

# On sustainable positioning of electric vehicle charging stations in cities: An integrated approach for the selection of indicators<sup>☆, ☆ ☆</sup>

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## ABSTRACT

Recent interest in planning a suitable charging infrastructure for electric mobility has motivated many studies. In this domain, attention towards key indicators of sustainable locations is crucial because they can provide informative signals to planning suitable charging station networks in cities according to multiple target attributes of sustainability. However, past literature has focused on “how to evaluate these key indicators of sustainable locations” by somewhat disregarding “which key indicators of sustainable locations were to be measured” based on the viewpoint of sustainability. This study presents a unified approach, identifying a long list of these indicators and then selecting a smaller set by applying an analytical hierarchy process, an algorithm, which aggregates weights and outcome marks, and a Monte Carlo simulation to an international survey. A relevant set of five overlapping key indicators of sustainable locations is designated by merging three different ranking methods. The results revealed a close semi-compensatory connection between transport and urban planning choices. These findings may support the planning of sustainable and suitable electric vehicle charging stations in cities according to a common set of key indicators of sustainable locations.

## 1. Introduction

Lately, electric mobility has been seen as one of the ways to increase the sustainability of the transport system, especially if vehicles can be powered by renewable energy, which may provide a reduction of additional load on the high-power density grid. The environmental benefits of these vehicles (e.g., cleaner environment, reduced exposure to noise and pollutants), their economic advantages (reduction of fuel costs, lower maintenance costs, free parking, no congestion charge, tax, and financial merits) and functional virtues (home charging, better technical performance) have been generally acknowledged and accepted (Bireslioglu et al., 2018; Faria et al., 2014).

Several countries are implementing long-term policies to encourage the development of the transition to electric mobility and to promote

citizen acceptance (Hall & Lutsey, 2017; Lieven, 2015, pp. 8-14). These policies include (but are not limited to): building a widespread electric charging infrastructure, regulations to issue a technological charging standard, and supporting adoption by citizens and businesses through subsidies (Bakker & Trip, 2013; Ma et al., 2017). These key points are part of the European Union’s Transport 2050 Strategy, which provides for the elimination of internal combustion engine (ICE) vehicles by that date (European Union, 2011).

Recently, this strategy was implemented into the “Fit for 55 package” of proposals, which aims to revise and update Directive 2014/94/EU into a regulation with several mandatory national targets such as a minimum coverage of public charging stations dedicated to light and heavy-duty vehicles (European Commission, 2014; European Commission, 2021). Policies and studies have highlighted that it would be

**Abbreviations:** AHP, Analytical Hierarchy Process; AWKISLS, Adjusted Weighted Key Indicator of Sustainable Location Score; BEV, Battery Electric Vehicles; CSV, Comma Separated Value; EV, Electric Vehicle; GIS, Geographic Information System; ICE, Internal Combustion Engine; KISL, Key Indicator of Sustainable Location; MM, Multiple-criteria Decision Making; PHP, Hypertext Pre-processor; PHEVs, Plug-in Hybrid Electric Vehicles; UA, Unified Approach; WKISLS, Weighted Key Indicator of Sustainable Location Score.

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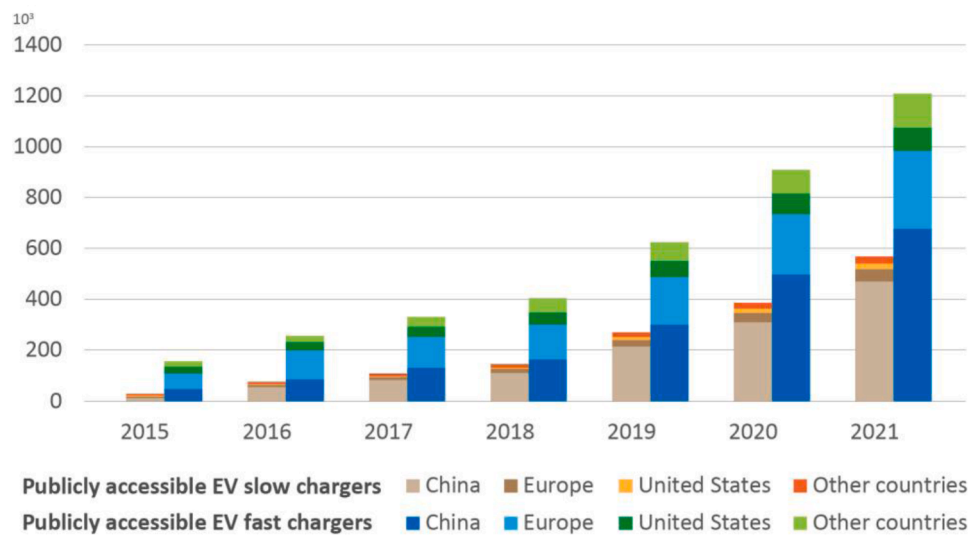


Figure 1. Slow and fast public chargers by country, 2015–2021 [Source: Authors elaboration from IEA (2022)].

relevant to provide easy access to charging station infrastructure. However, implementation faces challenges from (i) increasing home charging stations, (ii) defining technical charging standards, (iii) and the expansion of public charging stations into proper and suitable locations (e.g., Bakker & Trip, 2013; European Commission, 2014; Halbey et al., 2015). Specifically, the availability of public charging stations represents a crucial factor that influences consumer choices and, consequently, the adoption of Electric Vehicles (EVs).

Currently, the number of public chargers is constantly growing, with a positive +35% in 2021 and a total of 1.8 million public stations installed in 2020, of which a third are fast chargers (IEA, 2022). Fig. 1 shows that the largest increase of public charging stations has taken place in China, then Europe (especially the Netherlands), and in the United States, with a gap skewed towards slow vs fast charger stations. This rapid growth has attracted the attention of many academics and practitioners (e.g., providers, administrations) where planning their localisation is concerned.

Recently, some relevant reviews have investigated the issue of EV charging stations. For instance, Funke et al. (2018) compared framework conditions for public and private charging infrastructure needs in different countries. This research considered a dataset of parameters that could influence charging infrastructure requirements. These parameters seem to be especially clustered in technical-economical areas. Majhi et al. (2021) highlighted and evaluated several approaches to localising plug-in and wireless charging infrastructure. Specifically, the authors classified these approaches into three categories, (i) macroscopic, i.e., fast simulations on aggregate properties; (ii) microscopic, based on individual driver behaviour; (iii) mesoscopic, halfway between the previous two. Pagany et al. (2018) classified modelling theory and empirical applications in the domain of EV charging station localisation, focusing especially on spatial location planning perspectives.

However, policies and reviews do not present shared perspectives for planning “dense” charging infrastructure nor generally accepted sustainable principles upon which the infrastructure should be developed in the urban context. For instance, Orsi (2021) highlighted how EV charging stations impact land use and how they might indirectly and negatively affect urban dynamics of sprawl whilst increasing traffic congestion in cities. The author introduces the paradox in the issue of location as concerns clean energy, user satisfaction and land consumption. Consequently, many public administrations could be unprepared when asked to provide the proper location for these stations in their specific local contexts without a set of clear, effective, and crucial ‘driving’ indicators. Indeed, several criteria and indicators could

contribute to the simultaneous selection of different sites, which might affect the reliability, availability, and suitability of charging facilities (Bai et al., 2018; Sadeghi-Barzani et al., 2014; Wu et al., 2017) based on charging efficiency, speed, multiple types of connectors, and smart charging options (Giménez-Gaydou et al., 2016; Xi et al., 2013). It would appear to be appropriate to locate charging stations in the proximity of relevant attractors, with a high rate of functional mix (Csiszár et al., 2020; Karaşan et al., 2020) or accessibility to transit stops and stations (Chen et al., 2013; Guerra & Daziano, 2020; Philipsen et al., 2016). The selection of some sites might depend on population characteristics (Frade et al., 2011; Guler & Yomralioglu, 2020), e.g., aiming to prevent social and spatial inequity (Li et al., 2022), or on road traffic flow and transportation supply (Alhazmi et al., 2017; Pan et al., 2020; Sun et al., 2020). Finally, the definition of a proper location could be influenced by the impact of the place where the charging stations might be installed, which could affect stakeholders’ costs (Cui et al., 2018; He et al., 2015), grid stability (Erbaş et al., 2018; Porru et al., 2020), or environmental impoverishment (Feng et al., 2021; Guo & Zhao, 2015).

