



Towards social life cycle assessment of mobility services: systematic literature review and the way forward

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Abstract

Purpose The main purpose of this review is to describe the state of the art of social impact assessment with a focus on mobility services. Whereas the use phase plays an important role for the assessment of services in general, the evaluation of the use phase has been underrepresented in previous social life cycle assessment studies. For that reason, particular attention has been paid to indicators, which allow the assessment of social impacts during the use phase of mobility services.

Methods Continuous efforts to mitigate climate change and to improve quality of life in cities result in new mobility solutions based on collective use. This will have a huge impact on our society transforming the use of vehicles. In order to better understand the implications for cities, society and the automotive industry, it is essential to evaluate the social impact generated along a product life cycle with particular attention to the use phase. To reach the goal, a systematic literature review was carried out with a focus on social indicators that allow assessing use phase impacts of mobility services. The indicators were analysed and allocated to stakeholder groups. Based on the analysis, a core set of indicators is proposed under consideration of data availability.

Results and discussion Based on the selected search strings, 51 publications were selected for the literature review, including 579 social indicators. The analysis revealed a wide variety and diversity of indicators that are trying to measure the same aspect. The allocation to the respective stakeholder groups showed that most of the indicators (36%) evaluate impacts regarding the stakeholder group local community. The majority of analysed indicators are of quantitative nature (63%). Nevertheless, a clear assessment method was often missing in the respective publications. Therefore, for the core set of indicators, an assessment method is proposed for every indicator.

Conclusions The results from this study can help practitioners as well as researchers in the field of urban mobility assessment as it systematically analyses social sustainability aspects. The presented data gives an overview of various indicators that are suggested in other publications, and the proposed core set of indicators can be used to evaluate different mobility services in further research.

Keywords Mobility services · Social life cycle assessment · S-LCA · Use phase · Social sustainability indicators · Systematic literature review

1 Introduction

The automotive industry will have to navigate through a number of difficult challenges in the upcoming years. With advancing climate change, the pressure to reduce CO₂ emissions

is rising. Due to urbanisation and growing population, cities around the world are fighting with rising traffic, declining air quality and limited space availability (Gross 2019). Stricter regulations regarding emissions, restrictions for private car use in cities and limited parking options are only some of the consequences. As a result, private car ownership becomes less attractive in urban areas. In addition, greater health awareness and concern for the environment support this movement away from the personal car (Morrison and Beer 2017). Considering that more than 50% of the world's population live in cities (United Nations 2011), the automotive industry is seeking alternative business models to address the challenges that result from urbanisation. Numerous new passenger transportation options, collectively called mobility services,

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have been developed over the past 15 years. These mobility services have been identified as one possible option to address the current challenges (Gould et al. 2015). Mobility services are user-centric and responsive to the needs, habits and preferences of travellers and society. They enable users to have access to transportation services for short- and long-term periods and on demand. Mobility services often blur the lines between public transportation and private ownership (Kamargianni et al. 2016). Car-sharing, ride-hailing, ride-sharing, microtransit and bike-sharing are some examples of mobility services currently being developed. Each has its own underlying service characteristics and business model (Spulber et al. 2016). Hietanen (2014) gave one of the first comprehensive definitions of mobility as a service (MaaS). He describes MaaS as a mobility distribution model that delivers users' transport needs through a single interface of a service provider. It combines different transport modes to offer a tailored mobility package. Burrows et al. (2015) defines MaaS as a new way to provide transport, which facilitates the users to get from A to B by combining available mobility options and presenting them in a completely integrated manner. The most cited definition for MaaS, however, is from the European MaaS Alliance, which defines the concept as “the integration of various forms of transport services into a single mobility service accessible on demand” (Durand et al. 2018). Despite the novelty of the MaaS concept and the challenge to describe its nature, a set of core characteristics can be derived from literature review, such as personalisation, customisation, tariff options, real-time information, trip planning, booking and ticketing as well as employed technologies like GPS, E-ticket and E-payment (Jittrapirom et al. 2017). According to these definitions, the unifying feature of any MaaS implementation is the integration of multiple mobility services. This means that car-sharing, bike-sharing, ride-hailing, etc., are not themselves MaaS without meaningful multi-modal integration. Car manufacturers (such as Daimler, BMW or Volkswagen) identified mobility services and MaaS as additional business opportunity, especially in urban areas, and are involved in car-sharing or ride-hailing operations. The years 2018 and 2019 were full of merges, acquisitions and new players in the field of mobility services. In the past 3 years, close to 1000 cities have added car-sharing alone, which is an increase of 47% (Philipps 2019). Further, scooter and bike-sharing services are growing in numbers. Two types of scooter-sharing systems can be distinguished: standing electric and moped-style scooters. In Taiwan, for example, the number of moped-style electric scooters increased ten times from 2016 to 2018, mainly due to battery-sharing systems (Pham et al. 2019). The standing electric scooters, e.g. operated by Bird or Lime, can be found in over 100 metropolitan areas around the globe. The major standing scooter-sharing service in the USA, Bird, launched its service in over 50 cities across Europe in 2019 (Shaheen et al. 2020). However, not

only scooter- and car-sharing services are growing rapidly, also bike-sharing is on the rise. According to Moon-Miklaucic et al. (2019), approximately 95% of the 1600 bike-sharing operators in 2017 were launched since 2007, with more than 200 in 2017 alone.

As different mobility services are growing in cities around the world, the question that automatically arises is whether mobility services can lead to more sustainable transportation options, thereby improving quality of life in cities. In order to answer this question, it is important to analyse sustainability impacts of these mobility services in a systematic way, considering all three dimensions of sustainability: economic, ecological and social. This is essential to avoid burden shifting; for example, an improvement regarding ecological impacts could lead to negative social impacts. Life cycle-based methodologies have been developed over time for this purpose (Curran 1996; ISO 14040 2006; Finkbeiner et al. 2010). Although a lot of research has been done concerning economic and environmental assessment, a standardised approach for social life cycle assessment (S-LCA) has yet to be agreed on (e.g. Dubois-Iorgulescu et al. 2016). Different S-LCA indicators and impact assessment methods have been applied and tested in a number of case studies (Di Cesare et al. 2018). The use phase plays an important role for the assessment of mobility services; for example, shared cars are used in a very different way than conventional cars in private ownership. The evaluation of the use phase, however, has been underrepresented in previous S-LCA case studies (Petti et al. 2016). Therefore, it is important to focus on use phase social impacts, not only to have a consistent assessment along all three dimensions of sustainability and to avoid burden shifting but also to be able to measure positive impacts. The assessment of positive impacts is crucial when analysing the impacts of mobility services; for example, an improved access to mobility, a higher degree of security or affordability should also be captured. For a deeper understanding of the study and more background information, the methodology of social life cycle assessment is introduced (Section 1.1) before analysing mobility services in the context of S-LCA and use phase assessment (Section 1.2).

1.1 Social life cycle assessment, a methodological description

S-LCA is a rather new approach compared to life cycle assessment (LCA) and life cycle costing (LCC), and it aims to address the social impacts of goods and services along their life cycle. The starting point is the established methodology of LCA according to the ISO 14040 (2006). About 26 years ago, a “social welfare impact category” was proposed in the SETAC Workshop Report (1993): “A Conceptual Framework for Life Cycle Impact Assessment”. This started the discussion on how to deal with social and socio-economic

criteria in assessing a product along its life cycle. The main topic of discussion during the second half of the 1990s was to what extent a life cycle assessment of a product or a service taking into account social criteria is different from LCA. Just like LCA, it was proposed to conduct S-LCA in line with ISO 14040 (2006). A crucial differentiation point for S-LCA is that impact categories may be assessed using different indicators depending on the stakeholder group under consideration.

An important achievement in the ongoing development of S-LCA was the issuing of the UNEP/SETAC S-LCA Guidelines in 2009. According to the UNEP/SETAC Guidelines 2009 “a social and socio-economic Life Cycle Assessment (S-LCA) is a social impact (and potential impact) assessment technique that aims to assess the social and socio-economic aspects of products and their potential positive and negative impacts along their life cycle” (UNEP/SETAC 2009). The UNEP/SETAC Guidelines (also referred to as the Guidelines hereafter) provide a good framework on how S-LCA should be conducted. The framework includes five stakeholder categories as well as six impact categories with 31 subcategories, an inventory analysis and, finally, the impact assessment. The categories identified are the following: human rights, working conditions, health and safety, cultural heritage, governance and socio-economic repercussions. The five stakeholder categories are comprised of workers, local community, society, value chain actors and consumers. The five stakeholder categories have eight, eleven, three, four and five subcategories, respectively. These subcategories are characterised with the help of more than 100 inventory indicators and published in a separate document: “The methodological sheets for subcategories in social life cycle assessment” (UNEP/SETAC 2013). However, these indicators and the corresponding reference to required raw data are only suggestions. The user can select relevant indicators and data sources, e.g. generic or specific data sources.

After the publication of the Guidelines, many S-LCAs were conducted according to the given framework (Petti et al. 2016). Though, among other shortcomings, no clear methodology for the impact assessment is given in the Guidelines: “In the impact assessment step of an S-LCA the distribution and share of positive and negative impacts is important to consider. How this should be done is an issue of further research and testing in case studies” (UNEP/SETAC 2009). This is the reason why the S-LCA research community have used various methods for the impact assessment (Russo Garrido et al. 2016). In general, the impact assessment methods can be classified into two broad categories: the performance reference point methods (type I) and the impact pathway methods (type II), as shown in Fig. 1 (Parent et al. 2010; Chhipi-Shrestha et al. 2014).

Performance reference point methods assess social impacts using performance reference points based on minimum performance levels (Franze and Citroth 2011; Ramirez et al.

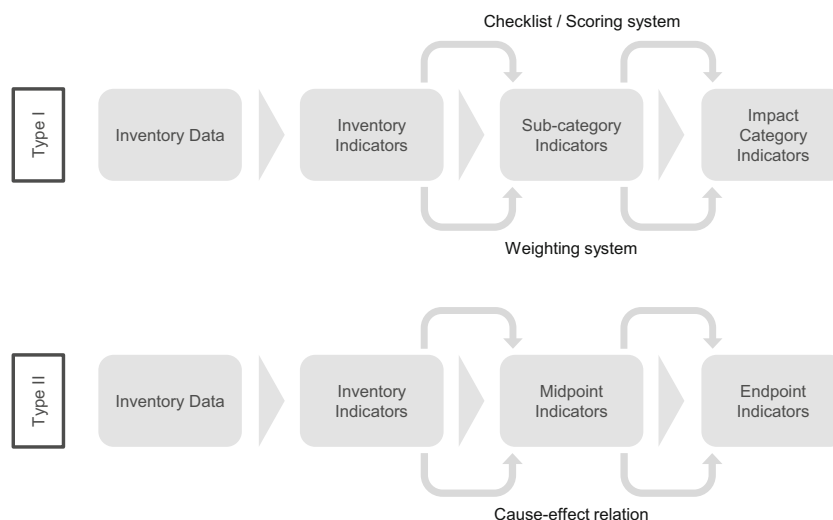
2014). For these kinds of minimum performance levels, internationally accepted standards are used such as International Labour Organization (ILO) Conventions, the ISO 26000 Guidelines and OECD Guidelines for Multinational Enterprises. Colour-coding, scoring and weighting systems are used for aggregating the inventory indicator data to impact categories (e.g. human rights). These approaches do not use cause-effect chains because the authors are of the opinion that “cause-effect relationships are not simple enough or not known with enough precision to allow quantitative cause-effect modelling” (UNEP/SETAC 2009). These approaches are included as type I impact assessment by UNEP/SETAC Guidelines.

Impact pathway methods, on the other hand, assess the social impacts by means of impact pathways as characterisation models. Midpoint indicators and/or endpoint indicators are used, comparable to LCA. These methods are based on social effects and mostly on quantitative indicators. Unlike performance reference point methods, for these methods, cause-effect chains are used (Weidema 2018). They are included in type II impact assessment by the UNEP/SETAC Guidelines. Figure 1 shows both performance reference point-based methods (type I) and impact pathway-based methods (type II).

