newTRENDs

D7.1 Focus Study report: Model developments to simulate sharing economy and new trends in transport

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Datasets and parts of the energy demand models, which are newly developed within this project, will be made open access latest at the end of the project and can then be found at https://github.com/H2020-newTRENDs. All previously existing datasets and model parts are explicitly excluded from this open access strategy.

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Executive Summary

The central aim of the 2015 Paris Agreement is to strengthen the global response to the threat of climate change by keeping the global temperature rise in this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius. To reach this ambitious goal, two central strategies have to be implemented in all countries: (i) enhancing energy efficiency (EE) and (ii) decarbonizing remaining energy supply and demand, in particular by large penetration of renewable energy sources (RES). Scenarios with different focusses and assumptions have been developed to map this development until 2050. While these scenarios present a major step forward beyond previous modeling approaches, much more progress is necessary. newTRENDs aims to contribute to this progress by identifying relevant trends and improving their modeling based on recent empirical findings. In this context, the project newTRENDs is developing the analytical basis for a "2050 Energy Efficiency Vision", taking into account New Societal Trends in energy demand modeling.

Against this background, this report focuses on advancing existing modeling approaches and, in particular, towards incorporating shared mobility in transport. It describes the development of a model that projects the demand for shared mobility in the future. The PRIMES-SHAREM Demand model enhances the modeling capabilities of the PRIMES-TREMOVE transport model by taking explicitly into account the following shared mobility options: car-service, car-pooling and car-sharing.

In order to develop the model, and in view of limited data availability, an extensive literature review on shared mobility was carried out to understand drivers and barriers for the uptake of the different options and to obtain quantitative and qualitative inputs that can help with the calibration of the model. The main findings of the literature review are that costs, distance, travel time and the purpose of the trip influence the decision making in conjunction with sociodemographic characteristics such as age, gender, household income and education. Literature also highlights specific barriers for extending the adoption of shared mobility. Most cited challenges are the higher perceived value of owning a car due to flexibility, certainty, reliability, control, compared to the incurred value of the vehicle itself, availability and accessibility of shared vehicles, lack of infrastructure, commercial and technological barriers, safety and security issues.

Several of these aspects are adopted in PRIMES-SHAREM. In particular, the model includes decision formulations across different household types, distinguished by 10 income classes and 32 different trip types within the urban and non-urban environment for private cars, car-service, car-pooling and car-sharing. Ultimately, for passengers, the key determinant is the total cost of the transport service, that includes important tangible and intangible aspects. Tangible aspects include, for instance, the purchase cost of the vehicle, and intangible aspects include, among others, the “pride” of owning a car. As such, the concept of the total cost of the transport service for each shared mobility option is embedded in PRIMES-SHAREM by quantifying actual costs, hidden costs and benefits of car ownership. Finally, another incorporated critical aspect is the value of time as it influences the passenger's decision.

To demonstrate the model, two scenarios were quantified as a case study for a single country (Italy). The Base scenario examines the development of shared mobility under the continuation of existing policies. The Decarb scenario examines the development of shared mobility in a context in which the energy system (and to a large extent road transport) achieve zero carbon emissions in road transport by 2050. The Decarb scenario without shared mobility options has lower activity than the Base scenario owing to shifts to other modes of transport (e.g., public transport). Including shared mobility options, in both scenarios, the activity of privately owned and used cars is projected to reduce over time (compared to scenario results without shared mobility options), owing to their gradual penetration. Compared to the reduction in Base, the activity reduction in Decarb is more pronounced. The lion's share across different shared mobility options is taken by car-pooling, however car-sharing increases its share notably, particularly in a decarbonization context. The use of car-pooling increases the overall occupancy rates, when compared to the parameters in scenarios without shared mobility options. Other important findings of the analysis are that higher income commuters are less likely to change their travel behavior and thus retain the use of private cars, shared mobility options are mainly used during off-peak hours, and commuting and business trips are the main trip types where shared mobility, and primarily car-pooling, is used.

It is concluded that the adoption of shared mobility options increases occupancy rates, leads progressively to the reduction of car ownership and traffic congestion and consequently enhances energy efficiency, thus contributing to long-term decarbonization.

The modeling can be improved if supported by detailed econometric analysis of the various parameters and assumptions undertaken. Furthermore, more iterations with the supply model (PRIMES-TREMOVE) will provide further useful insights, in particular on the interaction and potential substitution of public transport with shared mobility. These additional iterations will also provide quantified output on the impact of shared mobility on other indicators (e.g., CO_2 emissions, energy use).

The additional iterations with PRIMES-TREMOVE and insights thereof are planned to be carried out within the newTRENDs project. Specifically, PRIMES-SHAREM will be fully deployed to cover all EU countries and will be used to quantify the Reference and Decarbonization scenarios by an iterative linking process with PRIMES-TREMOVE. It will then feed into the macro-economic modeling carried out with GEM-E3 (D3.2), that will also quantify the macro-economic impacts of newTRENDs among them those of shared mobility.

Table of contents

List of figures

Table of tables

1. Introduction

The transportation sector accounts for about 27% of total energy-related CO_2 emissions (EPA, 2022). In the EU, transport is responsible for almost 30% of the CO_2 emissions in this region, 72% of which comes from road transport (European Parliament, 2019). An array of options is required for the sector to reduce its emissions so that it contributes adequately to decarbonization efforts. Among others, these options include fuel shifts from fossil fuels to low- or zero-carbon emitting fuels (e.g., biofuels or e-fuels), a transition to more efficient vehicle technologies (e.g., hybrid internal combustion engines, electric and fuel cell cars) and modal shifts (for example, from private modes of transport to public modes of transport). Further improvements on urban and spatial planning can promote non-motorized ways of transport and may reduce the amount of travelling by motorized means, thereby further reducing the impact of mobility on emissions.

In particular, urban mobility, being a large contributor to the sector's emissions, is a focus area, requiring a transition towards more sustainable modes. Current patterns are largely characterized by private car ownership, which leads to high energy consumption and related emissions. As such, besides the above-mentioned options, in the context of sharing economy, an emerging trend that may reduce private car ownership or use and related emissions, is that of shared mobility (e.g., Machado et al., 2018).

Shared mobility is the shared access and use of vehicles, motorcycles, bicycles, scooters for a limited time, on an on-demand basis rather than ownership (SAE 2022). The first application of sharing mobility was observed in the late 1940s with cars in Zurich, followed in 1970s in France and Amsterdam. However, its application did not last and had since disappeared (Ataç, Obrenovic, Bierlaire, 2021). In the broader sense, public transportation, taxi services and rental cars are also considered shared mobility. However, the trend as it emerges nowadays focuses on new types such as car-pooling, car-sharing, micro mobility, ride sourcing (ride-hailing) and micro transit. Thus, it is understood that shared mobility may be considered the cornerstone of the development of sustainable cities.

Shared mobility is seen as an environmentally sustainable alternative to car ownership and, therefore, a shift towards higher energy efficiency in the transport sector. This shift is largely enabled by changes in users' behavior in conjunction with digitalization. Specifically, users may choose shared mobility modes according to preferences such as ease of use, convenience, age, ticket pricing, driver's behavior, cleanliness of the car and due to tangible or intangible impacts on costs (cost of ownership, maintenance costs, travel time etc.) (Turon et al., 2020). Through the extended application of shared mobility, reduction of road congestion also acts as a driver for choosing shared mobility options (Machado et al., 2018). Factors other than sustainability concerns are found to influence the choice of shared mobility such as openness to new and innovative services (Turon et al., 2020). A counteracting trend was observed during the COVID-19 pandemic, as the value of car ownership was increased due to the fear of infection while using shared vehicles and public modes of transportation (Moody et al., 2021).

Each shared mobility option may have its own characteristics. Car-pooling, for instance, enables the users to share the journey and split the transportation cost with the other passengers (Machado et al., 2018). Dense urban regions are reported to have frequent use of car-sharing and car-pooling (Bachmann et al., 2018). According to literature, car-pool members are mostly employees who tend to drive because there is no other transport available and have more financial restrictions than car-share members (Bachmann et al., 2018). On the other hand, ride-sharing, as a service in which the car owner accepts ride requests from users in exchange for a fee (Machado et al., 2018). Ride-sharing (or car-sharing) can reduce the cost of a journey and the number of vehicles needed to cover the route and is used by highly educated young adults and high-income groups (Machado et al., 2018).

This background demonstrates that shared mobility in transport has several different options that are characterized by differences in decision criteria, cost structures and tangible or intangible parameters that ultimately affect the uptake of shared mobility. Energy systems modeling may help project the future demand for the different options. However, owing to these characteristics, shared mobility has not been represented adequately in energy systems modeling.

This report presents a model that has been developed in order to quantify shared mobility in different contexts (e.g., business-as-usual conditions, decarbonization), to demonstrate different dynamics that are observed and assess the extent to which shared mobility can contribute to decarbonization efforts.

To do so, a literature review is conducted in order to identify characteristics pertinent to different options and help delimit this emerging pattern further (section 2). The methodology implemented along with the key aspects incorporated in the model are presented in section 3. In section 4, the data used for the model development (PRIMES-SHAREM) are presented. Moreover, the scenarios developed to demonstrate the model and its results are presented in section 5, and the report concludes in section 6.

2. Literature Review

Several studies have been undertaken regarding shared mobility options. Most of the studies applied qualitative methods such as surveys and interviews. Based on the available literature, pertinent traits of different mobility options are identified and presented in the sections below.

The focus of the literature review is mainly on the factors affecting the decision-making of commuters towards the mobility option of their choice, the user characteristics and their willingness to pay for a shared mobility service. Another main subject of available literature on the topic of shared mobility has been its impact on congestion. Finally, barriers that may impede the adoption of shared mobility options solutions are also highlighted as found in literature.

2.1 Definitions of shared mobility options

Shared mobility is considered an “umbrella” term which includes a variety of alternative transportation modes, such as car-pooling, car-sharing and car-service, bike sharing etc. (Shaheen et al., 2016). This report is focusing mainly on the following shared mobility options, which, in the context of this report, are interchangeably referred to as transport modes (addressing passenger cars):

- Car-sharing: in this mobility option, private car owners or operators provide their cars for rent to other drivers on a short-term basis, which can be used by several people. This service is offered through online platforms (Machado, 2018). Car-sharing is divided in two categories, free floating and station-based (Machado, 2018). The former refers to trips where commuters begin and end the trip in different locations in designated locations (free-floating zones), while in the latter, the user should pick up and return the vehicle at the same location (Machado, 2018). The car-sharing option can be offered by car owners or by operators (companies), and the users are charged by the hour and mile (Machado, 2018).
- Car-service: refers to the traditional taxi service (or similar, e.g., Uber).
- Car-pooling: or ride-sourcing or ridesharing refers to the mobility option where the driver and owner of the car shares their vehicle with other individuals going to the same destination or to destinations on the same route (Machado, 2018). Car-pooling is widely used for business trips splitting the cost of the trip (Machado, 2018).

2.2 Literature on shared mobility

The following Table 1 summarizes the sources used in the review presented in this section. It should be mentioned that some of the sources refer to case studies in areas with different socio-economic and regional characteristics than those of EU countries. Such sources are used as indicative to draw insights on the potential reasons for differentiation across different regions.

Table 1 Sources used in the literature review

Source	Title	Methodology	Key Findings
Acheampong & Siiba (2019)	"Modeling the determinants of car-sharing adoption intentions among young adults the role of attitude, perceived benefits, travel expectations and socio-demographic fact"	Quantitative & Qualitative	Car-sharing: Alternative option to car ownership, reducing congestion and pollution & travel costs
Al-Salih & Esztergár-Kiss (2021)	"Linking Mode Choice with Travel Behavior by Using Logit Model Based on Utility Function"	Quantitative – Logit Model	Factors influencing user's choice
Becker, Ciaria, Axhausena (2017)	"Modeling free-floating car-sharing use in Switzerland: A spatial regression and conditional logit approach"	Quantitative – Spatial Regression & conditional logit analysis	car-sharing is mainly used for discretionary trips - inferior public transportation alternatives are available
Beojone and Geroliminis, 2021	"On the inefficiency of ride-sourcing services towards urban congestion"	Quantitative - agent-based simulation & trip-based MFD model	increase of the fleet of ride sharing vehicles leads to lower waiting time but also increases traffic and increasing travel time
Butler, Yigitcanlar and Paz (2021)	"Barriers and risks of Mobility-as-a-Service (MaaS) adoption in cities: A systematic review of the literature"	Qualitative	MaaS security – cyber-attacks vulnerability (highly sensitive data)
Culík, Kalašová, Synák(2021)	"Cost calculation and economic efficiency of car-pooling"	Qualitative	Car-pooling costs: fuel costs, maintenance and repairs, depreciation, insurance
De Souza Silva, de Andrade, and Alves Maia (2018)	"How does the ride-hailing systems demand affect individual transport regulation?"	Quantitative & Qualitative & Logistic Regression Model	safety factors affect more female commuters, ride-sourcing substitute taxi and public transport, acceptability is dependant on ticket price
Dowling, Maalsen, Kent (2018)	"Sharing as sociomaterial practice Car-sharing and the material reconstitution of automobility"	Qualitative	car-sharing's implications for the reconstitution of automobility.
Fagnant and Kockelman (2014)	"The travel and environmental implications of shared autonomous vehicles, using agent-based model scenarios"	Quantitative - agent-based model	Environmental & economic benefits from SAVs adoption, Cost saving: \$5-per hour travel-time and \$5-per-weekday parking costs, Barriers: technological,

Source	Title	Methodology	Key Findings
			regulatory, commercial barriers.
Fleury et al. (2017)	"What drive a corporate car-sharing acceptance? A French case study"	Qualitative	Commuters' characteristics (household income, age, education)
Garau, Masala and Pina (2016)	"Cagliari and smart urban mobility: Analysis and comparison"	Quantitative – synthetic indicators	Evaluation of policy implementation for smart cities, infrastructure investment
Greenblatt and Saxena (2015)	Autonomous taxis could greatly reduce greenhouse-gas emissions of US light-duty vehicles	Quantitative – powertrain tool	Reduction in GHG emissions for Automated Taxis by 63–82% by 2030.
Ho et al., (2018)	"Potential uptake and willingness-to-pay for Mobility as a Service (MaaS): A stated choice study"	Qualitative & Quantitative - multinominal logit model (MNL)	willing to pay $6.40 for an hour of access to car-share, with one-way car-share valued more than station-based car-share. Estimated willingness-to-pay for unlimited use of public transport is $5.90 per day which is much lower than the current daily cap
Hu et al., (2020)	"A Contrastive Study on Travel Costs of Car-Sharing and Taxis Based on GPS Trajectory Data"	Quantitative – cost comparison model	Actual costs for car-sharing and taxis, travelers take taxis for short time durations and short distances while car-sharing is used for long-distance travel. For medium-distance and medium-duration travel, the two modes compete
Lim and Taeihagh, (2018)	"Autonomous Vehicles for Smart and Sustainable Cities: An In-Depth Exploration of Privacy and Cybersecurity Implications"	Qualitative	Cybersecurity and data protection privacy issues are considered barriers for MaaS adoption
Machado et al. (2018)	"An overview of shared mobility	Quantitative	Car-sharing: reduction of frequency of car usage, reduction of car ownership, minimize the stock of cars, cost of trip awareness, social, environmental, and economic efficiency. Less expensive than acquiring and maintaining a vehicle.
McKenzie (2020)	"Urban mobility in the sharing economy: A spatiotemporal comparison of shared mobility services"	Quantitative	micro-mobility services offer faster trips than ride-hailing services, for non-urban trips