All previous research has shown that the issue of EV charging locations is almost entirely focused on “how to measure and manage KISL (e.g., modelling tools and methodologies) instead of “which KISL to measure” (e.g., Bilal & Rizwan, 2020; Kizhakkann et al., 2019). Moreover, deriving appropriate KISLs means focusing on their identification and selection. However, though few studies have focused on the evaluation of specific indicators, they have emphasised performance based on charging infrastructure location (Lucas et al., 2018). Moreover, justification of the choice of one indicator over another has often been unclear mainly due to poor data availability. Concurrently, the selection of indicators has often reflected the perspective of one stakeholder over another: mainly, charging stations’ providers and commercial parties (e.g., especially those interested in financial and economic indicators), public administrators and policymakers (e.g., those interested in the costs of mitigating emissions), grid operators (e.g., those interested in quality and positions that are safe) and then users (e.g., those interested in autonomy anxiety). Nevertheless, all these different perspectives are crucial and should be considered when embracing an interdisciplinary set of KISLs, because the goal of one stakeholder cannot be the same as another (e.g., Helmus & Van den Hoed, 2016; Pardo-Bosch et al., 2021). For instance, Bireselioglu et al. (2018) identified and mapped the motivators and barriers – i.e., factors – for the spread of EVs. They showed that these factors are shared among different levels of decision-making, i.e., individual units, collective units, and formal social units. Results showed that the main barriers largely embrace lack of charging

**Table 1**  
The breadth of indicators.

Source	#I	Perspectives				Types		Charging speed	Vehicle type	Selection
		PC	PA	GO	U	QT	QL			
(Boglietti et al., in press)	59	•	•	•	•	•	•	-	EV	L
(Xi et al., 2013)	19	•				•	•	S	EV	L
(Giménez-Gaydou et al., 2016)	18				•	•	•	-	BEV	L
(Kaya et al., 2020)	16	•		•		•	•	-	EV	L, S
(Lucas et al., 2018)	16		•			•	•	M <sup>1</sup>	EV	L
(Wu et al., 2017)	15	•				•	•	-	EV	L
(Zhou et al., 2020)	15	•				•	•	F	EV	L, S
(Bai et al., 2018)	15	•			•	•	•	F	BEV	L
(Yun et al., 2019)	14				•	•	•	-	PHEV	L
(Feng et al., 2021)	14		•			•	•	-	EV	L, S
(Sun et al., 2020)	12				•	•	•	S, F	EV	L
(Helmus & Van den Hoed, 2016)	12	•	•	•	•	•	•	-	EV	S
(Pan et al., 2020)	12				•	•	•	F	EV	L
(Philipsen et al., 2016)	11				•	•	•	F	BEV	S
(Cui et al., 2018)	11	•				•	•	-	EV	L, S
(Yi, Cheng, Zheng, & Liu, 2019)	10				•	•	•	-	EV	L
(Funke et al., 2018)	10	•				•	•	S, F	PHEV	L
(Erbaş et al., 2018)	10	•				•	•	-	EV	L, S
(Tian et al., 2018)	10				•	•	•	-	EV	L
(Chen et al., 2013)	10				•	•	•	S	EV	L
(Huang et al., 2016)	10	•	•			•	•	S, F	EV	L
(Frade et al., 2011)	9				•	•	•	S	EV	L
(Zhang et al., 2017)	9	•				•	•	F	EV	L
(Karaşan et al., 2020)	9	•	•			•	•	-	EV	L, S
(Guerra & Daziano, 2020)	9				•	•	•	-	EV	L
(Xu et al., 2017)	9				•	•	•	SL, F	BEV	L
(Guo et al. 2018)	9	•		•	•	•	•	-	EV	L
(Huang & Kockelman, 2020)	9	•				•	•	F	BEV	L
(Karolemeas, et al., 2021)	9		•			•	•	-	EV	S
(Guo & Zhao, 2015)	8	•	•		•	•	•	-	EV	L
(He et al., 2015)	8				•	•	•	-	BEV	L
(Guler & Yomralioglu, 2020)	7		•			•	•	-	EV	L
(Alhazmi et al., 2017)	7				•	•	•	-	PHEV	L
(Sadeghi-Barzani et al., 2014)	7	•		•		•	•	F	EV	L
(Pagany et al., 2019)	6				•	•	•	-	EV	L
(Yang et al., 2017)	6				•	•	•	-	EV	L
(Csiszár, et al., 2019)	6		•		•	•	•	-	EV	L, S
(Bilal & Rizwan, 2020)	6		•			•	•	-	EV	L
(Porru et al., 2020)	6		•			•	•	-	EV	L
(Wu & Sioshansi, 2017)	6	•			•	•	•	F	EV	L
(Bouguerra & Layeba, 2019)	6	•			•	•	•	F	EV	L
(Micari et al., 2017)	6	•				•	•	-	EV	L
(Kang et al., 2021)	5				•	•	•	-	EV	L
(Xu et al., 2020)	5				•	•	•	-	EV	L
(Dong et al., 2014)	5				•	•	•	SL, M, F	BEV	L
(He et al., 2018)	5	•			•	•	•	SL, M, F	EV	L
(Li et al., 2016)	4	•			•	•	•	F	EV	L
(Guo et al., 2018)	4	•			•	•	•	-	EV	L
(Csiszár, et al., 2020)	4				•	•	•	F	BEV	L
(Dong et al., 2019)	4	•				•	•	-	EV	L
(Kong et al., 2019)	4	•		•	•	•	•	F	EV	L
(Luo & Qiu, 2020)	4				•	•	•	F	EV	L
(Ren et al., 2019)	4	•		•	•	•	•	-	EV	L
(Ghamami et al., 2016)	4	•			•	•	•	-	EV	L
(Ma et al., 2017)	4		•		•	•	•	F	EV,PHEV	S, L
(Shahraki et al., 2015)	4				•	•	•	SL, F	BEV,PHE	L
(Efthymiou et al., 2017)	4				•	•	•	F	EV	L
(Wang et al., 2018)	4	•			•	•	•	F	EV	L
(Vazifeh et al., 2019)	3			•	•	•	•	-	EV	L

Table 1 is a representative but not comprehensive list of references.

#I number of indicators; CP Charging station operators and providers or commercial parties, PA Public administrators and policymakers, GO Grid operators, U Users (existing or candidates); QT Quantitative indicators, QL Qualitative indicators, TL Quantitative and qualitative indicators; F fast charging, SL slow charging, M medium charging; L Literature, S surveys on users, operators and/or experts and/or focus groups.

infrastructure, as well as technical and operational restrictions, etc. Therefore, key motivators, among others, appear to be the environmental, economic, and technical benefits associated with EVs. Moreover, KISLs that can be shared among several stakeholders could be viewed as a suitable solution, e.g., between technical feasibility and economic objectives of operators and the need for users' service and autonomy.

Thus, measuring a suitable location is both crucial and difficult due

to the number of issues and indicators involved. These indicators are a fundamental input in the process of determining location because they represent the same localisation features, whilst exploiting the suitability of each point and the sustainability of the charging system. In addition, if properly computed, they may help with the recognition of suitable and unsuitable locations for charging stations. Hence, selecting KISLs is a primary challenge for planning public charging stations, which requires a systematic and objective approach to improve their acceptability and

reliability among academics and practitioners (Barabino et al., 2020; Carrara et al., 2021; Castillo & Pitfield, 2010). Although there is a long list of many potential KISLs to be considered, selecting a compact subset is a crucial step. In addition, KISLs represent primary constructs of the EV charging station system. Hence, selecting more suitable KISLs is a challenging endeavour.

