Multidimensional Indicator of MaaS systems Performance

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Summary
The concept of MaaS has been described as a new way of managing urban and regional Mobility and facilitating the reduction of dependence on the individual vehicle. MaaS systems have been characterized through a single indicator so far, just providing information about the services available to the users or the level of technology used. However, to facilitate the comparison between various platforms by the potential users and facilitate the discussion between stakeholders, it is essential to provide a broader set of measures to evaluate each platform. In this work, we propose a multidimensional system based on three dimensions (coverage, functionality, and sustainability) based on pairs of indicators (geographical coverage and multimodality level; services and technology; contribution to social cohesion and the environment). The analysis of a dozen of mobility services in several European countries confirmed the notion that the MaaS is still in the preliminary development phase, and there is still a considerable margin of progress given the effective penetration in the market of large-scale systems, with advanced integration levels and effective demonstration of societal impacts.

1. Introduction

Mobility as a Service (MaaS) is commonly defined as an innovative, promising approach to rearranging Mobility and contributing to reducing vehicle ownership (Arias-Molinares & García-Palomares, 2020), even taking into account current unimodal car users are the least likely to adopt MaaS (Alonso-González et al., 2020). The MaaS vision is to consider "the whole transport sector as a cooperative, interconnected ecosystem, providing services reflecting customers' needs" (Hietanen, 2014). MaaS is neither new nor revolutionary but is rather an evolutionary continuation in terms of transport integration. Due to the high heterogeneity of existing mobility services, these services' classification as a single value is virtually impossible. For example, Uber is a very effective service due to its ease of use in different cities and continents. However, its level of intramodality is very limited. Ubigo or AMT Genova includes several tariffs, mobility packages, modes, and customisation modes but are based on very different technological platforms and reduced to limited geographic areas. While many MaaS systems have generic goals such as "reducing car ownership", few projects present active pricing strategies or incentives to encourage more sustainable transport choices. Esztergár-Kiss & Kerényi (2020) suggested mobility packages considering several city-specific parameters, but they argued that some cases are not environmentally conscious yet and congestion has not reached such a level, which would efficiently change travel behaviour. Sochor et al. (2018) explored multiple strategic and tactical actions on how MaaS platforms should be integrated with the public sector to ensure a minimally viable service from the point of view of the MaaS operator but responding to a set of societal challenges. However, from a practical point of view, it remains difficult to distinguish each platform's promotional rhetoric and public authorities and the effective contribution to sustainability and social cohesion of MaaS.

With the proposed multidimensional indicator presented in this paper, we intend to contribute, to improve the way stakeholders and users can assess technological performance and the societal contributions of the MaaS systems through a set of tangible indicators. In this paper, we consider a MaaS system, all operators delivering mobility services to end-users by enabling them to seamlessly plan, pay for or execute the use of public transport and other transport services through a single interface in line with the definition of (Smith et al., 2018).

2. Literature Review - Previous classification systems

This section briefly summarizes previous efforts by academia and other organizations to organize and develop topological systems for classifying MaaS systems. Based on relevant literature, two types of indices related to the MaaS schemes can be distinguished. The first category focuses on the local context (political, technological, infrastructure, social context), describing the region's readiness level for MaaS implementation (e.g., (Aaltonen, 2017), (Kamargianni & Goulding, 2018)). The second category, which is related to the framework of this paper, focuses on the level of development of MaaS schemes.

