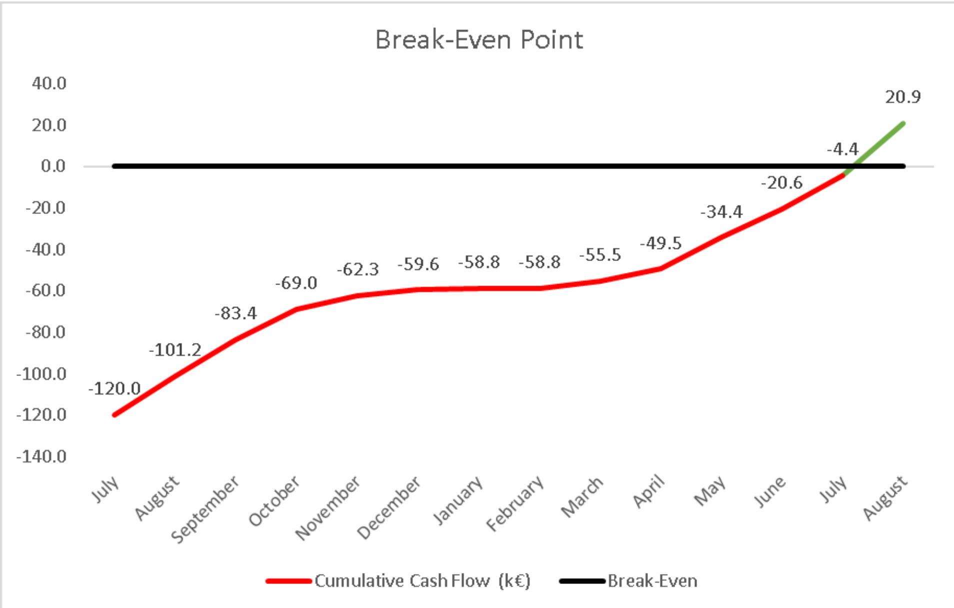


Figure 15: Break-Even-Point PP Calculation

Calculating the payback period (PP) reveals that the break-even point, based on cumulative cash flows, will occur after approximately 13.18 months relative to the initial investment. This indicates that it will take approximately 13.18 months for the project's cumulative cash inflows to equal the initial investment, after which the project will begin generating positive returns. The payback period provides valuable insight into the time it takes for an investment to recoup its initial costs, serving as a measure of risk and liquidity for stakeholders.

Socioeconomic costs and benefits

While direct costs are relatively easy to determine and to allocate to individual entities (e.g. passengers, public transport operators, municipalities, or private service operators), socio-economic benefits are much broader, though often not easily determined and hardly attributable to a specific activity. Socio-economic benefits also comprise broader benefits and avoided costs for the society. This includes avoided health costs through reduced levels of air- and noise-pollution, reduced costs related to accidents, or avoided costs of climate change. The socio-economic benefits will be calculated using the European Handbook on external cost of transport (European Commission, 2020). The assessment on the calculations of GHG emissions above. Costs and benefits related to air and noise pollution and road congestion will not be considered, due to the reasons given above.

Socioeconomic costs from greenhouse gas emissions (CO2e) are calculated as avoidance cost, based on the European Commission's handbook on the external costs of transport. The handbook suggests a span between 60 and 189€/t CO2e. Assuming a medium value of 100€, the scaled-up project would add additional costs of if all vehicles would be procured newly, or save an amount of more than EUR 1,500,000 (equivalent to 15,000tCO2e) annually, if the existing vehicles would be re-distributed over the entire city area (see chapter 4).

Social Impacts

The sharing solution is considered an add-on to the existing public transport service offer. The climate plan explicitly mentions the role of micro-mobility and sharing offers to enhance the service level and coverage of public transport offers. Thus, the project contributes to an increase of service quality. On the other hand, it needs to be noted that the solution is accessible only for a segment of the entire population (<18 not allowed; elderly persons and handicapped people cannot use the solution; not suitable for childcare or grocery shopping etc.). Thus, while the solution has obvious benefits in terms of reduced air and noise pollution and also increases the level of accessibility for a share of the population, it is important not to consider shared kick-scooter system as a means to improve general accessibility for all. Its strength lies in targeting user groups – such as commuters – that tend to use private cars for their purposes.