Given previous drawbacks and challenges, this study proposes a novel and unified approach for the identification and selection of a pool of best KISLs, useful for adequately providing informative signals towards planning a suitable urban EV charging station network based on multiple target attributes of sustainability. The indicators' relevance derives from their capacity to synthesize multidisciplinary and multi-perspective dimensions and to reflect best practices. Therefore, this study provides a high-level indication for evaluation processes to achieve suitable locations.

Specifically, this approach first identifies a long list of indicators from a literature review, frames components and attributes for KISLs according to a *tout court* sustainable perspective and involves academics and practitioners (hereinafter experts) to obtain multidisciplinary and multi-perspective judgments on each KISL. Next, it evaluates and adjusts KISLs by integrating an Analytical Hierarchy Process (AHP) with algorithmic methodologies. The evaluation of each KISL is based on an international survey of experts on EV charging systems, whilst adjustment is performed using Monte Carlo simulation methods for coverage of bias and uncertainties. Finally, the proposed approach returns the most promising sets of KISLs, which are then compared using different ranking methods. Therefore, this study focuses on selecting KISLs for planning EV charging stations and does not operationally address localisation to any specific case study.

The proposed approach instead builds on frameworks derived from works done by Barabino et al. (2020), Castillo and Pitfield (2010) and Carrara et al. (2021). However, the method mainly differs in its scope, its field of application, and in the experts involved. For instance, the framework studies were mainly focused on monitoring activities on sustainable transport (Castillo & Pitfield, 2010), transit quality (Barabino et al., 2020) and e-Powered micro-Personal Mobility Vehicles (Carrara et al., 2021). Moreover, Castillo and Pitfield (2010) and Carrara et al. (2021) concentrated on specific countries, the UK and Italy, respectively. In addition, Carrara et al. (2021) did not adopt any simulation models to adjust the list of their key sustainable parameters. Finally, unlike Castillo and Pitfield (2010) and Barabino et al. (2020), who considered a predefined list of indicators, this study builds on a long and adjusted list identified for investigation, which was expanded from the original proposed by Boglietti et al. (Boglietti et al., in press).

This study's aim is to contribute to developing a higher-level planning for Public EV charging station placement by shedding new light on a research area that has been thus far disregarded. For instance, on the one hand, experts could revise urban spaces needed to plan and locate EV charging stations, whilst on the other, public administrations could measure a set of KISLs to evaluate the most relevant sites for the installation of public EV charging stations.

The remainder of the article is organised as follows: Section 2 reviews related literature on KISLs. Section 3 shows the methodological approach, organised in three main phases for identifying and selecting KISLs. Section 4 presents the results of the best set of KISLs. Section 5 discusses some reflections in the context of the literature. Finally, Section 6 offers some conclusions whilst providing some additional research perspectives.

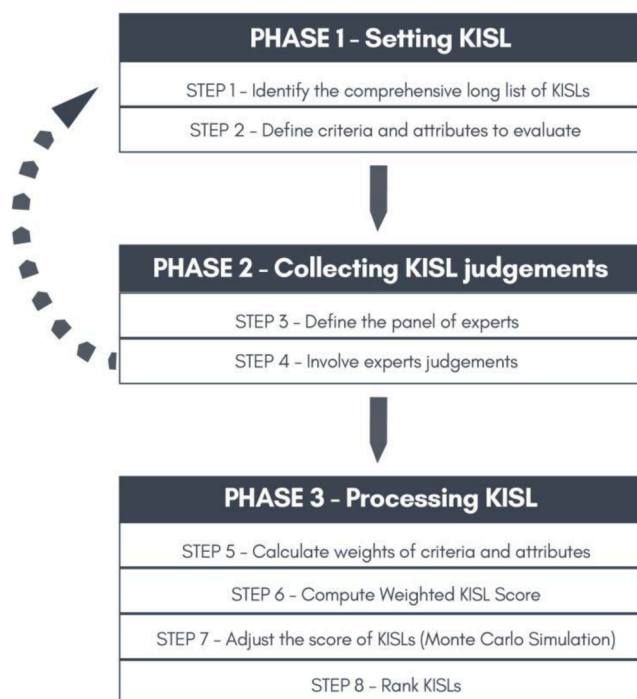
## 2. Comparative literature review on KISLs

Table 1 lists some of the recent literature on this issue and provides summary data for the localisation (or positioning) of EV charging stations. It shows a possible classification of studies that discuss the issue of

EV charging station placement according to the number of indicators (i. e., column #1). In addition, it details their organisation according to the perspectives considered, the types of indicators, charging speeds, the types of EVs and finally, the way these indicators have been identified. The items in Table 1 are sorted in descending order according to the number of indicators. Some considerations follow.

Boglietti et al. (in, press) compiled the highest number of indicators. That study represented the first attempt to collect criteria and indicators concerning EV charging location issues. Xi et al. (2013) developed a simulation-optimisation model to aid in the placement of EV charging stations. Aiming to maximise their use, they considered 19 indicators from several topics, i.e., transportation, economics, socio-demography, and technology. Giménez-Gaydou et al. (2016) deemed specificities of the recharging process to model localisation. They used 18 indicators to maximise demand coverage and use of stations, simultaneously guaranteeing benefits for users and operators. Hence, they applied indicators primarily from socio-demographic, technological and urban planning viewpoints. Kaya et al. (2020) addressed the problem of localisation by GIS mapping and a multi-criteria decision-making approach wherein 16 indicators were selected. Conversely, Lucas et al. (2018) adopted 16 indicators to evaluate existing charging infrastructure. Therefore, they used the indicators as a monitoring tool.

Table 1 shows how EV charging location can reflect different perspectives whilst accounting for several stakeholders involved in the charging station location process. These concerned parties mainly include commercial entities, grid operators, public administrators, and users. The perspective of commercial parties, i.e., operators (who guarantee access to charging stations) and providers (who supply equipment and components) is mainly focused on cost reduction and benefit maximisation associated with building charging stations and their operation. More precisely, they considered indicators that influence the choice of EV charging location directly, such as the costs for land, installation, repair, or maintenance, or indirectly, such as investment payback periods, budget limits, or energy efficiency (e.g., Wang et al., 2018; Xi et al., 2013). Therefore, economic sustainability appears to be the main issue (Wang et al., 2018). Grid operators focus on technical issues that concern the safety of electricity grid stability, i.e., reduction of impacts arising from the high-power load imposed by charging stations (Ren et al., 2019; Sadeghi-Barzani et al., 2014; Vazifeh et al., 2019). Since these indicators consider a specific aspect of localisation, the small number of sources under this perspective could be easily justified. Conversely, the general aspects of social, environmental and economic sustainability are more often considered from the standpoint of public administrators or policymakers. This view interacts with the location issue as a direct choice (goals, guidelines and/or planning constraints) that affect placement (Porru et al., 2020), or as indirect effects depending on (i) incentives and funding to build public and/or private charging infrastructure (Lucas et al., 2018; Ma et al., 2017), or (ii) the weighting of location criteria in the decision-making processes (Guo & Zhao, 2015; Karaşan et al., 2020; Karolemeas et al., 2021). Interestingly, Feng et al. (2021) extended the multi-criteria decision-making evaluation of locations to several sustainability criteria that also included technical and resource issues. Then, some studies are indirectly part of this category since they propose useful approaches to public administrations for the definition of efficient decisions and future strategies (Bilal & Rizwan, 2020; Guler & Yomralioglu, 2020; Huang et al., 2016). Finally, user perspectives have been defined in different ways such as customer satisfaction (Yang et al., 2017; Yi, Cheng, Zheng, & Liu, 2019), users' anxiety (Guo, Yang & Lu, 2018), preferences (Philipsen et al., 2016), or moving habits (Pagany et al., 2019; Yun et al., 2019). Only Helmus and Van den Hoed (2016) tried to analyse and systematise all possible perspectives. Other studies considered multi-objective perspectives (e.g., Bouguerra & Layeba, 2019; Ghamami et al., 2016; He et al., 2018; Li et al., 2016).