Source	Title	Methodology	Key Findings
			ride-hailing is found to be much faster.
Moody et al., (2021)	“The value of car ownership and use in the United States”	Quantitative	Cost of car ownership
Pantuso (2022)	“Exact solutions to a car-sharing pricing and relocation problem under uncertainty”	Quantitative - mixed-integer two-stage stochastic program	More demand and increased competition through price adjustments, 25% of demand satisfied leading to low availability
Shaheen & Chan (2015)	“Mobility and the sharing economy Impacts Synopsis”	Quantitative & Qualitative	new trips not previously accessible by traditional public - Car-sharing (1 vehicle replacing 9-13 vehicles) - Reduction GHG emissions Household savings 154- 435$
Standing, Standing, Biermann (2018)	“The implications of the sharing economy for transport”	Qualitative	economic and convenience Sharing mobility: solution to transport problems and congestion
Tchorek et al., (2018)	“Car-sharing in Poland – The Perspective of Operators and Cities in the First Comparative Research Study”	Qualitative	Ticket price formation and barriers (accessibility & availability)
Van Lier et al. (2014)	“How worthwhile is teleworking from a sustainable mobility perspective? The case of Brussels Capital region”	Quantitative	Quantification of marginal costs
Ye et al. (2020)	“Competition or cooperation: Relationship between car-sharing and other travel modes”	Quantitative & Qualitative	Factors affecting car-sharing adoption , car-sharing replaces public transport for long-distance non-urban trips with an average 40-50min travel time saving, taxi is more suitable for short to medium distance trips and by choosing car-sharing instead of taxis, the commuter can save up to 7.89€ per trip

Acheampong and Siiba (2019) modeled the determinants and the intentions of young adults for car-sharing adoption in Ghana by conducting a cross-sectional survey to 700 young adults (18-25 years old) and implemented a structural equation model by taking into account socio-demographic characteristics, perceived benefits and environmental attitudes. They concluded that car-sharing contributes to the reduction of congestion, pollution and minimized travel costs. They found that perceived benefits (i.e., safety, flexibility, travel cost minimization, reduction of environmental pollution) have the largest predictive effect on intentions to use car-sharing. Car-sharing can be considered as an alternative option of car-ownership as the authors concluded that 62% of the surveyed would join car-sharing the first year of its introduction.

The relationship between ride-sourcing and congestion has also been investigated for Shenzhen, China by using data from taxi trips from the megacity (20,000 taxis with global positioning system (GPS) data) and by applying an agent-based simulation with a trip-based Macroscopic Fundamental Diagram (MFD) model (Beojone and Geroliminis, 2021). Results showed that, although the increase of the fleet of ride sharing vehicles may reduce waiting time for accessing the vehicle, it also raises traffic and thus increases travel time. Additionally, it was observed that, due to congestion, ride-sharing may lose its attractiveness to public transportation.

De Souza Silva, de Andrade, and Alves Maia (2018) also investigated the ride-hailing demand in Brazil, taking into account sociodemographic and travel characteristics, derived by questionnaire in online survey (500 responses) via Google Forms (March to May 2017). Their research is focused on the Uber platform. After applying Logistic Regression model, they concluded that that cost in conjunction with safety are decisive factors for switching from public transport to car use. It was found that safety factors affected the female audience more. Moreover, the majority of ride-sourcing substitutes taxi and public transport. About 50% of ride-sharing users are former car users. Another key finding is that the acceptability of the ride-sharing service is highly correlated to the ticket price is which inversely proportional to the number of travelers.

Costs are considered a major factor for commuters' decision making. The cost estimation and the economic efficiency of car-pooling is investigated by Culík, Kalašová and Synák (2021). They quantified the car-pooling costs, which are divided into variable and fixed costs. Variable costs (fuel costs, maintenance and repair, tires, insurance) are related to operation of the vehicle and, more precisely, are dependent on travelled the distance. Another aspect that has been examined is the pricing of car-pooling. They concluded that the optional price for car-pooling is 2.5€/km, and the maximum cost efficiency is achieved when there are three passengers per ride. Moreover, it is found that the driver or the owner of the car-pooling vehicle can save up to 50% per specific ride with passengers.

Ye et al. (2020) examined the relationship between car-sharing and public transportation in Shanghai by taking into account trip characteristics provided by a database which records pick-up and drop-off station with time for each car-sharing order in conjunction with sociodemographic contributors (age, occupation, gender) of surveyed participants. They concluded some key factors affecting car-sharing such as trip purpose, travel distance, travel time and trip cost. The trip cost under car-sharing was estimated by taking into account in-vehicle-driving cost and the last-mile connecting cost multiplied by 0.6 charge rate for all car-sharing trips. Ye et al. (2020) compared car-sharing option with public transport (subway and buses) and they concluded that car-sharing replaces public transport for long-distance non-urban trips with an average 40-50 min saving on travel time. On the other hand, taxi is more suitable for short to medium distance trips and by choosing car-sharing instead of taxis, the commuter can save up to 7.89€ per trip.

Fagnant and Kockelman (2014) examined the environmental benefits of shared autonomous vehicles compared to vehicle ownership. They used an agent-based model in order to simulate the movement of travelers. Their case study approach concluded that the use of Shared Autonomous Vehicles (SAVs) leads to lower emissions and the SAV user can save $5-per hour travel-time and $5-per-weekday parking costs. However, they depict that there are technological, regulatory and commercial barriers.

Burns et al. (2013) employed queuing, network and simulation models using taxicab trip data for Manhattan to estimate and compare the cost of mobility services compared to existing taxi fees. They concluded that, in the Ann Arbor case study, the per-mile costs fall between $0.18 and $0.34 per mile when switching to SAVs. Moreover, they also concluded that SAVs are beneficial when economies of scale are reached. In Ann Arbor case study, 1000 customers and a fleet size of 18,000 vehicles may result in a wait time of less than a minute.

Concerning the characteristics of users of shared mobility solutions, Fleury et al., (2017) conducted a survey of 259 people in France, and the results revealed that the users' age is fluctuating between 30 – 39 years. Moreover, commuters have medium – high income while their education level is high, and they use shared mobility options for short distance trips. Another important conclusion is that perceived environmental friendliness has low impact on the decision making process of the commuters.

Micro-mobility has also been examined by McKenzie (2020) for Washington DC along with a comparison between existing modes of transportation and ride-hailing. The results revealed that during high traffic hours, micro-mobility services offer faster trips than ride-hailing services, while, outside of the downtown, ride-hailing is found to be much faster.

Shaheen and Chan (2015), present the benefits related to shared mobility. Cost savings, reduced emissions in conjunction with the access for new trips not previously accessible by public transport. Through the adoption of car-sharing, the monthly household savings per user in the US is estimated at approximately $154 - $435, as car-sharing users also walk, bike and carpool, often leading to decreased transportation costs. Concerning bike-sharing use, shifts are noticed from public transit to bike-sharing.

Regarding the users' willingness to pay for MaaS, Ho, et al. (2018), after conducting a survey of 252 individuals in Sydney and employing a MNL (Multinominal Logit Model), found that Sydney travellers are willing to pay $6.40 for an hour of access to car-share, with one-way car-share valued more than station-based car-share. On the other hand, it was found that users' willingness to pay for unlimited use of public transport is limited to $5.90 per day, which is lower than the current ticket price.

Machado et al. (2018), through literature review analysis, investigated the disengagement of transport use from ownership. They concluded that the adoption of shared mobility will alleviate problems caused by traffic jams and pollution by reducing the number of vehicles promoting the quality of life in cities.

Garau, Masala and Pina (2016) examined the policies and strategies promoting sustainable urban mobility in Cagliari (Italy). They used several synthetic indicators (public transport, cycle lanes, bike sharing, car-sharing, private mobility support system, public transport support system). They concluded that the administration should encourage cycling by creating real highways for bicycles and providing parking decks for them. Furthermore, the authors found that Cagliari should invest in infrastructure and, more precisely, in electric mobility capabilities.

According to Moody et al. (2021), users underestimate the actual costs of ownership. The shift towards shared mobility and the users' decision making are affected by cross-cutting attitudinal factors interplaying with socio-demographic characteristics.

Hu et al. (2020) examine car-sharing travel costs advantages from travelers' perspective while comparing car-sharing and taxis in Beijing, China. They used data derived from a GPS dataset of car-sharing orders. They employed a new model called CTTCM (car-sharing and taxi travel costs comparison model), which simulates the taxi market and its characteristics more realistically. They concluded that the traveler's decision-making is based on the proximity, weather conditions and purpose of trip. Proximity is considered in the form of walking time in the utility function, while the remaining elements are not captured explicitly but are rather included in the portion of customer. Travelers take taxis for short time periods and short distances, while car-sharing is used for long-distance travel. For medium-distance and medium-duration travel, the two modes compete and complement one another more. For short or medium time periods, car-sharing is more economical every day. The travel costs of car-sharing and taxis are also affected by peak and off-peak traffic periods. Compared with off-peak periods, it is more cost-effective for travelers to take taxis during peak traffic periods for various travel distances.

Pantuso (2022) examines the pricing decisions in conjunction with travelers' preferences concerning car-sharing. They used a mixed-integer two-stage stochastic program with integer decision variables and the L-Shaped method as an exact solution method in order to formulate the uncertainty in customer preferences. Their case study and the experiments are based on the city of Milan. It is taken into account that a portion of the preferences of each customer is unknown to the operator. The results indicate that the car-sharing operator is able to attract significantly more demand and increase competition by adjusting prices. However, with a vehicles-to-customers ratio of 1 to 12, the portion of the satisfied demand was, only approximately 25%, and thus the majority of the customers who would have used car-sharing did not have the chance to do so and users may perceive a low availability of the service.

Greenblatt and Saxena (2015) employed powertrain simulation tool Autonomie to model the energy use of hypothetical small-occupancy of battery-electric vehicles. The data used was derived by the US Federal Highway Administration providing information regarding the occupancy, and by the Energy Information Administration where projected GHG intensities of gasoline and electricity were presented. The results show a a reduction in GHG emissions for Automated Taxis by 63–82% by 2030.

Al-Salih and Esztergár-Kiss (2021) tried to link and analyze the interaction between the transport mode choice and travel behavior of the user. They used a multinomial logit model (MNL) and a nested logit model (NL) based on a utility function testing real observations in Budapest (Hungary). The utility function includes several parameters such as travel cost, travel time, the distance between activity places, and the individual characteristics to calculate the maximum utility of the mode choice. They concluded that “trip distance”, “travel time” and “activity purpose” were the most decisive factors which affect the choice of an individual.

Tchorek et al., (2018) examined the car-sharing adoption from operators’ perspective by investigating the car-sharing market in Poland. They conducted a survey and the results showed that the majority of the respondents (84%) are willing to use shared mobility services. Moreover, in their research, they provide useful information regarding the ticket pricing for car-sharing both for Germany and Poland. More precisely, they found the following:

- Average price per minute of driving (Poland): €0.13
- Average price per km of driving (Poland): €0.15
- Average price per minute of parking: €0.04
- For Germany the average price per minute of driving is fluctuating between €0.26 and €0.34

Furthermore, Tchorek et al. (2018) presented critical factors affecting the adoption of car-sharing. They concluded that the low accessibility of shared mobility and availability of parking spots exclusively dedicated to car-sharing are considered barriers that local authorities and operators should overcome.

Becker, Ciaria, Axhausena (2017) modeled free-floating car-sharing for Switzerland, as it considered not only an alternative to private cars, but also to public transportation. Through a smartphone app, free-floating car-sharing provides available vehicles and their location and reserves them for a short time prior to their rental. They used spatial regression and conditional logit analysis of original data provided by a free-floating car-sharing operator in Basel. The results indicate that station-based car-sharing relies on local public transportation access, whereas free-floating car-sharing bridges gaps in the public transportation network.

Another aspect that the review has revealed is that the MaaS demand has side barriers regarding cyber security and data protection leading to privacy issues (Lim and Taeihagh, 2018). Butler, Yigitcanlar and Paz (2021) concluded in their literature review analysis that MaaS is vulnerable to cyber-attacks due to its ability to store highly sensitive data.

Van Lier et al. (2014) have quantified marginal external costs of shared mobility and household savings that are presented below (Table 2). Further quantification of household savings from shared mobility are presented in Table 3.

Table 2 Marginal external costs of working from the office and teleworking

Categories	Headquarters (€/vkm)	Teleworking (from home) (€/vkm)
Climate Change	0.48	0.5
Noise	0.85	1.6
Accidents	2.83	3.08
Congestion	34.04	2.31

Source: Van Lier et al. (2014)

Table 3 Household savings from shared mobility

Categories	Savings	Source
Overview	$154 – 435 per member	Shaheen and Chan, 2015
Travel Time	$5 /hour travel-time	Fagnant and Kockelman, 2014
Parking Cost	$5 /weekday	Fagnant and Kockelman, 2014
Per-mile cost	$0.18 - 0.34 /mile	Ho, et al., 2018
Users' willingness to pay	$6.40 /hour of access	Ho, et al., 2018

A summary of key factors affecting the choice for shared mobility and across different options is presented in Table 4.

Table 4 Summary of key factors affecting choice of shared mobility

Key for shared mobility	Factors affecting choice
Easy to use	Driver behavior
Convenience at location	Charge / fees / cost
Reliability	Condition of the car
Cash Payment	Waiting time
Willingness to drive	Environmental friendliness

	Innovation

An overview of the key elements across the reviewed sources is presented in Table 5.