Kamargianni et al. (2016) surveyed selected 'mobility integration projects' and were roughly categorized under different integration levels: basic, advanced, and advanced with tailored mobility packages. Since it was found that the difference of MaaS schemes within the same category was not clear, a MaaS integration index was developed considering four major types of integration (ticketing, payment, ICT, and mobility package integration), which each one was scored and a final score that represents the integration level is obtained by summing up all scores. Although a final score is attributed, this can be disaggregated into the components to reflect each weight better. By improving the former method, Sochor et al. (2018) presented the most known topology for MaaS classification focused on responsibilities and business models. This topology is divided into five levels (0–4) describing varying levels of integration: 0 no integration; 1 integration of information; 2 integration of booking and payment; 3 integration of the service offered, including contracts and responsibilities; 4 integration of societal goals. In 2018, a very different approach was launched in the Traffic Technology International issue, which defined new levels of MaaS focused on the services provided and employed technology (open data standards, artificial intelligence, integration with other digitized services, the Internet of Things or IoT). The expectation is that MaaS will evolve so other systems such as food, groceries, entertainment, and sport will provide seamless interfaces encompassing the traveller's ecosystem (Traffic Technology, 2018). Lyons et al., (2019) developed a new 0–5 taxonomy, designed around the user perspective (including cognitive user effort), which was inspired by the SAE taxonomy for vehicles' automation. The authors emphasized the essential difference between the mobility intermediaries and the mobility system as a whole, containing further layers that collectively make up MaaS. In (Hensher et al., 2020), a comprehensive view of MaaS development and a detailed comparison of the previously mentioned taxonomies are provided. Other private companies such as Via ID suggest alternative approaches to MaaS aggregation from the simplest to the most complete (Level 1: information platform, 2: aggregation platform; 3: subscription platform), mostly aligned with (Sochor et al., 2018). However, these two approaches for MaaS schemes classification in terms of integration do not provide any information regarding, for instance, the geographic coverage of the mobility services (e.g., whether a scheme is focused on urban or rural or (inter)national). Esztergár-Kiss et al. (2020) carried out a systematic analysis of more than 30 MaaS services based on their penetration, area, web interfaces and other aspects related to service integration and personalization features. Those platforms were categorized into 3 main clusters, but a classification system was not provided. Table 1 presents a review of the main features of the MaaS classification strategies found in the literature.

Table 1. List of previous relevant MaaS classification systems.

Reference	Classification System	Coverage (geographic and modes)	Functionality, integration of services, ICT	Contributions for sustainability
(Kamargianni et al., 2016)	Ten levels (Transport modes (1 to 6) + 1 for ICT and mobility package integration	1 point for each transport mode. No geographic coverage	Integration of services (planning, payment, booking). **Focus on what is more appealing to travellers.**	Not directly addressed.
(Sochor et al., 2018))	Four levels 1-4	Possibility of adding layers of nuance, e.g. the number of modes - no clear assessment framework provided. No geographic coverage	Integration of functionality, from planning, ticketing, booking, and subscription**. Focus on responsibilities and business models.**	Integration of societal goals at level 4, but no clear assessment framework.
(Lyons et al., 2019)	Six Levels 0-5	Some levels depend on the inclusion of more than one mode. There is no clear classification for geographic coverage	Integration in terms of operations degree of seamlessness, information, and transactions (i.e., booking, ticketing, and payment via one interface). **Focus on the user perspective.**	Not directly addressed in the evaluation framework.
(Traffic Technology, 2018)	Seven Levels (O-6)	Some levels depend on the inclusion of more than one mode. There is no clear classification for geographic coverage	Integration in terms of **operations degree of seamlessness, information, data policy, and other smart city tools.**	Not directly addressed in the evaluation framework.
This paper	Five levels * 6 categories	Framework assessment for **geographic coverage and multimodality** considering local context	Framework assessment for considering **integration** of services, **technology, and personalization.**	Framework assessment for considering the contribution to en**vironmental and social pillars.**

The existing topological frameworks for classifying the MaaS platforms offer a set of relevant information about each system's functionality but, in general, neglect many other dimensions, such as geographic, multimodal coverage, and contributions for sustainability. It is also verified that it is difficult to establish a clear distinction between the integration of services provided and the ease of use and personalization of the platforms. This paper aims to address this gap by suggesting a MaaS classification framework to support users to know the potential scalability, services and societal impacts of MaaS systems; and support experts and regional policymakers to benchmark and compare their regional integrated mobility services' performance.

3. Methodology

3.1. Multidimensional Indicator concept

The proposed classification system results from intense discussions, workshops, and meetings with several experts (academia, ITS organizations) and stakeholders of the Interreg Europe PriMaaS project (PriMaaS, 2021). First, we explored various definitions of MaaS topological concepts to categorize different MaaS Services of seven European Regions. This preliminary assessment allowed us to conclude that current classification systems do not tackle key dimensions such as coverage, multimodality, infrastructure, and sustainability policies. Simultaneously, other variables related to the level of customization, personalization, and autonomous detection of individual and community mobility needs are not properly considered. Furthermore, the integration of societal challenges (considered as level 4 in (Sochor et al., 2018)) is a too vague concept that does not distinguish between rhetoric, objectives, and active social inclusion policies and environmental policies. This article proposes a complementary approach of classifying MaaS systems based on three main pillars addressing the coverage, functionality, and sustainability performance. Each pillar is divided into two sub-dimensions whose classification is assigned based on specific features (Figure 1).