**Figure 2.** The conceptual scheme by phases of the method. Source: Elaborated from the authors.

Concurrently, indicators presenting data of different natures, e.g., spatial (Csiszár et al., 2019; Erbas et al., 2018) and statistical (Efthymiou et al., 2017; Lojowska et al., 2011) were considered. Moreover, sometimes these data coexisted in the methods used. Therefore, a general classification identified indicators as either quantitative or qualitative. Whilst most studies used quantitative indicators, the qualitative were used in survey-focused studies (Karolemeas et al., 2021; Philipsen et al., 2016).

Remarkably, most studies did not specify the charging speed considered (i.e., slow, medium, fast). We can assume that most studies focused on slow charging as a standard technology with respect to fast. About 16 studies focused on fast charging, and only 8 considered more than one type when discussing localisation. For instance, Sun et al. (2020) defined a localisation model that discussed the moving habits of (i) short distance travellers that use slow charging and (ii) long-distance travellers that use fast charging. Therefore, they maximised the satisfaction from each charging type demand. Xu et al., and Yamamoto (2017) developed a mixed logit model to investigate factors that influence users' choices of charging mode. Therefore, they identified the main indicators for the choice of slow and fast charging modes. Like charging speed, almost all studies focused on Battery Electric Vehicles (BEVs), with a few exceptions that examined Plug-in Hybrid Electric Vehicles (PHEVs).

Finally, the studies mainly selected indicators using two approaches. The first derived indicators explicitly from previous literature sources or the knowledge of experts. This method characterised most of the cases analysed. The second approach based indicator selection on surveys carried out on users, operators and/or experts in the field. This process concerned almost all those studies that adopted multiple-criteria decision analysis procedures, which involve an initial selection from the literature as well as the authors' knowledge. Subsequently, the selection was further reduced or weighted by following the opinions of interviewees (e.g., Zhou et al., 2020). Alternatively, some indicators were derived from focus groups (Philipsen et al., 2016).

In summary, all these studies provided some interesting and engrossing results. However, some gaps still persist. First, the literature review showed a fragmentation of papers where indicators could be

identified. Thus, establishing one or two unambiguous sources as a long list, as occurred in studies on sustainable transportation (Castillo & Pitfield, 2010)<sup>1</sup> and transit service quality (Barabino et al., 2020)<sup>2</sup>, is quite difficult. Second, most studies showed that indicators were identified and selected by drawing on the existing literature. Therefore, it is fairly clear that a specific study that identifies a long list of potential KISLs and selects the most promising set according to a unified approach is still missing from the literature.

This study endeavours to fill those gaps and enhances the state-of-the-art by proposing a unified approach that mines a set of the best KISLs from a long list. They are taken and evaluated in an international survey, processed by the analytical hierarchy procedure, an algorithm for aggregating weights and outcome marks, and Monte Carlo simulation methods for reducing coverage bias and uncertainties. In this way, a more objective and comprehensive evaluation of KISLs can be obtained as opposed to the current state-of-the-art.

### 3. Methodology

To select the best set of KISLs, a unified approach (UA) is being proposed, which is organised in three phases (and related steps) according to the scheme illustrated in Fig. 2. Phase 1 – Setting KISL – identifies potential KISLs, defines evaluation criteria and related attributes. Phase 2 – Collecting KISL judgements – involves experts to elicit their judgments about criteria, attributes and KISLs. Phase 3 – Processing KISL – processes and analyses data to select the most promising pools of KISLs. Each phase (and their related steps) is described below.

<sup>1</sup> Castillo and Pitfield (2010) derived a list comprising 233 sustainable transport indicators in the UK from two documents, the UK Government's Integrated Transport White Paper (Department of the Environment, Transport, and the Regions, 1998) and the UK Sustainable Development Strategy (Department for Environment, Food, and Rural Affairs, 2005).

<sup>2</sup> Barabino et al. (2020) derived the list of 106 quality indicators in transit services from the technical norm CEN/TC 320 (2002).

**Table 2**  
Definition of criteria and attributes for evaluating KISLs.

Criteria	Attributes	Description
<b>Methodological Feature</b>	Measurability	KISLs should be able to be measured in a theoretically valid, reliable, and understandable way.
	Easy availability Fast availability	It should be possible to collect and calculate reliable data easily and at a reasonable cost. Indicators' data should be updated continuously to reduce the time that elapses between measurement and data processing and/or consecutive measurements.
	Interpretability	KISLs should be universally understandable and without any interpretive ambiguity. For instance, KISLs expressed in numerical values such as letters (e.g., A, B) or percentages are preferred, since these outputs are more user-friendly for technicians, senior managers, and users.
<b>Sustainability Relevance</b>	Economic growth and efficiency	A sustainable EV charging location system should contribute to economic competitiveness and growth (local Gross Domestic Product) and facilitate a positive business case. The system should be supporting market processes in terms of costs connected to EV charging location and optimisation (e.g., economic, environmental, and social; connection to consumers and producers).
	Environmental protection and improvement	A sustainable EV charging location system should contribute directly to protecting the environment and indirectly to improving it. Placement should safeguard the surrounding environment from destruction, minimising e.g., waste discharge and damage to vegetation and water. Indirectly, the efficiency and quality of the EV charging system location should stimulate demand for its services. Therefore, a sustainable EV charging location system should improve air quality by reducing gas emissions, pollution, energy consumption, habitat loss, as well as the related effects and costs from climate change and health problems.
	Social (and spatial) equity and security	A sustainable EV charging location system should support social and spatial equity, guaranteeing mobility and accessibility to the greatest number of users possible, avoiding any social, economic, or geographic segregation (e.g., disabilities, low incomes). It should also be a mitigating factor for health risks, traffic accidents and transport-related crime.
	Liveable of cities and neighbourhoods	A sustainable EV charging location system should support the integration between transport and land use by generating positive effects on social, cultural, and recreational activity. Its design should improve local features (physical, aesthetical, and perceptual whilst improving the feeling of freedom of movement).

Source: Adapted from Barabino et al. (2020); Castillo and Pitfield (2010); May et al. (2001), and Carrara et al. (2021).

### 3.1. KISL setting phases: which KISLs should be set and how to evaluate them

Phase 1 develops the basis to respond to the question: “Which indicators should I choose and what criteria can I use to evaluate them?” It consists of STEP 1 and STEP 2.

STEP 1 identifies the long and comprehensive list of KISLs for EV charging station localisation. Table 1, previous lists of indicators developed by Boglietti et al. (in press) and studies by Helmus and Van den Hoed (2016), and Lucas et al. (2018) show how different indicators were applied. Therefore, STEP 1 is developed by a literature review of academic research and operational practices (i.e., looking at indicators currently available in an operational environment) to identify a more comprehensive number of indicators.

STEP 2 defines criteria and attributes to evaluate the relevance of indicators in a manageable way.

The literature review mainly presents two evaluation criteria: (i) the capacity to handle indicators of a different “nature” and (ii) the pursuit of the objectives of a sustainable transport system and policy.

Though the first evaluation criterion is a “methodological feature”, it is very broad and widely interpretable. Furthermore, an “ideal” indicator should satisfy different related attributes, e.g., analytical validity, flexibility, and interoperability (Dhakal & Imura, 2003). Hence, as suggested by Castillo and Pitfield (2010), we considered the simplest of indicators, which presented with measurability, interpretability, and fast and easy availability as the main attributes of the methodological feature.