Table 5 Overview of key elements in the reviewed sources on shared mobility

Key elements	
Data sources	Surveys, questionnaires, geotagged social media, air pollution monitoring data, historical information available from European statistics, literature review
Factors influencing decision making	trip distance, travel time, activity purpose, household income, travel cost, vehicles per household, number of transfers in public transport, family size, age, gender, employment, education
Perceived costs (Actual Costs)	Travel costs, vehicle purchase cost, O&M costs, fuel costs
Non-Perceived/Hidden Costs	Availability, travel time, privacy & security
Barriers	technological, regulatory framework, commercial barriers, infrastructure, cybersecurity, user's age, willingness to pay, accessibility
Models Used	Tran's Alternative Fuel Vehicle (AFV) Model (Passenger Car market UK), Transition Lab Framework (Ground Vehicle Transportation), trip-based Macroscopic Fundamental Diagram (MFD) model, spatial regression and conditional logit model, multinomial logit model (MNL) and a nested logit model (NL), CTTCM (car-sharing and taxi travel costs comparison model), mixed-integer two-stage stochastic program and L-Shaped method, agent based simulation model, Logistic Regression model, powertrain simulation tool Autonomie

3. Method and Model Development

3.1 Model focal points

The aim of the PRIMES-SHAREM Demand model is to identify and quantify the determinants (factors and reasons) that drive the selection of different mobility options. Hence, the focal points of the model's mechanism are the dynamics that affect the decision making of the users on shared mobility options.

From the literature review (section 2), it is found that the factor that affects the commuters' choices the most is the total costs of the transport service. The total costs are divided into two main categories:

- **Private costs** (actual costs): they include purchase and operation and maintenance (O&M) of the vehicle, affecting the total cost of ownership (TCO)
- **Hidden costs and benefits**: i) social status / pride, ii) security/comfort from instant availability, iii) accessibility iii) privacy, iv) health concerns / safety and v) cost of time.

Even though there are contemporary shared mobility options like car-pooling that have lower cost per pkm when compared to private mobility options, there is no significant transition towards shared mobility options (Bachmann et al., 2018). This indicates that, today, hidden costs affect the users' choices the most compared to private costs.

This dynamic guided the focus of modeling shared mobility options to the following:

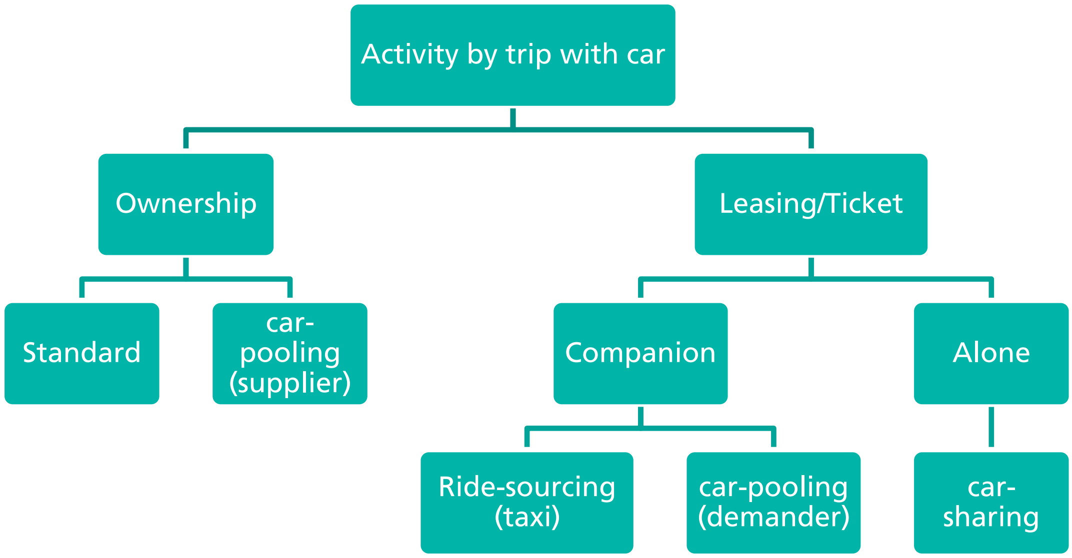
- Explicit representation of private and hidden costs
- Dynamic representation of how these costs change over time (endogenous, semi-endogenous, exogenous)

The model puts emphasis on the representation of households' and users' behavior as a utility function: utility maximization for households and passenger transport and cost minimization, taking into account budget and other constraints.

In economics, discrete choice models or qualitative choice models describe, explain and predict choices between two or more discrete alternatives, such as choosing between modes of transport or choosing amongst different mobility options, through the use of logit functions.

These are also applied in the PRIMES-SHAREM Demand model, in which the allocation of the activity of an upper level among lower level mobility options is defined through the use of logit functions. The decisive variable that is inserted in the logit function in order to calculate the shares of the lower level mobility options is the generalized cost of transport. The logit function compares the costs of the available choices of the lower level mobility options (e.g., ride-sourcing, car-pooling, car-sharing) and defines the share of every mobility option in the composition of the activity of the upper level. The above description of the mathematical structure of the PRIMES-SHAREM Demand model is summarized in Figure 1.

Figure 1 The nesting tree structure of the PRIMES-SHAREM Demand model



Source: newTRENDs - own visualization

The choice over shared mobility options depends dynamically on the following factors:

- The income of the decision maker
- The characteristics of the trip (i.e., rural/urban/motorway/metropolitan, peak/off-peak, short/long, commuting/business/non-working)
- Environmental considerations (for the development of different scenarios with different decarbonization policies)
- Total costs: actual and hidden costs

The logit functions are used to represent heterogeneity of preferences of individual consumers, as described by the equation below:

Equation 1

$$xsh_{cy,iup,ilow,hdcl,cls,tr,t} = \frac{mat_{cy,iup,ilow,hdcl,cls,tr,t} \cdot e^{-w_{cy,iup,tr,t} \cdot \frac{\text{P\_GCTRPpkm}_{cy,hdcl,cls,tr,ilow,t}}{av\_pg_{cy}}}}{\sum_{jlow \in map(iup,jlow)} mat_{cy,iup,jlow,hdcl,cls,tr,t} \cdot e^{-w_{cy,iup,tr,t} \cdot \frac{\text{P\_GCTRPpkm}_{cy,hdcl,cls,tr,jlow,t}}{av\_pg_{cy}}}}, \text{ for every } ilow \in map(iup, ilow)$$

where,

$mat_{cy,iup,ilow,hdcl,cls,tr,t}$: Maturities of Nested logit tree (iup,ilow) by class and trip purpose

$w_{cy,iup,tr,t}$: Exponent of Nested logit tree (iup) by class and trip purpose

av_pg_{cy}: Scaling parameter - average generalized cost of trips in Euros per pkm

The PRIMES-SHAREM Demand model includes further heterogeneity by distinguishing between households with different preferences in the choice of mobility option. Thus, for a better representation of household behavior, the model includes ten different household types distinguished by their income (from very low to very high income). Each household will maximize its utility and, given its preferences, such as the various technological options/costs, prices and budget, it allocates its demand for transport services to the different options in order to meet its budget constraint.

The aggregate pkm per trip purpose (based on PRIMES-TREMOVE), is allocated to different households either through fixed coefficients (representing base year demand) or through elasticity-driven choices. For a better representation, the model uses five distance classes for every trip purpose and household type. The classes are distinguished based on the distance of the trip (from shortest trip to longest). Every distance class has a different frequency. Table 6 depicts the different classes and frequencies respectively, based on own assumptions.

Table 6 Histogram of distance classes

	A1	A2	A3	A4	A5
Distance difference of each distance class compared to typical trip distance	-70%	-25%	+16%	+60%	+115%
Frequency	8.39%	37.26%	41.78%	10.84%	1.72%

Source: PRIMES-SHAREM Demand model (own assumptions)

Problem formulation

The PRIMES-SHAREM Demand model consists of two parts: supply and demand. The equilibrium comes when the two parts balance, that is, when the supply for passenger kilometers is equal to the demand for passenger kilometers for every trip.

On the demand side of the model, the decision maker (household) chooses between five different options for each trip. The choices can be categorized in three groups: self-service (private car owners operating their own vehicle), service from a company (car-service or car-sharing) and service from another car owner (car-pooling).

The convergence of supply and demand is achieved through an iterative method between the two models: PRIMES-SHAREM and PRIMES-TREMOVE. The model of

PRIMES-TREMOVE is appropriately expanded to include the part of the suppliers of private cars, car-services and car-sharing companies.

The PRIMES-SHAREM Demand Model calculates the demand for passenger kilometers for each of the five mobility options through a nested logit function and a constraint which ensures that the total demand of car-pooling for every trip is equal to the total supply of car-pooling.

The PRIMES-SHAREM Demand Model is written as a mixed complementarity problem. Therefore, the above constraint is split into two inequalities with two dual variables, the first one from the side of the supplier (Supply>Demand dualS>0), and the second one from the demander side (Supply<Demand dualD>0).

As a result, in the case that a household chooses car-pooling as demander and the total demand for car-pooling is more than the supply for car-pooling, then the dual variable in this trip is dualD>0 in order to balance demand to supply. In the case that there are not enough suppliers for car-pooling, the cost to use the car-pooling service (i.e. car-pooling ticket) increases so that demand and supply reach an equilibrium. This means that the demander has to pay more than the initial ticket price. The opposite happens when the demand is lower than the supply. In such cases, when the household chooses car-pooling as supplier and the total demand for car-pooling is lower than the supply for car-pooling, then in this trip the dual variable is dualS>0 in order to balance demand with supply. Therefore, in the case that there are not enough demanders for car-pooling, the agreed ticket price decreases and the household prefers not to choose car-pooling as supplier.

3.2 Costs

The Costs used in order to develop the model are divided into Actual Costs, Hidden Costs (see also section 3.1) and Benefits. The Costs that are taken into consideration are based on the findings and conclusions of the literature review (Section 2).

Actual costs

Actual Costs incorporate capital costs (the purchase of the car) which change over time because of technical progress, variable non-fuel costs, fixed costs, fuel costs which derive from exogenous price projections, carbon pricing and the agreed ticket price (where applicable), which is estimated by taking into account current market conditions and by applying general assumptions presented in section 4.

Hidden costs

As discussed in section 3.1, the role of hidden costs is crucial to generalized cost formation, affecting users' choice. The main hidden cost component that is considered in the model is the value of time. The value of time is defined as the monetary valuation of the total time invested in mobility-related activities. In order to calculate the total time of each trip, it is assumed that each trip includes five main attributes (see also section 4.5):

- the travel time of the trip which is equal to the inverse of the average speed
- the access time which is the time spent getting to and leaving from a car
- the waiting time which is the time spent waiting for the service
- the search time which is the time spent searching for a parking space
- the delay time which is the time spent for accessing the mobility service

All mobility options include the cost of time.

Another hidden costs that are taken into account is security, as literature notes that safety and security are considered major factors influencing the passengers' decision-making regarding shared mobility. The hidden costs of security are calculated as the extra amount that the user pays for the security and depend on the travel time. Households are differentiated depending on their income, assuming an income elasticity. Hidden costs of security are described by the following equation:

$$HiddenSecurityPerpkm_{h,cls,trip,t} = \frac{HiddenSecurity_{base}}{averageSpeed_{cls,trip,t} \cdot occrt_{trip,t}} \cdot \left(\frac{Income_{h,t}}{Income_{base}}\right)^{elasSecurity}$$

The car-pooling supplier faces an extra hidden cost for every trip that depends on the extra time/effort for the preparation/cleaning of the vehicle. Again, households are differentiated according to their income based on an income elasticity. Hidden costs of extra time and effort in preparation and cleaning of the vehicle are described as follows:

$$HiddenExtraPerpkm_{h,cls,trip,t} = \frac{HiddenExtra_{base}}{averageMileage_t} \cdot \left(\frac{Income_{h,t}}{Income_{base}}\right)^{elasExtra}$$

Hidden benefits

Benefits are divided into the benefit of ownership and the benefits of driving a car.

The benefit of ownership is the benefit that a household assumes by owning a vehicle, the prestige it may offer and the flexibility that is provided by owning a car. The benefit of ownership is calculated as a value provided to the household and depends positively on income elasticity. It is described by the following relationship:

$$BenefitOwnPerpkm_{h,t} = \frac{BenefitOwn_{base}}{averageMileage_t} \cdot \left(\frac{Income_{h,t}}{Income_{base}}\right)^{elasOwn}$$

The mobility options that include such benefit are the private car options: standard (std) and car-pooling as supplier (sup). In these two cases the decision maker is the owner of the car.

The benefit of driving a car is calculated as a value provided to the household when driving the car, and it depends on the travel time of each trip. In this case, the benefit of driving a car also correlates positively with income, based on an income elasticity. So, the following relationship is assumed:

$$BenefitDrivePerpkm_{h,cls,trip,t} = \frac{BenefitDrive_{base}}{averageSpeed_{cls,trip,t} \cdot occrt_{trip,t}} \cdot \left(\frac{Income_{h,t}}{Income_{base}}\right)^{elasDrive}$$

The mobility options that include this benefit are the driving options: standard (std), car-pooling as supplier (sup) and car-sharing. In these three cases, the decision maker is the driver of the car.

Not all cost and benefit components are applicable to all mobility options. An overview is provided in Table 7 that summarizes the costs and benefits applicable to each mobility option.

The sections that follow present the trip cost formulations for different shared mobility options.