Effect on service quality and accessibility

As implemented in the demonstration activity, shared e-kick-scooters are complementary to the existing transport system in areas with less dense public transport services. However, the target group for this solution is not universal, and excludes children, elderly people, and people with disabilities; e-kick-scooters are also not suited for trips related to childcare or groceries. It does, however, facilitate access for those groups of the population who tend to rely on private cars.

The effect on accessibility will be determined using the UrMoAc tool developed by DLR. As final results are not available yet, they will be provided in an addendum to this report issued by the end of the project.

Effect on employment

As economic details, including the required staff, related to operations of the private provider of e-kick-scooters is confidential information, the effect on employment of the demonstration project has not been evaluated.

4 ASSESSMENT OF THE SCALED-UP PROJECT

Based on the findings from the demonstration areas, this chapter assesses the likely impacts of upscaling of the activity to the entire city area of Hamburg.

4.1 Approach

Approximately 1.85 million people live in Hamburg. The demonstration areas in Langenhorn and Lokstedt together are host to 78,500 residents, constituting 4.25% of the city's population. Stated differently, there are 23,532 times more people living in Hamburg overall compared to just the project areas.

Other parameters, such as the proportion of scooter rides replacing car trips and the average distance of a car trip, have been derived from the findings within the project areas. These boundary parameters were crucial in shaping the analysis. Specifically, within the project areas, approximately 26% of scooter trips replace car-trips, with the average distance of a car trip being 5.6 kilometers.

During the observation period, 400 scooters were available within the project areas. Scaling this up to Hamburg indicates a total demand of 9,413 e-scooters city-wide.

For the trips to and from public transport, this results in 819,099.51 km driven with e-scooters for the whole of Hamburg. If all e-scooter trips are taken into account, this results in a total of 4,127,037.35 km per year for the whole of Hamburg.

Table 14: Parameters for the upscaling scenarios

NAME	DEMONSTRATION AREA	HAMBURG - UPSCALED
Number of e-scooters required	600 €	9,413 (400 * 23,532)
Kilometers of Scooter-Trips in Hamburg - First & Last Mile	34,808.07 km	819,099.51 km
Kilometers of Scooter-Trips in Hamburg – All trips	175.380,65 km	4,127,037.35 km

4.2 Scenarios

For the study of the project areas in Hamburg, 400 scooters were added to the fleet of an e-scooter operator and placed in the areas of Langenhorn and Lokstedt. This leads to two alternative scenarios for scaling up:

- Scenario I - Greenfield: The entire fleet of e-scooters has to be newly procured and consists of additional, newly produced vehicles.
- Scenario II - Brownfield: The existing fleet of e-scooters and operators is better distributed throughout the city and no new e-scooters need to be purchased. Currently, ca. 20,000 e-scooters operate in Hamburg and would be re-located across the entire city area.

4.3 Results

Scenario I

Greenfield - all e-scooters must be purchased new.

Table 15: Net avoided emissions: Scenario I Greenfield to and from public transport station

Only trips that start/end at public transport stations

ADDITIONAL EMISSIONS		
Scooter-km to/from public transport stations	819.099,51	vkm
Emission factor scooter-vkm (LCA)	70,00	gCO2e / vkm
ADDITIONAL EMISSIONS FROM E-SCOOTER TRIPS TO/FROM PUBLIC TRANSPORT (VKM*EMISSION FACTOR LCA)	57.336.965,88	gCO2e
AVOIDED EMISSIONS		
Number of scooter trips to public transport stations	833.099	vkm
Share of e-scooter trips that replace car trips	26	%
Number of replaced car trips	216.606	trips
Average distance of car trip	5,60	vkm/trip
Shifted vkm fom car to intermodal	1.212.992,63	vkm
Emission factor car-km	160	gCO2eq / vkm
AVOIDED EMISSIONS	194.078.821,56	gCO2eq / vkm
NET AVOIDED EMISSIONS	136.741.855,69	g CO2eq
	136.674,19	t CO2eq