Generally, EVs have become the main players in developing sustainable personal (and not only) transport systems as an alternative to conventional ICE vehicles (Feng et al., 2021). Hence, the second relevant and shared evaluation criterion is the ‘sustainability relevance’ of EV charging station localisation. However, there are multiple target attributes of sustainability, affecting several subjects. Therefore, the “ideal” indicator should be as pervasive as possible, i.e., relevant to a variety of sustainability attributes (Keirstead & Leach, 2008), and should not enhance, e.g., economic sustainability to the detriment of social and environmental sustainability (nor vice versa). In order to generate optimal and sustainable urban transport and land use strategies in cities, the literature and common practice have proposed (i) Economic growth

and efficiency, (ii) Environmental protection and improvement, (iii) Social (and spatial) equity and security, and (iv) Liveability of cities and neighbourhoods (May et al., 2001) as target attributes.

Table 2 briefly describes the structure of the selected criteria, and related attributes.

All criteria and attributes are general. However, each attribute may have a specific level of importance because this level can vary to reflect different perspectives.

### 3.2. KISL collecting judgement phase: involving international experts

Phase 2 develops the basis to respond to the question: “Which experts should be involved and how to obtain an assessment of the indicators’ value?” It comprises STEP 3 and STEP 4.

Assessment of the indicators is a complex task that requires a thorough knowledge of the subject. Moreover, the field of charging station location is broad and includes many facets (e.g., battery performance, land use compatibility, users’ preferences) Therefore, the adoption of participatory methods is considered an effective solution capable of summarising the complexity of the topic addressed. Consequently, STEP 3 is germane and should involve several international subjects considered experts in the field. In what follows, academics and practitioners were deemed (and referred to as) experts; users were not directly contemplated here due to the technical knowledge required. However, their viewpoints were accounted for indirectly in research by academics (e.g., Philipson et al., 2016). Experts can be selected based on their specific knowledge of EV charging station localisation: e.g., academics for their in-depth and theoretical knowledge at high levels and practitioners for their daily operational judgement and knowledge of road conditions. The opinion of experts should establish an overall assessment that answers many fundamental questions about how the infrastructure should be planned and implemented. Moreover, a variety of knowledge sources may fill in gaps between different perspectives, as suggested by Keirstead and Leach (2008).

Positive effects from heterogenous experts may clash with the varied perceptions of the criteria, attributes, and assessments linked to each indicator. Hence, many authors have suggested applying a weighting process that will derive the relevance of the indicators so this problem can be resolved objectively. Weighting can be assigned directly through

expert surveys. However, as the number of judgments increase, the possibility of biased opinions also increases, e.g., inconsistent values (e.g., Zelany, 1974). Thus, the proposed UA utilises the analytical hierarchy process (AHP)<sup>3</sup> for its positive mitigation of risks of bias (Saaty, 1977, 1987, 1994; Wind & Saaty, 1980).

The process consists of pairwise comparisons able to: (i) translate subjective judgments into objective weights, (ii) rely on the judgments of experts from different backgrounds to evaluate the problem according to different perspectives, and (iii) evaluate the consistency of judgements provided. The process should be applied here twice in a pairwise comparison between the two criteria and among the four attributes of each criterion.

Finally, STEP 4 focuses on how to involve experts. Several approaches can be used, such as paper and pencil interviews, computer-aided telephone surveys, web surveys, each, clearly, with its pros and cons. For this study, a web survey is proposed for the following reasons. First, the survey should involve as many international experts as possible incurring the lowest feasible operating costs (e.g., interview time, data coding, data processing). Second, this type of questionnaire is non-intrusive and requires less effort from respondents making it more compatible with their daily activities (e.g., Kaplan et al., 2012; Too & Earl, 2010). Moreover, it was found to be a crucial tool when applied during the Covid-19 pandemic period.

### 3.3. Data processing phase: KISL computation and rankings

Phase 3 develops the basis to respond to the question: “How should data be processed and handled to return a concise set of KISLs?” This phase runs according to STEP 5, STEP 6, STEP 7 and STEP 8. Specifically, it processes data collected among experts and returns the best score associated with each KISL. Next, the score is adjusted by introducing uncertainty, in the judgments provided by experts. Finally, the KISLs are ranked according to both their original and their adjusted scores. The original score is defined as the *Weighted Key Indicator of Sustainable Location Score* (WKISLS), which is obtained by applying AHP to translate subjective judgments (i.e., weights and marks) provided by experts into objective weightings (STEP 5).

Next, a simple additive weighting, which aggregates weights and outcome marks, computes the original score of each KISL (STEP 6). Let:

- $I$  be the set of KISLs and  $i \in I$  is a single KISL.
- $J$  be the set of experts interviewed and  $j \in J$  is a single expert.
- $M$  be the set of the attributes of the methodological feature criterion and  $m \in M$  is an attribute.
- $S$  be the set of the attributes of the sustainability relevance criterion and  $s \in S$  is an attribute.
- $w_{1j}$  be the weight of the methodological feature criterion returned by AHP, according to the judgement of expert  $j \in J$ .
- $w_{2j}$  be the weight of the sustainability relevance component returned by AHP, according to the judgement of expert  $j \in J$ .
- $w_{1jm}$  be the weight of attribute  $m \in M$ , returned by AHP, according to each judgement of expert  $j \in J$ .
- $w_{2jm}$  be the weight of attribute  $s \in S$ , returned by AHP, according to each judgement of expert  $j \in J$ .
- $A_{ijm}$  be the mark of indicator  $i \in I$  for attribute  $m \in M$ , according to the judgement of expert  $j \in J$ .
- $A_{ijs}$  be the mark of indicator  $i \in I$  for attribute  $s \in S$ , according to the judgement of expert  $j \in J$ .
- $\bar{M}$  be the average weight of the methodological feature criterion.
- $\bar{S}$  be the average weight of the sustainability relevance criterion.

<sup>3</sup> Dyer (1990) raises some criticism about this method. However, many scholars defend it and document the advantages deriving from its use in many fields of science (e.g., Saaty, 1990; CEN/TC 320 (2002) and Harker and Vargas (1990).

- $\bar{w}_m$  be the average weight of attribute  $m \in M$ .
- $\bar{w}_s$  be the average weight of attribute  $s \in S$ .
- $\bar{A}_{im}$  be the average mark of indicator  $i \in I$  for attribute  $m \in M$ .
- $\bar{A}_{is}$  be the average mark of indicator  $i \in I$  for attribute  $s \in S$ .

The following four-Step algorithm computes the WKISLS. For each indicator  $i \in I$

(S1) Compute  $\bar{M}$  and  $\bar{S}$ :

$$\bar{M} = \frac{\sum_{j \in J} w_{1j}}{|J|} \tag{1}$$

$$\bar{S} = \frac{\sum_{j \in J} w_{2j}}{|J|} \tag{2}$$

(S2) Compute  $\bar{w}_m$  and  $\bar{w}_s$ :

$$\bar{w}_m = \frac{\sum_{j \in J} w_{1jm}}{|J|} \quad \forall m \in M \tag{3}$$

$$\bar{w}_s = \frac{\sum_{j \in J} w_{2js}}{|J|} \quad \forall s \in S \tag{4}$$

(S3) Compute  $\bar{A}_{im}$  and  $\bar{A}_{is}$ :

$$\bar{A}_{im} = \frac{\sum_{j \in J} A_{ijm}}{|J|} \quad \forall m \in M; \forall i \in I \tag{5}$$

$$\bar{A}_{is} = \frac{\sum_{j \in J} A_{ijs}}{|J|} \quad \forall s \in S; \forall i \in I \tag{6}$$

(S4) Compute the values of WKISLS<sub>*i*</sub>

$$WKISLS_i = \bar{M} \left( \sum_{m \in M} \bar{w}_m * \bar{A}_{im} \right) + \bar{S} \left( \sum_{s \in S} \bar{w}_s * \bar{A}_{is} \right) \quad \forall i \in I \tag{7}$$

The original score provides a preliminary selection of the most promising KISLs. Nevertheless, several authors have highlighted the problem of coverage bias when the number of responses returned by experts is not too large (e.g., Dever et al., 2008). Since this issue usually affects findings obtained from web-based surveys, adjusting the original score may be required. Therefore, STEP 7 elaborates the statistical adjustments to reduce (or eliminate) bias. This step adopts a Monte Carlo simulation to transform the observed model, which is deterministic, into one that is stochastic. More precisely, the theoretical model for deriving WKISLS<sub>*i*</sub> is simulated to produce artificial data that need to be matched with the observed data (i.e., judgements by experts).