Another important document is the *Handbook for Product Social Impact Assessment (PSIA)*, first published in 2014 and last updated in 2018. The PSIA is a more practical approach, developed mostly by industry leaders but started from the main scientific literature. Those were analysed and compared against the company strategy to identify key social topics and stakeholder categories. The PSIA refers to four main stakeholder categories: workers, small-scale entrepreneurs, local communities and users. The PSIA defines social topics for every stakeholder group. Social topics are social areas related to stakeholder groups such as working hours, community engagement or child labour. For every social topic, a performance indicator is defined. As the name suggests, performance indicators measure the performance of each social topic, for example the number of working hours per week or minimum wage paid. The performance indicators can be quantitative or qualitative. Two different types of metrics can be used: either full quantification of all data or a reference-scale approach. For the reference-scale approach, a score ranging from -2 to $+2$ is proposed. This allows to measure positive as well as negative impacts. The impact assessment method described in the PSIA suggests aggregation of performance indicators into social topic scores, stakeholder scores and a total score (Fontes et al. 2016; Goedkoop et al. 2018).

The presented social topics in the PSIA are often overlapping with the subcategories of the Guidelines. The respective indicators, however, differ greatly and target different issues, as can be seen in Table 1. For example, regarding the

Fig. 1 Performance reference point-based methods (type I) and impact pathway-based methods (type II)



stakeholder group local community, both the Guidelines and the PSIA suggest indicators to assess impacts on local employment. Nevertheless, the Guidelines, in addition, include indicators that measure access to material and immaterial resources, which are missing in the PSIA. On the other hand, the PSIA includes indicators regarding skill development, which is not included in the Guidelines. As the stakeholder group consumers, respectively users, is of importance for use phase assessment of mobility services, a focus lies on this stakeholder group. According to the Guidelines, the stakeholder group consumer covers “end-consumers as well as the consumers who are part of each step of the supply chain” (UNEP/SETAC 2009). The PSIA, however, is referring to the term ‘user’ and makes a distinction between products developed for consumers and products developed for workers, which can be seen as professional users. In that way, a distinction between primary, secondary and passive users is made. In the example of a public bus transport, the differentiation of these three kinds of users is explained. A person taking the bus from A to B is a primary user. However, the driver or the person who cleans the bus can be seen as a secondary user. Further, people who do not use, drive or maintain the bus may also be impacted, for example by exposure to potential noise or congestion. This last group of stakeholders is referred to as passive users. Therefore, the definition by PSIA is broader as it includes consumers, workers and passive users (Goedkoop et al. 2018). When analysing the stakeholder group consumers (Guidelines) and users (PSIA) in detail, some similarities as well as major differences can be found. It is notable that in the Guidelines and in the PSIA, ‘privacy’ is one of the topics that overlap. The suggested indicators, however, vary to a great extent. Whereas the Guidelines suggest indicators focusing on country rankings or strength of policies regarding privacy, the PSIA lies the focus on company implementations concerning privacy. The Guidelines, in addition, include the number of consumer complaints or complaints by regulatory bodies related to privacy as quantitative indicator, whereas the PSIA includes scale-based

indicators assessing the company’s performance, without stating any quantitative indicators. Other categories show similar variations. ‘Health and safety’ are combined into one category in the Guidelines, whereas the PSIA separates this category into two social topics. The Guidelines include the subcategories ‘Feedback mechanism’, ‘Transparency’ and ‘End-of-life responsibility’, which are missing in the PSIA. The PSIA, though, includes ‘Responsible communication’, ‘Inclusiveness’ and ‘Effectiveness and comfort’, which are not included in the Guidelines. Consequently, the stated indicators for those subcategories and social topics are not overlapping and assess different aspects. In Table 2, a full list of suggested indicators is presented according to the Guidelines and the PSIA, which reveals the different indicators in detail. The major differences in the presented categories and indicators underline that no standardised approach has been defined for category and indicator selection and highlights the necessity of further research regarding the selection of categories and indicators for the assessment of mobility services.

1.2 Mobility services in the context of S-LCA and use phase assessment

Social welfare is considered one of the main development goals of modern society. Understanding and assessing what could improve or undermine well-being is a key element in public policies. In the last years, increasing concern about urban mobility can be observed through scientific and non-scientific literature. Sustainable urban mobility has become one of the main challenges. According to Gould et al. (2015), mobility services have the potential to improve quality of life in cities by reducing the use of private cars and encouraging the diffusion of electric vehicles within cities. Further, mobility services lead to increased mobility options that may result in time saved by users or higher comfort due to, for example, closer pick-up locations (Karlsson et al. 2019).

Table 1 Subcategories and social topics as presented in the Guidelines and in the PSIA

UNEP/SETAC Guidelines	<i>Handbook for Product Social Impact Assessment (PSIA)</i>
Local community	Local community
Delocalisation and migration	
Community engagement	Community engagement
Cultural heritage	
Respect of indigenous rights	
Local employment	Employment and skill development
Access to immaterial resources	
Access to material resources	Access to tangible resources
Safe and healthy living conditions	Health and safety
Secure living conditions	
Consumer	User
Health and safety	Health
Feedback mechanism	Safety
Privacy	Privacy
Transparency	Responsible communication
End-of-life responsibility	Inclusiveness
	Effectiveness and comfort
Worker	Worker
Freedom of association and collective bargaining	Freedom of association and collective bargaining
Child labour	Child labour
Fair salary	Remuneration
Hours of work	Work-life balance
Forced labour	Forced labour
Equal opportunities/discrimination	Discrimination
Health and safety	Health and safety
Social benefit/social security	
Value chain actors	Small-scale entrepreneurs
Fair competition	Fair trading relationships
Respect of intellectual property rights	Land rights
Supplier relationships	
Promoting social responsibility	Women's empowerment
	Child labour
	Health and safety
	Access to services and inputs
	Meeting basic needs
Society	
Public commitment to sustainability issues	
Prevention and mitigation of conflicts	
Contribution to economic development	
Corruption	
Technology development	

Ride-hailing services, like Uber or Lyft, claim higher safety for their users compared to traditional taxi services due to online tracking and user review options. On the other hand, rising numbers of accidents with shared electric scooters suggest higher health and safety risks for its users (Blomberg et al. 2019).

In the automotive industry, strict health and safety requirements exist, which are monitored and controlled with respective simulations and crash tests. Interior emissions, for example, are tracked and measured to ensure drivers' and passengers' health, not to mention emissions from the internal combustion engine. However, mobility services take social

Table 2 Full list of suggested indicators for the stakeholder groups consumer (Guidelines) and user (PSIA)

UNEP/SETAC Guidelines	Handbook for Product Social Impact Assessment (PSIA)
Consumer	User
Health and Safety	Health
Quality of or number of information/signs on product health and safety (quantitative, semi-quantitative)	There is solid science-based evidence that normal use of the product enables and significantly contributes to an improved health condition for user in comparison to alternative solutions (scale-based)
Presence of consumer complaints (at national, sectorial or organisational level) (quantitative, semi-quantitative)	The company has a dossier or other evidence that shows how the product or service has been designed to create a maximum contribution to health of the user and, if applicable, encourage a healthy lifestyle (scale-based)
Total number of incidents of non-compliance with regulations and voluntary codes concerning health and safety impacts of products and services and type of outcomes (quantitative, semi-quantitative, qualitative)	The product or service conforms to all national requirements in the markets where the product is offered (scale-based)
Number of consumer complaints (quantitative/semi-quantitative)	The normal use of the product has negative health impacts on the long run (scale-based)
Presence of management measures to assess consumer health and safety (qualitative)	Any use of the product has direct negative health impacts on short and long terms (scale-based)
Quality of labels of health and safety requirements (qualitative/semi-quantitative)	The company or facility has continuous user-facing education in place to raise awareness and educate users on health-related issues associated with the product (scale-based)
	Safety
	There is solid science-based evidence that normal use of the product is safer for active or passive users than alternative solutions and that the product or service eliminates a risk in common products and services used for the same purpose (scale-based)
	The company has a dossier or other evidence that shows how the product or service has been designed to create maximum safety for active and passive users (scale-based)
	The product conforms to all national requirements regarding product safety (scale-based)
	The normal use of the product or services can cause higher risks compared to alternative solutions (scale-based)
	Any use of the product can be regarded as unsafe (scale-based)
	The company has user-facing programmes in place to raise awareness and educate users on safety risks associated with the product (scale-based)
Feedback mechanism	
Presence of feedback mechanisms (e.g. after sale services) (by organisation or sector/country) (quantitative, qualitative and semi-quantitative)	
Number of consumer complaints at the sector level (quantitative, qualitative and semi-quantitative)	
Presence of a mechanism for customers to provide feedback (quantitative, qualitative and semi-quantitative)	
Management measures to improve feedback mechanisms (quantitative, qualitative and semi-quantitative)	
Practices related to customer satisfaction, including results of surveys measuring customer satisfaction (quantitative, qualitative and semi-quantitative)	
Privacy	Privacy
Country ranking related to regulations on data-sharing (semi-quantitative)	The company has a policy to protect user data privacy (scale-based)
Country ranking related to strength of laws protecting privacy against organisations and government (semi-quantitative)	The company shares or sells one or more types of sensitive private data without user consent and without transparency that it does so (scale-based)
Country ranking related to the strength of regulatory powers to investigate privacy-related complaints (semi-quantitative)	The company uses and processes one or more types of sensitive private data without user consent and without giving users access to the content of that data and the purposes for which it is used (scale-based)
Strength of internal management system to protect consumer privacy, in general (qualitative or semi-quantitative)	The way private data are used complies with the local law in the jurisdiction where the product or service is offered (scale-based)
Number of consumer complaints related to breach of privacy or loss of data within the last year (quantitative)	If no regulation exists, the company or facility does not collect, process and share sensitive data, or the company does not store, (re)sell or use any privacy-related data (scale-based)
Number of complaints by regulatory bodies related to breach of consumer privacy or loss of data within the last year (quantitative)	The company has a PDCA process in place to exceed the minimum legal standard and to actively rise above the requirements (scale-based)
	The company has established a grievance mechanism (scale-based)

Table 2 (continued)

UNEP/SETAC Guidelines	<i>Handbook for Product Social Impact Assessment (PSIA)</i>
Transparency	<p>The company does not get any revenue from (re)selling personal data to other entities (scale-based)</p> <p>The company's commitments are publicly available (scale-based)</p>
Presence of a law or norm regarding transparency (by country and/or sector) (semi-quantitative/qualitative)	Responsible communication The product is labelled according to the regulations in the country of sale (scale-based)
Sector transparency rating; number of organisations by sector which published a sustainability report (quantitative/semi-quantitative/qualitative)	The company has a responsible communication policy (scale-based)
Non-compliance with regulations regarding transparency (semi-quantitative/qualitative)	A grievance mechanism is in place to enable feedback from users (scale-based)
Consumer complaints regarding transparency (semi-quantitative/qualitative)	No incidents of misleading communication have been found in the last year (scale-based)
Publication of a sustainability report (semi-quantitative/qualitative)	The company adheres to commonly accepted principles (scale-based)
Quality and comprehensiveness of the information available in the sustainability report or other documents regarding the social and environmental performance of the organisation (qualitative)	The communication by the company and its resellers is deliberately designed to avoid misleading claims (scale-based)
Communication of the results of social and environmental life cycle impact assessment (semi-quantitative/qualitative)	Claims made in marketing and product documentation that the product or its use supports a more sustainable lifestyle are all backed up with science-based evidence, 3rd-party market research or research following international and national standards. The evidence is publicly available and easy to access for all users and potential users (scale-based)
Certification/label the organisation obtained for the product/site (semi-quantitative/qualitative)	A mechanism in place to engage in dialogues with users and consumers (scale-based)
Company rating in sustainability indices (Dow Jones Sustainability Index, FTSE4Good, ESI, HSBC, Corporate Sustainability Index, etc.) (semi-quantitative/qualitative)	
End-of-life responsibility	
Strength of national legislation covering product disposal and recycling (semi-quantitative)	
Do internal management systems ensure that clear information is provided to consumers on end-of-life options (if applicable)? (Semi-quantitative)	
Annual incidents of non-compliance with regulatory labelling requirements (quantitative)	<p>Inclusiveness</p> <p>The company has a policy to design and market a product or service with an objective to improve affordability and accessibility (scale-based)</p> <p>The solution offered by the company is designed in such a way that it does not hinder or improve the access and use of an essential product or service by vulnerable groups (scale-based)</p> <p>The solution offered by the company is designed and marketed to give access to essential products and services to all users/to the most vulnerable groups/an income class that would not otherwise be able to afford it (scale-based)</p> <p>The company offers products and services at lower cost than the traditional solutions (scale-based)</p> <p>The solution offered by the company is not accessible or useable by vulnerable people, even though these groups could really benefit from having access (scale-based)</p>
	<p>Effectiveness and comfort</p> <p>The product is best in class in terms of effectiveness, efficiency or comfort (scale-based)</p> <p>The product or service solution performs average in terms of effectiveness or comfort or does not affect it compared to standard solutions (scale-based)</p> <p>The product or service solution makes users less effective or comfortable compared to standard solutions (scale-based)</p> <p>The product or service solution contributes to ineffectiveness or discomfort (scale-based)</p> <p>The company has a dossier or other evidence that shows how the product or service has been designed to maximise effectiveness, efficiency or comfort (scale-based)</p> <p>There is science-based evidence or 3rd-party market research that the offered product and service solution makes the user or use much more effective or comfortable compared to standard solutions (scale-based)</p>

impacts to a new level, as the stated examples emphasise. To be able to better understand the implications of mobility services and to improve quality of life in cities, it is therefore essential to evaluate the social impacts in a systematic way, including all related stakeholder groups. In doing so, it is necessary to be able to measure potential positive impacts, for example time saved or increased comfort.

