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Potential values of maas impacts in future scenarios

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ABSTRACT

Mobility as a Service (MaaS) is considered a strategy that can provide potential solutions for a sustainable transport system. The current literature claims that MaaS can deliver net positive impacts for the transport system. However, whether these impacts are marginal or significant is unclear, as estimations typically are based on a few pilot tests. The lack of understanding of these impacts could create barriers for decision-making on policy and regulation in adopting MaaS strategy. The paper proposes a feasible evaluation to explore how and to what extent MaaS leads to, for example, reduced emissions, reduced fossil energy consumption, reduced car ownership and vehicle kilometres travelled on a large scale. The aim of this paper is to provide potential values of MaaS impacts based on analysis of future scenarios. The potential values of MaaS impacts can be used to support decision-making within both public organisations and among service developers for MaaS implementation and development.

Introduction

Due to rapid urbanisation in recent years, there is an increasing pressure on urban transport services, which in turn increases dependence on personal transport modes, causing adverse social and environmental impacts (Bramley & Kirk, 2005). There is a need for providing innovative shared mobility services, as they could support a shift from car ownership to usership (Shaheen & Chan, 2016). Recent innovations in information and communication technology (ICT), as well as digital technologies, have started the transition from a motor age to a digital age. The uncertainty of climate change requires new ways to reduce the impacts of travel.

Mobility as a Service (MaaS), a concept that can enable the integration of on-demand transport modes with shared transport services, is suggested as a potential solution for sustainable travel (Wong et al., 2006; Ho et al., 2018). MaaS can be defined as a customisable travel management platform which bundles together different modes of transport (public, intermediate and private) and allows users to plan, book and pay for their trip all at the same time (Hensher & Mulley, 2021). MaaS aims to facilitate seamless multimodal travel, with the intention of providing a sustainable alternative to private cars. The previous literature claims that MaaS can encourage more sustainable travel behavior and deliver net positive impacts on the transport system (Sochor et al., 2016; Strömberg et al., 2016, 2018). However, whether these impacts are marginal or significant is unclear, as the evaluations are based on limited MaaS pilot tests.

Public officials and practitioners have, for several years, sought assessments of the sustainability of MaaS for informed decision-making, governance and service design (Karlsson et al., 2019). It is important to gain knowledge about user acceptance, business models and public/private stakeholders' collaboration related to MaaS. Knowledge of impacts from MaaS is crucial for policymakers, regulators and planners to make decisions on developing and implementing MaaS (Pangbourne et al., 2020). This knowledge can help public authorities to set incentives, subsidies and fiscal policies for integrating MaaS into the transportation system. Service operators can then formulate agreements with partners, promote procurement activities and implement MaaS based on this knowledge. However, MaaS deployment and outcomes vary by geography (urban vs rural) and are influenced by socioeconomics and demographics, overall trip patterns and the quality/coverage of existing public transit systems (Maria Kamargianni et al. (2018). MaaS deployment is also affected by the availability and quality of regional communications infrastructure, such as the availability of real-time data to support transit planning and services (Smith et al., 2018). Impact assessment with pilots have proven to be insightful tools to understand how users will perceive these services and what its consequent societal-level impacts could be (Hensher et al., 2021), however, it takes time and complex efforts to set up a MaaS pilot programme (Eckhardt et al., 2018).

This paper therefore aims to evaluate the potential impacts of MaaS through future scenarios without depending on a limited pilot programme or specific case. The evaluation can provide a generic framework and can be easily adapted to different scenarios and scales.

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The paper applies a scenario analysis method to understand MaaS impacts on a large scale. Scenario analysis is useful for exploring plausible futures of the social-ecological system (Bengston et al., 2012); it accommodates both quantitative and qualitative data and can be combined with other modelling tools (Bekessy & Selinske, 2017). Mobility is a complex system and evolves dynamically along with changes in social, economic, technological, political and environmental situations; scenario analysis can capture and expose a variety of foreseen impacts (Zahraei et al., 2019). Additionally, scenario analysis requires consideration of various perspectives and involvement of multiple stakeholders, which can enhance the possibility of identifying how alternative strategic uncertainties may affect the future and enable better strategic decisions (Khosravi & Jha-Thakur, 2019).

Therefore, based on scenario analysis, the paper explores how and to what extent, under each plausible future scenario, MaaS contributes to a sustainable transport system. This not only requires exploration of current pilot programms but also requires an understanding of its long-term evolution. The potential values of MaaS impacts are evaluated based on key performance indicators such as private car usage, emissions, energy consumption and vehicle kilometres travelled. These indicators are high-level estimates of the potential impact of MaaS. The knowledge generated from the impact evaluation provides guidance to understand the environmental, economic and social impacts of ongoing MaaS pilot programms. This knowledge is also essential to assist in developing proposed MaaS roadmaps and adapt actions by both public organizations and MaaS service developers so that the potential of MaaS as a sustainable mobility solution can be achieved.

The paper is structured into six sections. Section II presents the state of the art in evaluations of MaaS impacts. Section III introduces the four future scenarios. Section IV generates the potential values for MaaS impacts under each scenario. Section V discusses the results and how they can be interpreted as knowledge for guidance. Section VI concludes the paper with key takeaways.

Related literature

Urban demand for mobility is growing quickly, and solutions for seamless and sustainable travel are being developed all over the world. Mobility as a Service (MaaS) is one of the potential solutions that may deliver transport services with improved energy efficiency and lead to a more sustainable transport system through on-demand shared mobility that reduces private car use and emissions (Hartikainen et al., 2019; Laine et al., 2018; Machado et al., 2018; Sarasini & Linder, 2018).

Key public and private stakeholders have started evaluating the potential of MaaS to improve service design, change business models and improve decision-making (Hartikainen et al., 2019; Maria & Goulding, 2018; Sochor et al., 2016). MaaS studies are still emerging, and their focus is limited to few aspects, such as policy support (Eckhardt et al., 2018; Li & Voege, 2017; Smith et al., 2018), business models (Kamargianni & Matyas, 2017; Polydoropoulou et al., 2018), user acceptance (Ho et al., 2020; Kamargianni et al., 2016b; Ratilainen, 2017; Sochor et al., 2015; Strömberg et al., 2016) and influences on public transport (Hensher, 2017; Ho et al., 2017). Sochor et al. (2018) and Lyons et al. (2019) have developed different suggestions for MaaS topologies based on indicators of integration content and degrees. Sochor et al. (2018) and Lyons et al. (2019) propose MaaS topologies with five and six levels of MaaS, respectively. Sochor et al. (2018) considered the social aspects of policy and regulation, while Lyons et al. (2019) emphasized transport modes and cognitive user effort. Such topologies can help to better understand MaaS in terms of the aforementioned different aspects.