Table 16: Net avoided emissions: Scenario I Greenfield all trips in Hamburg

All trips in Hamburg

ADDITIONAL EMISSIONS		
Scooter-km in demonstration area	4.127.037,35	vkm
Emission factor scooter-vkm (LCA)	70,00	gCO2e / vkm
COMBINED ADDITIONAL EMISSIONS FROM E-SCOOTERS IN DEMO AREA (VKM*EMISSION FACTOR LCA)	288.892.614,39	gCO2e
AVOIDED EMISSIONS		
Number of scooter trips to public transport stations	833.099	number
Share of e-scooter trips that replace car trips	26	%
Number of replaced car trips	216.606	trips
Average distance of car trip	5,60	vkm/trip
Shifted vkm fom car to intermodal	1.212.992,63	vkm
Emission factor car-km	160	gCO2eq / vkm
AVOIDED EMISSIONS	194.078.821,56	gCO2eq / vkm
NET AVOIDED EMISSIONS	- 94.813.792,83	g CO2eq
	- 9.481,38	t CO2eq

Under the Greenfield Scenario under which all 9,400 e-scooters would be newly procured, a saving of ca. 13,700 t of CO2e annually could be achieved when only intermodal trips (i.e. trips to and from public transport stations) are considered. If all trips are taken into account, however, Scenario 1 leads to additional greenhouse gas emissions of ca. 9,500t CO2e per year.

Scenario II:

Brownfield - existing scooters are distributed throughout the city.

20,000 scooters already operate in Hamburg. Under the premise that the existing scooters can accommodate all additional trips in Hamburg, and that 86% of LCA-based emissions per scooter-km stem from production stage (Schünemann et al., 2022), the LCA values per vehicle-km are reduced to 14%; from 70gCO2e to 9.8g. Again, two perspectives on this scenario were considered: one under which only trips to and from public transport stations are considered and counted as intermodal trips, and one where all e-scooter trips were taken into account.

Table 17: Net avoided emissions: Scenario II Brownfield, Trips to and from public transport stations

Only trips that start/end at public transport stations

ADDITIONAL EMISSIONS		
Scooter-km to/from public transport stations	819.099,51	vkm
Emission factor scooter-vkm (LCA)	9,80	gCO2e / vkm
ADDITIONAL EMISSIONS FROM E-SCOOTER TRIPS TO/FROM PUBLIC TRANSPORT (VKM*EMISSION FACTOR LCA)	8.027.175,22	gCO2e
AVOIDED EMISSIONS		
Number of scooter trips to public transport stations	833.099	vkm
Share of e-scooter trips that replace car trips	26	%
Number of replaced car trips	216.606	trips
Average distance of car trip	5,60	vkm/trip
Shifted vkm fom car to intermodal	1.212.992,63	vkm
Emission factor car-km	160	gCO2eq / vkm
AVOIDED EMISSIONS	194.078.821,56	gCO2eq / vkm
NET AVOIDED EMISSIONS	186.051.646,34	g CO2eq
	18.605,16	t CO2eq

Table 18: Net avoided emissions: Scenario II Brownfield, All trips in Hamburg

All trips in Hamburg

ADDITIONAL EMISSIONS		
Scooter-km in demonstration area	4.127.037,35	vkm
Emission factor scooter-vkm (LCA)	9,80	gCO2e / vkm
COMBINED ADDITIONAL EMISSIONS FROM E-SCOOTERS IN DEMO AREA (VKM*EMISSION FACTOR LCA)	40.444.966,01	gCO2e

AVOIDED EMISSIONS		
Number of scooter trips to public transport stations	833.099	number
Share of e-scooter trips that replace car trips	26	%
Number of replaced car trips	216.606	trips
Average distance of car trip	5,60	vkm/trip
Shifted vkm fom car to intermodal	1.212.992,63	vkm
Emission factor car-km	160	gCO2eq / vkm
AVOIDED EMISSIONS	194.078.821,56	gCO2eq / vkm
NET AVOIDED EMISSIONS	153.633.855,55	g CO2eq
	15.363,39	t CO2eq

The calculations showed that a greenhouse gas emission reduction of 18,605.16 tons of CO2e per year can be achieved if only trips to and from public transportation are considered; if all e-scooter trips are included, a savings of 15,363.39 tons of CO2e could be achieved.