Table 7 Costs and benefits of each mobility option

	Suppliers	Private Car		Car-service	Car-pooling	Car-sharing
	Mobility options	Std	Sup	Serv	Pool	carserv
Actual costs	Fuel Costs	+	+			+
	Capital Costs	+	+			
	Variable non-fuel Costs	+	+	+	+	+
	Fixed Costs	+	+			
	Agreed Fee (ticket value)		-	+	+	+
Hidden costs and benefits	Cost of Time	+	+	+	+	+
	Travel time	+	+	+	+	+
	Access time	+	+	+	+	+
	Wait time		+	+	+	+
	Search time	+	+		+	+
	Delay time		+	+	+	+
	Hidden Cost of security		+	+	+	
	Extra Hidden Cost		+			
	Benefit of owning	-	-			
	Benefit of driving	-	-			-

3.2.1 Trip cost: Ownership/standard occupancy rate

The cost for the commuter to use their own car (i=std) is provided by the following equation:

Equation 2

$$P\_GCTRPpkm_{cy,hdcl,cls,tr,i,t} = fuelcostOfTripPerPkmD_{cy,cls,tr,I,t} + fxcostOfTripPerPkmD_{cy,i_{private},t} + varNoFuelcostOfTripPerPkmD_{cy,tr,I,t} + capcostOfTripPerPkmD_{cy,tr,i_{private},t} + timeValueOfTripPerPkmCls_{cy,hdcl,cls,tr,I,t} - BenefitDrivePerPkm_{cy,hdcl,cls,tr,i,t} - BenefitOwnPerPkm_{cy,hdcl,cls,tr,i,t}$$

In case of car ownership, the costs depend on:

Actual costs:

- Fuel cost (fuelcostOfTripPerPkmD$_{cy,cls,tr,i,t}$
- Fixed Cost (fxcostOfTripPerPkmD$_{cy,i_{private},t}$)
- Variable non-fuel costs (varNoFuelcostOfTripPerPkmD$_{cy,tr,i,t}$)
- Cost of purchase – Capital cost (capcostOfTripPerPkmD$_{cy,tr,i_{private},t}$)

Hidden costs and benefits:

- Cost of time (timeValueOfTripPerPkmCls$_{cy,hdcl,cls,tr,i,t}$)
- Benefit of traveling with your car (BenefitDrivePerPkm$_{cy,hdcl,cls,tr,i,t}$)
- Benefit of owning a car (BenefitOwnPerPkm$_{cy,hdcl,cls,tr,i,t}$)

3.2.2 Trip cost: Ownership/car-pooling (as a supplier)

In this case, the owner of the car is also considered the supplier (i=sup) and thus, the cost per trip is provided by the following equation:

Equation 3

$$P\_GCTRPpkm_{cy,hdcl,cls,tr,i,t} = fuelcostOfTripPerPkmD_{cy,cls,tr,i,t} + fxcostOfTripPerPkmD_{cy,i_{private},t} + varNoFuelcostOfTripPerPkmD_{cy,tr,i,t} + capcostOfTripPerPkmD_{cy,tr,i_{private},t} + timeValueOfTripPerPkmCls_{cy,hdcl,cls,tr,i,t} + hiddenCostOfTripPerPkm_{cy,hdcl,cls,tr,sup,t} - BenefitDrivePerPkm_{cy,hdcl,cls,tr,i,t} - BenefitOwnPerPkm_{cy,hdcl,cls,tr,i,t} - \left[\frac{ticketValueOfTripPerPkmCls_{cy,hdcl,cls,tr,pool,t} * occrtid_{cy,\,tr,pool,t}}{occrtis_{cy,\,tr,i,t}}\right]$$

From the equation above (2), the cost of the trip is dependent on the following:

Actual costs:

- Fuel cost (fuelcostOfTripPerPkmD$_{cy,cls,tr,i,t}$)
- Fixed costs (fxcostOfTripPerPkmD$_{cy,i_{private},t}$)
- Cost of purchase (capcostOfTripPerPkmD$_{cy,tr,i_{private},t}$)
- Variable non-fuel costs (varNoFuelcostOfTripPerPkmD$_{cy,tr,i,t}$)

- Agreed fee ($ticketValueOfTripPerPkmCls_{cy,hdcl,cls,tr,pool,t}$)

Hidden costs and benefits:

- Cost of time ($timeValueOfTripPerPkmCls_{cy,hdcl,cls,tr,i,t}$)
- Hidden cost ($hiddenCostOfTripPerPkm_{cy,hdcl,cls,tr,sup,t}$)
- Benefit of traveling with your car ($BenefitDrivePerPkm_{cy,hdcl,cls,tr,i,t}$)
- Benefit of owning a car ($BenefitOwnPerPkm_{cy,hdcl,cls,tr,i,t}$)

3.2.3 Trip cost: service car

The cost for the commuter of using a service car is given by the following equation (i= serv):

Equation 4

$$P\_GCTRPpkm_{cy,hdcl,cls,tr,i,t} = varNoFuelcostOfTripPerPkmD_{cy,tr,i,t} + ticketValueOfTripPerPkmCls_{cy,hdcl,cls,tr,i,t} + hiddenCostOfTripPerPkm_{cy,hdcl,cls,tr,sup,t} + timeValueOfTripPerPkmCls_{cy,hdcl,cls,tr,i,t}$$

In this case, the trip cost depends on:

Actual costs:

- Variable non-fuel costs ($varNoFuelcostOfTripPerPkmD_{cy,tr,i,t}$)
- Agreed fee ($ticketValueOfTripPerPkmCls_{cy,hdcl,cls,tr,pool,t}$)

Hidden costs:

- Cost of time ($timeValueOfTripPerPkmCls_{cy,hdcl,cls,tr,i,t}$)
- Hidden cost ($hiddenCostOfTripPerPkm_{cy,hdcl,cls,tr,sup,t}$)

3.2.4 Trip cost: car-pooling

The cost of a trip for the commuter, when choosing the car-pooling option (as a demander), can be estimated by the following equation:

Equation 5

$$P\_GCTRPpkm_{cy,hdcl,cls,tr,i,t} = varNoFuelcostOfTripPerPkmD_{cy,tr,i,t} + ticketValueOfTripPerPkmCls_{cy,hdcl,cls,tr,pool,t} + hiddenCostOfTripPerPkm_{cy,hdcl,cls,tr,sup,t} + timeValueOfTripPerPkmCls_{cy,hdcl,cls,tr,i,t}$$

In this case, the trip cost depends on:

Actual costs:

- Variable non-fuel costs ($varNoFuelcostOfTripPerPkmD_{cy,tr,i,t}$)
- Agreed fee ($ticketValueOfTripPerPkmCls_{cy,hdcl,cls,tr,pool,t}$)

Hidden costs:

- Cost of time ($timeValueOfTripPerPkmCls_{cy,hdcl,cls,tr,i,t}$)
- Hidden costs ($hiddenCostOfTripPerPkm_{cy,hdcl,cls,tr,sup,t}$)

3.2.5 Trip cost: car-sharing

The cost of a trip for the user, when choosing the car-sharing option, is provided by the following equation:

Equation 6

$$P\_GCTRPpkm_{cy,hdcl,cls,tr,i,t} = \\ + fuelcostOfTripPerPkmD_{cy,cls,tr,i,t} + varNoFuelcostOfTripPerPkmD_{cy,tr,i,t} \\ + ticketValueOfTripPerPkmCls_{cy,hdcl,cls,tr,pool,t}\ timeValueOfTripPerPkmCls_{cy,hdcl,cls,tr,i,t} \\ - BenefitDrivePerPkm_{cy,hdcl,cls,tr,i,t}$$

In this case the trip cost depends on:

Actual costs:

- Variable non-fuel costs ($varNoFuelcostOfTripPerPkmD_{cy,tr,i,t}$)
- Fuel cost (fuelcostOfTripPerPkmDcy,cls,tr,i, t)
- Agreed fee – ticket price ($ticketValueOfTripPerPkmCls_{cy,hdcl,cls,tr,pool,t}$)

Hidden costs and benefits:

- Cost of time ($timeValueOfTripPerPkmCls_{cy,hdcl,cls,tr,i,t}$)
- Hidden costs (security) (hiddenCostOfTripPerPkmcy,hdcl,cls,tr,i,t)
- Benefit of traveling with the car ($BenefitDrivePerPkm_{cy,hdcl,cls,tr,i,t}$)

3.3 Ticket pricing

The model assumes that there are three types of mobility suppliers: private car, car-service and car-sharing. Car owners can use their car for self-service or as a supplier of a car-pooling service for an agreed fee. So in the model there are three mobility services options that include a ticket: car-pooling, car-service and car-sharing.

The final ticket price includes a minimum fee and depends on two factors: the total travel time and the total distance of the trip. As such, there are three different charges: (i) the minimum charge ($ticketEurosmin_{i,t}$), (ii) the charge per hour ($ticketEurosperhour_{i,t}$), and (iii) the charge per vehicle kilometer ($ticketEurosperVkm_{i,t}$), as described by the following formulation:

Equation 7

$$ticket_{i,trip,cls,t} = \min\left(ticketEurosmin_{i,t}, ticketEurosperVkm_{i,t} \cdot TripVkm_{i,trip,cls,t} + ticketEurosperhour_{i,t} \cdot TripTime_{i,trip,cls,t} \right)$$

All the above charges change in time in order to replicate the total cost of supplier plus a markup.

3.4 Model linkages

The PRIMES-SHAREM model is a sub-model and an expansion of the demand module of PRIMES-TREMOVE.

PRIMES-TREMOVE calculates the total demand for passenger km per trip purpose. The PRIMES-SHAREM model allocates this demand in four different mobility options (from the supplier’s side): private car (standard), car-service, car-pooling and car-sharing.

The inputs that PRIMES-SHAREM uses from PRIMES-TREMOVE are: (i) the total demand for passenger km per country and trip purpose, and (ii) all the actual costs per mobility option (capital costs, fuel costs, variable non-fuel costs, fixed costs, taxes). PRIMES-SHAREM also uses inputs from the GEM-E3 model on income of households and the labour cost of car-service.

The outputs of PRIMES-SHAREM that are used by PRIMES-TREMOVE are: the demand for passenger km per mobility option for every trip purpose and the occupancy ratio per mobility option for every trip purpose. The PRIMES-TREMOVE is modified in order to include two more suppliers beyond the private cars, namely car-service and car-sharing.

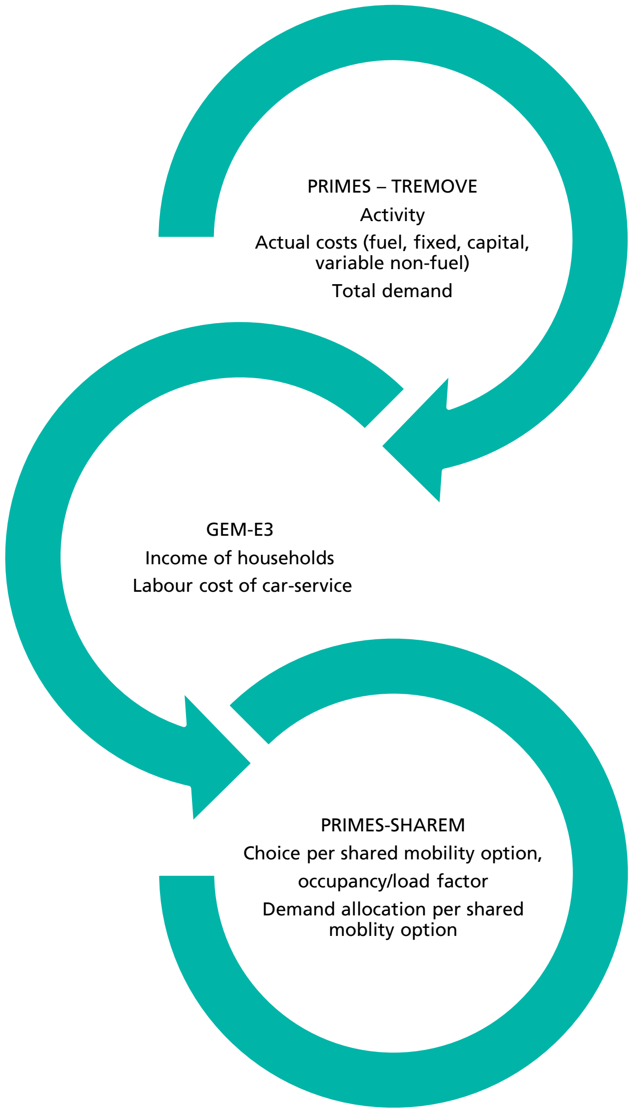
PRIMES-TREMOVE satisfies the demand for vehicle km, calculates the new investments for every supply mode and technology, and optimizes the operation of the supply modes in order to satisfy the demand. As such, actual costs of fuel consumption and stock of all supply modes are calculated by the PRIMES-TREMOVE model. Moreover, the PRIMES-TREMOVE model calculates the impact on energy and GHG emissions.

A secondary effect of the iterations between these two models is the change of activity between private and public transport. The shift of activity is due to the reallocation of car mobility options owing to the change of the average general price of car options in the upper level of the decision tree of PRIMES-TREMOVE demand module. The total demand for transport activity of PRIMES-TREMOVE is also affected by the household demand modules that provide to PRIMES-TREMOVE inputs for work-from-home and shopping-from-home that in turn directly affect the demand for passenger kilometers.

The outputs of PRIMES-SHAREM to GEM-E3 are the average occupancy rate of private transport and the shares of the mobility options in the three categories private car, car-service and car-sharing. The GEM-E3 model calculates the impact on the economic system from adopting shared mobility options (e.g., impact on disposable income, demand for vehicles, rebound effect).

Figure 2 below presents the linkages between PRIMES-SHAREM and PRIMES-TREMOVE and GEM-E3.

Figure 2 Model linkages



Source: newTRENDs - own visualization

4. Input Data Preparation

Intensive data collection was conducted to explore main characteristics of shared mobility and obtain insight into factors that affect the user choices. The collected data are secondary as they are derived from research, reports and statistical sources, and are complemented also from the PRIMES-TREMOVE model databases. Information was searched at a country level, however, most data was found for Italy and Germany. These countries formed the basis for the PRIMES-SHAREM Demand model development.

The PRIMES-SHAREM Demand model is calibrated to 2015 historical data. The stock of vehicles per transport mode (private cars, car-service, car-sharing), annual mileage and occupancy rate are key parameters and are used in the phase of model calibration. The outcome of this calibration is adjustments in the annual mileage, split in total activity per transport mode by trips and purpose and adjustments in occupancy rates.

An overview of the main data sources used is presented in section 4.8.

4.1 Activity and stock of cars

Two main parameters that are used for the model development are the activity of passenger cars (Gpkm) and the stock of registered cars (in thousands vehicles). These parameters were derived from EUROSTAT's POCKETBOOK (European Commission 2021).

The fleet of different transport modes (cars) that is used in the model is distinguished in three categories: private cars (for own use and car-pooling), car-service (taxis) and car-sharing.

The stock of private cars, used also for car-pooling, is assumed to be the difference between the total stock of passenger cars and the sum of shared mobility options, namely car-service and car-sharing. The total stock of passenger cars is provided by the EUROSTAT POCKETBOOK for each year per country (European Commission 2021). It is concluded that the average share of private cars in the total passenger cars is estimated to be 99.7% in 2015.

As far as the car-sharing stock is concerned, in the absence of data from EUROSTAT, we rely on data from Statista (2022) and Fluctuo (2022)[1]. Statista (2022) provides information for 8 EU countries at a country level (AT, DE, DK, ES, FR, IT, NL, SE,). Fluctuo (2022) provides data at the city level (several EU cities) but not at the country level. Therefore, the data was combined in order to populate the dataset of passenger cars used in car-sharing for all EU countries, based on the following data-driven assumptions:

1 Fluctuo is a company which provides data regarding shared mobility so as to accelerate the growth of shared mobility

- For AT, DE, DK, ES, FR, IT, NL and SE, the share of shared mobility in total registered cars fluctuates between 0.02% and 0.04%, taking into account the data provided for the aforementioned countries according to Statista (2002).
- For the remaining EU countries, a share of 0.03% of shared mobility to total registered cars was assumed, which was derived based on Fluctuo (2022).