For a more detailed analysis at the policymakers and technical discussion level, a more complex system could be presented (e.g., 4.5 x 4.3 x 2.1). For users, a more simplified system indicating only the minimum of each pillar (e.g., 4 x 4 x 1) (similar to the air quality indicator with different pollutants) can be disseminated. Naturally, for a competitive ranking, the ratio between the sum of all scores divided by the maximum possible score (30) can be considered. This makes it possible to ascertain the overall performance of MaaS platforms of a given region compared to an optimal solution (5+5; 5+5; 5+5) and based on a holistic set of indicators. However, the key contribution of this article is the inclusion of other dimensions based on tangible criteria.

The following sections detail our proposal for classifying MaaS platforms in different domains. This classification makes it possible to include other mobility services, which do not always fully fit the traditional concept of MaaS. Depending on the factor to be analysed, some indicators are built on a progressive scoring logic (e.g., (Sochor et al. (2018)); others are made using a cumulative scoring or percentual system.

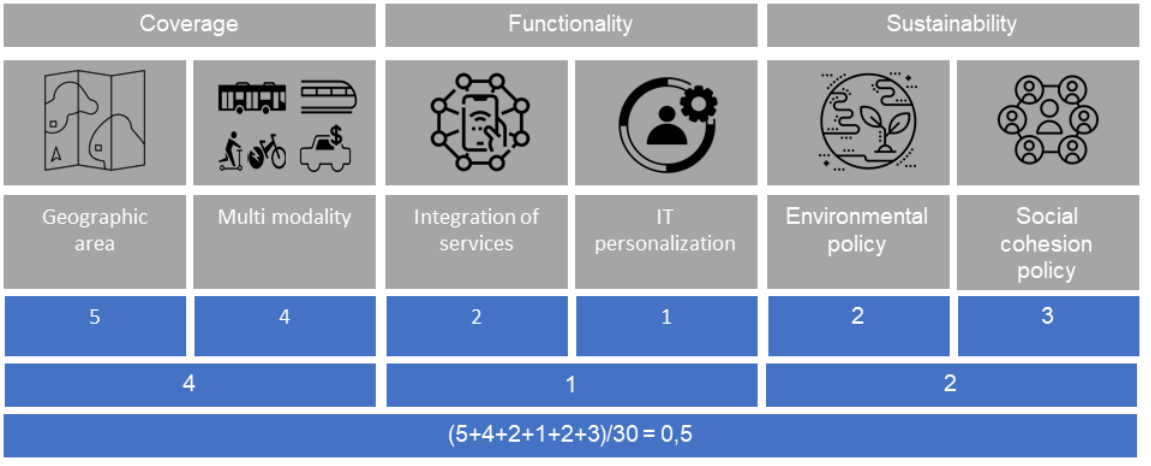

Figure 1. Illustration of the Multidimensional performance indicator and example of scoring possibilities in blue.

3.2. Coverage

The coverage of MaaS platforms is analyzed from the perspective of the platform's geographic served area and diversity of transport modes.

3.2.1. Geographic coverage

The geographic availability of a MaaS service is an important factor for its attractiveness. Although most MaaS services are located in cities (e.g., Whim, Ubigo), there are several examples of mobility services at different scales and digitalization levels. For instance, some recent MaaS pilots in rural areas are focused on demand-responsive transport and integrated transport of other user groups (Eckhardt et al., 2020). Flixbus provides an app for users travelling through various countries acting exclusively in the digital dimension at international levels. Note that we are only concerned with the geographic extension of PT operators belonging to the platform in this sub-indicator, excluding, for example, renting a car service with no defined geographical limit due to its nature.

We consider that the minimum basic coverage is the urban or municipal territorial (level 1). Level 2 includes all MaaS services operating in a large metropolitan area, including several urban and suburban services. This level also includes the MaaS platforms mainly focus on a defined urban area but includes a punctual long-distance service (e.g., long-distance train). Level 3 includes national platforms, while level 4 includes the services that can be used in different cities and countries with the same app and user account but with some geographic discontinuity. Level 5 corresponds to a generalized cross-border service with geographic continuity among different nations (Table 2).

Table 2. Classification of MaaS services regarding geographic coverage.

Score	Characteristics	Examples
1	Single Municipality	Erfurter Verkehrsbetriebe GmbH (EVAG)
2	Metropolitan Area	SL (Stockholm Public Transport), Navigogo
2	City + single longer distance PT service	DB-Regio
3	National Level	Resplus (via Samtrafiken) BlaBla car
4	Multiple discontinued cities/regions	Uber
5	Generalized cross border service	Flixbus, Google maps

3.2.2. Multimodality coverage

Existing evaluation schemes do not adequately reflect this aspect in particular, as the number of included transport modes is not considered at all or is summarized in such a way that, for example, the complete public transport service has the same value as just one bike-sharing provider (e.g., (Kamargianni et al., 2016)).