Matching is obtained using a probability distribution that best represents the current state of knowledge. In this study, the Monte Carlo simulation is applied to the set of KISLs related to each attribute belonging to sets  $M$  and  $S$ , respectively. The observed distribution of the marks given by experts is simulated  $K$  times for each indicator  $i \in I$  in the [1,10] interval. Next, the mark is rescaled to an interval of [0-1], and the result is used as the value of considered distribution simulated for several trials equal to the number of considered attributes. Next, by replying to the four-step algorithm for simulated data, an adjusted Weighted Key Indicator of Sustainable Location Score (AWKISLS) is computed for each KISL.

Finally, STEP 8 identifies the final set of the best KISLs by returning the lists arranged in decreasing order of WKISLS and AWKISLS,

**Table 3**  
The adjusted AHP rating scale for comparing criteria and attributes.

Level of relevance	Definition	Description
1	Equal relevance	The two elements compared contribute equally
3	Medium relevance	The judgment slightly favours one element over the other
5	Strong relevance	The judgment strongly favours one element more than the other
7	Very strong relevance	One element is much more strongly favoured than the other
9	Overall relevance	One element is maximally more relevant
2, 4, 6, 8	Intermediate values between the previous defined assessments	If judgments do not fit the relevance scale at the previous five levels, an "intermediate" value may be more suitable

respectively. The best indicators have the highest estimated WKISLS<sub>i</sub> and AWKISLS<sub>i</sub>, correspondingly. The first top  $n$  KISLS are relevant to driving the planning of EV charging stations.

## 4. Results

### 4.1. KISL setting phase: the long list of KISLS

According to STEP 1 of phase 1, and building on Table 1, the more comprehensive original list of 118 potential indicators was retrieved. Next, a shared terminology for resolving the multiplicity of different nomenclatures for the same KISLS<sup>4</sup> was derived. A (long) list of 99 specific indicators was compiled at the end of this reasoned process. In addition, this list was further enriched during the KISL collecting judgement phase<sup>5</sup>, and a final list of 102 unique indicators was gathered, as shown in Appendix A (see Table A1). Moreover, these indicators were clustered according to 6 topics and 13 sub-topics, representing several issues that characterise the localisation question. Many indicators can belong to more than one topic, but we have chosen the most appropriate ones according to the topic orientation of the references that applied to them.

Topics (and related sub-topics) were classified as follows:

- **Environmental**, which includes indicators focusing on ecological impact and environmental benefit deriving from charging station placement (e.g., fine particulate matter emission, degree of destruction of vegetation and water).
- **Economic-financial**, which considers indicators of costs and benefits of companies/commercial parties, users, and public administrations (e.g., operating costs, service fees). Because there are different interested parties, several reasons and investment scales coexist. Therefore, charging station development is highly sensitive to economic issues and political, commercial, and individual priorities.
- **Socio-demographic and behaviour**, which includes indicators of the population's characteristics, and the impact that charging stations or charging needs can have on their life (e.g., average income, autonomy anxiety factor, habit compatibility). This social outlook may influence everyone's transportation choices, whether EV users or non-EV users.
- **Technological**, which encompasses indicators including technical characteristics of the power grid, vehicles and charging stations (e.g., impact on grid stability, vehicle type, number of connectors, etc.). This topic contributes to a sustainable transport system by improving the performance requirements of each device included in the

charging process. However, while charging station developments are relatively slow, when they do happen, they are particularly important.

- **Transport planning**, which includes indicators linked to the demand and supply of mobility (e.g., road traffic flow, parking capacity). Moreover, this indicator considers the operation, provision, and management of services to achieve sustainable transport.
- **Urban planning**, which embraces indicators influenced by spatial and land use patterns. Therefore, indicators should consider land use and accessibility from an urban planning perspective (e.g., number of relevant attractors, building density, distances from public transport stops). Coordination between the transportation system and spatial patterns is essential to guide the sustainable development of urban areas.

In addition, sub-specifications of some indicators were listed to understand the indicators' nuances more easily (e.g., consumption, size, performance, battery autonomy) and so that differences do not affect their choice.

Next, according to STEP 2, criteria and attributes represent data input for the following steps.

### 4.2. KISL collecting judgement phase: the survey

According to STEP 3 and STEP 4 of phase 2, the international panel of experts selected was heterogeneous, coming from several fields of application, yet focused on the EV charging station location issue. The selection was made through scientific databases (i.e., Scopus and Web of Science) and the survey of different associations of experts (e.g., European Transport Safety Council, European Parking Association) to reflect the perspectives of academics and practitioners.

The survey was organised in two stages. In Stage 1, experts were asked to evaluate criteria and attributes through a pairwise comparison, useful to collect data easily for the AHP. They compared the two criteria and the four methodological and sustainability attributes according to an adjusted 1-9-point Saaty scale, as shown in Table 3.

In Stage 2, the experts evaluated each indicator. The evaluation consisted of a specific rating from 1 (the lowest value) to 10 (the highest value) given to each methodological and sustainability attribute for each indicator of the long list. Examples of the survey's Stage 1 and Stage 2 questionnaires are shown in Appendix B (see Figs. B1, and B2, respectively).

The overall survey was submitted by email and required several data collection sessions carried out between January and July 2021. Since Stage 1 was not very time consuming, it was completed in just one sitting. Conversely, due to the large number of indicators involved and the judgments required, Stage 2 was divided into five successive sessions, each containing about 25 indicators to be rated. Moreover, since the survey was submitted to experts, it was assumed that the questions would not be difficult for them to understand. Nonetheless, to prevent possible incomprehension, each email illustrated the aim and scopes of the research project, provided links to each stage, and contained information on criteria and attributes. In addition, to further reduce biases, pre-testing and piloting were applied before full submission.

<sup>4</sup> For instance, battery capacity vs battery performance became 'battery' with sub-specifics of 'consumption, size, performance, autonomy'; operating hours vs service availability became service availability with sub-specifics of 'probability that connectors are not available and operating hours'.

<sup>5</sup> Experts were also asked to list the five most relevant indicators for localising charging stations. Although most of the responses already included identified indicators from an analysis of the literature, some additional indicators were added, or other sub-specific ones were pointed out.

**Table 4**  
Sample composition and participation of experts in the survey.

Expert	N. EmailTotal	N. Emailverified	Email rate(verified)	N. of responses	Response rate(verified)
<b>STAGE 1</b>					
Academics	346	180	88.67%	41	22.78%
Practitioners	237	84	74.34%	20	23.81%
<i>Total</i>	<i>583</i>	<i>203</i>	<i>83.54%</i>	<i>61</i>	<i>23.11%</i>
<b>STAGE 2</b>					
Academics	346	149	73.40%	41	27.52%
Practitioners	237	83	73.45%	18	21.69%
<i>Total</i>	<i>583</i>	<i>234</i>	<i>74.05%</i>	<i>59</i>	<i>25.21%</i>

**Table 5**  
Experts' distribution worldwide and participation rate.

Expert	Continent	N. of mails	STAGE 1			STAGE 2		
			Verifiedemails	N.of responses	% of reply distribution	Verifiedemails	N.of responses	% of reply distribution
Academics	Africa	2	1	0	0.00%	2	0	0.00%
	America	77	39	5	12.82%	34	8	23.53%
	Asia	135	65	6	9.23%	56	4	7.14%
	Europe	124	71	28	39.44%	54	29	53.70%
	Oceania	8	4	2	50.00%	3	0	0.00%
	<b>Total</b>	<b>346</b>	<b>180</b>	<b>41</b>	<b>22.78%</b>	<b>149</b>	<b>41</b>	<b>27.52%</b>
Practitioners	Africa	0	0	0	0.00%	0	0	0.00%
	America	44	24	5	20.83%	20	4	20.00%
	Asia	99	21	2	9.52%	32	7	21.88%
	Europe	92	39	13	33.33%	30	7	23.33%
	Oceania	2	0	0	0.00%	1	0	0.00%
	<b>Total</b>	<b>237</b>	<b>84</b>	<b>20</b>	<b>23.81%</b>	<b>83</b>	<b>18</b>	<b>21.69%</b>
<b>Total</b>		<b>583</b>	<b>203</b>	<b>61</b>	<b>30.05%</b>	<b>234</b>	<b>59</b>	<b>25.31%</b>