Data availability on the stock of taxis (car-service) per country is also limited. The total number of taxis is derived from a case study of the European Commission (2016) that provides data provided for 5 countries (DE, ES, FR, SE and PL)[2]. In order to estimate the number of taxis (car-service) in each country, the following assumptions have been made:

- GDP per capita (Trading Economics, 2021) was used as indicator in order to order the countries and to approximate the share of taxis in total car registrations.
- 6 classes of countries were defined based on the EC case study and then the share of taxis in the total number of registered cars for each country was estimated.
- The remaining countries were ordered based on their GDP per capita. EU countries were split into 6 categories, based on the point above, and the share of taxis for the countries was applied to each country. Then, this share was multiplied with each country's total car registrations to find the total number of taxis per EU country.

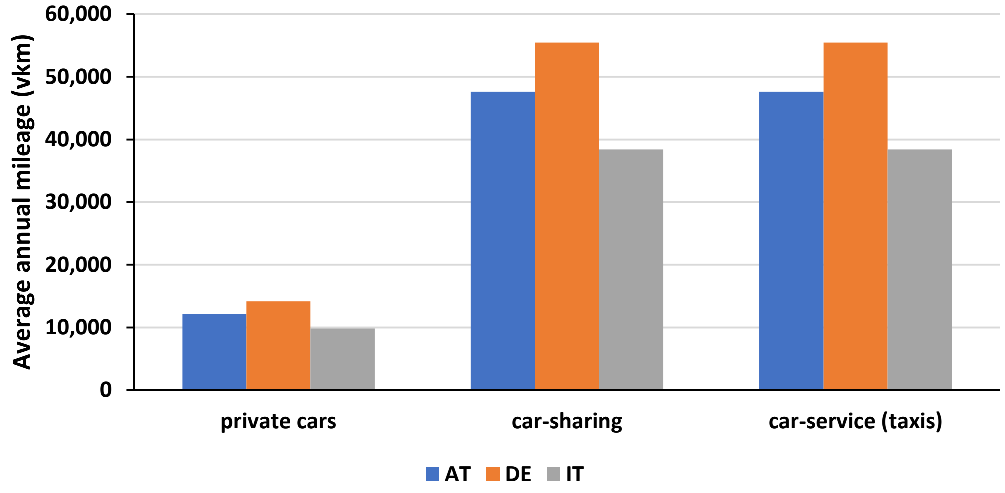
4.2 Annual mileage

Mileage is a second critical data point for which data is required to develop the model. For private cars, it is estimated by dividing activity and stock. Both stock and activity for private cars is also provided by EUROSTAT POCKETBOOK (European Commission 2021).

Mileage of taxis (car-service), was estimated based on Asamer et al. (2016). This work provided data for taxis in Austria and concluded that taxis travel approximately 136 km per day, while their operation is estimated on average 350 days per year, adding up to 47,600 km annually. On that basis, and in order to estimate the annual mileage for remaining countries, several assumptions have been made. It was assumed that the annual mileage of taxis is equal to the percentage of the mileage of private cars in each country, multiplied by Austria's annual taxis mileage (see section 4 for AT, IT and DE).

2 Though not in the EU27, also data for the UK were collected based on Gov.uk (2021).

Figure 3 Average annual mileage per mobility option



Source: newTRENDs - own calculation

Regarding the annual mileage of cars used in shared mobility, it is assumed that it is equal to that of taxis mileage due to limitation of data.

4.3 Trips classification

Another parameter used for the development of the model is trip classes. The model distinguishes 32 trip classes (Table 8). More precisely, passenger trips are divided into three main categories regarding the purpose of the trip: non-working, commuting and business trips.

Each trip category is further distinguished in 5 classes characterized by different frequency and distance, depicting behavioral changes during the year and a probability distribution for each class. The second level of the tree decomposes mobility by region and road types: urban areas (distinguished into metropolitan and other urban areas) and non-urban areas (distinguished into short distance and long-distance areas). Regarding the non-urban distinction, both short distance and long distance are also distinguished between motorway and other non-urban.

Last but not least, the next level of the tree decomposes the time of the day when the trip takes place and relates to congestion: peak and off-peak hours. The classification of traffic time was derived from PRIMES-TREMOVE model in a less aggregated form as no differentiation regarding the size of the cars (small and big cars) was taken into account (E3-Modeling 2018).

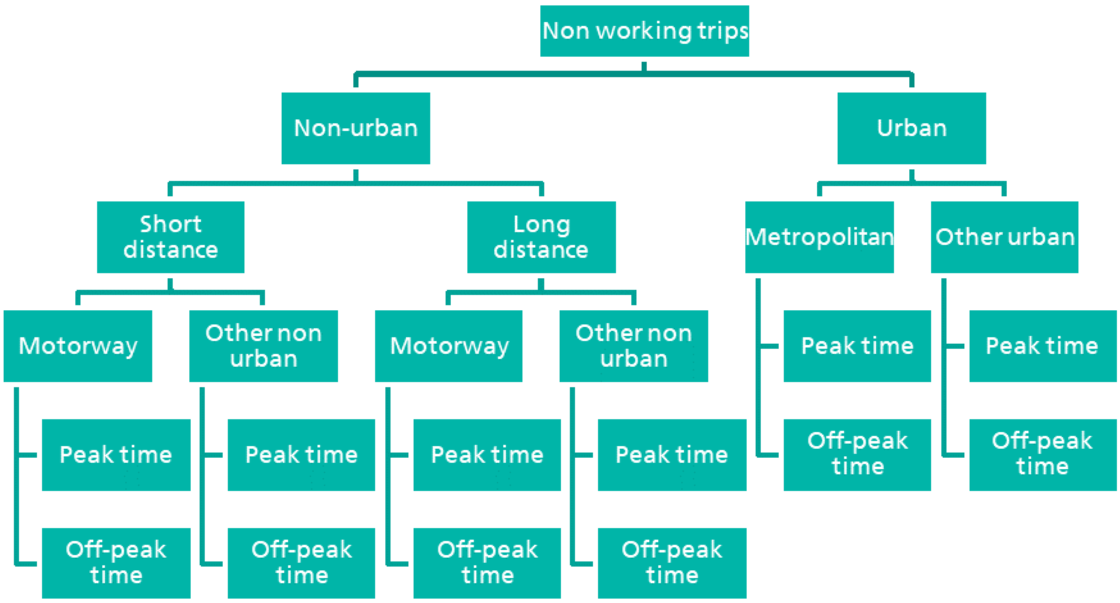
Table 8 Trips classification

Trips classification in PRIMES-SHAREM	
Trip 1	Non-working/Non-urban/short distance /motorway/peak time trip
Trip 2	Non-working/Non-urban/short distance /other non-urban/peak time trip
Trip 3	Non-working/Non-urban/short distance /motorway/off-peak time trip
Trip 4	Non-working/Non-urban/short distance /other non-urban /off-peak time trip
Trip 5	Non-working/Non-Urban/long distance /motorway/peak time trip
Trip 6	Non-working/Non-Urban/long distance /other non-urban /peak time trip
Trip 7	Non-working/Non-Urban/long distance /motorway/off-peak time trip
Trip 8	Non-working/Non-Urban/long distance /other non-urban /off-peak time trip
Trip 9	Commuting/Non-Urban/long distance /motorway/peak time trip
Trip 10	Commuting/Non-Urban/long distance /other non-urban /peak time trip
Trip 11	Commuting/Non-Urban/long distance /motorway/off-peak time trip
Trip 12	Commuting/Non-Urban/long distance /other non-urban /off-peak time trip
Trip 13	Non-working/Urban/Metropolitan /urban/peak time trip
Trip 14	Non-working/Urban/Metropolitan /urban/off-peak time trip
Trip 15	Non-working/Urban/Other urban /urban/peak time trip
Trip 16	Non-working/Urban/Other urban /urban/off-peak time trip
Trip 17	Commuting/Urban/Metropolitan /urban/peak time trip
Trip 18	Commuting/Urban/Metropolitan /urban/off-peak time trip
Trip 19	Commuting/Urban/Other urban /urban/peak time trip
Trip 20	Commuting/Urban/Other urban /urban/off-peak time trip
Trip 21	Business/Non-Urban/short distance /motorway/peak time trip
Trip 22	Business/Non-Urban/short distance /other non-urban /peak time trip
Trip 23	Business/Non-Urban/short distance /motorway/off-peak time trip
Trip 24	Business/Non-Urban/short distance /other non-urban /off-peak time trip
Trip 25	Business/Non-Urban/long distance /motorway/peak time trip
Trip 26	Business/Non-Urban/long distance /other non-urban /peak time trip
Trip 27	Business/Non-Urban/long distance /motorway/off-peak time trip
Trip 28	Business/Non-Urban/long distance /other non-urban /off-peak time trip

Trips classification in PRIMES-SHAREM	
Trip 29	Business/Urban/Metropolitan /urban/peak time trip
Trip 30	Business/Urban/Metropolitan /urban/off-peak time trip
Trip 31	Business/Urban/Other urban /urban/peak time trip
Trip 32	Business/Urban/Other urban /urban/off-peak time trip

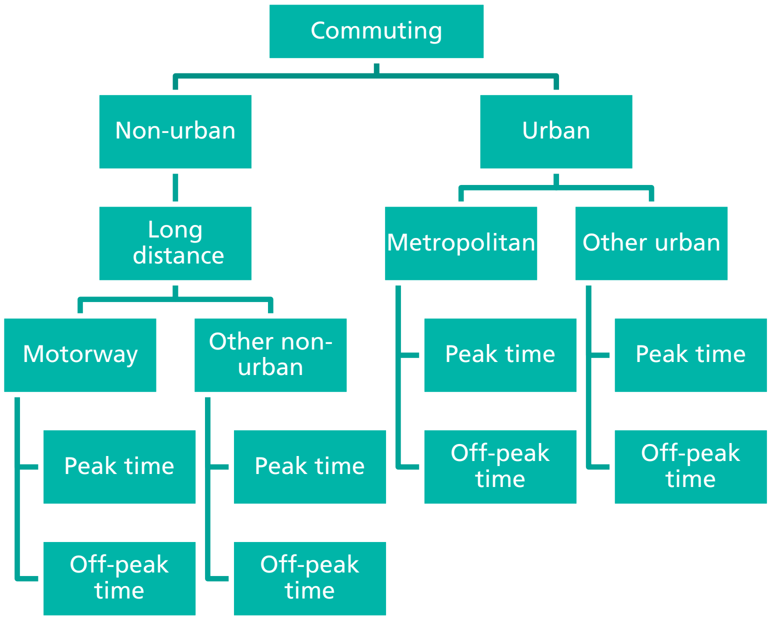
Figure 4 to Figure 6 depict the decomposition of the trips in the classes based on the trip purpose.

Figure 4 Non-working trips decomposition



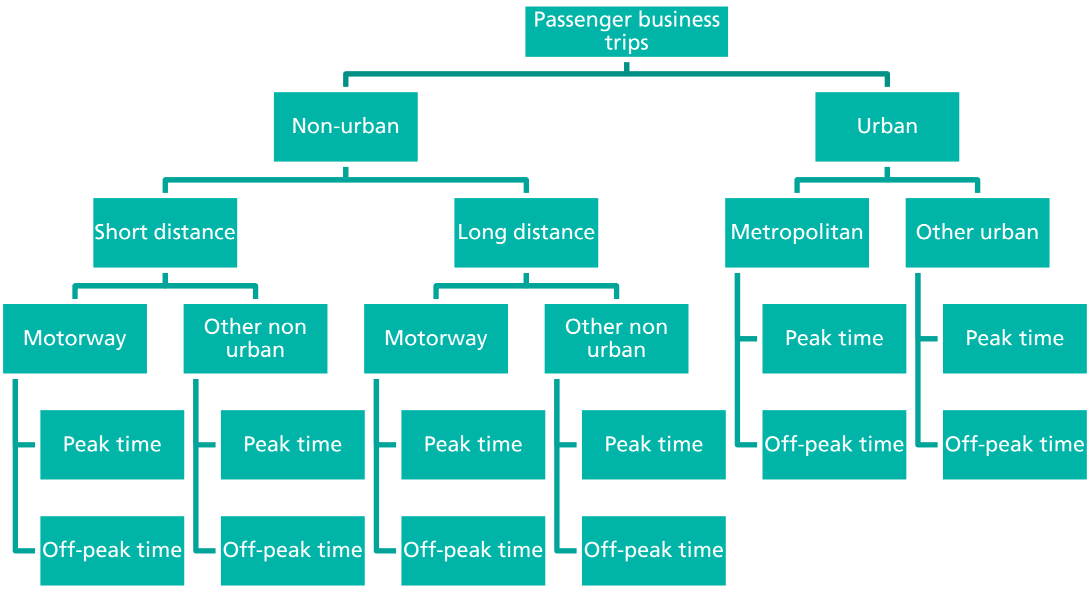
Source: newTRENDs - own visualization

Figure 5 Commuting trips decomposition



Source: newTRENDs - own visualization

Figure 6 Business trips decomposition



Source: newTRENDs - own visualization

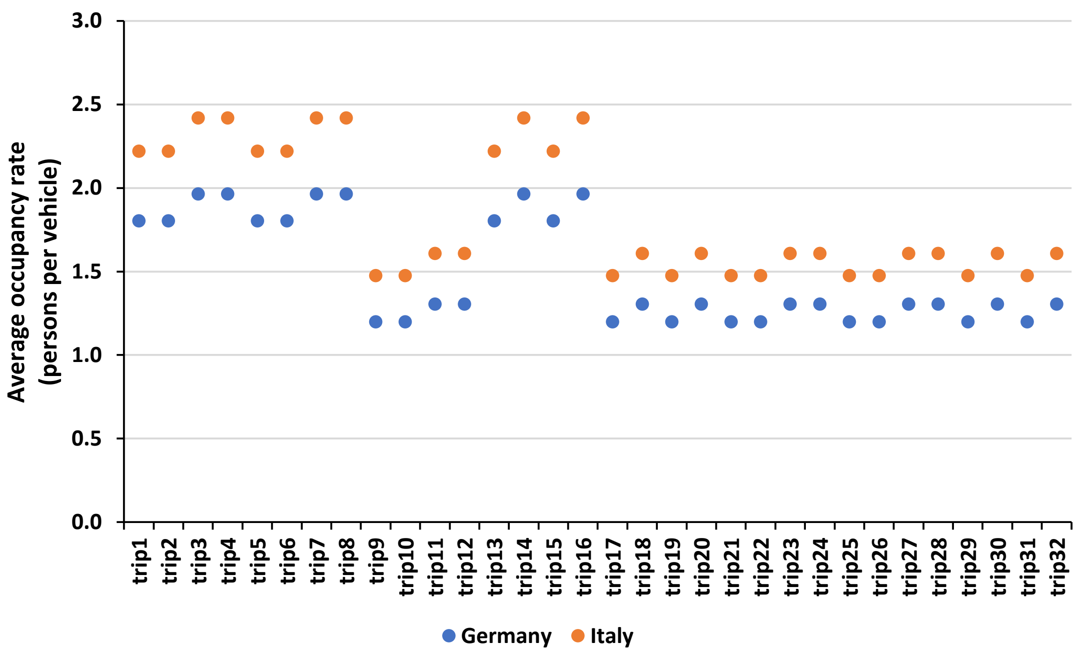
4.4 Occupancy rate and average speed

The occupancy rate of different options plays a crucial role in the decision-making process of the shared mobility user. The occupancy rate is defined as the average number of passengers in the vehicle when on duty. The average occupancy rate for private cars was derived from the PRIMES–TREMOVE model (E3-Modeling 2018).