Conclusion

In the greenfield scenario, where all e-scooters must be procured anew, there are notable savings of 13,674.19 tons of CO2 equivalents per year for trips to and from local public transport. However, the overall impact is tempered by excess emissions of 9,481.38 tons of CO2 equivalents per year across all trips. Conversely, in the brownfield scenario, where existing infrastructure is better distributed throughout the city, significant improvements are observed. Savings of 18,605.16 tons of CO2 equivalents per year for trips to and from local public transport, along with 15,363.39 tons of CO2 equivalents per year across all trips, underscore the benefits of leveraging existing resources. This comparison emphasizes the potential for cities with established e-scooter infrastructure to enhance their CO2 footprint by redistributing surplus e-scooters, ultimately contributing to environmental sustainability.

4.4 Financial Upscaling

For the upscaling initiative, the team aimed to not only assess the environmental impact in terms of greenhouse gas emissions but also prioritize the financial feasibility of implementing a city-wide e-scooter service in Hamburg. Regarding sustainability metrics, the team utilized the same scale-up factor as for the sustainability KPIs to calculate monthly city-wide trips, which were then computed to costs and revenues for cash flow projections.

For the assessment of the financial viability of the upscaled project the same three financial KPIs were computed (Net Present Value, Internal Rate of Return and Payback Period).

Net Present Value (NPV):

The Net Present Value (NPV) of an investment represents the present value of its anticipated future cash inflows minus the present value of its cash outflows. It's a crucial metric for gauging a project's profitability. To calculate the NPV for the pilot project, we needed to establish a discount rate. Lacking specific data, the project team chose a conservative estimate of 6%, reflecting the potential return from alternative investments for the company. While 6% might seem high for alternative investment profit, it serves as a cautious measure to evaluate the pilot project's profitability in Hamburg, based on projected monthly cash flows.

Following the same methodology used for the demo area, the team applied the scale-up factor to extrapolate scooter numbers for initial purchase and monthly replacements, resulting in a month 1 investment of €4.6 million. The computed NPV for the project amounted to €805,300 over a 14-month period, considering the initial investment. A positive NPV suggests financial viability and potential profitability, indicating returns exceeding the initial investment. Further examination of the data reveals a distinct decrease in both revenues and costs during Hamburg's winter months, followed by a gradual rise through spring, peaking in the summer.

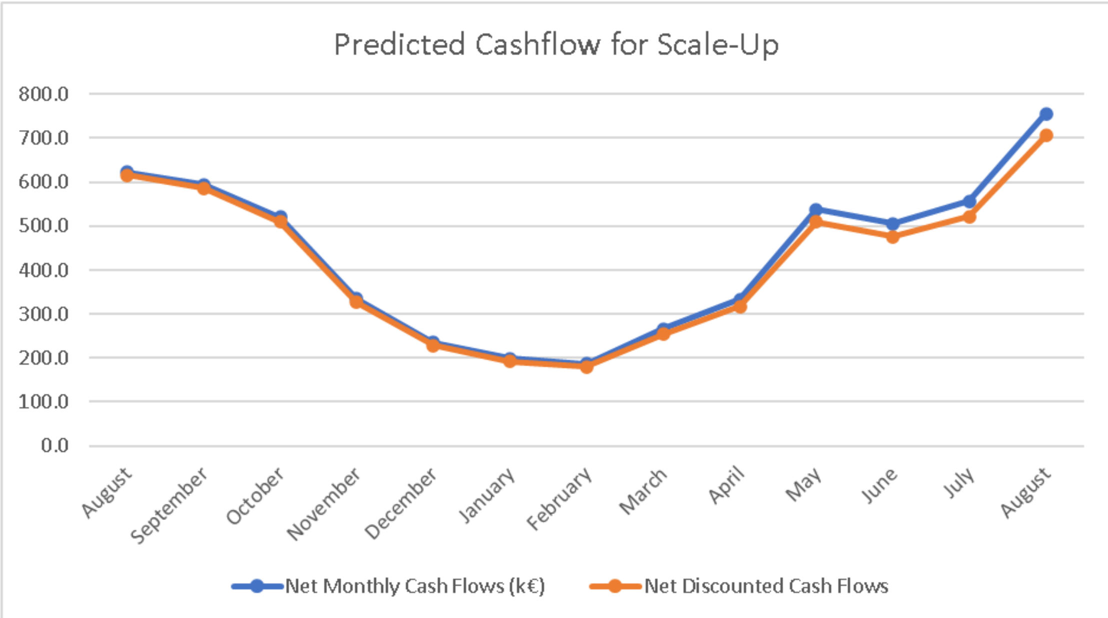


Figure 16: NPV-Cash-Flow Prediction for Scale-Up Scenario

Internal Rate of Return (IRR):

The internal rate of return (IRR), also known as the discounted cash flow rate of return, is the discount rate that makes net present value equal to zero. It is used to estimate the profitability of a potential investment. In the context of the up-scaled project for Hamburg, the computed cash flows resulted in an IRR of 2.9% (slightly higher than the 2.3% from the demo area) for the entire project duration, considering the initial investment. This indicates that the project is expected to yield a return of 2.9% over its lifespan, considering the timing and magnitude of cash inflows and outflows.