Although the UNEP/SETAC Guidelines as well as the PSIA are applicable for both products and services, most applications focus on products. Petti et al. (2016) systematically investigated S-LCA case studies that have been conducted according to the UNEP/SETAC Guidelines between 2010 and 2015. Among the analysed case studies, 32% used system boundaries from ‘cradle to grave’ and 3% from ‘gate to gate’, making it only 35% of the studies that consider use phase impacts. In addition, only 7% of the studies conducted according to the UNEP/SETAC Guidelines consider the stakeholder group ‘consumers’. Zanchi et al. (2018) analysed S-LCA applications in the automotive sector. Out of the thirteen identified S-LCA applications in the automotive sector, only four considered the stakeholder group ‘local community’ and none of the analysed S-LCA applications considered the stakeholder group consumers. Tarne et al. (2017) focused on LCSA in the automotive industry and thereby analysed S-LCA studies. A comparatively low maturity of S-LCA in the automotive sector was identified. Whereas most of the applications in the automotive sector focus on materials and automotive parts, none of the analysed studies applied the S-LCA framework to mobility services (Zanchi et al. 2018). Consequently, the question is whether the suggested indicators in the Guidelines and the PSIA are adequate for the assessment of mobility services, especially the ones recommended for the stakeholder group consumers and users (Table 2).

Indicators help to transfer complex issues into understandable figures and allow to monitor goals as well as to measure targets. They can establish a common language to communicate impacts and support in decision-making. The choice of indicators is therefore essential as it directly affects management and decision-making. Nevertheless, choosing the right indicators is challenging, as hundreds of indicator systems are available, typically each developed for a specific purpose (Huovila et al. 2019). Considerable efforts have been made to develop indicators that can be used to assess urban mobility, often in the context of measuring the sustainability of a city as a whole. However, these indicators do not fulfil the specific requirements to measure the impact of mobility services. For this reason, a systematic literature review was carried out with a focus on social indicators that allow the assessment of the use phase impacts of mobility services. The indicators were analysed and allocated to stakeholder groups in order to identify hotspots as well as weaknesses. Finally, the indicators are compared to the ones suggested in the Guidelines and the PSIA in order to lead the way towards a comprehensive

and inclusive set of indicators for the assessment of mobility services.

2 Methods

For the systematic literature review, Web of Science, ScienceDirect and Springer Link were used. As search strings, multiple notations of ‘life cycle assessment’, ‘S-LCA’, ‘sustainable urban mobility’, ‘social sustainability’ or ‘sustainable urban transportation’ were used in combination with the following keywords:

- (LCA OR ‘Life Cycle Assessment’ OR ‘Life-cycle assessment’ OR ‘Life-cycle-assessment’) AND ‘Mobility’ AND ‘Mobility Service*’
- (LCA OR ‘Life Cycle Assessment’ OR ‘Life-cycle assessment’ OR ‘Life-cycle-assessment’) AND ‘Sustainable City’
- (LCA OR ‘Life Cycle Assessment’ OR ‘Life-cycle assessment’ OR ‘Life-cycle-assessment’) AND ‘City’ AND ‘Indicator*’
- (‘Social life cycle assessment’ OR ‘Social LCA’ OR ‘S-LCA’) AND ‘Mobility’ AND ‘Mobility Service*’
- (‘Social life cycle assessment’ OR ‘Social LCA’ OR ‘S-LCA’) AND ‘Sustainable City’
- (‘Social life cycle assessment’ OR ‘Social LCA’ OR ‘S-LCA’) AND ‘City’ AND ‘Indicator*’
- (‘Sustainable urban mobility’) AND (‘Social indicator*’)
- (‘Social sustainability’) AND (‘transportation systems’)
- (‘Sustainable urban transportation’) AND (‘social indicator*’)

Excluded from the results were all secondary studies, duplicate studies, primary studies not written in English or grey literature. Only articles from peer-reviewed journals written in English were selected, published between 2011 and 2019. The selection process can be described in four phases. In the first phase, only publications that include social indicators were filtered. In the second phase, the social indicators were categorised according to associated stakeholder groups and clustered in an analytical grid. The selection of the stakeholder groups was done in accordance with the Guidelines (UNEP/SETAC 2009) and the corresponding methodological sheets (UNEP/SETAC 2013): workers, local community, society, value chain actors and consumers. While identifying the stakeholder group, it was also analysed whether the indicators are of quantitative (q), semi-quantitative (s) or qualitative/descriptive (d) nature. In some cases, the indicator type was not stated and was therefore not identified (n.i.). In the third phase, indicators were selected based on their relevance for mobility services. For this purpose, ‘relevance’ was defined as suggested by Laprise et al. (2015): the indicator reflects the

performance in relation to a given criterion. In this case, the criterion is sustainable urban mobility. This allows to select, for example, an indicator assessing impacts on space occupancy and, at the same time, allows to not select, for example, an indicator assessing the number of beds of medical institutions per capita, as this does not measure the performance of a mobility service in relation to sustainable urban mobility. In a subsequent step, measurability as well as data availability were examined. For the selection based on measurability, the following criteria were fixed: (1) The indicator is already being measured or can be measured with little extra effort, (2) the measurement will show change over a year and (3) the measurement can be compared with other mobility services (Kunstler et al. 2016). In the fourth phase, the selected indicators were supplemented by missing aspects presented in the Guidelines and the PSIA. In Fig. 2, the four phases are illustrated. After the systematic literature research in the stated databases and identification of all publications that include relevant social indicators, a total of 51 papers were selected, as shown in Table 3.

3 Results and discussion

Based on the search strings and the focus on urban mobility, the selected publications focus on sustainability assessment of cities (47%), transportation systems (21%), neighbourhoods (16%) or infrastructure/building projects (8%). Only a few studies matched the search criteria with a different focus, for

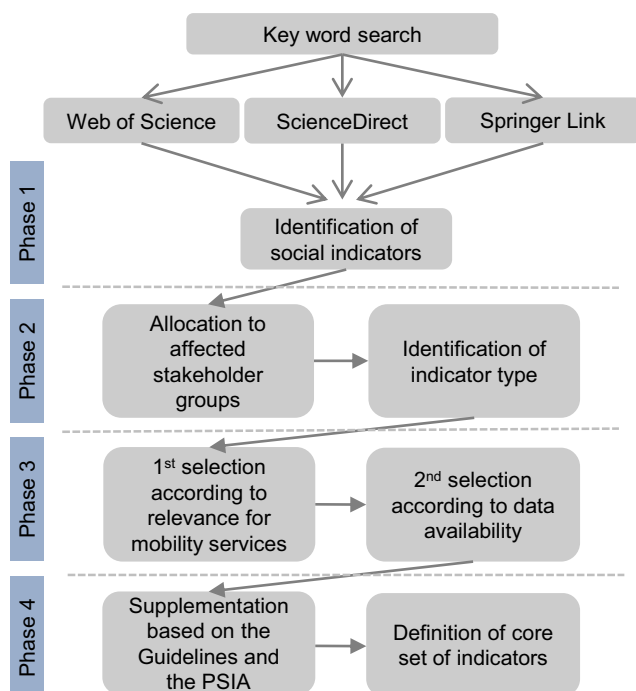


Fig. 2 Method for the definition of set of indicators to assess social sustainability of mobility services

example social aspects in the mining sector or domestic water reuse (8% others) (see Fig. 3).

In total, 579 social indicators were identified (phase 1). The allocation of the indicators to associated stakeholder groups and the identification of the indicator type (phase 2) demonstrate that out of the identified indicators, 209 (36%) assess social impacts that affect the stakeholder group local community. One hundred seventy (29%) of the indicators are societal or institutional, whereas 159 (28%) target the stakeholder group ‘consumer’. Thirty-seven (6%) of the analysed indicators assess social impacts related to the stakeholder group ‘worker’ and only 4 (1%) ‘value chain actors’, which can be seen in Fig. 4.

The fact that the stakeholder group worker is underrepresented might be unexpected. This result differs from other S-LCA case study reviews where 32% considered workers (Petti et al. 2016). However, this outcome can be explained by the focus of this literature review on the assessment of use phase impacts. Consequently, indicators assessing impacts regarding the local community, society or consumers become more prominent, whereas workers and value chain actors get less attention.

Out of the total amount of 579 social indicators, 365 (63%) are quantitative, whereas 74 (13%) are semi-quantitative. Sixty-one indicators (10%) are of qualitative or descriptive nature, and for 79 (14%), the assessment method was not stated and therefore the type of indicator could not be identified (see Fig. 5). An overview of the results of phase 2 can be seen in Table 4.

In the subsequent step, for each stakeholder group, all indicators that fulfil the defined precondition regarding relevance for the assessment of mobility services were filtered and grouped into categories. For every indicator, data availability was analysed. For this purpose, different possible data sources were examined, including geographic information systems, publicly available data from mobility service providers as well as the social hotspots database (SHDB) and data collection possibilities described by the methodological sheets (UNEP/SETAC 2013). For the analysis of data availability, three classifications were used in line with Litman and Burwell (2006): (1) limited, may require special data collection; (2) often available but not standardised; and (3) usually available in standardised form. This is necessary, as some indicators require data that may be difficult to obtain or evaluate. The costs of data collection and ease of use should be taken into consideration when selecting indicators. Nevertheless, indicators should not be selected only based on data availability, as important aspects may be missed (Science for Environment Policy 2018).