It was assumed that the occupancy rate for both car-sharing vehicles and car-service options (e.g., taxis) is the same as that of private cars (e.g., as shown in Figure 7 per trip type). On the other hand, the occupancy rate of car-pooling would be higher as was estimated based on the occupancy rate provided by Bosch et al. (2017) for Switzerland (derived by a Swiss transportation micro-census). More precisely, according to Bosch et al. (2017), the occupancy rate of car-pooling options differs during peak and off-peak periods. The occupancy rate during off-peak hours is higher compared to peak hours. Furthermore, higher occupancy rates are also observed in non-working trips during off-peak hours. Such differentiation was applied to all trips (see section 4.3) by taking into account the average occupancy rate per trip. The occupancy rate for the remaining countries is calculated by employing the same methodology. Figure 7 shows the estimated the average occupancy rates per trip type for Italy and Germany.

Average speed (km/h) is also classified per trips over time. It is observed that, through the years, the average speed is increased. Average speed data were derived from the PRIMES-TREMOVE model and are not differentiated per shared mobility option (i.e., it is assumed that all shared mobility options have the same average speed) (E3-Modeling 2018).

Figure 7 Average occupancy rates per trip without shared mobility options



Source: newTRENDs - own calculation

4.5 Distance and trips

Another parameter taken into account is distance (km per trip). Information on distance per trip was provided by the PRIMES-TREMOVE model (E3-Modeling 2018). Note that while the route per trip type (distinguishing between e.g., urban and rural trips) is the same across all shared mobility options, they differ in elements that characterize each shared mobility option such as the detour required or the time spent for parking. These elements comprise the cost of time that is incorporated in the decision making (see section 4.6).

In order to estimate the total distance and the time of the trip, five additional attributes were incorporated into each trip affecting the travel time and the cost of the trip. More precisely, the five attributes are the following:

- The actual travel time of trip
- Access time refers to the time spent getting to and leaving from a car
- Wait time is time while the commuter is waiting for the transport mode
- Search time is the time spent in searching for a parking space
- Delay time is the time spent for accessing the mobility service

The trips and time categories are also divided into the following categories:

- Private car (standard – travelling alone/ with family members)
- Car-pooling (supplier side)
- Car-service (taxis)
- Car-pooling (demander side)
- Car-sharing

The distances per trip for all categories (i.e., private cars – own use, car-service, car-pooling and car-sharing) are the same. The distances range from 27 km (lower limit) for urban short-distance trips to 342 km (upper limit) for non-urban motorway trips.

Additional costs relate to the additional distance that the shared mobility option covers due to detours in order to pick-up a passenger. For car-pooling, the detour distance is on average 2000 m. Other actions are translated into additional time relating with waiting time, delay, access time and search time.

4.6 Time

According to literature, a factor which plays a crucial role in the users' decision making is time. Data on this aspect is based on previous research.

An assumption has been made to estimate the amount of time for each trip. We use as reference the approach taken in PRIMES-TREMOVE for passenger cars, where the volume of time is calculated based on the average speed and the sum of the travelled km and the extra time needed for other related actions (access time, search time, wait time, delay time). The same approach is applied on each shared mobility category.

Value of time

The data used in order to estimate the value of time were derived by Wardman et al. (2016). This paper provides data for car commuting and business trips with cars and takes into account parameters such as access time, wait time, search time and late arrival. The value of time for the parameters was calculated by considering multipliers for congestion, urban or inter urban trips etc. These time-related multipliers were implied by their meta-model. After applying the aforementioned factors and multipliers, the value of time (€/hr) per type of trip is provided and summarized the following Table 9.

Table 9 Value of time (€/hr) per trip type

Trips	Purpose	Peak / Off-peak	car	access	wait	search	delay
trip1	*Non-working*	PK	10.93	17.39	16.40	18.70	33.46
trip2	*Non-working*	PK	10.93	17.39	16.40	18.70	33.46
trip3	*Non-working*	OP	7.70	12.24	11.55	13.17	23.56
trip4	*Non-working*	OP	7.70	12.24	11.55	13.17	23.56
trip5	*Non-working*	PK	10.93	17.39	16.40	18.70	33.46
trip6	*Non-working*	PK	10.93	17.39	16.40	18.70	33.46
trip7	*Non-working*	OP	7.70	12.24	11.55	13.17	23.56
trip8	*Non-working*	OP	7.70	12.24	11.55	13.17	23.56
trip9	*Commuting*	PK	7.92	12.59	11.88	13.54	24.24
trip10	*Commuting*	PK	7.92	12.59	11.88	13.54	24.24
trip11	*Commuting*	OP	7.70	12.24	11.55	13.17	23.56
trip12	*Commuting*	OP	7.70	12.24	11.55	13.17	23.56
trip13	*Non-working*	PK	7.92	12.59	11.88	13.54	24.24
trip14	*Non-working*	OP	5.57	8.86	8.36	9.52	17.04
trip15	*Non-working*	PK	7.92	12.59	11.88	13.54	24.24
trip16	*Non-working*	OP	5.57	8.86	8.36	9.52	17.04
trip17	*Commuting*	PK	8.99	14.29	13.49	15.37	27.51
trip18	*Commuting*	OP	6.33	10.06	9.50	10.82	19.37
trip19	*Commuting*	PK	8.99	14.29	13.49	15.37	27.51
trip20	*Commuting*	OP	6.33	10.06	9.50	10.82	19.37
trip21	*Business*	PK	24.13	38.36	36.19	41.26	73.82
trip22	*Business*	PK	24.13	38.36	36.19	41.26	73.82
trip23	*Business*	OP	16.99	27.01	25.49	29.05	51.99
trip24	*Business*	OP	16.99	27.01	25.49	29.05	51.99
trip25	*Business*	PK	24.13	38.36	36.19	41.26	73.82
trip26	*Business*	PK	24.13	38.36	36.19	41.26	73.82

Trips	Purpose	Peak / Off-peak	car	access	wait	search	delay
trip27	*Business*	OP	16.99	27.01	25.49	29.05	51.99
trip28	*Business*	OP	16.99	27.01	25.49	29.05	51.99
trip29	*Business*	PK	17.47	27.78	26.21	29.87	53.46
trip30	*Business*	OP	12.29	19.54	18.44	21.02	37.61
trip31	*Business*	PK	17.47	27.78	26.21	29.87	53.46
trip32	*Business*	OP	12.29	19.54	18.44	21.02	37.61

4.7 Pricing

Cost is one of the main parameters which determine the usage of shared mobility options. The purchase cost, operating costs, fixed and variable costs of a vehicle are provided by the PRIMES-TREMOVE model.

However, the cost regarding the shared mobility options (car-service, car-pooling and car-sharing) is calculated based also on ticket price[3]. The ticket price depends on the traveled distance and time and is provided per vkm (i.e., the charge is on a vkm basis). The ticket price paid by each passenger depends on the number of passengers per vehicle (i.e., ticket price per vkm divided by the number of passengers (occupancy rate)).

The data used for the estimation of the car-service fare were provided by Numbeo (2022) and is equal to day time charge per km. Car-pooling cost for users per km was derived by Bosch et al. (2017) and was calculated based on taxi pricing. Regarding car-sharing, the cost per km is also provided in Bosch et al. (2017) adjusted to car-pooling pricing. Pricing (per km) remains constant for all trips.

Two pricing elements for the tickets are incorporated: the minimum ticket price and the ticket price per hour.

The minimum price of ticket per trip is used (also constant for all trip classes). Specifically:

- Car-service (taxis): the minimum price is equal to the initial/starting charge (base tariff), which is estimated approximately to 2.5 € (Numbeo, 2022).
- Car-pooling and car-sharing: the minimum price is also equal to base tariff reported by Bosch et al. (2017). However, the base tariff was adjusted based on car-service pricing.

The ticket price per hour is also used in the model. In order to estimate the aforementioned variable, the following were taken into consideration:

3 Car-service is based on a ticket price, car-pooling from the demander side is based on a ticket price, and from the supplier side it is the same as private car costs minus the received ticket price, car-sharing includes both a ticket price and operating costs.

- Car-service (taxis): the ticket price is calculated based on the hourly income of the car-service driver income (€/h). The data used were provided by the ERI Institute (2022).
- Car-pooling and car-sharing: it is assumed that the ticket prices per hour for both car-pooling and car-sharing are equal refer to average transportation cost per hour. The data is based on Bosch et al. (2017).

4.8 Overview of sources and data

Table 10 below presents the sources and the data that were used in the development of the model.

Table 10 Data sources used in model development

Source	Year (data)	Data used	Data / Parameter
Eurostat (2022)	2016	Total registered Cars	“Passenger cars, by age”
Eurostat (2022)	2016	Population	“Population on 1 January by NUTS 2 region“
PRIMES-TREMOVE (in E3-Modeling 2018)	2015	Mileage	“Ratio: activity & stock”
Fluctuo (2022)	2015	Car-sharing (IT, DE, DK, FR)	“European Shared Mobility Index”
Statista (2022)	2015	Car-sharing (DE, FR,NL, IT, AT, SE, ES)	“Car-sharing vehicles in Europe by country 2014”
European Commission (2016)	2015	Nr. of taxis (DE, ES, FR, SE, PL)	“Study on passenger transport by taxi, hire car with driver and ridesharing in the EU”
Gov.uk (2022)	2015	Nr. of taxis (UK)	“Taxis, private hire vehicles and their drivers“
Trading Economic (2022)	2015	GDP per capita	“Taxis, private hire vehicles and their drivers”
Asamer et al. (2016)	2015	Taxis annual mileage (AT) km per day and operating days per year	"Optimizing charging station locations for urban taxi providers"
ERI Institute (2022)	2015	Taxi driver income (IT)	“Taxi driver salary – Italy”
Numbeo (2022)	2015	Taxi tariffs (IT)	“Taxi fares in Italy”

Source	Year (data)	Data used	Data / Parameter
Bösch, et., al. 2018	2015	Car-sharing & car-pooling (CZ): ticket price/ hour Occupancy rate cost per km the minimum price	"Cost-based analysis of autonomous mobility services"
Wardman et al. (2016)	2015	value of time, access time, wait time, search time and late arrival	"Values of travel time in Europe: Review and meta-analysis"

4.9 Limitations of input data

The model developed is based mainly on data provided by statistical sources, reports and previous studies. However, there was limited data regarding the stock of cars for each category (car-sharing, car-pooling and car-services). So several assumptions have been made (presented across the sub-chapters of section 4) in order to approximate the number of cars in each shared mobility category.

5. Results

5.1 Scenario description

In order to demonstrate how the PRIMES-SHAREM Demand model captures shared mobility and to investigate further the potential role of shared mobility in contributing to emissions reduction, we quantify and compare two scenarios.

The “Base” scenario is aligned with the EU Reference 2020 scenario, which has been developed on the basis of latest statistical information (e.g., on stock of cars, transport activity based on EUROSTAT, ACEA, APIA, INSEE), and it includes existing (end of 2019) policies of the EU and its Member States. In particular, for the transport sector among others, it includes CO_2 standards for cars and vans, the Clean Vehicles Directive, the Directive on Alternative Fuels Infrastructure, the Renewable Energy Directive (RED II), the Fuel Quality Directive, and the TEN-T regulations. The scenario achieves 15% and 36% emission reduction in transport in 2030 and 2050 compared to 2015, respectively.

The “Decarb” scenario is based on an intensification of existing policies and the implementation of new or additional policies towards the decarbonization of the transport sector. This scenario implements a carbon tax in transport, more stringent CO_2 standards for cars and vans, and, in particular, zero emissions for new car and van sales from 2040 onwards, as well as other policies (e.g., increased availability of alternative fuel infrastructure). The scenario achieves 26% emissions reduction in 2030 and about 95% emissions reduction in road transport in 2050, compared to 2015.

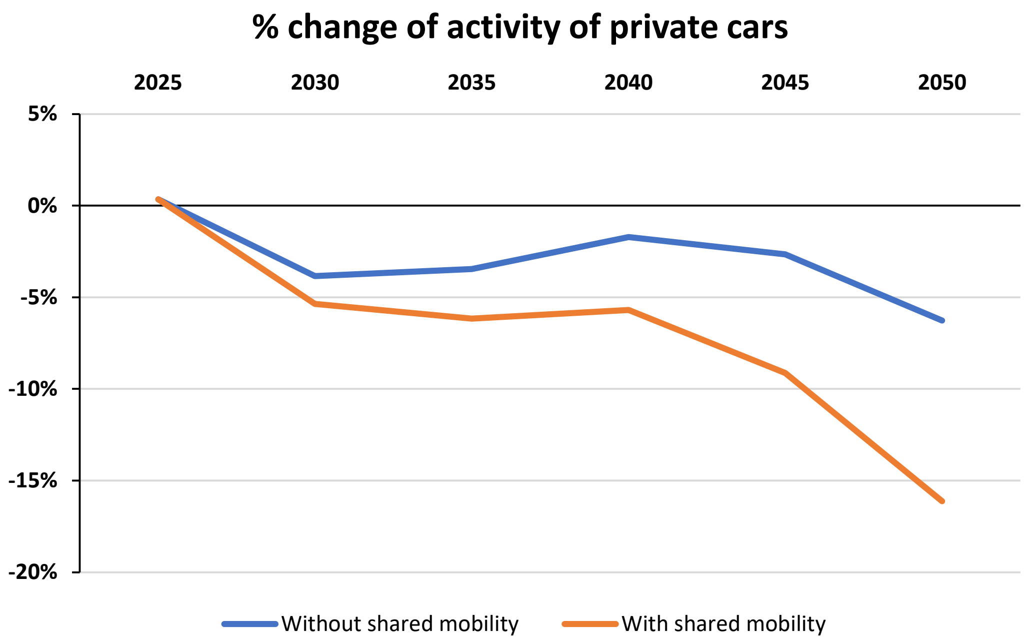
5.2 Scenario results

We present results for Italy, for a number of indicators that quantify the impact of shared mobility in road transport. The indicators are activity of passenger cars, average occupancy rate, generalized cost and distinction of demand for shared mobility across different households and trips. These key outputs, as derived by PRIMES-SHAREM, serve as an input to the PRIMES-TREMOVE transport model (see also section 3.4). PRIMES-SHAREM is demonstrated for the case of Italy. Finally, the function of the model and the impact of shared mobility on the above-mentioned indicators is derived by comparing the same scenarios (Base and Decarb), including and excluding shared mobility options.