The classification is based on a score that assesses two aspects. Firstly, the diversity in terms of the coverage of 4 main categories of transport solutions: i) mass urban public transport (buses, metro, light rail, BRT, urban trains, water transport); ii) regional and long-distance transportation (coaches, regional and high-speed trains, ferries); iii) micro-mobility (E-rideable, E-bikes, E-scooters, Bicycles, Scooters, Mopeds, Active travel modes); and iv) small capacity - car-based solutions (e.g., rent a car, car sharing, ride-hailing, taxis). The second aspect addresses the service coverage modes within each category.

Additionally, it is necessary to recognize that the capacity of the MaaS system to offer mobility solutions depends on the variety of transport operators in each region. For this reason, classification is dependent on the type and number of services in each area, as shown in Table 3.

The final ranking on multimodality reflects the variety and percentage of main categories covered and the percentage of services that the MaaS platform serves in a region according to the average percentage of contained mobility service operators. A potential disadvantage of this scoring is that the same service may have different scores in other areas. However, it presents a considerable advantage over other classification schemes by simultaneously reflecting the offer's heterogeneity percentage of covered modes and does not penalize the classification of new MaaS systems deployed in areas of low population density and with less supply of transport.

Table 3. Classification of MaaS services regarding geographic coverage.

	Services categories coverage (CC)		Service modes Coverage (SC)	
Main Category (G)	Regional Offer (RO)	MaaS Offer (MO)	Nº of Regional Offer services (MO)	Nº of MaaS Offer Service (MO)
C1 Mass Urban Public Transport (Bus, Train Tram, LRT, BRT, Water transport, etc)	Y = 1, N = 0	y=1, no = 0	A	a
C2 Long-distance Transport (Coaches, Bus, Ferries, Regional and IC trains)	Y = 1, N = 0	y=1, no =0	B	b
C3 Micromobility (E-redeables, -E-bikes, E-sootters, Bicycles. Scooters, Mopeds, Active travel modes, etc)	Y = 1, N = 0	y=1, no =0	C	c
C4 Small/medium capacity and car-based solutions (Flexible on Demand, Taxi, Ride-hailling, car-sharing, rent a car)	Y = 1, N = 0	y=1, no = 0	D	d
		CC=∑MO/ ∑RO		SC=(a+b+c+d)/A+B+C+D)
Multimodality	(CC+SC)/2			
Ranking Multimodality	< 20 % = 1; 0-39 (%) = 2; 40-59% = 3 ; 60-79% = 4; > 79% = 5			

3.3. Functionality

The functionality is defined in two sub-pillars. The first field refers to the level of integration of services available. This sub-indicator is close to the characteristics addressed by Sochor et al. (2018). Since the information, planning, payment, and subscription services can be provided independently; a cumulative scale has been designed. One point is accumulated for each service related to general information (maps, timetables), trip planning, and ticketing. Two points are assigned for platforms offering bundling or subscription services, as we consider bundling a differentiating feature inherent to the most advanced MaaS services and an added value compared to the traditional services (Table 4).

Table 4. Classification of MaaS services regarding the integration of services (left) regarding personalization (right).

Score	Characteristics	Example	Score	IT+ Personalization	Example
Yes +1, No 0	General Info	Aimo	Yes +1, No 0	App	EU-BIKE
Yes +1, No 0	Trip Planning	Movit	Yes +1, No 0	Voyage Customisation	orariotrasporti
Yes +1, No 0	Payment and or Booking	AMT Genoa	Yes +1, No 0	Personalization	AMT
Yes +2, No 0	Bundling-Subscription	Ubigo, Navigogo,	Yes +2, No 0	Automated personalization	Google mpas
			Yes +1, No 0	IoT Integration	

The second sub-indicator is related to personalization, customization integration of the platform in a broader context of IoT and smart devices. This indicator aims to reflect the platform's potential to adapt to users' preferences, obtaining a higher ranking for platforms that do it autonomously. The category 'personalization' includes the possibility for storing personal data and preferences in the MaaS-service, such as frequently used/preferred locations, modes, stops, or trips. Voyage customization consists of the possibility for tailoring and filtering functionalities of the MaaS-service. Specific filters can be applied to customize the user trip based on some preferences. This feature includes, for instance, frequently used/preferred modes, trips, and routing criteria such as price, time, barrier-free, carbon footprint. The degree of, and need for, human intervention decreases as MaaS matures (Lyons et al., 2019). The highest level corresponds to the generalized integration mobility with other digitized services.