**Table 6**  
Average weights of the criteria.

Criteria	Aggregate average weight ( $\mu$ )	Standard deviation( $\sigma$ )	Coefficient of variation % ( $\sigma/\mu$ )
Methodological feature ( $\bar{M}$ )	0.483	0.298	61.7
Sustainability relevance ( $\bar{S}$ )	0.517	0.297	57.6

In both stages, the survey was constructed and managed through a web-based questionnaire specifically built in PHP language, which collected the response data in a database function for processing. Conversely, contacts of experts were managed through the Mailchimp automation and email marketing service platform. This platform offered several advantages, already available from the free account: data could be imported and exported via CSV file; mailing lists could be timed; the activities function returned statistics from emails opened, clicked, bounced and the location (countries) where the email was opened. Finally, contacts were free to unsubscribe and no longer be contacted. Mailchimp's service enabled us to check the completion rate, dropout rate, and contact verification rate in greater detail. The level of corre-

**Table 7**  
Average weights of attributes.

Criteria / Attributes	Aggregateaverage weight ( $\mu$ )	Standard deviation( $\sigma$ )	Coefficient ofvariation % ( $\sigma/\mu$ )
<b>Methodological feature</b>			
Easy availability ( $\bar{w}_2$ )	0.268	0.142	49.5
Interpretability ( $\bar{w}_4$ )	0.259	0.162	50.3
Fast availability ( $\bar{w}_3$ )	0.242	0.180	71.0
Measurability ( $\bar{w}_1$ )	0.231	0.152	55.3
<b>Sustainability relevance</b>			
Liveable of cities and neighbourhoods ( $\bar{w}_8$ )	0.335	0.151	49.0
Social (and spatial) equity and security ( $\bar{w}_7$ )	0.241	0.143	54.2
Economic growth and efficiency ( $\bar{w}_5$ )	0.221	0.165	79.4
Environmental protection and improvement ( $\bar{w}_6$ )	0.203	0.112	47.0

**Table 8**  
Final ranking of Weighted Key Indicators (first quartile).

N.	Topic	Sub-topic	Indicator	WKISLS	AWKISLS	Var.Rank
1	Urban planning	Accessibility	Distance between charging stations	7.759	7.397	=
2	Urban planning	Accessibility	Distances from public transport stops	7.451	7.054	=
3	Urban planning	Accessibility	Distances from activities	6.789	6.737	▲
4	Urban planning	Accessibility	Number and types of stops/stations	6.122	6.663	△
5	Technological	Charging station	Charging power	6.892	6.467	▼
6	Urban planning	Accessibility	Number of vehicles served	6.397	6.455	▲
7	Urban planning	Accessibility	Accessibility by car	6.654	6.411	=
8	Urban planning	Land use	Population density	6.012	6.383	▲
9	Transportation planning	Supply	Existing charging station locations	6.726	6.347	▲
10	Urban planning	Accessibility	Proximity to pedestrian and cycle paths	5.953	6.323	△
11	Economic-financial	User costs	Time spent charging	5.818	6.304	△
12	Economic-financial	User costs	Annual time taken to reach the charging stations	6.556	6.303	▼
13	Urban planning	Land use	Existing gas stations	6.603	6.264	▼
14	Economic-financial	User costs	Average cost per kilometre for the user	6.757	6.258	▼
15	Urban planning	Land use	Build-up density	6.537	6.246	▼
16	Transportation planning	Demand	EV fleet distribution	6.517	6.189	▼
17	Technological	Charging station	Energy charged	6.466	6.136	▼
18	Technological	Charging station	Connector type	6.426	6.118	▼
19	Technological	Charging station	Average duration of charging	6.484	6.103	▼
20	Technological	Charging station	Number of connectors	6.348	6.089	=
21	Socio demographic and behaviour	Population characteristics	Average age	6.446	6.058	▼
22	Technological	Charging station	Charging efficiency	6.478	6.025	▼
23	Transportation planning	Supply	Average speed along corridors	6.018	5.992	△
24	Socio demographic and behaviour	Population characteristics	Average income	6.333	5.990	▼
25	Urban planning	Accessibility	Proximity to travel corridors	6.061	5.964	△
26	Technological	Charging station	Charge for multiple types of vehicles	6.575	5.961	▼
...	...	...	...	...	...	...
27	Urban planning	Accessibility	Distances from vegetation	6.169	5.940	▼
28	Technological	Charging station	Charging process type	6.370	5.932	▼
30	Transportation planning	Demand	Charging demand	6.173	5.882	▼
36	Technological	Electricity grid	Electricity consumption	6.206	5.832	▼
39	Economic-financial	Company or commercial parties' costs	Budget limit	6.229	5.806	▼
44	Socio demographic and behaviour	Population characteristics	Family size	6.215	5.768	▼

▲ Improvement or ▼ worsening in ranking between preliminary and final values, = unchanged position, △ new indicators not present in the preliminary ranking of KISLS.

spondence between the number of verified emails and completion/abandonment rates indicated the effectiveness of data collection, i.e., level of consistency and relevance of the survey (Kaplan et al., 2012).

A summary of sampling and participation rates can be found in Table 4 and Table 5, respectively. A total of 583 experts was surveyed, of which about 59% were academics. The email verification rate was on average 54%; therefore, 316 experts effectively opened the emails. Unverified emails were the number of bounced or un-clicked emails at all stages by the contact. Stage 1 and Stage 2 received a similar number of replies for both stages except for practitioners, which showed a slight decrease in responses (-2). However, the response rate was higher in Stage 2 due to the smaller sample verified.

Overall, the participation rate confirmed the interest of experts, and the response rate was consistent with response rates expected from web surveys (Kaplan et al., 2012; Sivo et al., 2006). Therefore, the incidence of nonresponses did not affect the validity of the inferences.

Finally, it is interesting to highlight how the response rate was much higher among European experts, with a distributed response rate of 39.44% and 33.33%, respectively, in Stage 1. This result confirmed the growing interest in electric mobility on this continent, as shown previously in Fig. 1. In Stage 2, the percentage increases among academics (53.70%) and decreases among professionals (23.33%): it was due to a greater number of responses from the Asian continent. Furthermore, data showed that the issue was probably of little concern in the continents of Africa and Oceania (Table 5). Generally, the response rate was higher in Stage 1 (30.05%) than in Stage 2 (25.31%), with a decrease of 5%, perhaps due to the length and number of replies required for Stage 2.

### 3.3. Data processing phase: weighing, scoring, and provisional and final ranking

Next, Phase 3 was run. More precisely, according to STEP 5 of UA, the AHP was applied to calculate weights of criteria and attributes, representing each expert's judgment. Next, the average weights were computed according to Eqs. from (1) to (6). Moreover, results were reported in an aggregate and disaggregate manner by type of expert.

Table 6 shows the average weight of the attributes (Column 2), the standard deviation (Column 3) and the coefficient of variation (Column 4). Specifically, the average weight (i.e.,  $\mu$ ) of the attributes was computed by applying Eqs. (1) and (2) to the overall data sample, whereas the standard deviation (i.e.,  $\sigma$ ) and the coefficient of variation (i.e.,  $\sigma/\mu$ ) were computed by applying well-known statistical formulas. Nevertheless, findings showed that, on average, experts slightly preferred the sustainability criterion (i.e.,  $\bar{S}$ ) over the methodological (i.e.,  $\bar{M}$ ) according to the aggregate average weighting. Even though, in essence, they are almost the same. The result probably shows how both issues related to localisation were viewed as equally important. However, the standard deviation and the coefficient of variation in Table 6 indicate that the distribution of scores concerning the methodological feature is a bit more dispersed than that of sustainable relevance. Indeed, related standard deviations and coefficients of variation presented the highest values.