While such studies contribute informative and valuable knowledge for understanding the potential impacts of MaaS on urban mobility and society, empirical evidence from real MaaS trials are in an initial phase and have not yet been evaluated in many contexts. There is indeed a relevant number of MaaS pilot programme and experiments, mostly focussed in urban settings (Kamargianni et al., 2016; Sochor et al., 2016) and some operating in rural settings (Barreto et al., 2018; Eckhardt et al., 2018), that have been conducted in order to reveal whether MaaS can deliver solutions that enable sustainable transport systems. Mobility services that fall under the lower levels of the MaaS topology (Lyons et al., 2019; Sochor et al., 2018), such as taxis and public transport, have existed for a long time. Car-pooling, ride sharing and last-mile micro mobility have also experienced rapid growth and spread in the last decade, following the development of ICT technologies (Shaheen et al., 2020). There are also MaaS pilot programmes (e.g., Whim and Moovel) that aim to provide a high-level MaaS, as described by Kamargianni et al. (2016a) and Jittrapirom et al. (2017). New pilot programmes in different contexts are being implemented along with technological developments in shared mobility and vehicle automation (Nikitas et al., 2017).

Jittrapirom et al. (2017), Kamargianni et al. (2016), Utriainen & Pöllänen (2018) and Arias-Molinares & García-Palomares (2020) have reviewed and discussed existing MaaS trials to support MaaS development and implementation. They show that even if stakeholders were willing to test whether MaaS could provide sustainable mobility solutions, the trials were often at limited scales and over short durations, which made it difficult to capture the impacts on various scenarios and scales to support decision-making. It was also noted that although these pilot programmes vary in scope, function and service integration, it is not feasible to generalise findings from specific MaaS trials to a larger scale or to apply them in other contexts due to differences in strategies, policies and regulations.

Although the aforementioned studies add certain new knowledge on MaaS, in reality, empirical knowledge of actual MaaS impacts is lacking (Falconer et al., 2018; Laine et al., 2018). The indication of overall potential impacts of MaaS on economic, environmental and societal perspectives have not yet been captured (Karlsson et al., 2019). This critical issue is mainly due to the fact that the amount of continuous and large-scale empirical evidence is still limited (Pangbourne et al., 2020). It requires time and effort to conduct and follow these pilot programmes, and there is also a lack of standards for data sharing among stakeholders (Pangbourne et al., 2020; Smith et al., 2018). Data related to existing pilot programmes and experiments are therefore either limited in terms of participants' responses or unavailable due to data sharing restrictions. It also requires time to reveal what impacts MaaS platforms could bring to individuals, organisations and society (Casady, 2020). Although empirical knowledge on the potential values of MaaS impacts is critical to support MaaS development and implementation, such evaluations are still lacking in the current literature (Karlsson et al., 2019; Matyas & Kamargianni, 2019; Signor et al., 2019). In order to assist decision-makers in adjusting and developing policies and regulations that can be adapted to MaaS, the potential values of MaaS impacts on a large scale are needed.

Scenario analysis method

As discussed, stakeholders are keen to know whether the introduction of MaaS can contribute to sustainable mobility for people and goods. However, a large range of resources are required to set up MaaS trials/pilot programmes, since a transition to MaaS depends on the service bundles offered and on individuals' choices. Existing trials/pilot programmes cannot cover the large operational and varied circumstances under which MaaS is implemented and operated in order to provide empirical evidence that can be applied in general. Therefore, scenario analysis is applied to assess the potential impacts of MaaS on improving sustainable transportation.

Scenario analysis explores possible outcomes based on assumed scenarios and real information (Swart et al., 2004). Scenario analysis has been applied in the context of sustainable development and has become a primary method for evaluating long-term socioeconomic and environmental goals (Miller et al., 2014). This method has become an efficient tool for exploring plausible pathways to achieving environmental goals, since it can structure changes and identify consequences under uncertain and changing settings (Mahmoud et al., 2009; Schandl et al., 2016).

Therefore, to answer our research question about the potential values of MaaS in providing sustainable mobility solutions, a scenario analysis method has been conducted. This section describes how the scenario analysis was applied to design four plausible futures for MaaS operation to evaluate their impact.

Strategic uncertainties

The first essential step in building the scenarios was to identify strategic uncertainties. In order to do so, the literature was analysed to find out uncertainties in terms of indices and important aspects in developing MaaS. Following the method proposed in Pernestål Brenden et al. (2017), the most impactful and the most uncertain trends considered in this paper are: i) policy and regulatory actions to enable MaaS and ii) public transport operators' openness to integration with MaaS.

Policy and regulatory actions to enable MaaS

This strategic uncertainty determines whether policymakers and decision-makers act proactively and quickly on MaaS development and implementation or instead act more conservatively and slowly based on user and market reactions. Kristoffersson & Pernestål Brenden (2018) showed that policy and regulation are one of the main aspects that are crucial and necessary in setting future scenarios for transport systems in general. The European platform on sustainable urban mobility plans (Signor et al., 2019) also emphasises the importance of policy and regulations that enable and support MaaS for its successful implementation. In a similar vein, Maria Kamargianni & Goulding (2018) included policy, regulation and legislation as one of the maturity indices of MaaS. Therefore, policy and regulations are considered an uncertainty, first because there is limited understanding of MaaS regulatory schemes (Kao et al., 2020), and second, because of the possibility that such policies will be unsuccessful (Coldefy et al., 2019).

Public transport operators' openness to integration with MaaS

This strategic uncertainty determines whether the public transport sector is willing to share data, platforms, services and so on to form an advanced integrated mobility platform or instead will only share information with private service providers on a limited basis. Public transport operators' openness to integration with the private sector is crucial in the transportation system (Kristoffersson & Pernestål Brenden, 2018), and especially for the successful implementation of MaaS (Signor et al., 2019; Kao et al., 2020). First, public transport operators' openness is considered as key uncertainty because public transport operators could be unwilling to open their ticketing systems, entailing negative consequences for MaaS implementation (Kao et al., 2020). Second, it is considered an uncertainty because it is difficult to change customer behaviour if some modes of transportation, such as public transport, are not included in the service (Sakai, 2019). A smooth collaboration between public transport operators and private service providers is important (Kao et al., 2020). It is therefore essential to consider and evaluate openness with respect to the data-sharing aspect (Kamargianni & Goulding, 2018).

Levels of MaaS

The second step is to determine what level of MaaS is appropriate in each scenario. Additional assumptions and modifications are made in this step.

First, a certain level of MaaS is assumed to be available regardless of the scenario but depending on the outcome of the strategic uncertainties.

Second, as long as a MaaS level is assigned to a scenario, that MaaS level is assumed to remain unchanged during the analysis. The MaaS levels used in this paper are adapted from the topologies proposed by Lyons et al. (2019) and Sochor et al. (2018). The adaptation of the levels has been made by taking into account the governance aspect, users' cognitive effort and the integration of information and service functions.