The analysis of the filtered and grouped indicators (phase 3, see Fig. 2) reveals that most of the indicators of the stakeholder group local community assess impacts on public space (29%). Many different indicators can be found in this

Table 3 Summary table of the analysed publications

Author	Year	Focus area	Title
Ameen and Mourshed	2019	Cities	Urban sustainability assessment framework development: the ranking and weighting of Iraqi indicators using analytic hierarchy process (AHP)
Anisurrahman and Alshuwaikhat	2019	Cities	Determining sustainability assessment indicators for the Holy City of Makkah, Saudi Arabia
Aparcana and Salhofer	2013	Others	Development of a social impact assessment methodology for recycling systems in low-income countries
Azami et al.	2015	Cities	Recognition of urban unsustainability in Iran
Bandeira et al.	2018	Transportation systems	A fuzzy multi-criteria model for evaluating sustainable urban freight transportation operations
Bui et al.	2017	Others	Proposal of an indicator-based sustainability assessment framework for the mining sector of APEC economies
de Oliveira Cavalcanti et al.	2017	Cities	Sustainability of urban mobility projects in the Curitiba metropolitan region
Choon et al.	2011	Cities	A sustainable city index for Malaysia
Ding et al.	2015	Cities	An inclusive model for assessing the sustainability of cities in developing countries
Dizdaroglu and Yigitcanlar	2014	Neighbourhoods	A parcel-scale assessment tool to measure sustainability through urban ecosystem components: the MUSIX model
Dur et al.	2014	Neighbourhoods	A spatial-indexing model for measuring neighbourhood-level land-use and transport integration
Feleki et al.	2018	Cities	Characterisation of sustainability in urban areas: an analysis of assessment tools with emphasis on European cities
Fouda and Elkhazendar	2019	Cities	A criterion for modelling the 'live-and-work' city index using sustainable development indicators
Gonzalez-Garcia et al.	2018	Cities	Assessing the sustainability of Spanish cities considering environmental and socio-economic indicators
Haghshenas and Vaziri	2012	Cities	Urban sustainable transportation indicators for global comparison
Harijani et al.	2017	Others	A multi-objective model for sustainable recycling of municipal solid waste
Hély and Antoni	2019	Cities	Combining indicators for decision making in planning issues: a theoretical approach to perform sustainability assessment
Jasti and Ram	2018	Transportation systems	Integrated performance assessment and service level benchmarking of urban bus system using fuzzy logic
Kawakubo et al.	2018	Cities	Sustainability assessment of cities: SDGs and GHG emissions
Laprise et al.	2018	Neighbourhoods	An operational monitoring tool facilitating the transformation of urban brownfields into sustainable neighbourhoods
Li and Li	2017	Cities	Assessing urban sustainability using a multi-scale, theme-based indicator framework: a case study of the Yangtze River Delta region, China
Lu et al.	2017	Neighbourhoods	Measuring sustainability at the community level: an overview of China's indicator system on National Demonstration Sustainable Communities
Lu et al.	2016	Cities	Sustainability investigation of resource-based cities in north-eastern China
Mansourianfar and Haghshenas	2018	Infrastructure or building projects	Micro-scale sustainability assessment of infrastructure projects on urban transportation systems: case study of Azadi district, Isfahan, Iran
Mapar et al.	2017	Cities	Sustainability indicators for municipalities of megacities: integrating health, safety and environmental performance
Miller et al.	2016	Transportation systems	Analysing the sustainability performance of public transit
Onat et al.	2014	Transportation systems	Towards life cycle sustainability assessment of alternative passenger vehicles
Opher et al.	2018	Others	Comparative life cycle sustainability assessment of urban water reuse at various centralization scales
Oregi et al.	2016	Neighbourhoods	Sustainability assessment of three districts in the city of Donostia through the NEST simulation tool
Oses et al.	2017	Transportation systems	A multidisciplinary sustainability index to assess transport in urban areas: a case study of Donostia-San Sebastian, Spain
Oswald Beiler and Mohammed	2016	Transportation systems	Exploring transportation equity: development and application of a transportation justice framework
Papoutsis et al.	2018	Transportation systems	Sustainability assessment of retail logistics solutions using external costs analysis: a case-study for the city of Antwerp
Phillis et al.	2017	Cities	Urban sustainability assessment and ranking of cities
Rajak et al.	2016	Transportation systems	Sustainable transportation systems performance evaluation using fuzzy logic
Rajaonson and Tanguay	2017	Cities	A sensitivity analysis to methodological variation in indicator-based urban sustainability assessment: a Quebec case study
Reisi et al.	2014	Cities	Transport sustainability index: Melbourne case study
Robati et al.	2015	Cities	Urban environment quality assessment by using composite index model
Saleem et al.	2018	Infrastructure or building projects	Life cycle thinking-based selection of building facades
Shi et al.	2011	Cities	Temporal changes in sustainable development level for Lijiang City
Shmelev and Shmeleva	2018	Cities	Global urban sustainability assessment: a multidimensional approach
Stender and Walter	2018	Infrastructure or building projects	The role of social sustainability in building assessment
Tan et al.	2018	Cities	A system dynamics model for simulating urban sustainability performance: a China case study
Ustaoglu et al.	2017	Infrastructure or building projects	Scenario analysis of alternative land development patterns for the Leipzig-Halle region: implications for transport-land-use sustainability
Verseckiene et al.	2017	Transportation systems	Evaluation of alternatives to integrate special transportation services for people with movement disorders
Wey and Huang	2018	Transportation systems	Urban sustainable transportation planning strategies for liveable city's quality of life
Wu et al.	2018	Cities	Examining component-based city health by implementing a fuzzy evaluation approach

Table 3 (continued)

Author	Year	Focus area	Title
Xu and Coors	2012	Neighbourhoods	Combining system dynamics model, GIS and 3D visualization in sustainability assessment of urban residential development
Yi et al.	2019	Cities	Assessment of city sustainability using MCDM with interdependent criteria weight
Yigitcanlar et al.	2015	Neighbourhoods	Towards prosperous sustainable cities: a multiscale urban sustainability assessment approach
Zheng et al.	2017	Neighbourhoods	Neighborhood sustainability in urban renewal: an assessment framework
Zope et al.	2019	Transportation systems	Benchmarking: a tool for evaluation and monitoring sustainability of urban transport system in metropolitan cities of India

category. However, most of them measure green space or park area in square metres, often in relation to the total population of the study area. Although most of the indicators in this category are quantitative, few qualitative or semi-quantitative indicators can also be found, for example the assessment of harmony with the surroundings. Twenty-three percent of the indicators for the stakeholder group local community assess impacts on air quality. Most of the indicators in this category are quantitative, measuring air pollutant emissions. Nevertheless, mortality effects of air pollutants or actions to reduce air pollutants are additional measurements suggested in the reviewed literature. Indicators that evaluate impacts on local employment take third place with 16%. In this category, the variety of indicators is much smaller, often measuring the same aspect formulated in different ways. The indicators primarily target job opportunities, job availabilities or unemployment rate. Indicators assessing noise pollution (12%) and community engagement (8%) follow. All of the indicators stated to measure noise pollution are quantitative; however, the indicators themselves differ a lot. Some measure the area in square metres, others the percentage of population that is affected by noise pollution and yet others suggest measuring noise complaint cases. The indicators that assess impacts on community engagement are mostly qualitative, targeting, for example, the degree of population participation, the degree of information access or the existence of a response system. Seven percent of the indicators target effects on space

occupancy. Here, again a great variety of indicators was found in the reviewed literature. Some indicators measure land consumption or green space destruction, and others focus on per capita area of paved roads or the proportion of land paved for transport facilities. Only 2% of the indicators focus on citizens’ satisfaction measured either qualitatively (degree of social acceptance) or quantitatively (number of complaints or number of citizens satisfied with their local area). Three percent of the indicators measure other aspects not previously stated, such as light emissions or the impact on non-motorised transportation.

Regarding the stakeholder group consumers, the majority of indicators target accessibility (41%). Here, the indicators partly assess the expansion of infrastructure, e.g. measuring the length of mass transport network or road density, and partly the transportation options itself, e.g. the number of transport points or the number of passengers per transport mode. Indicators assessing safety take the second position (25%), followed by indicators assessing convenience (11%). The indicators assessing safety can also be classified into indicators measuring the safety of the infrastructure, e.g. safe pedestrian pathways, and indicators assessing safety of the transport mode itself, e.g. mortality rate or accidents rate. The analysed indicators assessing convenience are mostly qualitative or semi-qualitative. They measure many different aspects ranging from thermal comfort and ventilation potential to supply the reliability and punctuality of deliveries.

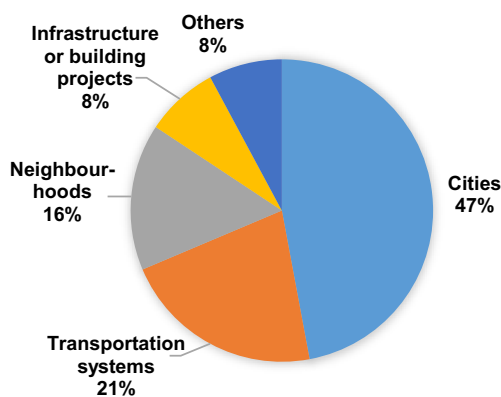


Fig. 3 Identified focus areas from indicators analysed

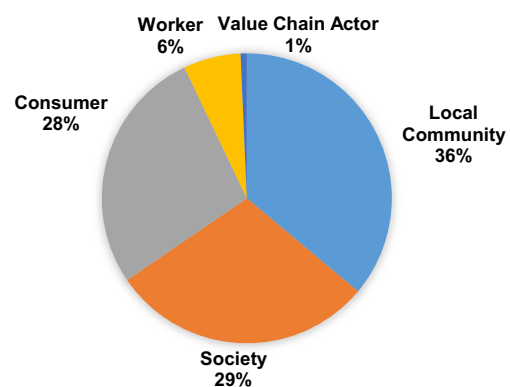


Fig. 4 Social indicators categorised by stakeholder groups from the 51 reviewed publications

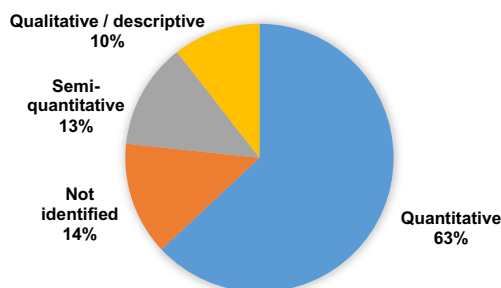


Fig. 5 Social indicators categorised by the type of indicator

Indicators targeting inclusiveness and affordability take the last place with 7%, respectively. All of the reviewed indicators measuring inclusiveness are either semi-quantitative or qualitative. They evaluate, for example, inclusive design or the degree of universal access. Indicators assessing affordability, however, are mostly quantitative and measure e.g. household expenses on transportation or costs for public transport services. Nine percent of the indicators that assess impacts on consumers target other aspects, for example the average duration of travel to work or intermodal terminals.

The vast majority of indicators that assess impacts regarding the stakeholder group worker assess health and safety issues (53%). Different aspects are suggested to measure in the reviewed literature for this category, mainly of quantitative nature, such as the number of fatal and non-fatal accidents or compensated occupational problems. However, semi-quantitative indicators are also stated, for the assessment of work environment or appropriate working equipment. Thirteen percent of the indicators for workers assess fair salary. Here, not only the compensation itself is suggested to measure but also whether the workers are paid regularly. Nine percent of the indicators evaluate training and education, including the existence of educational programmes for self-development and the number of school absences of children. To evaluate discrimination, the suggested indicators (6%) assess equality and diversity as well as whether formal policies against discrimination exist. Only small numbers (3%) of indicators are found in the reviewed literature that evaluate child labour, freedom of association and collective bargaining as well as work-life balance. At this point, it should be highlighted that due to the selected search terms and the focus on mobility services, the stakeholder groups worker and value chain actors are underrepresented, as stated above (Fig. 4). Concerning the stakeholder group value chain actors, all of the identified indicators assess supplier relationships. It can therefore be assumed that other categories and indicators may need to be added for a holistic assessment. For the stakeholder group society, 63% of the analysed indicators assess health impacts, mainly in the form of CO₂ emissions or other greenhouse gases. Twenty-five percent of the indicators focus on urban development and evaluate the existence of an urban development plan or compatibility with local urban mobility

policies. Finally, 13% of the reviewed indicators of the stakeholder group society target tax income.

In Table 5, the filtered and grouped indicators are shown for the respective stakeholder groups, including information regarding indicator type and data availability (results of phase 3). For reasons of clarity and comprehensibility, indicators that are mentioned several times or evaluate the same aspect are only stated once. Overall, Table 5 not only demonstrates a huge variety and diversity of indicators intending to measure the same aspect. Many indicators are, in addition, not clearly defined, which makes them difficult to measure. The lack of concrete calculation methods in combination with a lack of data constitutes a major challenge and leads to the necessity for experts and decision-makers to select a calculation method of their own.

Therefore, on the basis of the above-stated analysis, a core set of indicators is proposed, including a description and concrete measurement for each indicator. For this core set of indicators, data availability and consultations of experts in the field of urban mobility were taken into account. For a holistic set of indicators, the results from the literature review were compared to the social topics, subcategories and indicators in the Guidelines and in the PSIA. Missing aspects, especially for the stakeholder groups workers and value chain actors, were added for a comprehensive assessment. Here again, only missing aspects that fulfil the defined precondition regarding relevance for the assessment of mobility services were added. This core set of indicators is presented in Table 6 (results of phase 4). For all core set indicators, a 5-point scale from -2 to +2 is defined, including underlying performance reference points. In addition to Table 6, the reference scale and performance reference points can be found in Table 7 (quantitative indicators) and Table 8 (qualitative indicators).