Payback Period:

The payback period (PP) calculation indicates that the break-even point, based on cumulative cash flows, will occur after approximately 12.55 months, compared to the 13.18 months of the demo project, relative to the initial investment. This means that it will take around 12.55 months for the scale-up project's cumulative cash inflows to match the initial investment, marking the point where the project starts yielding positive returns. The accompanying figure illustrates the cash flow projection over one year. Notably, there's a decline in expected cash flow after approximately 6 months, reflecting the assumption that the project duration aligns with that of the pilot project (August to August).

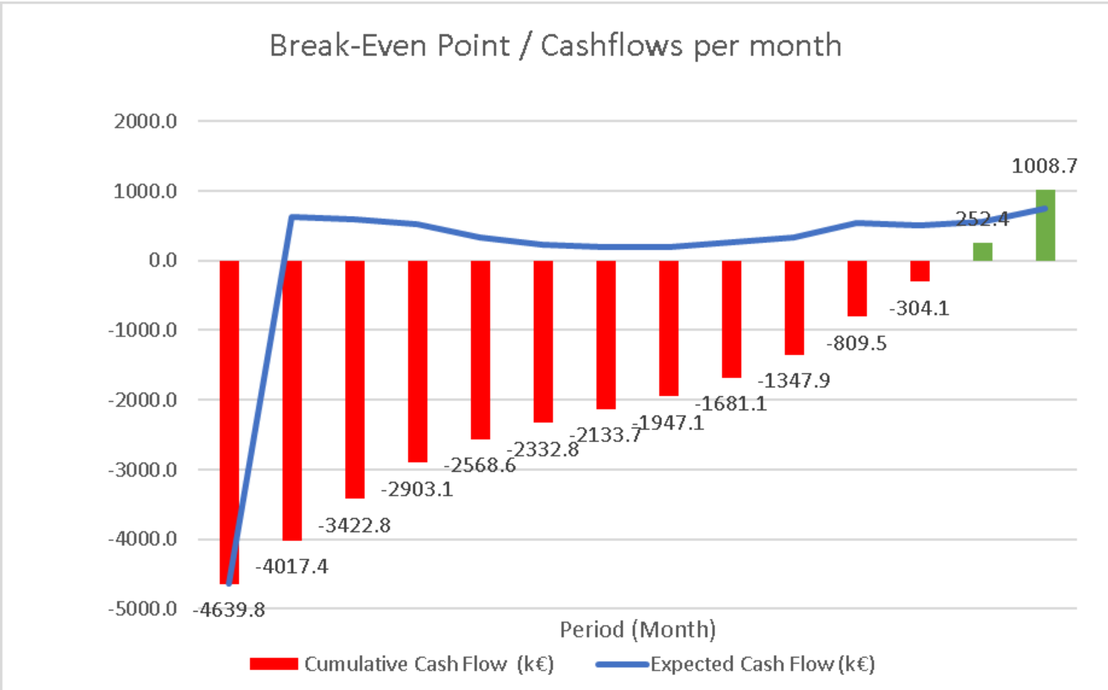


Figure 17: Break-Even Point PP Calculation Scale-Up

Considering the financial Key Performance Indicators (KPIs), an upscaled project appears significantly more financially viable, as indicated by the assumptions and computations derived from the e-scooter provider's data. This observation aligns with financial principles such as increasing returns to scale. Additionally, several factors that could further enhance financial viability haven't been factored into the calculations. These include leveraging existing e-scooters for the project, potential price reductions for large orders, and other strategic maneuvers. Incorporating these assumptions would likely bolster the financial attractiveness of the project even more in favor of the e-scooter providers, potentially amplifying returns and lowering costs, thereby enhancing overall profitability.