The four MaaS levels adopted in this paper are shown in Fig. 1. Each of the levels assumes that the functions of the previous level are already in place. The functions considered are the following:

(1) Service coverage: The geographical extent is classified as partial or full coverage based on the boundary within which the MaaS service is operational. Coverage can range from a city centre or a specific rural area to an entire city, region or country.
(2) Online and app platforms: The extent to which the MaaS service offers secure and dynamic platforms to ensure efficient use of different travel options, information, updates etc.
(3) Multimodal: The extent to which different mobility options are integrated within the MaaS.
(4) Information, plan, book and pay- The extent to which the MaaS offers service functions with timely, updated information, along with a one-stop service process that allows users to plan, book and pay for a trip.

MaaS Level 1-Partial info: The service at this level is available to users in both urban and rural regions of the country and only provides information through an app or online service. Common information includes transport modes and timetables, while price information is only available for a few transport modes included in the service. At this level, all transport modes are independent of each other, and only one transport mode can be chosen at a time (for example, e-bike, e-scooter, car rental, taxi or public transport). Planning, booking and paying for a journey combining different modes is not possible at this level.

MaaS Level 2-Multimodal planner: The services aggregate different information regarding multiple transport modes through an app or online platform and offer full coverage of both urban and rural areas. Multimodal plans can be offered, including information on transfer time, wait times and cost. However, the number of transport modes that are integrated in the service is still limited. Users can choose between different optimization schemes when planning their trips: e.g., fastest or cheapest route. Planning, booking and paying at one go is not available.

MaaS Level 3-Planning, booking and paying with partial service coverage: The services allow users to plan, book and pay for a whole trip through one app. Payment options such as ticketing schemes, subscriptions and travel cards can be also included in the app. Multimodal options are available for users to choose from. However, the services are accessible only in a certain area, which means that geographical coverage is limited to an area such as a city center, a specific work hub or designated rural areas.

MaaS Level 4-Planning, booking and paying, with full-service coverage: The same services as in Level 3 are provided. In this level, the provided services are more adaptable to different scales of on-demand needs, from city center to suburbs to certain rural areas. The services fulfil various transport needs at the highest coverage level, including both urban and rural areas. Multimodal and multi-service modes of transport are offered, as are parking facilities. MaaS definitions in the literature have been evolving over the past year, the MaaS Level 4 in this paper corresponds to Hensher & Mulley's (2021) definition of MaaS as a digital platform providing bundled services by combining multimodal and non-transport related services (for example, co-working spaces, parking facilities etc.). In the modification of the MaaS levels, the perspective of society was not included, such as incentives and enforcements of policies, as Sochor et al. (2018) defined in the fifth-highest level. The reason is that the societal aspect is reflected in the 'policy and regulation' strategic uncertainty. Furthermore, the number content of integration levels and their content is also changed: the two lowest levels are merged, and the application coverage feature is added. The modified MaaS level 1 is not assigned to any scenario, since this lowest level is not applicable to multimodal travel and does not provide information for estimating the

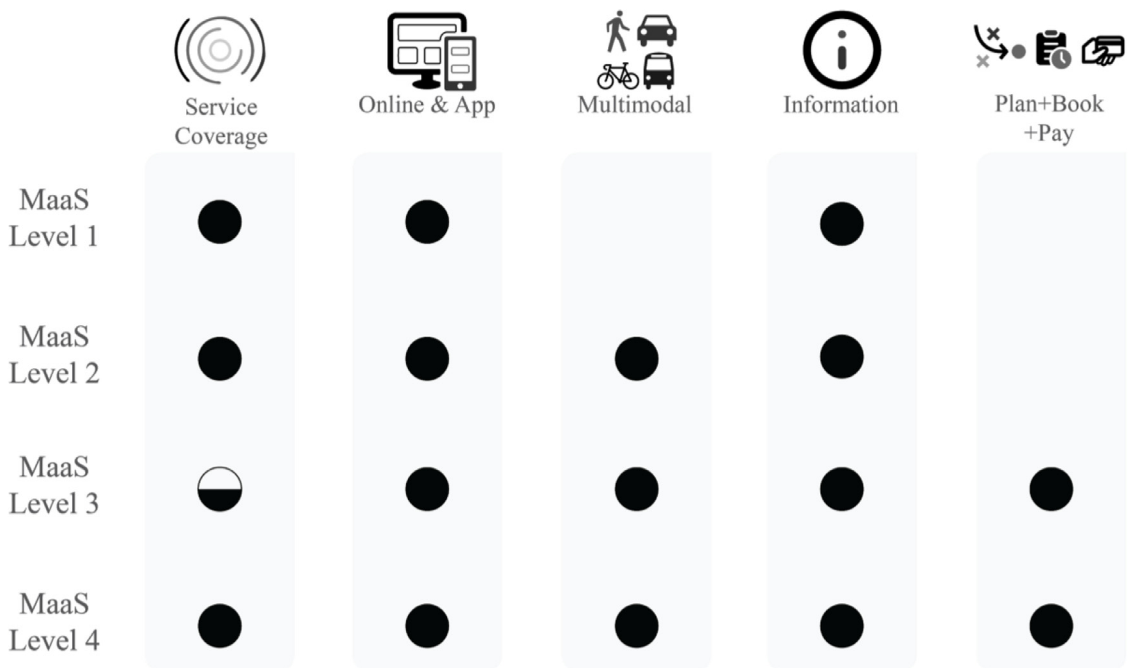

Fig. 1. MaaS levels with different service functionalities and application coverage.

potential values of MaaS impacts, since there is no innovative feature linked to MaaS.

The defined scenarios

In constructing the scenarios, the required transport services infrastructures, ICT infrastructures and technologies are assumed to be in place accordingly. This assumption implies that maturity indices 4 and 5 in Kamargianni and Goulding (2018) are satisfied.

Finally, it is assumed that users are satisfied once they have used the MaaS services and they keep using the services. This addresses the index of citizen familiarity and willingness to use MaaS (Kamargianni & Goulding, 2018). With the two strategic uncertainties and MaaS levels in place, the four scenarios have been defined as follows, and are illustrated in Fig. 2.

Scenario A-The addition of private vehicles: In this scenario, private mobility service providers are unable to get public transport operators onto their platform, as the public transport operators do not want to collaborate to build integrated mobility services. Meanwhile, policies and regulatory actions are conservative and do not specifically support MaaS. Private mobility service providers only integrate on the level of sharing basic information and are not willing to fully share data and integrate platforms among each other due to market-share competition. Private mobility service providers focus on promoting services that are profitable for their businesses but that are not necessarily optimal for the city or the environment, since there are no restrictions in the policies and regulations.

In this scenario, MaaS is on level 2. Level 2 MaaS does not respond to most travellers' needs for seamless travel and is not able to attract enough users to trigger the shift towards shared mobility services. The low level of integration of MaaS, especially the failure to integrate with public transport, fails to provide an alternative with a one-stop-shop platform that suggests different modes and allows users to plan, book and pay through the same gateway. The lack of simplicity, impartiality and flexibility forces people to maintain private vehicle ownership for convenience and comfort.

Scenario B-The rise of private shared services: In this scenario, policies and regulations are reformulated to enable shared mobility services. The policies actively support mobility services that integrate all modes of transport and allow users to plan, book and pay for their travel through the same application. However, since public transport operators are not willing to share or collaborate with other mobility service providers, the MaaS services in this scenario cannot provide all transport modes.