In the classification system reported in Table 4, the basic existence of an app is awarded one point. Manual customization and personalization options are also granted one point each. If the process involves some degree of autonomy and artificial intelligence in recognizing users' preferences, an extra point is added. The maximum score of 5 points is awarded if the MaaS platform connects beyond Mobility, interfacing with the IoT, smart buildings, and smart cities as proposed in the highest level of Traffic Technology (2018) classification system. Although experts anticipate this possibility as the most advanced level of MaaS integration, we are not aware of this feature's existence on European MaaS platforms.

3.4. Sustainability

The proposed indicator was developed to reflect the external contribution of the MaaS service in terms of sustainability. In this pillar, we consider the social sub-pillar and the environmental sub-pillar independently. In this context, for each sub-pillar, a score is defined that rewards generic objectives in a less incisive way and strongly rewards active tariff policies promoting social inclusion and environmental sustainability (Table 5).

Regarding the environmental component, a single point is an award if the service provides information on the environmental impacts of the trip or includes a generic target in the platform strategy related to environment and sustainable Mobility (e.g., contributing to reducing car ownership). In case the platform allows users to customize their trip planning based on environmental criteria (e.g., carbon footprint), the platform receives a score of 2 points. The ranking increases as the incentives for promoting eco-friendly behaviour are available. Level 3 includes gamification strategies and incentives (e.g. store discounts) to reward sustainable transport mode choices. If these incentives are based on active smart pricing policies (e.g., pricing correlated to carbon footprint), a 4-point rating is assigned. An additional bonus point is assigned if the MaaS platform is integrated with wider regional or urban planning strategies. This bonus is only assigned to those platforms, supported by a coherent public policy framework (e.g., SUMP plan), and includes clear targets and an evaluation framework to enable that the impact of MaaS on travel behaviour could be measured against local transport policy goals (Table 6).

Table 5 Classification of MaaS services regarding environmental policy.

Score	Description	Example
1	Generic Environmental Information or strategic target	Tripshare SEStran
2	Customization Environmental Goals	Free Now
3	Gamification for promotion of Environmental goals	Navigogo
4	Active or Dynamic Pricing with environmental goals. Discounts for sustainable travel choices	MTR Express
+1	Integration with regional or urban planning strategies. Clear Evaluation Framework	Riviera Transport

Table 6 Classification of MaaS services regarding societal contribution.

Score	Description	Example
+ 1	Discounts for selected groups	Stockholm MTR Express, SMTUC (Coimbra)
+ 1	Data sharing	Uber, Whim
+ 1	Promoting disability independence	Uber Stockholm, AMT Genoa TPL Linea (Liguria), Moovit Scotland
+1	Promoting healthier lifestyles and livability	Nysse public transport (Tampere), STPT / Velo TM system (Timissoara)
+1	Improving the accessibility of low-density areas	Resplus (via Samtrafiken)

Social contribution is assessed under different domains based on a cumulative scoring system as each feature can be provided independently. The inclusion of discounts for vulnerable groups through subsidized tickets or other pricing schemes is scored with 1 point. Likewise, concerns with accessibility plans and guarantees of accessibility to rural areas are also rewarded. Another considered factor is promoting disability independence by providing information and or means of transport adapted to this population's needs with special needs. The platform's data policy is also considered, namely, the use and sharing of open data. By promoting healthier lifestyles and livability, it is rewarded the initiatives that allow the integration of active modes with Public transport, crowding information or discounts, and free rides for persons with a child in a stroller/pram. It is intended to enhance the platform's contribution to increasing the network's efficiency, enabling operators to adapt the offer to the population's specific needs. Regarding this point, it should be noted that the role of platforms can be complicated since there are cases in which platforms act mutually as a marketplace and service providers. Given this ambivalence, a point to be improved is the necessity of MaaS systems to communicate the data privacy policy and the aggregated or individual data made available to operators, cities, and regional transport authorities (e.g., demand variability, OD matrices, etc.).