5 DISCUSSION

Previous assessments of the impact of shared micro-vehicles have tended to look at point-to-point journeys. Most micro-vehicle journeys are up to 2 km and take 4-6 minutes, according to the results of the demonstration project. This means that point-to-point trips will not replace typical car trips, which tend to be longer, but rather walking and cycling. In line with this, evaluations attribute little added value to shared vehicles, or even increased negative impacts (Deutsche Energie-Agentur 2021; EY 2020; Hollingsworth, Copeland and Johnson 2019; International Transport Forum 2021; Severengiz, Schelte and Bracke 2021). The demonstration activity, however, aims at shifting car trips to intermodal trips and thus uses a broader scope. The contribution of micro-mobility to public transport as part of intermodal trip chains has not been studied in detail and empirical data is lacking. The SOLUTIONSplus team developed an excel-based tool to assess the likely impact and financial implications.

The results of the demonstration project (D 1.6) show that the provision of micromobility at public transport stops has led to a limited shift from cars to intermodal journeys. Public transport benefits by expanding the area served by public transport stations. It can be expected that the positive effects will be amplified by extending the service to more public transport stations as part of the scale-up approach. Experience has shown that increased visibility and availability of services leads to increased use. This is particularly important in the outer districts where e-kick-scooters are not yet widespread. However, when expanding the use of e-kick-scooters, it is important to consider and minimise potential negative impacts. These include the negative reputation that e-kick-scooters may have among citizens due to issues such as improperly parked vehicles on the streets, illegal use on pavements, obstruction of pedestrians and cyclists, or an excessive number of vehicles in the city centre. Conflicts can arise between riders of electric scooters and cyclists on narrow cycle paths due to their different speed levels.

In addition, e-kick-scooters have negative environmental impacts due to:

- the predominant replacement of journeys that were made on foot or by bike.
- the short life span of vehicles, as well as the poor environmental balance of their production process.
- operational journeys, such as moving the vehicles or replacing batteries, that cause additional car trips - often made with combustion vehicles.

Input data were derived from a set of sources, including official statistics, mobility data reports, scientific analysis, or public transport operators. Those input data can be adapted if needed, for example when more specific and validated data are available. The tool also allows exploring the impact of factors such as GHG emissions from maintenance and relocation of e-scooters, the durability of concession agreements and public tenders.

In the scaled-up scenario we assumed that shared vehicle services are provided in the entire city area, using a similar ratio of vehicles per inhabitant as in the demonstration area. Assumed that the required ca. 9,000 e-scooters would be newly built vehicles, greenhouse gas emissions would rise by ca. 9,500t CO2e. However, if the currently operative 20,000 e-scooters would be re-distributed across the city area, an emission reduction of 15,400 tCO2e could be achieved. Compared to a total of 3.435.000t CO2e, this would amount to ca. 0,4% of transport-related greenhouse gas emissions.

The demonstration activity has indicated that shared micro-vehicles can support the decarbonisation of mobility, given that the number of new vehicles is limited and LCA-based emissions per scooter-km are at the lower end of the range of estimations. Tendering for concessions with attached provisions on vehicles and operations can encourage e-vehicle providers to become more sustainable. Low-carbon operations and extending vehicle lifetimes are crucial for achieving a positiv e-scooters, or GHG emissions embedded in the vehicles from raw material extraction and processing, and disposal.

The assessment based on data from the demonstration project and a scan of scientific studies did provide sound evidence on the impact of the demonstration project due to high margins of uncertainty in relation to indirect emissions related to the production, transport, servicing, relocating and disposal of e-kick-scooters. The assessment showed, however, that the use of shared e-kick-scooters can contribute to greenhouse gas mitigation given that vehicle lifetime exceeds the assumptions in the assessment, a relevant share of scooter-trips replaces car-trips, and servicing and re-location is done using electric vehicles rather than diesel vans. Some of the studies already assume emissions in a respective range (below 40gCO2eq/vkm), while studies at the higher end tend to focus on 1st generation e-scooters with fixed, integrated batteries and service provision with diesel vans. As detailed in the SOL+ Roadmap for Hamburg, operators and cities do have options to influence those factors, for example via e climate impact of shared micro-vehicles. Achieving higher replacement rates for private car trips require push measures, including the removal of parking spaces in inner cities, the extension of parking management, or pedestrianisation of urban space.