In this scenario, Level 3 MaaS services are limited to partial coverage, primarily in city centres. Thus, within the service boundaries, users can get easy access to private shared mobility services, along with public transport, as an alternative to personal vehicles. However, for those who live outside the MaaS service boundaries, dependence on private vehicles and ownership is high, and private vehicles are considered the most reliable, flexible and convenient alternative for daily travel.

Scenario C-MaaS trends win over policies: In this scenario, the public transport operator is open to collaborating with private mobility service providers. However, support from policymakers is lacking. Private mobility service providers are willing to collaborate with public transport operators to maximize their market share and profits, since the policies do not provide incentives. This is also beneficial for public transport operators, since integration can lower costs, ease the pressure of travel demands and increase the attractiveness of transport services. Public transport operators take the role of integrating all the mobility services in a single platform that allows users to plan, book and pay for every trip.

In this scenario, the level of MaaS is also on level 3. Although the Level 3 MaaS services are partially available within certain geographical boundaries, the integration of public transport and other mobility services can fulfil most travel demands, especially in urban areas. Even with a lack of regulations and incentives, MaaS trends win out over policies and attract users to shift towards shared mobility solutions.

Scenario D-MaaS wins over the masses: In this scenario, policies and regulations are quick and proactive in supporting integrated mobility services. The public transport operator and other mobility service providers work together to provide highly integrated MaaS services. The MaaS services aim to make customers' journeys as seamless and efficient as possible. Together, the strategic decisions of the authorities and actions from public and private stakeholders provide flexible, integrated transport options with all possible transport modes and broad coverage.

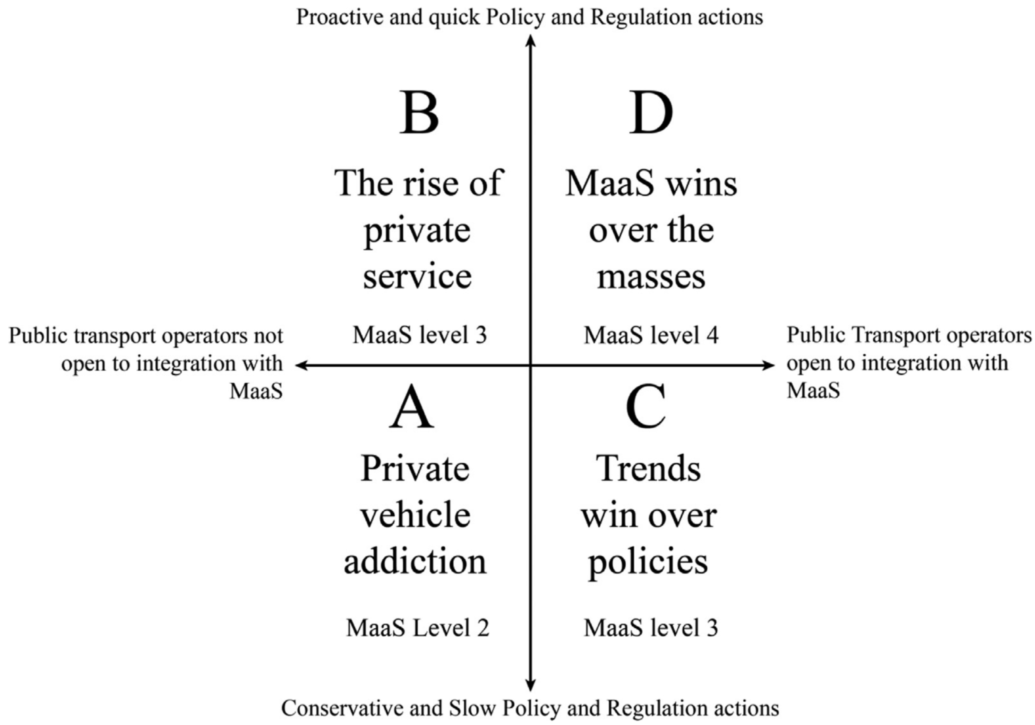

Fig. 2. Four plausible future scenarios based on two strategic uncertainties and three assigned MaaS levels.

Mobility services in this scenario are distributed over a wide geographical range, from central cities to rural areas to intercity routes. On-demand services are optimally distributed with the best combination of transport modes to address various users' needs. MaaS level 4 is available in this scenario, and plan, book and pay is possible through a single app. User-friendly travel plan tools and an easy to use application enable different groups of people to access services and fulfil their travel needs efficiently and seamlessly.

Potential MaaS impacts in the future scenarios

In this section, the potential impacts under each scenario are estimated. To enable the evaluations, first, a set of key performance indicators was selected through a literature review. Then, the diffusion of Rogers' (2003) innovation theory is used to set user acceptance rates in each scenario. Finally, based on the assumed user acceptance rates and real travel data, the indicators are estimated and compared among the scenarios. The baseline dataset used to estimate the indicators was retrieved from trafikanalys in Sweden (Trafa, 2018, 2020). The process and the calculations are described in detail in the following sections.

Key performance indicators to evaluate MaaS impacts

To evaluate the impacts of MaaS, a set of key performance indicators (KPIs) were selected. In this paper, the selection of KPIs was based on a literature review. The selection of KPIs is important to provide a holistic view that supports the scenario analysis and sets the focus for the measurements of the potential impacts of MaaS under each scenario. The literature search is mainly conducted through databases like Google Scholar, ResearchGate and Scopus. The keywords applied in the search were 'mobility as a service', 'MaaS', 'impact', 'evaluation', 'potential' and 'indicator'. The search resulted in a range of strategic transport policy documents from EU and Swedish policies, as well as from studies that have defined and/or applied KPIs in measuring MaaS impacts. The KPIs in the literature can be grouped into various categories such as travel, social, economic, business, organisational and environmental (energy use and emissions) (Sochor et al., 2015; Karlsson et al., 2017; Karlsson et al., 2019). Therefore, there is a wide range of KPIs that can be used to measure the impacts of MaaS in those aforementioned categories. In this paper, in order to enable the empirical evaluation of the constructed scenarios and due to limited data availability, two categories were considered: (1) travel and (2) energy use and emissions, as is shown in Table 1.

Within the travel category, one essential KPI is rate of private car usage, since it measures whether MaaS can drive the shift from private car usage to shared mobility (Li & Voege, 2017; Mulley, 2017). Vehicle kilometres travelled (VKT) is important, as it is linked to congestion and energy consumption (Tirachini & Gomez-Lobo, 2020).

Within the energy use and emission category, fossil fuel consumption and CO_2 emissions are two important KPIs. In defeating climate change, the reduction of fossil fuel use and greenhouse gas (GHG) emissions in the transport sector is a global goal (IPCC Working Group III, 2014). Transport is responsible for 30% of total CO_2 emissions through fossil fuel use, of which 72% comes from road transport. In road transport, private cars account for about 50% of transport emissions (Ten Brink, 2010). The European Union (EU) aims to reduce GHG emissions by at least 40% by 2030, and by 2050 the EU target for transport is to reduce CO_2 emissions by 60% compared to 1990 (European Parliament, 2018; Parliament, 2019). It is therefore crucial to measure the potential impacts of MaaS on fossil fuel consumption and CO_2 emissions under each scenario.