For the assessment of impacts regarding public space, the majority of indicators focus on the assessment of green areas or public open space (see Table 5). Mobility services, just like other transportation systems, require infrastructure, which may lead to green space destruction. At the same time, higher efficiency or occupancy rate may also lead to less space occupancy and, consequently, to new possibilities for green or open space. Therefore, an indicator evaluating these aspects is essential and included in the core set. For the evaluation of air quality, relevant air pollutants, as suggested in the reviewed literature, are selected and measured per passenger kilometre. For the effects on employment, two indicators are suggested for the core set. One measures the percentage of employees hired and the other the percentage of employees hired locally during the study period. In that way, general job creation as well as local effects can be measured. For the assessment of noise pollution, two main assessment methods were identified. One targets the populated area in square metres that is exposed to noise pollution (Mansourianfar and

Table 4 Analysis of the indicators and allocation to stakeholder group (count and type of indicator)

Author	Year	Focus area	Local community	Consumers	Worker	Value chain actors	Society
Ameen and Mourshed	2019	Cities	12 d	11 d	2 d		11 d
Anisurrahman and Alshuwaikhat	2019	Cities	3 s	3 s			8 s
Aparcana and Salhofer	2013	Others			26 s		
Azami et al.	2015	Cities	2 q	1 q			4 q
Bandeira et al.	2018	Transportation systems	3 q	1 q			1 q
Bui et al.	2017	Others	5 q		3 q		
de Oliveira Cavalcanti et al.	2017	Cities	4 q	8 q			1 q
Choon et al.	2011	Cities	3 q	2 q			6 q
Ding et al.	2015	Cities	2 n.i.	2 n.i.			1 n.i.
Dizdaroglu and Yigitcanlar	2014	Neighborhoods	3 q	1 q			
Dur et al.	2014	Neighborhoods	9 q	9 q			1 q
Feleki et al.	2018	Cities	8 q	2 q			1 q
Fouda and Elkhazendar	2019	Cities	9 q	4q			11 q
Gonzalez-Garcia et al.	2018	Cities	2 q	2 q			4 q
Haghshenas and Vaziri	2012	Cities	2 q	4 q			
Harijani et al.	2017	Others	4 d	1 d	1 d	1 d	
Hély and Antoni	2019	Cities	5 d	3 d			
Jasti and Ram	2018	Transportation systems	1 q, 1 n.i.	8 q, 1 n.i.			
Kawakubo et al.	2018	Cities	7 q	1 q			14 q
Laprise et al.	2018	Neighborhoods	19 s	5 s			5 s
Li and Li et al.	2017	Cities	6 q	2 q			2 q
Lu et al.	2017	Neighborhoods	4 q				7 q
Lu et al.	2016	Cities	6 q				3 q
Mansourianfar and Haghshenas	2018	Infrastructure or building projects	5 q	2 q			
Mapar et al.	2017	Cities	9 n.i.	7 n.i.	3 n.i.	3 n.i.	15 n.i.
Miller et al.	2016	Transportation systems	5 q	9 q			
Onat et al.	2014	Transportation systems	3 q		2 q		1 q
Opher et al.	2018	Others	1 q, 2 d	2 q, 4 d			1 q, 1 d
Oregi et al.	2016	Neighborhoods	3 s	2 s			3 s
Oses et al.	2017	Transportation systems	4 q	3 q			1 q
Oswald Beiler and Mohammed	2016	Transportation systems	1 q	3 q			2 q
Papoutsis et al.	2018	Transportation systems	5 q	3 q			
Phillis et al.	2017	Cities	6 q	1 q			16 q
Rajak et al.	2016	Transportation systems	1 q, 7 n.i.	3 q, 8 n.i.			2 q, 2 n.i.
Rajaonson and Tanguay	2017	Cities	5 q	1 q			7 q
Reisi et al.	2014	Cities	2 q	3 q			1 q
Robati et al.	2015	Cities	2 q	1 q			2 q
Saleem et al.	2018	Infrastructure or building projects	1 q				
Shi et al.	2011	Cities	3 q				3 q
Shmelev and Shmeleva	2018	Cities					3 q
Stender and Walter	2018	Infrastructure or building projects	3 d				
Tan et al.	2018	Cities	4 q	1 q			4 q
Ustaoglu et al.	2017	Infrastructure or building projects	3 n.i.	9 n.i.			
Verseckiene et al.	2017	Transportation systems	2 q	1 q, 6 n.i.			1 q
Wey and Huang	2018	Transportation systems	2 q	3 q			1 q
Wu et al.	2018	Cities	8 q	2 q			5 q
Xu and Coors	2012	Neighborhoods	2 q	1 q			5 q
Yi et al.	2019	Cities	4 q				4 q
Yigitcanlar et al.	2015	Neighborhoods	4 q	7 q			

Table 4 (continued)

Author	Year	Focus area	Local community	Consumers	Worker	Value chain actors	Society
Zheng et al.	2017	Neighborhoods	7 q	2 q			8 q
Zope et al.	2019	Transportation systems	2 q	4 q			2 q

q, quantitative indicator(s); s, semi-quantitative indicators; d, qualitative (descriptive) indicator(s); n.i., indicator type not identified

Haghshenas 2018; Fouda and Elkhazendar 2019), and the other measures the hindrance of population by traffic noise based on a weighting factor for population density (Oses et al. 2017). Due to the difficult data situation for noise pollution, both indicators were adopted for the core set and can be applied according to data availability. For the evaluation of community engagement, though, the literature review presents many different qualitative indicators and, often, a clear assessment method is not stated in the respective publications (Mapar et al. 2017; Laprise et al. 2018; Ameen and Mourshed 2019). Therefore, it is proposed to use the qualitative, scale-based assessment method according to the PSIA, which evaluates the degree of population participation. This international handbook offers a transparent and clearly defined 5-point scale from -2 to $+2$, including underlying performance indicators, that is already internationally recognised for the assessment of community engagement (Goedkoop et al. 2018). This type of assessment method is part of type I impact assessment (see Fig. 1). A major advantage and reason for the selection of this type of assessment approach is the possibility to measure positive as well as negative impacts.

As previously mentioned, the literature review revealed various indicators for the assessment of space occupancy, often with a focus on a specific transportation mode. For the core set, however, the indicators stated in the literature are summarised and generalised. That way, three indicators are suggested for the core set, namely direct and indirect space occupancy for the different mobility modes in relation to passenger kilometre and in relation to the total study area. Direct space occupancy refers to e.g. roads, cycle lanes or railways, whereas indirect space occupancy refers to open or private parking, stations, service areas or petrol stations (WBCSD 2015). As data availability might be limited for this indicator, space occupancy (excluding infrastructure) in relation to green and open space is also included. Hereby, the different indicators can be applied according to data availability. In the reviewed literature, 2% of the indicators evaluate citizens' satisfaction. However, the indicator evaluating community engagement already includes citizens' opinion and the possibility to give feedback, which is why this aspect is not included additionally in the core set.

As already stated, two main aspects were identified in the reviewed literature to evaluate accessibility for the stakeholder group consumers. One is the expansion of infrastructure, e.g. the length of mass transport network or road density and the

other transportation options itself, e.g. the number of transport points or the number of passengers per transport mode. For the core set, the latter is selected, as the expansion of infrastructure is difficult to capture with one single indicator that is suitable for the different mobility options (Robati et al. 2015; Li and Li 2017; Fouda and Elkhazendar 2019). Out of the indicators that were suggested in the literature to assess safety of consumers, the number of fatal and non-fatal accidents in relation to passenger kilometre was adopted as a quantitative indicator, for data availability reasons. As previously mentioned, diverse indicators were found in the literature to measure convenience, most of them of qualitative or semi-qualitative nature. However, with the aim of quantifying convenience and for data availability reasons, punctuality of deliveries was selected for the core set, measuring the number of punctual trips in relation to the total number of trips. For mobility options, which can be used on demand without waiting time, zero delayed trips can be assumed. This indicator supplements the indicator selected for accessibility, as the number of transport points within the study area also indirectly affects convenience. The higher the number of e.g. car-sharing cars or electric scooters within the study area, the lower the necessary walking time to the nearest transport point, which, in turn, leads to higher convenience. For the assessment of inclusiveness, all of the indicators in the reviewed literature were either semi-quantitative or qualitative or the assessment method was not stated (Verseckiene et al. 2017; Jasti and Ram 2018). This emphasises the difficulty to quantify inclusiveness. Therefore, the scale-based indicator as stated in the PSIA with the already mentioned clearly defined 5-point scale with corresponding performance indicators is suggested for the core set (Goedkoop et al. 2018). For the assessment of affordability, however, a quantitative indicator is selected, evaluating the trip fare for different transport modes in relation to average income. This way, local income differences can be considered. Although no indicators were found in the reviewed literature that measure data privacy or evaluate consumers' feedback, these two indicators were stated in the Guidelines and in the PSIA (see also Table 2). Therefore, these two indicators were included in the core set. For the assessment of data privacy, the scale-based approach was adopted according to the PSIA (Goedkoop et al. 2018), whereas to measure consumer satisfaction, the number of consumer complaints was selected based on the Guidelines (UNEP/SETAC 2013).

Table 5 Most frequently assessed categories and indicators used for the respective stakeholder groups

Category	Frequency in %	Indicator	Type of indicator	Data availability
Local community Public space	29	Public access to open space	Quantitative	2
		Green space area in m ² /total number of population	Quantitative	2
		Green areas availability	Semi-quantitative	2
		Ratio green coverage of built-up areas	Quantitative	2
		Per capita park green area	Quantitative	2
		Harmony with the surroundings	Qualitative	1
		Proximity to green spaces	Semi-quantitative	1
		Coverage of public green space in built area	Quantitative	2
		Averaged green space per resident (m ² per capita)	Quantitative	2
		Land use change	n.i.	1
Air quality	23	Land use mix	Quantitative	1
		Concentration of air pollutant gases and particulates in microgram/m ³	Quantitative	3
		Particulate matter formation potential (PMFP) based on ReCiPe	Quantitative	3
		Number of days with exceeded thresholds for monitored concentrations of SO ₂ , NO ₂ , CO, O ₃ , PM ₁₀ and PM _{2.5}	Quantitative	3
		Average annual emissions of NO ₂	Quantitative	3
		Total health/medical costs, crop losses, building damages, etc., caused by the impacts of air pollution	Quantitative	1
		Emission intensity of air pollutants (SO ₂ , CO, NO _x , PM ₁₀ and PM _{2.5})/km	Quantitative	3
		Emissions of particles per year (%)	Quantitative	3
		Air quality index	Quantitative	3
		Mortality effects of air pollutants	Quantitative	1
Local employment	16	Actions to reduce air pollutant emissions	Semi-quantitative	2
		Creating job opportunities	Qualitative	1
		Maintenance work hours	Quantitative	2
		Number of employees	Quantitative	3
		Proportion of work carried out by local companies	Semi-quantitative	1
		Jobs availability	Semi-quantitative	1
Noise pollution	12	Disposable income of urban residents	Quantitative	2
		Unemployment rate	Quantitative	3
		% area inhabited exposed to traffic noise pollution greater than 65 dB	Quantitative	1
		Exposure to noise level above 65 dB in m ²	Quantitative	1
		Percent of noise pollution exceeding national standard (%)	Quantitative	2
Community engagement	8	Average emissions of noise	Quantitative	2
		Noise complaint cases	Quantitative	1
		Reclamation system	Qualitative	2
		Participatory process	Qualitative	2
		Social cohesion	Qualitative	1
		Local residents participation in planning process	Semi-quantitative	2
		Stakeholder consultation	Qualitative	2
		Degree of population participation	Semi-quantitative	1
Degree of information access	Semi-quantitative	1		
Space occupancy	7	Degree of integration of an evaluation process	Semi-quantitative	1
		Existence of a direct participation structure	Qualitative	2
		Existence of quick response system	Qualitative	2
		Space occupancy in m ²	Quantitative	2
		Land consumption in m ²	Quantitative	2
		Green space destruction	Quantitative	1
		Land area consumed by transit facilities	Quantitative	1
		Per capita area of paved roads	Quantitative	1
Citizens satisfaction	2	Portion of land paved for transport facilities	Quantitative	1
		Surface for transportation infrastructure	Quantitative	1
		Social acceptance	Qualitative	1
		Total number of complaints	Quantitative	1
Other	3	Total number of citizens satisfied with their local area	Quantitative	1
		Light pollution	Semi-quantitative	1
		Degree of prevention of light emissions	Semi-quantitative	1
Consumers Accessibility	41	Impact on non-motorised transport	Semi-quantitative	1
		Number of transport points within the study area	Quantitative	1
		Number of passengers	Quantitative	2
		Transport diversity/integration	n.i.	1
		Public transport to work (%)	Quantitative	1