5.2.1 Activity of private cars

Figure 8 presents the change in activity of passenger cars between Base and Decarb with and without shared mobility. It is shown that, in the Decarb scenario, the activity of private cars reduces owing to decarbonization efforts (e.g., modal shifts) compared to the base scenario (“Without shared mobility”; Figure 8). The reduction is about 4% in 2030 and 6% in 2050. However, when incorporating shared mobility options the activity of private cars reduces further ("With shared mobility", Figure 8), i.e., by 5% in 2030 and 16% in 2050. As such, it can be concluded that shared mobility has an impact on the activity of private cars, reducing it and thus contributing to decarbonization efforts. It should be mentioned that total activity (in passenger-kilometers) between the scenarios with and without shared mobility options is the same. However, due to the higher share of shared mobility options that have higher occupancy ratio (as shown in section 5.2.2), the total travelled vehicle-kilometers are lower leading to less emissions in the scenarios with shared mobility options.

Figure 8 Percentage change of passenger car activity in the Base and in the Decarb scenario with and without shared mobility

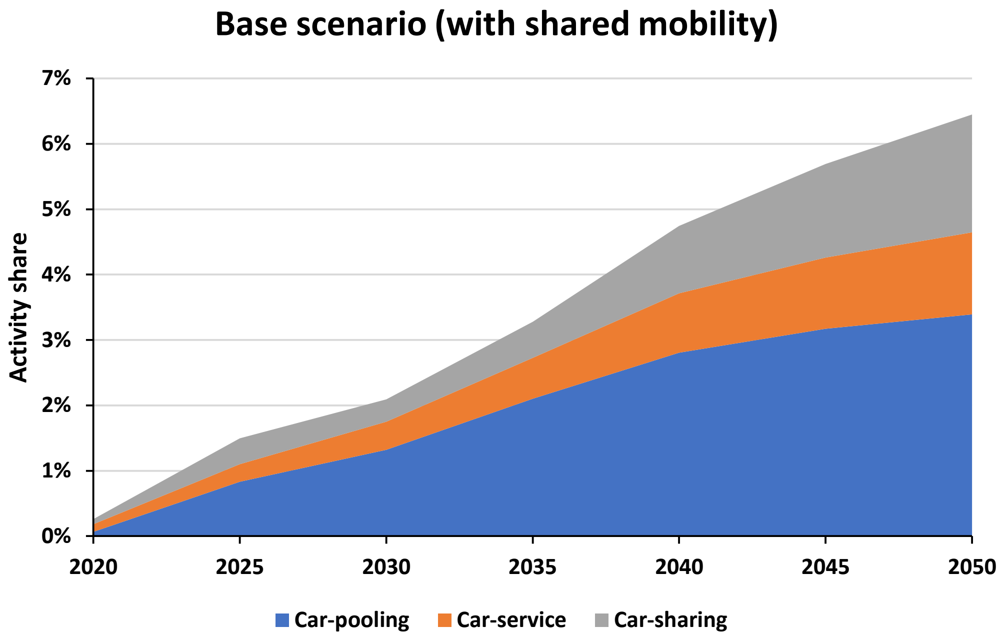


Source: newTRENDs - own calculation

Base Scenario (with shared mobility)

Figure 9 shows the contribution of different shared mobility options in the Base scenario. In 2030, car-pooling is the predominant shared mobility option with about 63% activity across all shared mobility options, followed by car-service (21%) and car-sharing (16%). By 2050, car-sharing increases its share to 28% to the detriment of car-pooling and car-service. From about 15 Gpkm in 2030, the activity of shared mobility reaches more than 50 Gpkm in 2050 (see also Table 11).

Figure 9 Contribution of shared mobility options to total passenger cars activity in the Base scenario



Source: newTRENDs - own calculation

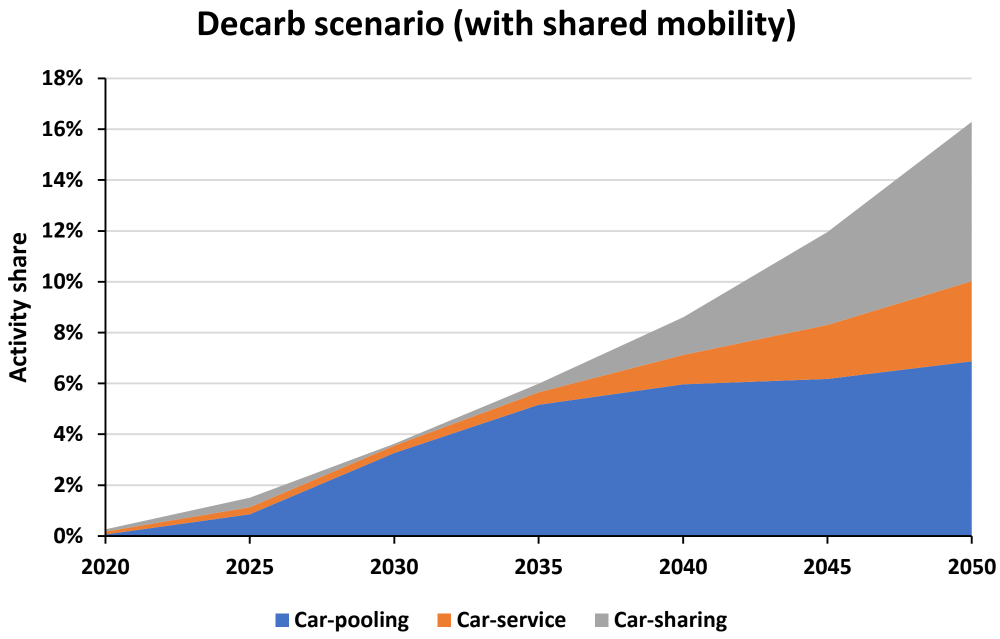
Decarb scenario (with shared mobility)

Figure 10 shows the contribution of different shared mobility options in the Decarb scenario. As mentioned above, the activity of private cars in the Decarb scenario reduces compared to Base (Figure 8). As shared mobility options are taken up, their activity increases notably and in terms of relative contribution to passenger transport by car (Figure 10) and in terms of the absolute volume of activity compared to Base (Table 11).

In 2030, car-pooling is the predominant shared mobility option with more than 90% activity across all shared mobility options, followed by car-service (8%) and car-sharing (2%). By 2050, car-sharing increases its share to 38% to the detriment of car-pooling and car-service. From about 25 Gpkm in 2030, the activity of shared mobility reaches almost 120 Gpkm in 2050 (see also Table 11).

From the above results, it can be concluded that, in the Decarb scenario context, the contribution of shared mobility increases, thereby further reducing the activity of private passenger cars. Car-pooling is the first choice for shared mobility, especially in the shorter-term. While car-pooling remains the first choice for shared mobility also in the long-term, a gradual shift in user preferences is observed owing to user acceptance and reduced prices; car-sharing increases its market share notably, especially in the decarbonization context, and becomes a key preference for shared mobility as well. Car-service, on the other hand, remains the last choice of shared mobility service, owing to its higher ticket price.

Figure 10 Contribution of shared mobility options to total passenger cars activity in the Decarb scenario



Source: newTRENDs - own calculation

Table 11 Activity in passenger cars in Gpkm in the Base and in the Decarb scenario

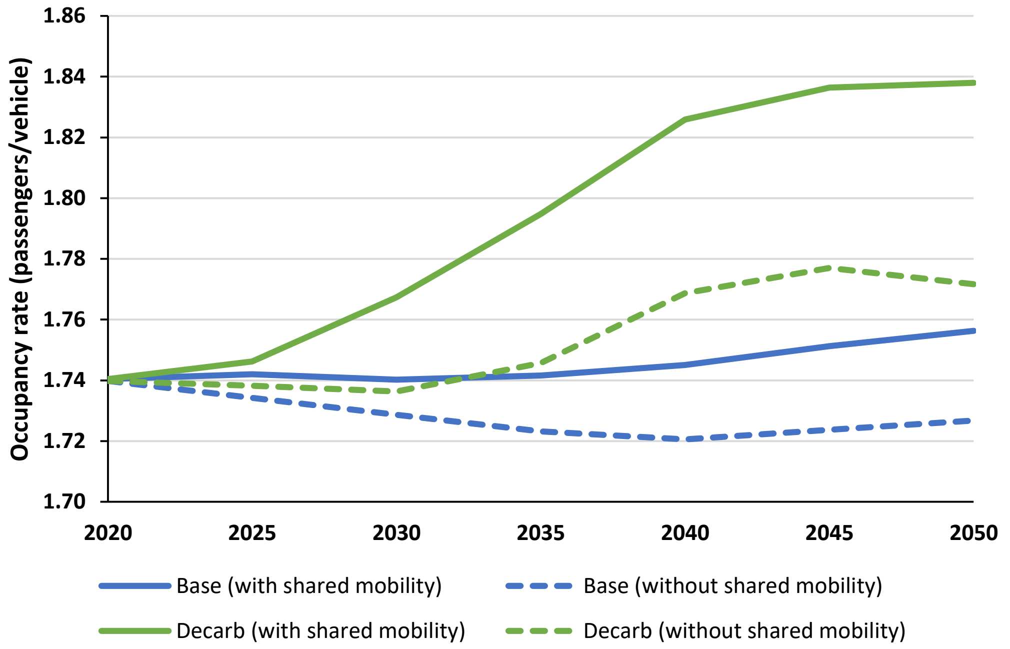
		Base		Decarb		Decarb vs Base	
Mobility options	**2020**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**
Total	511	712	785	684	736	-3.8%	-6.2%
Private cars	501	697	735	659	616	-5.4%	-16.1%
Car-pooling	0.39	9.37	26.62	22.35	50.61	138%	90.8%
Car-service	0.58	3.05	9.86	1.92	23.19	-36.9%	135%
Car-sharing	0.40	2.44	14.16	0.57	46.12	-76.4%	226%

5.2.2 Occupancy rate

A direct impact of shared mobility can be observed on occupancy rates. Figure 11 shows that the occupancy rates increase in the Decarb scenario compared to the Base scenario. What is, however, of importance is that shared mobility options increase the average occupancy rates of vehicles most notably in the Decarb scenario. In particular, in the Decarb scenario, the increase in average occupancy owing to shared mobility doubles compared to the Base (i.e. from 1%

to 2% in 2030, and from 2% to 4% in 2050). It should be noted that in the Base context shared mobility options reverse the trend of occupancy rates, that tend to reduce with time when shared mobility services are not available. The average occupancy rate increases mainly due to the contribution of car-pooling due to its higher market share and its higher occupancy factor compared to the other shared mobility services.

Figure 11 Average occupancy rate of cars across scenarios with and without shared mobility options

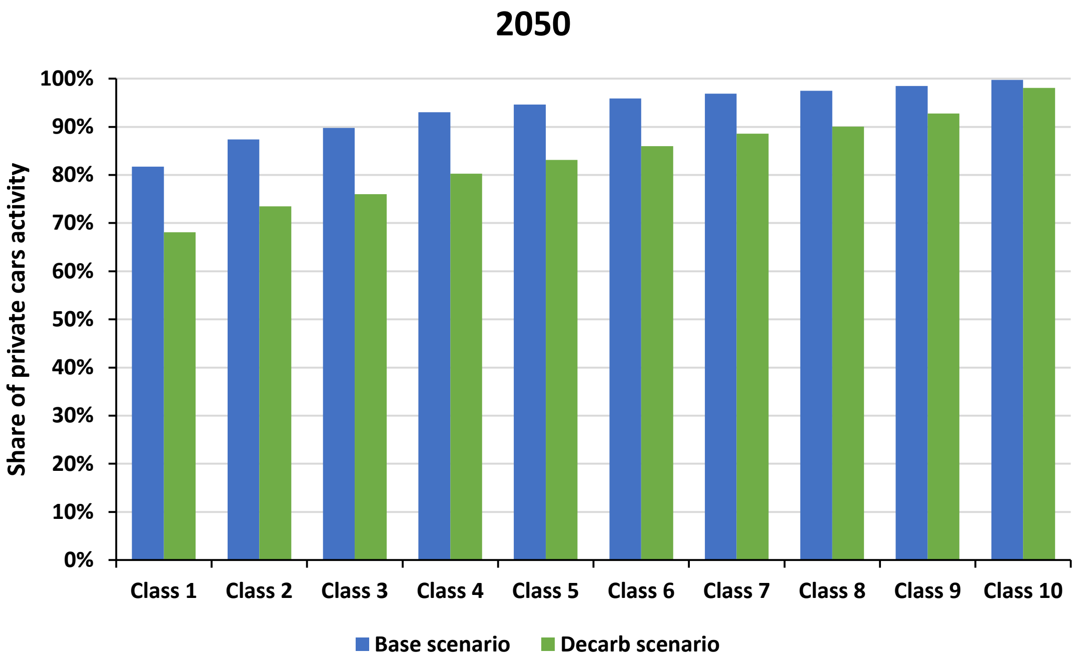


Source: newTRENDs - own calculation

5.2.3 Effects of household income

Household income is a crucial socio-economic variable for the decision-making process of the user. Figure 12 shows the activity of private cars in 2050 for 10 different income classes/households ranging from lower income classes (Class 1) to higher income classes (Class 10). It is observed that in both Base and Decarb scenarios, as income increases, users are less likely to change their travel behavior when it comes to transport by car, as they persist in using their own private cars rather than switching to shared mobility options. This finding is also in line with literature. Reversely, the lower the income class the more prone are its users to switch to shared mobility options as this choice maximizes their utility due to lower total costs. Similar findings apply across the whole period from 2020 to 2050.