User acceptance rates

To investigate the potential impacts of MaaS, the portion of the population that uses the service is a crucial parameter. In this paper, Rogers' the Diffusion of Innovation Theory (DoIT) Rogers (2003), as illustrated in Fig. 3, is taken into account to set user acceptance rates. DoIT has been used in transport inquiries such as the acceptance and diffusion of green fuel vehicles and integrated multimodal mobility (Keller et al., 2018; Peters & Dütschke, 2014; Petschnig et al., 2014). Keller et al. (2018) stated that DoIT is a comprehensive framework that incorporates multiple factors and perspectives, such as users, innovation, incentives and society. DoIT has been used to understand how

Table 1
Key Performance indicators (KPIs) applied to measure the potential values of MaaS impacts.

Category of Indicators	Description	Chosen Indicators	References
Individual Travel	Individuals' travel preferences and habits such as kilometres travelled, no. of trips, choice of transport modes etc.	Private car usage Vehicle kilometres travelled	• >Cascajo, 2005; • A sustainable future for transport: Towards an integrated, technology-led and user-friendly system, 2009 • A European vision for passengers: Communication on passenger rights in all transport modes, 2011 • Burrows et al., 2015; • Karlsson et al., 2017 • >Ringenson et al., 2018
Energy Use & Emissions	Consumption of fossil fuels for transportation & pollution due to use of private vehicles. For example, CO2 emissions affecting air quality due to petrol and diesel vehicles	CO_2 emissions Fossil fuel consumption • Diesel consumption • Gasoline consumption	

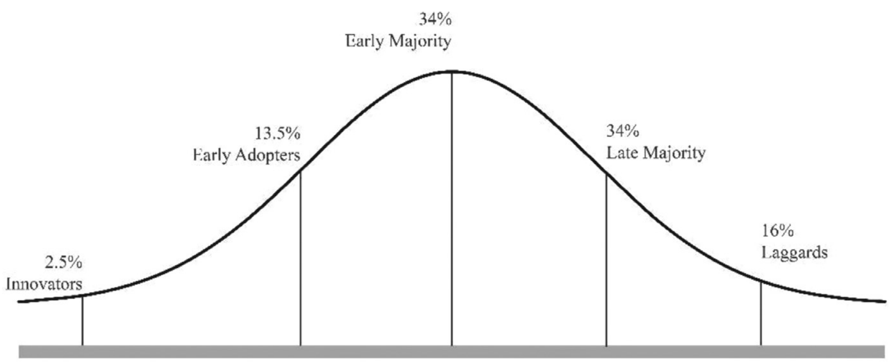

Fig. 3. The rates of adopters in diffusion of innovations theory (source: Rogers, 2003).

MaaS, as a transport innovation, has been implemented, how business models have changed and how individuals have accepted the services (Caiati et al., 2017; Jittrapirom et al., 2018; Sochor et al., 2018) As MaaS is presented as an innovation enabled through technology, it is acknowledged that diffusion of this innovation is likely to take place. Therefore, it is consistent to use DoIT to estimate the behavioral shifts of users.

It has been noted that the application of DoIT in the aforementioned MaaS studies, directly linked users categorized as 'innovators', 'early adopters' and 'early majority' to a specific sample group. However, the sample groups usually had a limited number of participants' answers, which made it challenging to generalize the findings. Diffusion of an innovation such as MaaS in transport is rather slow, since it requires many factors to work together (Kamargianni & Matyas, 2017). It also has the risk of overestimating adoption rates, since people involved in the pilot programme or survey are more inclined towards the innovation (Jittrapirom et al., 2018).

Strömberg et al. (2016) viewed the diffusion of MaaS as a new practice: an adoption process of a new travel behavior through which adopters seek information to reduce travel uncertainty regarding the innovation. The authors looked at the shift from private car usage to MaaS service usage to make the analysis possible. The focus on impacts on private car usage may underestimate the potential that MaaS innovation could have brought. However, private car travel still dominates personal mobility and is a mode that generates many negative impacts on society. It is therefore reasonable and practical to look at the shift from private cars to MaaS services. The shift could be that users just replace private car trips with MaaS service trips while continuing to own cars or it could be that MaaS adoption reduces both private car trips ship and private car ownership.

This paper therefore first looks into the influence of MaaS services on use of private cars by applying the rates of Rogers' DoIT based on the MaaS levels and the scenarios. Once the potential rate of reduction of private care usage is set, this rate is linked to the user acceptance rates. Using this method, the KPI for private car usage and car ownership, as well as 'residents' familiarity and willingness to use MaaS' index (Kamargianni & Goulding, 2018) can be addressed.

Table 2
Assumed reduced rates of private car usage and ownership corresponding to the adoption rates.

	$reduc_{usage}$(Percentage of reduction in private car usage)	$reduc_{own}$(Percentage of reduction in private car ownership)
Scenario *A*	0–2.5%	0%
Scenario *B*	2.5–16%	2.5%
Scenario *C*	16–50%	2.5–16%
Scenario *D*	> 50%	> 16%

To be more specific, as is shown in Table 2, in Scenario A, the MaaS services provided in a level 2 scenario may induce 2.5% of users, at most, to replace their private car trips with travel using MaaS. However, the MaaS services provided are rather limited, since public transport is not integrated. There are no strong incentives from the authorities based on slow and conservative policy and regulatory actions. Users may accept use of MaaS services to replace some private car travel, but they do not accept giving up car ownership.

In Scenario B, the MaaS services provided at level 3 may lead 2.5–16% users to replace private car trips with travel using MaaS. Although the MaaS services do not include public transport, this does not cause much hassle, since people are used to using public transport as a separate platform. Also, there are strong incentives from the authorities to motivate people to use the MaaS services, and so some users realize that they can fulfil their travel needs without owning a car. These users accept use of MaaS services by giving up ownership of their car; that reduction could be 2.5%, meaning that these 'innovators' fully shift to MaaS services.

In Scenario *C*, the MaaS services provided at level 3 may lead 16–50% users to replace private car trips to travel using MaaS services. Although there are still no obvious enforcements from the authorities, there are no actions against the MaaS services. The MaaS services are integrated with public transport and other sharing transport modes. Many users realise that they can fulfil their travel needs more seamlessly and efficiently without owning a car. These users accept using MaaS services and give up ownership of their car; this reduction could be 2.5–16%,

Table 3
Traffic data statistics from swedish transport analysis, 2018.