Table 5 (continued)

Category	Frequency in %	Indicator	Type of indicator	Data availability		
Safety	25	Length of mass transport network	Quantitative	2		
		Public transport service availability	Semi-quantitative	1		
		Bicycle path availability	Semi-quantitative	1		
		Improvement in the connectivity	Qualitative	1		
		Diversity of transport modes	Semi-quantitative	2		
		Road density	Quantitative	2		
		Kilometres of total rail lines	Quantitative	2		
		Public transit ridership (% of transit commuters)	Quantitative	2		
		Passenger vehicle kilometres	Quantitative	1		
		Quality of products	Qualitative	1		
		Security by design	Qualitative	1		
		Protection from high temperatures and sunlight	Qualitative	1		
		Fatal and non-fatal traffic accidents	Quantitative	2		
		Average crash frequency	Quantitative	2		
		Degree of security	Semi-quantitative	1		
		Mortality rate	Quantitative	2		
		Accidents rate	Quantitative	2		
		Safe pedestrian pathways	n.i.	1		
		Safe urban road networks	n.i.	1		
		Safety for elderly and disabled people	n.i.	1		
Convenience	11	Supply reliability	Qualitative	1		
		Ventilation potential	Semi-quantitative	1		
		Daylight availability	Semi-quantitative	1		
		Thermal comfort	Semi-quantitative	1		
		Smart and appropriate location	Semi-quantitative	1		
		Transport performance	Qualitative	1		
		Quality of service	Semi-quantitative	1		
		Punctuality of deliveries	Semi-quantitative	2		
		Traffic congestion	n.i.	1		
		Inclusiveness	7	Inclusive design (ageing and disabled)	Qualitative	1
Adaptation for social inclusion	Qualitative			1		
Potential of social diversity	Semi-qualitative			1		
Degree of universal access	Semi-qualitative			1		
Affordability	7	Household expenses on transportation	Quantitative	2		
		Travel costs	Semi-quantitative	2		
Other	9	Costs for public transport services	Quantitative	3		
		Average duration of travel to work	Quantitative	1		
		Intermodal terminals	Semi-quantitative	2		
Worker	53	Commuting distance	Quantitative	1		
		Health and safety	2			
		Human health-DALY-the number of years lost due to disability, illness or early death		Quantitative		
		Number of fatal and non-fatal injuries		Quantitative		
		Damage to worker		Semi-quantitative		
		Work environment		Semi-quantitative		
		Occupational accidents		Quantitative		
		Occupational diseases		Quantitative		
		Number of fatalities at work per year		Quantitative		
		Compensated occupational problems		Quantitative		
		Appropriate working equipment		Semi-quantitative		
		Vaccination for workers		Quantitative		
		Fair salary		13	The compensation of employees, wages and salaries	Quantitative
					Minimum income according to legal framework	Quantitative
					Regular payment for the workers	Semi-quantitative
Training and education	9	Existence of educational programmes for self-development		Semi-quantitative		
		No school absence of children	Semi-quantitative			
Discrimination	6	Formal policy against discrimination	Semi-quantitative			
		Equality and diversity	n.i.			
Child labour	3	No child labour	Semi-quantitative	2		
Freedom of association and collective bargaining	3	Presence of collective bargaining	Semi-quantitative	2		
Work-life balance	3	Fulfilment of overtime agreed in working contracts	Semi-quantitative	2		
Other	9	Willingness to continue working in the same company or sector	Semi-quantitative	2		
		Work satisfaction	Semi-quantitative	3		

Table 5 (continued)

Category	Frequency in %	Indicator	Type of indicator	Data availability
Value chain actors		Willingness to be trained regarding the work activities	Semi-quantitative	4
Supplier relationships	100	Supplier relationships	Semi-quantitative	2
Society				
Health	63	CO ₂ emissions	Quantitative	3
		CO ₂ -eq emissions	Quantitative	3
		Greenhouse gases	Quantitative	3
		Acidification potential	Quantitative	3
		Eutrophication	Quantitative	3
Urban development	25	Existence of urban development plans	Qualitative	1
		Compatibility with local urban mobility policies	Semi-quantitative	2
Tax income	13	Taxes per km	Quantitative	1

Data availability: (1) limited, may require special data collection; (2) often available but not standardised; and (3) usually available in standardised form

The reviewed literature revealed that the majority of indicators assessing impacts on the stakeholder group worker evaluate health and safety issues. Therefore, the indicator that measures the number of fatal and non-fatal injuries was selected for the core set as a quantitative indicator with good data availability (Onat et al. 2014; Bui et al. 2017). For the evaluation of remuneration, though, two indicators were included in the core set of indicators. The first indicator measures a combination of wages and social benefits received by workers, a scale-based indicator as proposed by the PSIA. This indicator was included, as it not only assesses the wages for workers but also comprises social benefits. The second indicator measures the percentage of workers whose wages meet at least legal or industry minimum standards. This indicator was added to the core set of indicators, especially for the application in countries where violation of the law regarding minimum wage is a problem. This indicator might not be of relevance in every country. Hence, it can be used depending on the respective legal environment. For the assessment of discrimination, no clearly defined assessment method was stated in the reviewed literature (Aparcana and Salhofer 2013; Ameen and Mourshed 2019). As the PSIA suggests a scale-based indicator to evaluate prevention of discrimination, this assessment method was adopted. Only a few indicators were found in the reviewed literature regarding child labour, freedom of association and collective bargaining as well as work-life balance with again no clearly stated assessment method (Aparcana and Salhofer 2013). This is why, for the assessment of these aspects, the suggested scale-based indicators of the PSIA were adopted again. When comparing the indicators that were found in the reviewed literature to the indicators that are stated in the Guidelines as well as in the PSIA (Table 1), one can see that forced labour is suggested for evaluation in both the Guidelines and the PSIA, which, however, was not found in the reviewed literature. This is why the assessment of forced labour is included in the core set. For the assessment method, the scale-based indicator as stated in the PSIA was selected for

consistency reasons. The literature review revealed that, in addition, 9% of the indicators evaluate training and education possibilities. Though, one of the two selected indicators for the evaluation of remuneration measures a combination of wages and social benefits. The social benefits comprise training and education possibilities. This is why no indicator evaluating training and education is included additionally in the core set.

Similar to the approach for the stakeholder group workers, the indicators found for the stakeholder group value chain actors were compared to the indicators stated in the Guidelines and in the PSIA and missing aspects were added to the core set. In the case of value chain actors, only supplier relationships were evaluated in the reviewed literature, as already mentioned. Therefore, the assessment of fair competition and intellectual property rights, as well as promoting social responsibility, was added for a holistic evaluation (Table 1). Here again, the adoption of a 5-point scale from – 2 to + 2 is proposed in order to be consistent. The proposed 5-point scale including underlying performance indicators can be found in Table 8. For the evaluation of social responsibility promotion, a quantitative indicator assessing the percentage of audited suppliers is additionally included in the core set, as suggested by the Guidelines (UNEP/SETAC 2013). Depending on data availability, one or the other indicator can be selected.

For the assessment of impacts on the stakeholder group society, the indicators that were found in the reviewed literature mainly evaluate health impacts in the form of greenhouse gases and other emissions that affect society as a whole (63%). Here, the suggestions from the reviewed literature were followed and indicators assessing global warming potential, acidification potential and eutrophication potential were included in the core set. Another important aspect revealed by the literature review is the existence of an urban development plan and the extent to which the mobility company is engaging with city authorities for the promotion of urban development. Hence, this indicator is included in the core set with the

Table 6 Core set of indicators for the assessment of mobility services

Category	Indicator	Description	Calculation formula and performance indicators	Reference scale	Source
Local community Public space	Green and open space per capita	Measures park green area and open space in relation to the total number of inhabitants	$\text{Green and open space} = \frac{\text{Park green area and open space (m}^2\text{)}}{\text{Number of inhabitants}}$	See 5-point scale in Table 7	Robati et al. (2015) Lu et al. (2017)
Air quality	Emission intensity of NO _x	Measures the emission intensity of NO _x per passenger kilometre	$\text{Emission intensity NO}_x = \frac{\text{NO}_x \text{ (mg)}}{\text{Passenger kilometre}}$	See 5-point scale in Table 7	Fouda and Elkhazendar (2019)
	Emission intensity of PM ₁₀	Measures the emission intensity of PM ₁₀ per passenger kilometre	$\text{Emission intensity PM}_{10} = \frac{\text{PM}_{10} \text{ (mg)}}{\text{Passenger kilometre}}$	See 5-point scale in Table 7	Miller et al. (2016) Bandeira et al. (2018)
	Emission intensity of PM _{2.5}	Measures the emission intensity of PM _{2.5} per passenger kilometre	$\text{Emission intensity PM}_{2.5} = \frac{\text{PM}_{2.5} \text{ (mg)}}{\text{Passenger kilometre}}$	See 5-point scale in Table 7	Xu and Coors (2012) Zope et al. (2019)
	Emission intensity of SO ₂	Measures the emission intensity of SO ₂ per passenger kilometre	$\text{Emission intensity SO}_2 = \frac{\text{SO}_2 \text{ (mg)}}{\text{Passenger kilometre}}$	See 5-point scale in Table 7	Kawakubo et al. (2018)
Employment	Percentage of employees hired	Measures the percentage of employees that are hired during the study period	$\text{Job creation} = \frac{\text{Number of employees hired}}{\text{Total number of employees}} \times 100$	See 5-point scale in Table 7	Xu and Coors (2012) Bandeira et al. (2018)
	Percentage of employees hired locally	Measures the percentage of employees that are hired locally during the study period	$\text{Local job creation} = \frac{\text{Number of employees hired locally}}{\text{Total number of employees hired}} \times 100$	See 5-point scale in Table 7	Fouda and Elkhazendar (2019)
Noise pollution	Noise pollution greater than 65 dB	Measures the percentage of inhabited area that is exposed to traffic noise pollution greater than 65 dB	$\text{Noise pollution} = \frac{\text{Inhabited area with noise pollution} > 65 \text{ dB in m}^2}{\text{Total study area in m}^2} \times 100$	See 5-point scale in Table 7	Mansourianfar and Haghshenas (2018)
	Average emissions of noise	Measures the hindrance of population by traffic noise pollution greater than 65 dB per passenger kilometre based on a weighting factor for population density	$\text{Noise index} = \frac{\text{Area} > 65 \text{ dB in cm}^2 \times \text{MWF}}{\text{MWF [study area]} \times \text{Passenger kilometre}}$ MWF is the measurement weight factor (depending on population density of the area, considering 12 density classes) MWF [study area] = MWF according to inhabitants/ha in study area	See 5-point scale in Table 7	Fouda and Elkhazendar (2019) Osés et al. (2017)
Community engagement	Degree of population participation	The extent to which the company or facility engages with community stakeholders through ongoing open dialogue and responds to their concerns and inquires fairly and promptly, to continuously foster greater trust and relationship with the local community	See performance indicators defined by Goedkoop et al. (2018), page 58.	See 5-point scale defined by Goedkoop et al. (2018), page 58	Goedkoop et al. (2018)
	Infrastructure efficiency	Measures the amount of direct and indirect space occupied by mobility mode i in relation to passenger kilometre	$\text{Infrastructure efficiency} = \frac{\text{Direct+Indirect space for mobility mode i [m}^2\text{]}}{\text{Passenger kilometre}}$	See 5-point scale in Table 7	Miller et al. (2016)
Space occupancy	Infrastructure space occupancy	Measures the amount of direct and indirect space occupied by mobility mode i in relation to the total study area	$\text{Infrastructure space occupancy} = \frac{\text{Direct+Indirect space for mobility mode i [m}^2\text{]}}{\text{Total study area [m}^2\text{]}}$	See 5-point scale in Table 7	Wey and Huang (2018)
	Space occupancy	Direct: fast transit roads, other roads, cycle lanes, railways Indirect: open parking, private parking, stations, service area and petrol stations	$\text{Space occupancy} = \frac{\text{Space occupancy (m}^2\text{)}}{\text{Park green area and open space (m}^2\text{)}}$	See 5-point scale in Table 7	