Figure 12 Share of private cars activity by income class in the Base and in the Decarb scenario



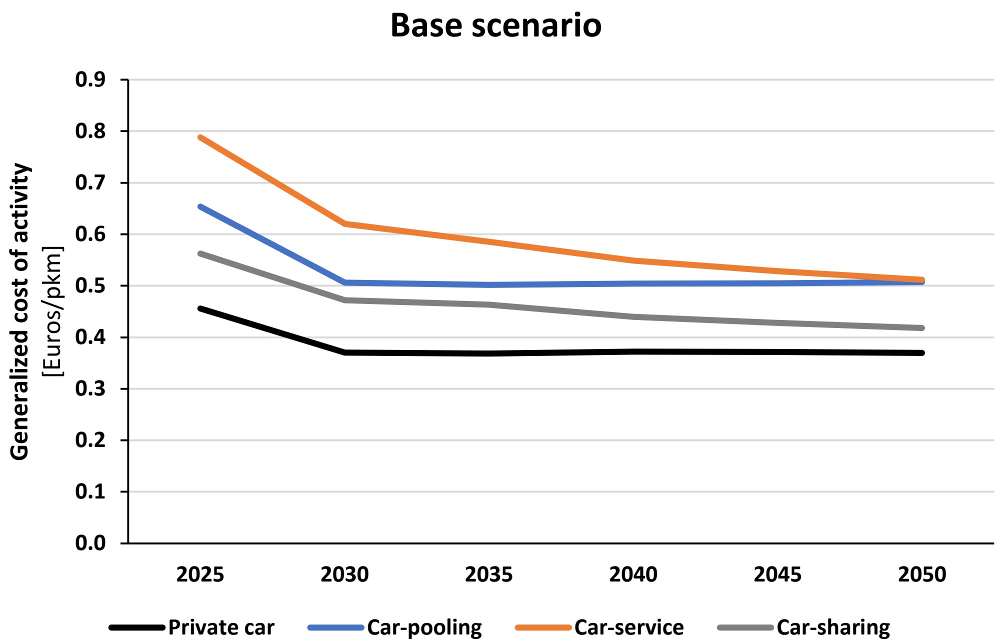
Source: newTRENDs - own calculation

5.2.4 Generalized cost

In Figure 13 (Base scenario) and in Figure 14 (Decarb scenario), the generalized costs of all transport options in PRIMES-SHAREM is presented (i.e., for private cars and for shared mobility options). It should be noted that the generalized costs includes actual costs and hidden costs (see section 3.2). Moreover, in the figures below, average generalized costs are presented. Differences per trip type and household type explain the different user choices, leading to the overall impacts presented in the sections above. As the generalized costs include hidden costs, it provides an explanation as to why private car is less costly than shared mobility (in the absence of hidden costs, certain shared mobility options could come at lower cost compared to private modes). Moreover, the figure is representative for the weighted average across all different trip types. The decision, however, is made per trip, which may lead to a different order of generalized cost per trip type compared to what is presented below. In addition, as the generalized cost includes supply-demand equilibrium, it increases the price of shared mobility options in case there is no availability of the shared option (particular for the Base). Finally, car-sharing is modeled and operates as company including a profit.

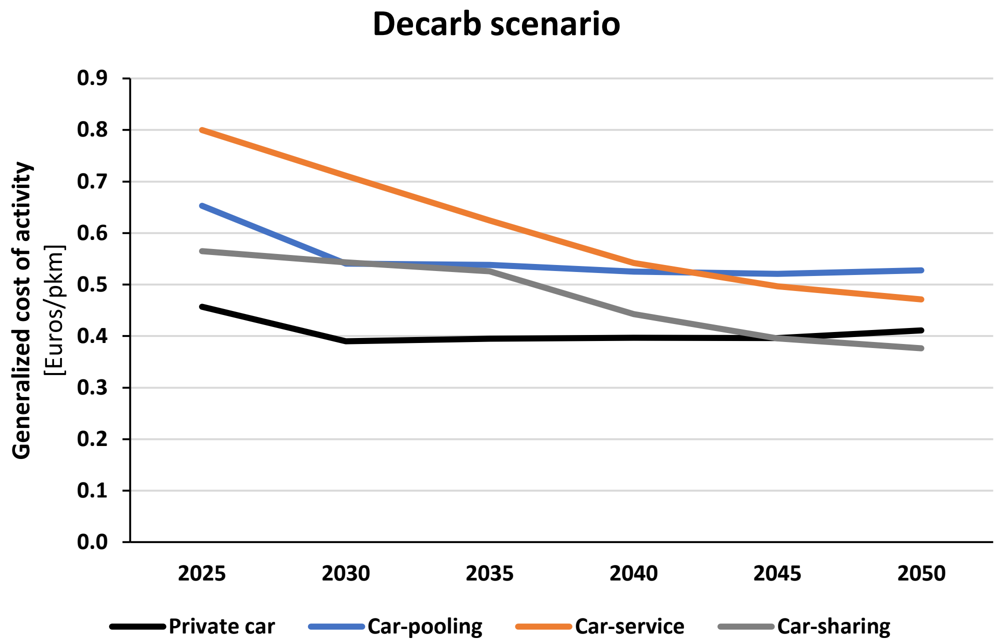
In both Base and Decarb, the generalized cost decreases between 2025 and 2030. In the Base scenario, private cars have the lowest generalized cost compared to the shared mobility options. The generalized cost of private cars remains relatively stable with time. On the other hand, shared mobility options have a higher generalized cost, however, the costs of car-sharing and of car-service reduces with time. The reduction of generalized costs is higher in the Decarb scenario. The steeper reduction of generalized costs in Decarb sets the average generalized cost of lower than the generalized cost of private cars, explaining the higher uptake of this option in the Decarb compared to the Base scenario.

Figure 13 Generalized cost of activity per transport option by car in the Base scenario



Source: newTRENDs - own calculation

Figure 14 Generalized cost of activity per transport option by car in the Decarb scenario



Source: newTRENDs - own calculation

Car-service has the highest generalized cost, owing to a higher ticket price (mainly due to the value of time which is higher in the car-service option) compared to the other options.

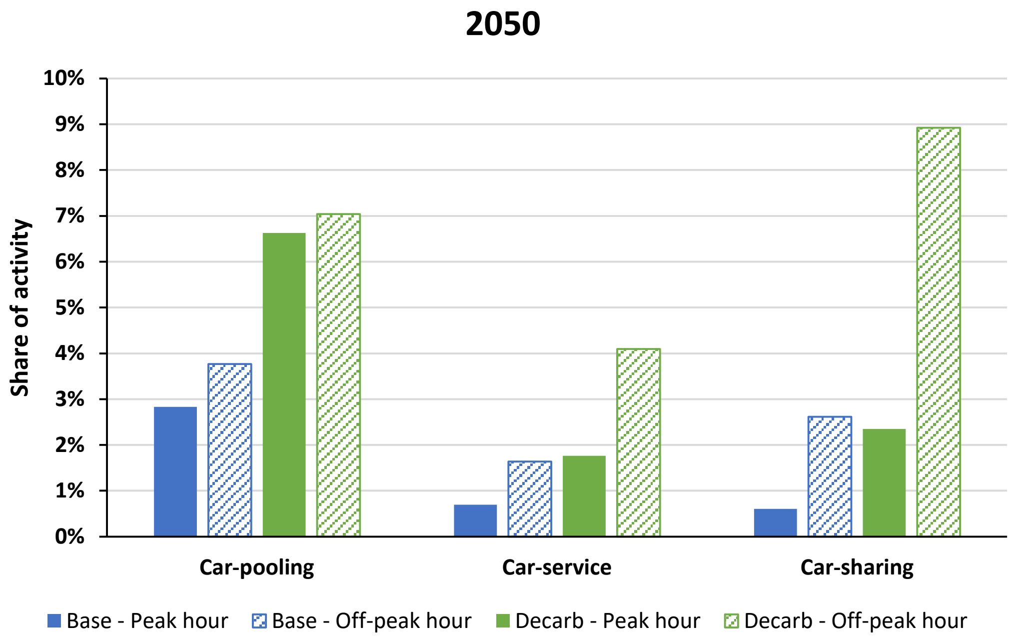
Non-monetized aspects that further explain user choice, and in particular perceived costs, include commercial barriers, infrastructure, as well as privacy and security issues linked with shared mobility options.

5.2.5 Shared mobility and trips

Uptake of shared mobility per time of travel (peak, off-peak)

Figure 15 presents the uptake of shared mobility options as a share in total passenger transport activity by car in different time periods, namely during peak hours and during off-peak hours. A first finding is that shared mobility options are preferred during off-peak hours. Car-sharing in particular increases its share notably during the off-peak time slice and becomes the main shared mobility choice in the Decarb context, which is aligned with literature. During peak hours the preferred mobility option in both Base and Decarb is car-pooling. The main reason for this is that people prioritize the actual travel time, when evaluating the preferences for the various shared mobility options (see section 4.6). During peak hours travel time between shared and private mobility options is similar, thus the former becomes a less competitive and less attractive preference. Similarly, hidden cost parameters (e.g., waiting time) is higher during peak hours, which further reduces the competitiveness of shared mobility options at these time slices.

Figure 15 Share of activity per hour of travel by shared mobility option in 2050



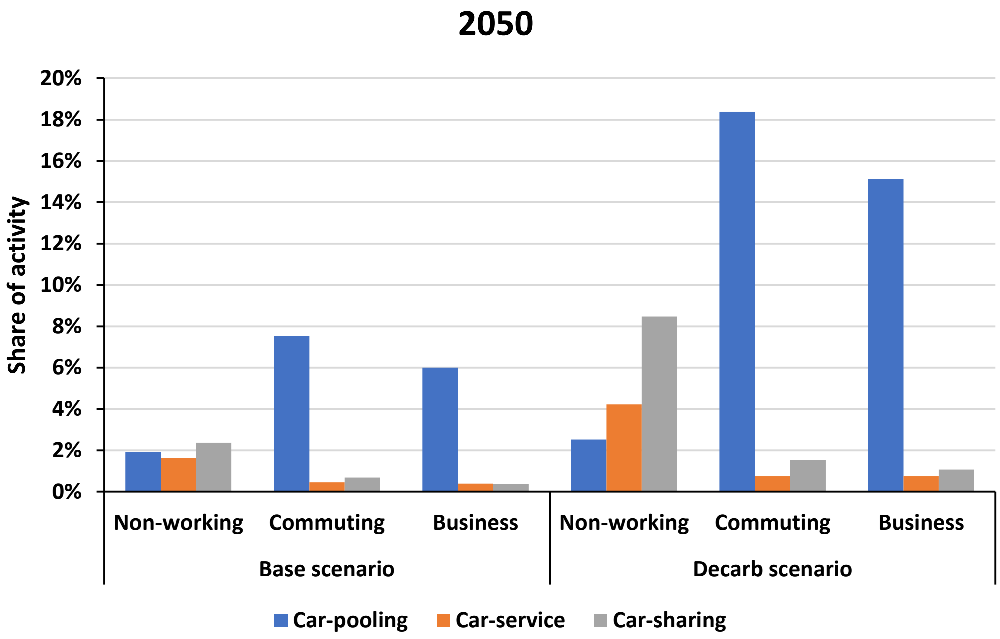
Source: newTRENDs - own calculation

Uptake of shared mobility by trip purpose (non-working, commuting, business)

When looking into the uptake of different shared mobility options by trip purpose, differences are observed across the various options (Figure 16). Firstly, car-pooling is used primarily for commuting purposes or business trips in both scenarios, since colleagues may arrange joint business trips or trips to work by sharing a ride.

In the Base scenario, shared mobility is used only marginally for non-working purposes. Moreover, in the Base scenario, other shared mobility options such as car-service or car-sharing have limited use for commuting or business purpose. In the Decarb scenario, while these mobility options have little uptake, the share of car-sharing for leisure purpose increases.

Figure 16 Share of activity per trip purpose per each shared mobility option in 2050



Source: newTRENDs - own calculation

6. Conclusions

This report demonstrates the development and implementation of the PRIMES-SHAREM Demand model, with the aim to identify and quantify the determinants (factors and reasons) that drive the selection of different mobility options. Ultimately, the model is intended to predict the share of demand for different shared mobility options, namely car-service, car-pooling and car-sharing. The literature highlights that the factor that affects the commuters' choices the most is the total costs of the transport service. Other factors relate to value of time, safety considerations and sociodemographic characteristics. These aspects are captured in the modeling. Moreover, PRIMES-SHAREM incorporates the concept of ticket pricing to compare the different options for the users. The modeling applies a nested discrete choice for shared mobility options. Results are presented for one country (Italy). Two policy scenarios were quantified in order to investigate the role of shared mobility in different contexts. The first scenario (Base) is aligned with EU Reference scenario and the second scenario (Decarb) induces deep decarbonization in transport.

The model successfully demonstrates the impact of shared mobility across several indicators and contexts. It is found that in the Decarb scenario context the contribution of shared mobility increases, thereby further reducing the activity of private passenger cars. Car-pooling is the first choice for shared mobility, especially in the shorter-term. While car-pooling remains the first choice for shared mobility also in the long-term, a gradual shift in user preferences is observed owing to user acceptance and reduced prices; car-sharing increases its market share notably, and especially in the decarbonization context, and becomes a key preference for shared mobility as well. Car-service, on the other hand, remains the last choice of shared mobility service, owing to its higher ticket price. Average occupancy rates of vehicles increase most notably in the Decarb scenario mainly due to the contribution of car-pooling because of its higher market share and its higher occupancy factor compared to the other shared mobility services. Socio-demographics, in line with literature, are shown to influence the choice for shared mobility options. It is observed that, as income increases, users are less likely to change their travel behavior when it comes to transport by car, as they persist in using their own private cars rather than switching to shared mobility options. Finally, with respect to different trip types, it is found that shared mobility options are preferred during off-peak hours, and that car-pooling is mainly preferred for commuting or business trips, while car-sharing is also preferred for non-working related activities, though mainly under a decarbonization context.

A next step is to further explore and quantify the impacts of shared mobility through iterations with the PRIMES-TREMOVE transport model for all EU countries. This will also reveal interactions and potential substitution of shared mobility with public transport, and it will help to quantify further the impact on fuel consumption and emissions. The additional iterations with PRIMES-TREMOVE and insights thereof are planned to be carried out within the newTRENDs project. Specifically, PRIMES-SHAREM will be fully deployed to cover all EU countries and will be used to quantify the Reference and Decarbonization scenarios by an iterative linking process with PRIMES-TREMOVE. It will then feed into the macro-economic modeling carried out with GEM-E3 (D3.2) that will also quantify the macro-economic impacts of newTRENDs, among them those of shared mobility.

Main challenges remain. Firstly, a tangible way of addressing the impact of policies on hidden costs and benefits is required, as these are main drivers for the modeling. In this respect, sensitivity analysis could help shed light onto the influence of empirical parameters and assumptions related to hidden costs and benefits, as they are not adequately quantified by available data. Secondly, further disaggregation of options could take place (e.g., different types of cars) so as to demonstrate whether impact on specific segments is relevant. Importantly, data limitations can be tackled either by advancing the review of literature or by detailed econometric analysis of the various parameters and assumptions undertaken. Other aspects that relate to decarbonization of mobility include urban and spatial planning measures that may reduce the amount of travelling by motorized means. While such aspects are not covered explicitly in the modeling, they may include links with shared mobility that would be important to explore in the future.

Further utilizing the PRIMES-SHAREM Demand model can support policy making in several crucial areas encompassing decarbonization of the transport segment.

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