Parameter	Description	Value	Data source
vkt_{tot}	km driven in Sweden, 2018	$68.7 \times 10^9 km$	Trafa (2018)
vkt_g	km driven in Sweden, 2018, with gasoline-fuelled vehicles	$30.0 \times 10^9 km$	Trafa (2018)
vkt_g	km driven in Sweden, 2018, with gasoline -fuelled vehicles	$32.7 \times 10^9 km$	Trafa (2018)
em	emissions per km	$123 gCO_2/km$	Transportstyrelsen (2016)
N_y	number of passenger cars in Sweden, 2018	$6.22 \times 10^6 cars$	Trafa (2020)
$cons_g$	average gasoline-fuelled vehicle consumption in Sweden, 2018	$0.058 L/km$	Trafikverket (2019)
$cons_d$	average diesel-fuelled vehicle consumption in Sweden, 2018	$0.051 L/km$	Trafikverket (2019)

Table 4
Equations applied to calculate KPIs.

vkt_{reduc}	Reduction of vehicle km travelled (km)	$vkt_{reduc} = vkt_{tot} \times reduc_{usage}$
em_{reduc}	Reduction of emissions (ton CO_2)	$em_{reduc} = vkt_{reduc} \times em = vkt_{tot} \times reduc_{usage} \times em$
$cons_{reduc,g}$	Reduction of gasoline consumption (L)	$cons_{reduc,g} = cons_g \times vkt_g \times reduc_{usage}$
$cons_{reduc,d}$	Reduction of diesel consumption (L)	$cons_{reduc,d} = cons_d \times vkt_d \times reduc_{usage}$
Nv_{reduc}	Reduction of vehicle ownership (number of vehicles)	$Nv_{reduc} = Nv \times reduc_{own}$

meaning that innovators, as well as some ‘early adopters’, fully shift to MaaS services.

In Scenario D, the MaaS services provided at level 4 may lead at least 50% of users to replace private car travel with MaaS travel. The MaaS services and the promotion actions by the authorities provide people with a transport solution that wins out over private car ownership. Among these users, he 16% who are early adopters and who have experienced the services in an early stage would give up their car ownership, at a minimum.

Traffic data and calculation

To enable the evaluation of other KPIs, this paper applies the traffic data statistics from Sweden as an implementation reference. Data from Transport Analysis, the Swedish government agency for transport policy analysis (Trafa, 2018), Swedish Transport Agency (Transportstyrelsen, 2016) and Swedish Transport Administration (Trafikverket, 2019) are used. The registered number of private cars, fossil fuel consumption, VKT, and CO_2 emission have been retrieved and are listed and described in Table 3.

The KPIs are calculated based on the equations presented in Table 4. The variable *reduction of vehicle kilometres travelled* (vkt_{reduc}) is calculated by taking into consideration the reduction in usage of private cars in each of the four scenarios and the total number of kilometres driven in Sweden. The variable *reduction of CO_2 emissions* (em_{reduc}) is calculated using vkt_{reduc} and the emissions per kilometre based on data from Transportstyrelsen (2016). The variables *reduction in consumption of gasoline* ($cons_{reduc,g}$) and *reduction in consumption of diesel* ($cons_{reduc,d}$) in litres are calculated by using the reduction in usage of private cars for the four scenarios, kilometres driven with gasoline-fuelled vehicles and diesel-fuelled vehicles, respectively, and the average consumption of gasoline and diesel fuels in Sweden. Finally, the variable *reduction in the number of passenger cars* (Nv_{reduc}) is calculated by taking into account the reduction in private car ownership in the four scenarios and the total number of passenger cars in Sweden.

Results

Figs. 4, 5 and 6 present the outcomes of the selected KPIs that measure MaaS impacts under each scenario. Fig. 4 presents the potential values of reduced car ownership and reduced private car usage under each scenario. Fig. 5 shows the potential reduction of VKT and CO_2 emissions under each scenario. Fig. 6 illustrates the potential reduction of fossil fuel consumption (gasoline and diesel) under each scenario.

Scenario A-Private vehicle addiction: In this scenario, the reduction in private car use is 2.5% at most (Fig. 4), given that no incentives or subsidies are provided from policies, and public transport is not integrating with MaaS services. Moreover, car ownership does not decrease, since users are not ready to give up ownership.

Scenario B-The rise of private shared services: In this scenario, public transport is not willing to integrate with private mobility services providers. The incentives and subsidies from the quick and proactive implementation of policies have promoted private service providers to improve services, and hence users are also prompted to try the new shared mobility services. The MaaS platform has attracted more users to use the service to fulfil their transport needs: the adoption rate is between 2.5 and 16%. Amongst the users, innovators start to give up car ownership, yielding a reduction in the range of 0% to 2.5%. The reduction in private car usage is between 2.5 and 16%, corresponding to the increased adoption rate: this triggers a further reduction of VKT, fossil fuel consumption and CO_2 emissions.

Scenario C-MaaS trends wins out over policies: In this scenario, even though policies are conservative and slow in terms of MaaS development and implementation, public transport operators are fully open to integration with the private mobility services providers in building the MaaS platform. The highly integrated MaaS platform provides features that attract more users to adopt the platform to fulfil their transport needs, and hence the adoption rate is between 16 and 50%. Amongst the users, the early adopters also start to give up their car ownership, which results in a reduction of 2.5 to 16%. Although MaaS coverage is mainly in the central urban area, the reduction of private car usage is in the range of 16 to 50%. The KPIs of VKT, fossil fuel consumption and CO_2 emissions show further reductions.

Scenario D-MaaS wins over the masses: In this scenario, the public transport and other mobility service operators work together to build the MaaS platform, with the support of quick and proactive policies and regulations. The seamless and efficient on-demand travel services and the wide coverage cater for travel needs of different users in various locations and have boosted the adoption rate to at least 50%. At least 16% of adopters are willing to give up car ownership. The upper limits of KPIs reduction in Scenario 3 become the new lower limits in this scenario. However, it is hard to estimate the new upper limits: perhaps the change will be slower due to diffusion, but the potential impacts of the KPIs will continue to grow as long as the MaaS services can be improved and meet people’s travel needs.

Discussion

The results presented above show the potential values of MaaS impacts in each of the four scenarios. Positive impacts in reducing private car usage and ownership, VKT, fossil fuel consumption and CO_2 emis-