4. Results

This section is devoted to present how the developed ranking scheme can be applied to a representative set of mobility services highlighted in Table 7. The scores were attributed considering the data available on each platform's website, and the managers of each service were not contacted for this purpose. Therefore, city authorities' direct involvement and responsibility for each mobility service could lead to changes in the final ranking. The selection of services considered the objective of obtaining a heterogeneous set of Mobility services in countries belonging to the PriMaaS consortium. For instance, we include the Nordic MaaS references Whim and Ubigo, travel planners (Google maps and Moovit), unimodal platforms (Flixbus and Uber), ticket integrators (Resplus), the vehicle for hire (FreeNow), and public transport concessionaires (AMT GENOA). Moreover, we compare the classification against previous topological MaaS classification systems.

Table 7 allows drawing some conclusions. Among the various services analyzed, there is a clear tradeoff between coverage and functionality. Naturally, the services that cover a higher geographical area have some limitations on the perspective of the diversity of modes (Flixbus or Uber) or are mainly intended for information and travel planning purposes (Google maps). On the other hand, services with a high level of integration and multimodality have limited geographic coverage (Ubigo, AMT) or imply the existence of several accounts to operate in several cities (e.g., Whim).

Table 7 Examples of Classification of MaaS service according to the developed PriMaaS Multidimensional indicator

	Coverage		Functionality		Sustainability		Overall	Sochor et al., 2018	Transport Tech., 2018	Lyon et al., 2019
	Geo	Modes	Integration	Person	Environ	Social				
Whim (Helsinki, FI)	2	4	5	2	1	1	0.50	3	4	4
SWA Mobil (Augsburg, DE)	2	4	3	3	0	0	0.40	3	4	4
VMT App (Erfurt, DE)	2	3	3	3	0	0	0.37	2	4	4
DB Navigator (DE)	3	2	3	3	0	0	0.37	2	4	
Google Maps (Erfurt, DE)	5	3	2	4	0	1	0.50	1	0	1
Moovit (Coimbra, PT)	4	1	2	2	1	0	0.30	1	0	1
AMT (Genoa, IT)	2	4	3	3	1	3	0.60	3	3	4
Uber (Stockholm, SW)	4	1	3	3	2	1	0.40	1	NA	2
Ubigo (Stockholm, SW)	2	4	5	2	1	1	0.50	3	4	4
Resplus (Swdeen)	3	4	5	1	1	1	0.50	3	2	3
FreeNow (Timisoara, RO)	4	1	3	3	0	0	0.30	1	NA	2
Flixbus (International)	5	1	3	1	0	0	0.33	1	NA	2

Regarding sustainability, most of the companies have generic goals of contributing to green Mobility and healthier cities. Moreover, it may be expected that offering integrated mobility services could contribute to reducing private vehicle ownership. However, in practice, since MaaS systems are the last interface between mobility providers and users, we could expect more measures for actively promoting environmentally friendly Mobility (gamification, active dynamic pricing related to carbon footprint) and clear frameworks and indicators to evaluate these impacts. A clear missing indicator, for example, is the average CO_2 emissions per km travelled by a MaaS user and non-users in a given region to allow a fair assessment of the MaaS system to green Mobility

5. Discussion and conclusions

The Multidimensional indicator developed here is not intended to be considered a static indicator and replace any other previously proposed MaaS evaluation system but rather to broaden the analysis spectrum based on a holistic approach and concrete criteria. Regarding the comparison between indicators, since the scope or objectives are different, it is normal for differences to exist among the various classification systems. Each work contributed significantly to understand the MaaS phenomenon better.

The classification scheme proposed in this article involves more time-consuming work in assigning levels to each dimension, and despite the existence of concrete criteria, there is still room for uncertainty and discussion. The scoring criteria established so far are sufficiently ambitious. There is scope for progression of the various platforms in the short to medium term and should be updated as the systems evolve as with other existing classification systems (e.g. energy efficiency labelling). From the preliminary analysis, we point out the following opportunities for improvement in the MaaS ecosystem. As highlighted by previous research, to achieve the vision that MaaS proposes, there is a need for more changes to produce greater positive attitudes towards sharing and effective, sustainable MaaS. Based on this work, the following recommendations can be made:

- Progressive and bi-directional convergence in terms of geographic coverage, integration of modes and services, more ambitious vision and implementation of measures to promote green mobility and accessibility to all;
- Greater clarity in data sharing standards - upstream (mobility offer data that feeds MaaS systems) and downstream data (which aggregated demand data and with what granularity should be provided by the MaaS systems to public authorities);
- Existence of transparent indicators in terms of modal distribution and average ecological footprint of the users of each MaaS service.

The economic dimension both in terms of the viability of the MaaS platforms themselves and their contribution to the local economy should be explored in further research.

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