Table 6 (continued)

Category	Indicator	Description	Calculation formula and performance indicators	Reference scale	Source
Consumers	Space occupancy in relation to green and open space	Measures the space that is occupied by mobility mode i (excluding infrastructure) in relation to green and open space in the respective city			Mansourianfar and Haghshenas (2018)
	Accessibility	Number of transport points	$\text{Accessibility [1]} = \frac{\text{Total number of transport points}}{\text{study area [km}^2\text{]}}$	See 5-point scale in Table 7	Zheng et al. (2017)
Safety	Number of passengers	Measures the total number of passengers per mobility mode i	$\text{Accessibility [2]} = \text{total number of passengers per mobility mode}$	See 5-point scale in Table 7	Yigitcanlar et al. (2015)
	Fatal and non-fatal traffic accidents	Measures the number of fatal and non-fatal accidents per mobility mode i in relation to passenger kilometre	$\text{Safety} = \frac{\text{Number of fatal and non-fatal accidents}}{\text{Passenger kilometre}}$	See 5-point scale in Table 7	Choon et al. (2011) Xu and Coors (2012) Oswald Beiler and Mohammed (2016)
Convenience	Punctuality of deliveries	Measures the punctuality of the different mobility modes with a 3-min tolerance	$\text{Punctuality} = \frac{\text{Number of punctual trips within a 3-min tolerance}}{\text{Total number of trips}}$	See 5-point scale in Table 7	Jasit and Ram (2018) Miller et al. (2016)
Inclusiveness	Inclusive design (ageing and disabled)	Measures the extent to which a product design, marketing and company business models affect the affordability and accessibility of products or services to different groups of people, e.g. disabled persons, the elderly and persons with low income	See performance indicators defined by Goedkoop et al. (2018), page 53	See 5-point scale defined by Goedkoop et al. (2018), page 53	Goedkoop et al. (2018)
Affordability	Trip fare	Measures the trip fare for a distance of 5 km within the study area in relation to the average income	$\text{Affordability} = \frac{\text{Fare of 5-km trip within the study area}}{\text{Average income}}$	See 5-point scale in Table 7	Miller et al. (2016) Verseckiene et al. (2017)
Privacy	Data privacy	Measures the extent to which a company respects and protects users' data privacy	See performance indicators defined by Goedkoop et al. (2018), page 51	See 5-point scale defined by Goedkoop et al. (2018), page 52	Goedkoop et al. (2018)
Feedback mechanism	Consumer complaints	Measures the number of consumer complaints in relation to passenger kilometres	$\text{Consumers satisfaction} = \frac{\text{Total number of complaints}}{\text{Passenger kilometre}}$	See 5-point scale in Table 7	UNEP/SETAC (2013)
Worker Safety	Fatal and non-fatal injuries	Measures the number of fatal and non-fatal injuries of workers in relation to the total number of employees during the study period	$\text{Safety} = \frac{\text{Number of fatal and non-fatal injuries}}{\text{Total number of employees}}$	See 5-point scale in Table 7	Onat et al. (2014) Bui et al. (2017)
	Remuneration	The extent to which management compensates workers. This indicator measures a combination of wages and social benefits received by workers	See performance indicators defined by Goedkoop et al. (2018), page 42	See 5-point scale defined by Goedkoop et al. (2018), page 42	Goedkoop et al. (2018)
Discrimination	Minimum wage paid	Measures the percentage of workers whose wages meet at least legal or industry minimum standards	$\text{Minimum wage paid} = \frac{\text{Number of workers with at least minimum wage}}{\text{Total number of employees}} \times 100$	See 5-point scale in Table 7	Aparcana and Salhofer (2013)
	Prevention of discrimination	Measures the extent to which a company is engaged in preventing discrimination and pro-actively promoting non-discrimination at the workplace. Discrimination refers to	See performance indicators defined by Goedkoop et al. (2018), page 45	See 5-point scale defined by Goedkoop et al. (2018), page 45	Goedkoop et al. (2018)

Table 6 (continued)

Category	Indicator	Description	Calculation formula and performance indicators	Reference scale	Source
Child labour	Prevention of child labour	any distinction, exclusion or preference which has the effect of nullifying or impairing equality of opportunity or treatment Measures the extent to which a company works towards eradicating child labour and pro-actively raising awareness of issues associated with child labour	See performance indicators defined by Goedkoop et al. (2018), page 43	See 5-point scale defined by Goedkoop et al. (2018), page 43	Goedkoop et al. (2018)
Freedom of association and collective bargaining	Freedom of association and collective bargaining	Measures the extent to which workers have the right to establish and to join organisations of their choice without prior authorisation, to promote and defend their interests and to negotiate collectively with other parties	See performance indicators defined by Goedkoop et al. (2018), page 46	See 5-point scale defined by Goedkoop et al. (2018), page 46	Goedkoop et al. (2018)
Work-life balance	Healthy work-life balance	Measures the extent to which a company enables workers to have choices over when, where and how they work and encourages healthy work-life balance	See performance indicators defined by Goedkoop et al. (2018), page 47	See 5-point scale defined by Goedkoop et al. (2018), page 47	Goedkoop et al. (2018)
Forced labour	Prevention of forced labour	Measures the extent to which forced labour is occurring and the mechanisms to prevent this	See performance indicators defined by Goedkoop et al. (2018), page 44	See 5-point scale defined by Goedkoop et al. (2018), page 44	Goedkoop et al. (2018)
Value Chain Actors					
Fair competition	Fair competitive activities	Measures the extent to which the organisation's competitive activities are conducted in a fair way and in compliance with legislations preventing anti-competitive behaviour, anti-trust or monopoly practices	See performance indicators defined in Table 8	See 5-point scale in Table 8	UNEP/SETAC (2013)
Intellectual property rights	Respect of intellectual property rights	Measures the extent to which the organisation's actions safeguard and value intellectual property rights	See performance indicators defined in Table 8	See 5-point scale in Table 8	UNEP/SETAC (2013)
Supplier relationships	Purchasing behaviour	Measures the extent to which a company is minimising negative impacts of procurement and purchasing decisions on other organisations	See performance indicators defined in Table 8	See 5-point scale in Table 8	UNEP/SETAC (2013)
Promoting social responsibility	Social responsibility support	Measures the extent to which a company supports suppliers in terms of consciousness-raising and counselling concerning social responsibility issues	See performance indicators defined in Table 8	See 5-point scale in Table 8	UNEP/SETAC (2013)
Society Health	Percentage of audited suppliers	Measures the percentage of suppliers the enterprise has audited with regard to social responsibility during the study period	$\text{Promoting Social Responsibility} = \frac{\text{Number of audited suppliers}}{\text{Total number of suppliers}} \times 100$	See 5-point scale in Table 7	UNEP/SETAC (2013)
	GWP ₁₀₀ (CO ₂ equiv.)	Measures global warming potential (GWP) per passenger kilometre	$\text{GWP}_{100} = \frac{\text{CO}_2 \text{ equiv. (g)}}{\text{Passenger kilometre}}$	See 5-point scale in Table 7	Reisi et al. (2014) Oses et al. (2017)

Table 6 (continued)

Category	Indicator	Description	Calculation formula and performance indicators	Reference scale	Source
Urban development	Acidification potential (SO ₂ equiv.)	Measures acidification potential (AP) per passenger-kilometre	$AP = \frac{SO_2 \text{ equiv. (mg)}}{\text{Passenger kilometre}}$	See 5-point scale in Table 7	Rajak et al. (2016) Verseckiene et al. (2017)
	Eutrophication potential (PO ₄ equiv.)	Measures eutrophication potential (EP) per passenger-kilometre	$EP = \frac{PO_4 \text{ equiv. (mg)}}{\text{Passenger kilometre}}$	See 5-point scale in Table 7	Rajak et al. (2016) Verseckiene et al. (2017)
Tax income	Urban development plans	Measures the extent to which a company is engaging with city authorities to actively contribute to urban development	See performance indicators defined in Table 8	See 5-point scale in Table 8	de Oliveira Cavalcanti et al. (2017) Kawakubo et al. (2018)
	Taxes per pkm	Measures taxes that are paid by the company per passenger kilometre	$\text{Tax income} = \frac{\text{Paid taxes (€)}}{\text{Passenger kilometre}}$	See 5-point scale in Table 7	Rajak et al. (2016) Bandeira et al. 2018

proposed 5-point scale (see Table 8). The last indicator found in the reviewed literature for the assessment of impacts regarding the stakeholder group society targets tax income. This indicator is also included in the core set, evaluating taxes paid per passenger kilometre. The stakeholder group society is included in the Guidelines; however, it is not listed in the PSIA (Table 1). Therefore, the same approach as for the stakeholder groups worker and value chain actors could not be applied. This is why in this case, no additional indicators from the two documents were included in the core set. Further, the number of social aspects in the core set of indicators should be kept to a reasonable amount for applicability reasons. This is also why all indicators that were mentioned in less than 2% of the reviewed literature (summarised under the category ‘Other’ in Table 5), were not taken into consideration for the core set.

4 Conclusion and recommendations

The UNEP/SETAC Guidelines as well as the PSIA handbook substantially contributed to the progress in S-LCA. Whereas different S-LCA indicators and impact assessment methods have been applied and tested in a number of case studies, the use phase has been underrepresented in previous S-LCA case studies and there is still uncertainty regarding use phase evaluation. Use phase impacts, however, play an important role for the assessment of mobility services. Both the Guidelines and the PSIA present different subcategories and social topics for the stakeholder group consumers or users, but still they are not enough to assess products and services where the use phase plays a prevalent role, such as mobility services or a building. This gap is analysed in this paper by starting with a critical literature review. The focus of the literature review on the use phase aims to supplement other life cycle stages of mobility, for which the UNEP/SETAC Guidelines as well as the PSIA handbook have already been applied and tested (Ekener-Petersen et al. 2014; Chang et al. 2015; Reuter 2016; Zanchi et al. 2018).