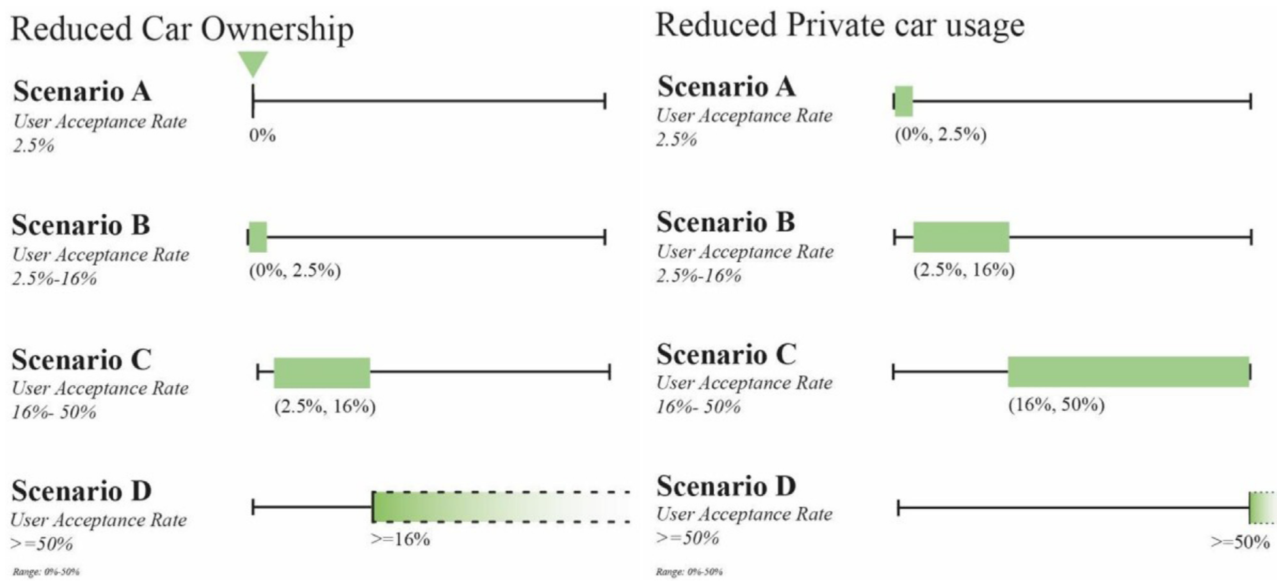

Fig. 4. The potential values of reduction of VKT (left) and reduction of CO_2 emissions (right), indicating MaaS impacts under each scenario.

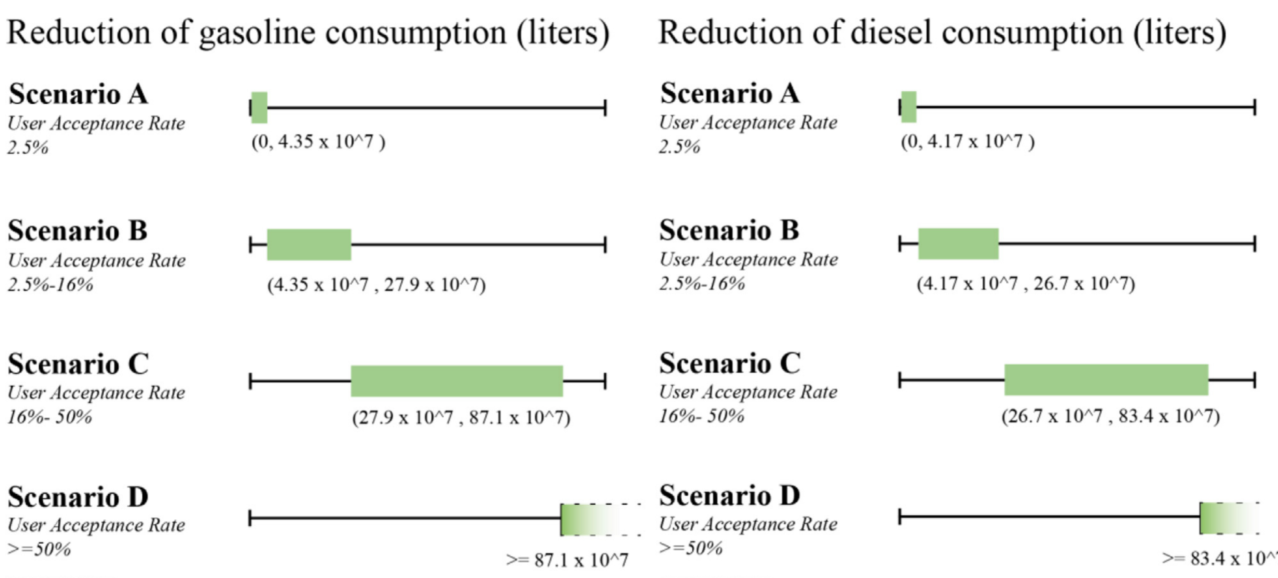

Fig. 5. The potential values for reduction of fossil fuel consumption (gasoline on the left and diesel on the right), indicating MaaS impacts under each scenario.

sions can all be seen in the four scenarios, but to different extents. These results rely on the following assumptions:

First, all vehicles included in the MaaS services are assumed to be environmentally friendly, using green fuel and producing zero CO_2 emissions. This assumption is in line with the inevitable trend of replacing fossil fuels with environmentally friendly fuels following market trends (Brătucu et al., 2019; Hawkins et al., 2012). This assumption may reflect an overestimation of the reduction of fossil fuel consumption and CO_2 emissions. However, the aim of this paper is not to provide exact numbers for MaaS impacts but rather to provide potential values to be used in MaaS decision-making.

Second, this paper only checked the KPI of VKT from private cars. The change in VKT in the MaaS sector was not analyzed, since the usage of multimodal transport is quite complicated to estimate. The shift from private car usage to the use of MaaS services could cause an increased use of shared cars in forms of taxi, carpools and ride sharing, which may lead to an increase in total VKT (Li & Voege, 2017). The potential increase in VKT could then be argued to make the congestion problem worse. However, the potential increase in VKT is based on the assumption that the capacity of vehicles in MaaS is not optimally used (Tirachini & Gomez-Lobo, 2020). It is possible that people are making more trips than before to fulfil various needs because MaaS services are more accessible and flexible. There is no evidence that a potential VKT increase from using MaaS worsens congestion. On the contrary, with the maturity of autonomous technology and the optimal use of vehicle capacity, congestion may decrease even with increased VKT (Hensher, 2018; Metz, 2018).

Third, regarding fuel consumption, the numbers that are used in this paper are the average numbers applicable to new vehicles purchased in 2018, based on the report from Trafikverket (2019). The real fuel consumption numbers could be higher, since not all vehicles are newly purchased in 2018, and older vehicles tend to consume more fuel. Therefore, the fuel consumption that could be reduced due to shift to MaaS services would be higher in each scenario. Given that the evaluation aims to provide estimates that can be used as informative guidelines for decision-makers, this bias should be taken into consideration and the