From a strategical perspective, it is important to understand the solution as complementary to the existing transport system in areas with less dense public transport services. The model targets those groups that tend to use private cars for their purposes and increases the attractiveness of public transport services. However, the target group for this solution is not universal, and excludes children, elderly people, and people with disabilities; e-kick-scooters are also not suited for trips related to childcare or groceries. Importantly, they cannot be considered as a solution to universally increase accessibility of public transport. To overcome these shortcomings, other new mobility services such as ride hailing, ride sharing and car sharing services could be explored to cover all use cases and user groups.

REFERENCES

1. Agora Energiewende. (2022). Die Energiewende in Deutschland: Stand der Dinge 2021. https://www.agora-energiewende.de/fileadmin/Projekte/2021/2021_11_DE-JAW2021/A-EW_247_Energiewende-Deutschland-Stand-2021_WEB.pdf
2. Bürgerschaft der Freien und Hansestadt Hamburg. (2023a). Strategie Mobilitätswende. Mitteilung des Senats an die Bürgerschaft. Drucksache 22/13670. https://www.hamburg.de/contentblob/17833704/b1a960f846cdb6ea869fb5e69ed07151/data/senatsdrucksache.pdf
3. Bürgerschaft der Freien und Hansestadt Hamburg. (2023b). Strategie Mobilitätswende. Drucksache 22/13670. hamburg.de. https://www.hamburg.de/contentblob/17833704/b1a960f846cdb6ea869fb5e69ed07151/data/senatsdrucksache.pdf
4. City of Hamburg. (2024). Neue Hamburger Klimaschutzziele. https://www.hamburg.de/klimaplan/17236396/der-hamburger-klimaplan/
5. destatis. (2023). Pkw-Dichte im Jahr 2022 erneut auf Rekordhoch. https://www.destatis.de/DE/Presse/Pressemitteilungen/2023/09/PD23_N048_46.htm
6. Deutsche Energie-Agentur. (n.d.). Tool: Vergleich Alternative Antriebe. Retrieved 10 February 2024, from https://alternativ-mobil.info/alternative-antriebe/vergleich-alternative-antriebe
7. European Commission. (n.d.). Trans-European Transport Network (TEN-T). https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t_en
8. ICCT. (2024). On the way to real-world CO2 values? (January 2024; White Paper). https://theicct.org/wp-content/uploads/2024/01/ID-76-%E2%80%93-EU-WLTP_final.pdf
9. infas, DLR, IVT, & infas 360. (2020). Mobilität in Deutschland—MiD. Regionalbericht Stadt Hamburg.
10. Kager, R., Bertolini, L., & Te Brömmelstroet, M. (2016). Characterisation of and reflections on the synergy of bicycles and public transport. Transportation Research Part A: Policy and Practice, 85, 208–219. https://doi.org/10.1016/j.tra.2016.01.015
11. Planersozietät, urbanista, & Argus. (2020). VEP HH Einblick in die Zustandsanalyse und Herausforderungen. https://www.hamburg.de/contentblob/13882148/d11dac943b130e8129053c18ef625c1f/data/16-sitzung-mobilitaetsbeirat-anl-2-vortrag-argus-zustandsanalyse-herausforderungen.pdf
12. Schünemann, J., Schelte, N., & Severengiz, S. (2022). Environmental Impact of Electric Scooter Sharing. Life Cycle Assessment of the TIER Mobility VI e-Scooter. https://production.web.cms.tier.exu.dev/uploads/TIER-VI-LCA-Publication.pdf

13. Statistisches Amt für Hamburg und Schleswig-Holstein. (2020). Bevölkerung in Hamburg am 31.21.2019. https://www.statistik-nord.de/fileadmin/Dokumente/Statistische_Berichte/bevoelkerung/A_I_S_1_j_H/A_I_S1_j19.pdf
14. Umweltbundesamt. (2023a). CO_2-Emissionen pro Kilowattstunde Strom stiegen in 2022. https://www.umweltbundesamt.de/themen/co2-emissionen-pro-kilowattstunde-strom-stiegen-in
15. Umweltbundesamt. (2023b). Projektionsbericht 2023 für Deutschland. https://www.umweltbundesamt.de/sites/default/files/medien/11740/publikationen/2023_08_21_climate_change_39_2023_projektionsbericht_2023_0.pdf

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