The literature review was necessary to categorise and systematically analyse indicators that were used for the assessment of urban mobility in previous studies. In total, 579 indicators were identified, analysed and grouped according to the stakeholder groups mentioned in the Guidelines. On the one hand, it was revealed that the stakeholder groups worker and value chain actors were underrepresented in the reviewed literature, and on the other hand, many indicators could be directly used from the Guidelines and the PSIA handbook. Furthermore, the indicators that were found in the reviewed literature present a huge variety and diversity, and this makes it difficult to define a consistent assessment method. However, based on the reviewed literature and supplemented by missing aspects from the

Table 7 Reference scale and performance reference points for all quantitative indicators

Category	Indicator	Unit	Reference scale and performance reference points ^a				
			-2	-1	0	1	2
Local community							
Public space	Green and open space per capita	$\frac{(m^2)}{\text{Inhabitants}}$	0–5	5–10	10–25	25–50	> 50
Air quality	Emission intensity of NO _x	$\frac{NO_x (mg)}{P_{km}}$	> 1000	475–1000	50–475	1–50	0–1
	Emission intensity of PM ₁₀	$\frac{PM_{10} (mg)}{P_{km}}$	> 20	15–20	10–15	5–10	0–5
	Emission intensity of PM _{2.5}	$\frac{PM_{2.5} (mg)}{P_{km}}$	> 20	15–20	10–15	5–10	0–5
	Emission intensity of SO ₂	$\frac{SO_2 (mg)}{P_{km}}$	> 1	0.75–1	0.5–0.75	0.25–0.5	0–0.25
Employment	Percentage of employees hired	Ratio	> -10	-10 to -5	-5 to +5	5–10	< 10
	Percentage of employees hired locally	Ratio	0–20	20–40	40–60	60–80	80–100
Noise pollution	Noise pollution greater than 65 dB	Ratio	> 20	10–20	1–10	0.1–1	0
	Average emissions of noise	Ratio	> 20	10–20	1–10	0.1–1	0
Space occupancy	Infrastructure efficiency	$\frac{(m^2)}{P_{km}}$ *	> 1	0.75–1	0.5–0.75	0.25–0.5	0–0.25
	Infrastructure space occupancy	Ratio	> 50	10–50	1–10	0.1–1	0–0.1
	Space occupancy in relation to green and open space	Ratio	> 50	10–50	1–10	0.1–1	0–0.1
Consumers							
Accessibility	Number of transport points	Ratio	< 50	50–100	100–500	500–1000	> 1000
	Number of passengers	count (in millions)	< 10	10–100	100–250	250–500	> 500
Safety	Fatal and non-fatal traffic accidents	Ratio **	> 2.0	1.0–2.0	0.5–1.0	0.1–0.5	0–0.1
Convenience	Punctuality of deliveries	Ratio	< 80	80–90	90–95	95–99	100
Affordability	Trip fare	€	> 4.5	3.5–4.5	2.5–3.5	1.5–2.5	0–1.5
Feedback mechanism	Consumer complaints	Ratio *	> 0.04	0.03–0.04	0.02–0.03	0.01–0.02	0–0.01
Worker							
Safety	Fatal and non-fatal injuries	Ratio ***	> 60	45–60	30–45	15–30	0–15
Fair salary	Minimum wage paid	Ratio	< 80	80–90	90–95	95–99	100
Value chain actors							
Promoting social responsibility	Percentage of audited suppliers	Ratio	0–20	20–40	40–60	60–80	80–100
Society							
Health	GWP ₁₀₀ (CO ₂ equiv.)	$\frac{CO_2 \text{ equiv. (g)}}{P_{km}}$	> 160	120–160	80–120	40–80	0–40
	Acidification potential (SO ₂ equiv.)	$\frac{SO_2 \text{ equiv. (mg)}}{P_{km}}$	> 400	300–400	200–300	100–200	0–100
	Eutrophication potential (PO ₄ equiv.)	$\frac{PO_4 \text{ equiv. (mg)}}{P_{km}}$	> 100	75–100	50–75	25–50	0–25
Tax income	Taxes per pkm	€	0–0.02	0.02–0.04	0.04–0.06	0.06–0.08	> 0.08

^a Performance reference points are defined based on possible min/max values

*Indicator values ×1000 for reference scale

**Per million passenger kilometre

***Per 1000 employees

Guidelines and the PSIA, a holistic set of 39 indicators for the assessment of mobility services is proposed, including an assessment method for every indicator. Out of the total set of indicators, 25 are of quantitative and 14 of qualitative nature. For the stakeholder group local community, 13 indicators are proposed, out of which only one is a qualitative indicator. Out of the eight indicators suggested for the stakeholder group consumers, two are qualitative. However, the stakeholder group workers also comprises eight indicators from which six are qualitative. For the stakeholder group

value chain actors, five indicators are proposed, with four qualitative indicators and one quantitative indicator. Contrary, for the stakeholder group society, five indicators are proposed in total, out of which only one is qualitative.

It is the first time that indicators from previous studies in the field of urban mobility were systematically analysed, evaluated and allocated to stakeholder groups in order to find suitable indicators for social sustainability of mobility services. Thus, this systematic approach as well as the resulting insights constitute not only a novelty

Table 8 Defined reference scale and performance indicators for all qualitative indicators that are not part of the PSIA

Value Chain Actors			
Fair Competition			
2	The company or facility has a system in place to enforce fair competition, which the employees are regularly trained on. Suppliers also need to behave in a competitive way.	1–3 AND 5–6	
1	The company or facility has a system in place to enforce fair competition, which the employees are regularly trained on.	1–3 AND 5	
0	The company or facility has a system in place to enforce the policy that prohibits anti-competitive behavior and violations of anti-trust and monopoly legislation AND There is evidence that there is no violation of fair competition.	1–3	
–1	Incidents of anti-competitive behavior or violation of anti-trust and monopoly legislation were discovered and a corrective action plan with a clear timeline for completion has been developed OR The company or facility has a policy that prohibits anti-competitive behavior, but does not have a system in place to enforce it.	1 OR 4	
–2	Anti-competitive behavior or violations of anti-trust and monopoly legislation have been discovered within the company or facility, however, a corrective action plan with a clear timeline for completion has not been developed.	–	
1.	The company or facility has a policy that prohibits anti-competitive behavior and violations of anti-trust and monopoly legislation.		
2.	The company or facility has a system in place to enforce the policy that prohibits anti-competitive behavior and violations of anti-trust and monopoly legislation.		
3.	There is no evidence that the company or facility has acted in an anti-competitive way and no violations of anti-trust or monopoly legislation are registered.		
4.	If incidents have been discovered that the company or facility is/has been in violation of anti-trust and monopoly legislation, the company has developed a corrective action plan with a clear timeline for completion.		
5.	Employees are trained regularly on the importance of compliance and fair competition.		
6.	Suppliers are only chosen by the company or facility if they also act in a competitive way without violation of anti-trust and monopoly legislation and suppliers are requested to foster fair competition themselves.		
Supplier Relationships			
2	The company or facility has a system in place to not only enforce the policy safeguarding fair trading conditions but to actively raise awareness for it. The commitments and progress of programmes are reported publicly.	1–3 AND 5–6	
1	The company or facility has a system in place to not only enforce the policy safeguarding fair trading conditions but to actively raise awareness for it.	1–3 AND 5	
0	The company or facility has a system in place to enforce the policy safeguarding fair trading conditions AND There is evidence that there is no misuse of power over suppliers.	1–3	
–1	Incidents of misusing the power over suppliers have been discovered and a corrective action plan with a clear timeline for completion has been developed OR	1 OR 4	
Intellectual Property Rights			
2	The company or facility has a PDCA process in place to raise awareness of intellectual property rights and compliant behavior. The commitments, performance, progress and effectiveness of programs are reported publicly.	1–3 AND 5–6	
1	The company or facility has a PDCA process in place to raise awareness of intellectual property rights and compliant behavior.	1–3 AND 5	
0	The company or facility has a system in place to enforce the policy safeguarding and valuing intellectual property rights AND No incidents have been discovered that the company or facility has been neglecting intellectual property rights.	1–3	
–1	Incidents of misuse of intellectual property rights have been discovered within the company or facility and a corrective action plan with a clear timeline for completion has been developed OR The company or facility has a policy safeguarding intellectual property rights but does not have a system in place to enforce it.	1 OR 4	
–2	Incidents of misuse of intellectual property rights have been discovered within the company or facility, however, a corrective action plan with a clear timeline for completion has not been developed.	–	
1.	The company or facility has a policy that safeguards and values intellectual property rights.		
2.	The company or facility has a system in place to enforce the policy that safeguards and values intellectual property rights (patents, copyrights and trademarks).		
3.	There is no evidence that the company or facility has neglected intellectual property rights.		
4.	If incidents have been discovered that the company or facility is/has been neglecting intellectual property rights, the company has developed a corrective action plan with a clear timeline for completion.		
5.	The company or facility has a PDCA process in place to raise awareness of intellectual property rights and compliant behavior.		
6.	Company commitments and progress on PDCA model are reported publicly.		
Promoting Social Responsibility			
2	The company or facility has a system in place to not only enforce but actively raise awareness for social responsibility. Suppliers also need to demand for social responsibility in their supply chain.	1–4 AND 5–6	
1	The company or facility has a system in place to not only enforce but actively raise awareness for social responsibility.	1 + 2 AND 4 + 5	
0	The company or facility has a system to enforce the principles of the code of conduct that protects human rights of workers among suppliers AND Contracts with suppliers include defined standards regarding ethical, social, environmental and gender equality criteria.	1 + 2 + 4	
–1	The company or facility has a code of conduct that protects human rights of workers among suppliers, but does not have a system to enforce the code of conduct.	1	

Table 8 (continued)

Value Chain Actors

The company or facility has a policy safeguarding fair trading conditions but does not have a system in place to enforce it.	
-2	Incidents of misusing the power over suppliers have been discovered, however, a corrective action plan with a clear timeline for completion has not been developed.
1.	The company or facility has a policy that safeguards fair trading conditions, including sufficient lead time, reasonable volume fluctuations and on time payments to suppliers.
2.	The company or facility has a system in place to enforce the policy that safeguards fair trading conditions.
3.	There is no evidence that the company or facility has misused their power over suppliers and no incidents regarding unfair trading conditions were reported.
4.	If incidents have been discovered that the company or facility is/has been misusing their power over suppliers, the company has developed a corrective action plan with a clear timeline for completion.
5.	The company or facility is actively raising awareness for fair trading conditions (e.g. by trainings for employees).
6.	Company commitments and progress regarding fair trading conditions are reported publicly.
Society	
Urban development	
2	The company or facility is a member in a joint initiative of city authorities and mobility service providers to jointly develop sustainable urban mobility concepts and its mobility solutions contribute to city's development plans.
1	The company or facility has a system in place to ensure that decisions regarding mobility solutions are in line with city development plans
AND	
The company or facility is in regular exchange with city authorities to positively contribute to city development.	
0	The company or facility has a system in place to ensure that decisions regarding mobility solutions are in line with city development plan.
-1	The company or facility is only in exchange with city authorities to inform about their plans or clarify legal frameworks.
-2	The company or facility is not in exchange with city authorities to inform about their plans or contribute to city development.
1.	The company or facility has a system in place to ensure that decisions regarding mobility solutions are agreed by city authorities and decisions are in line with city development plans.
2.	The company or facility is regularly in exchange with city authorities to positively contribute to city development.
3.	The company or facility is a member in a joint initiative of city authorities and mobility service providers to develop sustainable urban mobility concepts together with city representatives.
4.	The company or facility is only in exchange with city authorities to inform about their plans or clarify legal frameworks.
-2	There is no code of conduct that protects human rights of workers among suppliers.
1.	The company or facility has a code of conduct that protects human rights of workers among suppliers.
2.	The company or facility has a system in place to enforce the principles of the code of conduct that protects human rights of workers among suppliers.
3.	The company or facility is a member in an initiative that promotes social responsibility along the supply chain.
4.	In a purchasing policy or contracts with suppliers, criteria regarding ethical, social, environmental and gender equality standards are defined and must be fulfilled.
5.	The company or facility is actively raising awareness for social responsibility issues (e.g. by trainings for suppliers).
6.	The suppliers of the company or facility themselves are requested to demand for so-cial responsibility in their supply chain.

but also a major strength of this study. For the literature review, three major databases were selected and search terms were defined in order to find suitable publications with relevant social indicators. The selected search terms needed to be both general enough to find social indicators and specific enough to find social indicators that meet the particular needs of mobility services. To overcome this

challenge, general search terms like 'Social LCA' were combined with specific search terms like 'Mobility Services' or 'Transportation Systems'. The selection of search terms influences the results, which is why the selected databases as well as the defined search terms can be seen as a limitation of this study. Additional keyword combinations in more databases could improve the results.

To validate the applicability of the suggested indicators and the proposed assessment method, further research and implementation to real case studies are necessary. The obvious next step is therefore the application of the proposed set of indicators to mobility service case studies. This application and the subsequent evaluation are regarded as essential for the validation. In a further step, the results of the social impact assessment can be combined with an environmental impact assessment, for a holistic approach. Special attention should be paid to social indicators that might already be included in the environmental dimension, for example indicators assessing air quality. These indicators should only be included once, either in the social or in the environmental dimension, to avoid double counting. The combined assessment of social and environmental impacts of mobility services is considered as an important part of future research objectives. In addition, further research concerning the development of impact pathways helps to better understand the implications of mobility services and can help to facilitate the application of indicators. In that way, the proposed set of indicators may help to answer the frequently asked question whether mobility services can improve quality of life in cities.

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