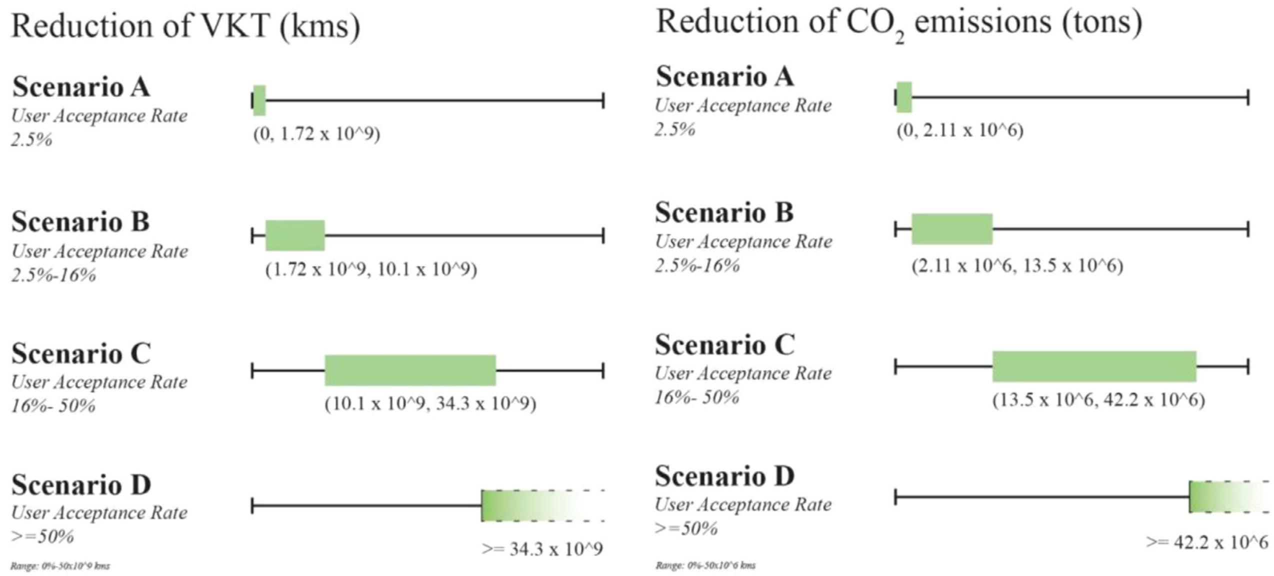

Fig. 6. The potential values of reduced car ownership (left) and reduced private car usage indicating MaaS impacts under each scenario.

possibility of making more accurate estimates be noted if all required data were available should be noted.

Fourth, in this paper the rates of change in private car usage due to use of MaaS are based on the numbers proposed by Rogers's diffusion of innovation theory. These numbers are further linked to the rates of user acceptance and the reduction of private car ownership, as the analysis does not take into account the entire population and hence the overall number of users of the MaaS service. These rates may not fully capture MaaS adoptions in a specific scenario. While we are aware of that, ultimately, these MaaS services are designed for users, in this study, we look at the MaaS system from a macro level perspective rather than considering users from an individual level. It must be noted that the scenario analysis conducted in this paper is based on assumptions that foresee MaaS being implemented on a large scale, while in reality this has not yet been achieved. The rates are therefore considered in the strategic uncertainties and the adapted MaaS levels used in the evaluation. Overestimation or underestimation may occur; however, if a scenario does happen in reality and there is empirical evidence available, the rates can be easily replaced for a more accurate estimate.

The different impacts of MaaS in the different scenarios do not mean one scenario is worse than the other. Instead, it is important to know that the impacts of MaaS depend on how it is implemented and adopted, which in turn depends on the policies that are implemented and the business ecosystem that exists (embodied in the strategic uncertainties in this paper). In this study, scenario D shows the most positive impacts, with a potential reduction of CO_2 from the private car sector of up to 50%, which may be most favourable by decision-makers. However, the transport data used are from Sweden, and the size of the impact may differ in other contexts. A scenario includes many other dynamic factors for decision-making, such as the various needs of key stakeholders and the various strategies that are used to achieve different sustainable development goals.

Limitations

There are two main limitations of this study.

(1) Due to limited data availability to enable empirical evaluations, the KPIs that have been chosen are focused only on the travel perspective and on the environmental perspective. (2) Certain assumptions had to be made in order to perform the scenario analysis, and the estimated potential values of MaaS impacts are biased to some degree.

Therefore, in the future work, KPIs such as perceived accessibility, individual attitudes towards MaaS offerings, health and wellbeing, cost of services, employment, quality of travel etc., and real data from large-scale MaaS empirical evidence will be valuable to compensate for the theoretical estimates and scenario analysis in order to understand better MaaS impacts. Along with this, other theories, such as the unified theory of acceptance and the conceptual modelling framework (Caiati et al., 2017), may also be applied with empirical evidence from a large-scale MaaS implementation for further analysis of MaaS impacts.

Conclusion

Mobility as a Service (MaaS) is considered one of the potential solutions for achieving a seamless, efficient and sustainable transport system. Although there are studies claiming that MaaS can deliver net positive impacts on the transport system, whether these impacts are marginal or significant is either unclear or is only limited to a few pilot tests. The lack of knowledge of MaaS's potential impacts creates barriers for decision-making on MaaS in terms of policy and regulation strategies. MaaS trials require a range of resources and time to set up and enable the transition. Existing trials cannot encompass the large scale of MaaS operations or cover the various contexts where MaaS could be widely used. This paper therefore provides potential values for MaaS impacts by evaluating them using scenario analysis. The paper explores how and to what extent MaaS leads to reduced CO_2 emissions, reduced fossil fuel consumptions, reduced private car ownership and reduced vehicle kilometres travelled.

This paper defines four future scenarios based on two strategic uncertainties: first, whether policy and regulatory actions enable MaaS, and second, whether public transport operators are open to integration with MaaS. The four scenarios are respectively (1) private vehicle addiction, (2) the rise of private sharing services, (3) MaaS wins out over policies, (4) MaaS wins out over the masses. The four scenarios are assigned different MaaS levels, representing different degrees of functional integration and geographic coverage of the services. Based on diffusion of innovations theory, 2.5, 16 and 50% are used to represent the adoption rate of MaaS under each scenario. KPIs for private car usage and ownership, VKT, fossil fuel consumption and CO_2 emission were chosen to measure the impacts. Current traffic data statistics from official agencies in Sweden were used to estimate the KPIs. The adoption rates and traffic data can be replaced if so, needed for a specific context. The extent of reduction is different among the scenarios. The extent of reduction may be different due to the real-world situation.

The potential values of MaaS impacts provided in this paper will inform both public and private key stakeholders on how to adapt actions in MaaS development and implementation. Two main takeaways emerge from this paper. First, the results show that MaaS can lead to sustainable reductions in mobility and CO_2 emissions from the private car sector, ranging from 2.5 to 50%, if the vehicle capacity can be optimised and technologies enable the use of green fuel. Second, the potential reduction in private car usage and CO_2 emissions depend on policies and the receptiveness of the public transport sector, for example, by supporting MaaS implementation and green vehicles, data sharing and service integration.

Conflicts of Competing Interest

(On behalf of all authors, the corresponding author states that there is no conflict of interest.)

CRediT authorship contribution statement

Xiaoyun Zhao: Writing – original draft, Conceptualization, Methodology, Writing – review & editing, Investigation, Funding acquisition. **Claudia Andruetto:** Methodology, Data curation, Writing – review & editing. **Bhavana Vaddadi:** Methodology, Visualization, Writing – review & editing, Investigation. **Anna Pernestål:** Writing – review & editing, Investigation, Funding acquisition.

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Availability of data and material

(All data used in this work is transparent and can be publically used.)

Code availability

(No specific code has been generated in this work.)

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