Table 7 shows the results of the average weights and dispersion (i.e., standard deviations and coefficients of variation) for each methodological (i.e.,  $m \in M$ ) and sustainable attribute (i.e.,  $s \in S$ ).

Nevertheless, experts considered *Easy Availability* and *Interpretability*

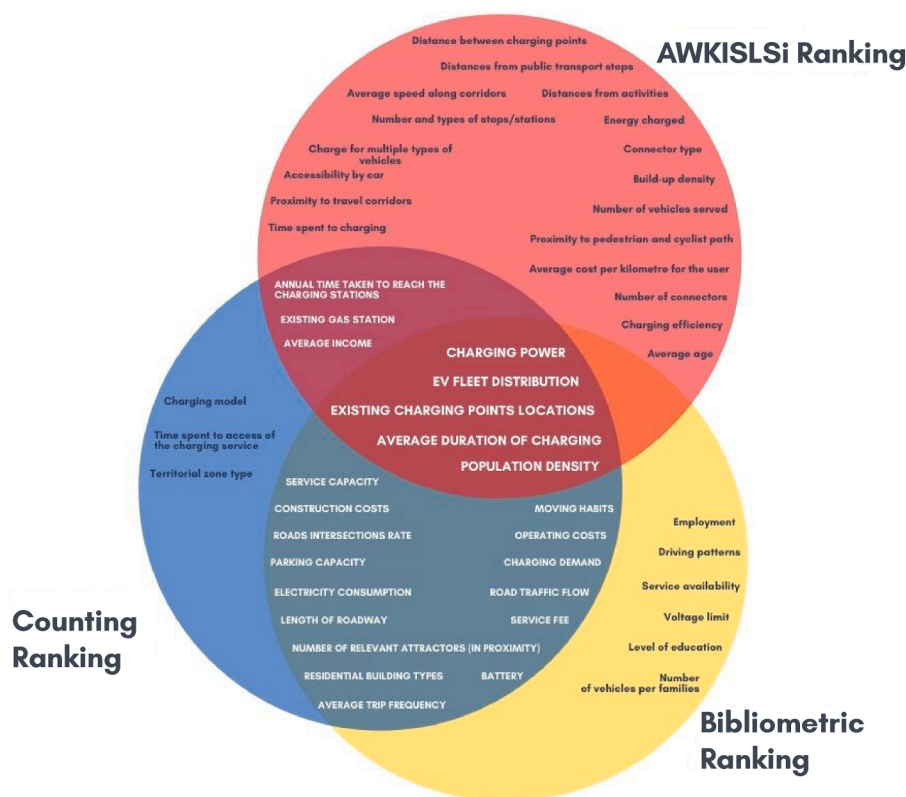


Figure 3. Top KISLs ranked by AWKISLS<sub>i</sub>; counting, and bibliometric methods. Source: Elaborated by authors.

as the most relevant methodological criterion attributes. Thus, data collection and output were crucial for an understandable and affordable localisation indicator. Likewise, the experts identified the attributes of *Liveable cities* and *Social (and spatial) equity and security* as the most important sustainability criteria. The *Social (and spatial) equity and security* attribute is connected to users' perspectives, which were those most considered in the literature. The *Liveable cities* attribute addressed compatibility between transport and land use, i.e., among users' habits in a positive way. Indeed, these attributes directed the location to maximise the number of users adopting EVs.

Nevertheless, the standard deviations and the coefficients of variation in Table 7 provided evidence that the distribution of scores concerning easy availability presented the lowest dispersion in the methodological feature because the coefficient of variation was lower than 50%. Conversely, as for sustainability relevance, both liveable cities and environmental protection and improvement presented the lowest coefficient of variation. Therefore, these results pointed out that those attributes were relatively 'stable' for the experts.

A two-tailed z-test comparison ( $p\text{-value} < 0,05$ ) of each pair of weightings revealed no significant differences between the weightings attached to the criteria and related attributes provided by academics and practitioners. There was, however, a difference in the weight of the easy availability attribute ( $p\text{ value } 0,024$ ), which academics weighted higher than practitioners. Nevertheless, weights were considered in an aggregate form in the following steps.

Next, according to STEP 6 and STEP 7, the original score of each indicator (i.e., WKISLS<sub>i</sub>) and the adjusted score (i.e., AWKISLS<sub>i</sub>) with 4,000,000+ Monte Carlo simulations were computed by applying Eq. (7). Next, as described in STEP 8, the final set of best KISLs was returned,

as shown in Table 8. Columns 2 and 3 of Table 8 show the classification by topic and sub-topic identified that characterise the problem of charging station localisation. Column 4 shows the indicator considered. Columns 5 and 6 show the weighted -WKISLS- and adjusted score -AWKISLS-, respectively. Finally, a summary of variations between original and adjusted (final) rankings is shown in the last columns. For the sake of synthesis, we considered (i) a restricted set of the first 26 KISLs corresponding to the first quartile of the rank-ordering distribution of all indicators, and (ii) the KISLs that were included in the first quartile of the distributions of the unadjusted scores (i.e., WKISLS<sub>i</sub>); in Appendix C (see Table C1 and Table C2, respectively), the overall ranking is provided.

In table 8, AWKISLS indicators were in descending order.

### 5. Discussion: some reflections

Table 8 enabled us to make some important considerations.

First, the KISLs returned by the two different scores were similar and shared 21 of 26 KISLs. The 'new entry' KISLs that fell within the final ranking were defined by the white triangle and included charging process type, budget limit, family size, electricity consumption, charging demand, and distances from vegetation. Therefore, the Monte Carlo simulation strengthened the scores of each indicator without misrepresenting its importance. However, adjusting original scores through Monte Carlo simulations changed the position and the related score. Specifically, there was an almost absolute reduction trend of the WKISLS<sub>i</sub> according to an average of about -0.223. This trend may depend on the distribution of real judgments [1-10], which formed the basis of the probability distribution. Variation was maximum (decreasing) in the

case of the “Charge for multiple types of vehicles” indicator, which moved from rank 9 to 26 (-0.614) and in the (increasing) case of the “Number and types of stops/stations”, which moved from rank 30 to 4 (+0.541). Generally, indicators no longer included in the final ranking were characterised by a worsening score of an average of -0.367. Conversely, the best rank of some KISLs entered in the final ranking depended either on an improvement in adjustment (e.g., number and types of stops/stations, proximity to pedestrian and cycle paths, time spent charging) on average +0.442 or on a stabilisation between WKISLs and AWKISLs (e.g., distances from activities, number of vehicles served, average speed along corridors, proximity to travel corridors) on average  $\pm 0.058$ .

Second, five of six topics of EV charging stations localisation are included in the ranking for at least one KISL. The relevance of the Urban planning topic (11 KISLs) emerged both in terms of accessibility (8) and land use (3) but also where technological topics related to characteristics of charging stations themselves (7) were concerned. Moreover, results showed relevance to transport issues of supply (2) and demand (1), economic-financial cost of users (3) and socio-demographic characteristics of the population (2). Conversely, no KISL was included in the environmental topic. This result may initially suggest that it is viewed as less relevant, as emerged in the average weight of the Environmental protection and improvement attribute. However, it could be argued that the environmental indicators identified are more effective in the monitoring phase than in planning the charging station infrastructure.

Third, the ranking clearly showed that eight of the top ten adjusted KISLs concerned urban planning rather than the four from the original rankings. This can be understood as “access planning”, i.e., integration or simultaneousness between urban planning and transport planning. In summary, relevance to the proximity between origins and destinations, the density of activities and population, the quality of the public mobility system, and the needs of the communities that live and work in the city emerged. Finally, some studies identified 6 and 7 of the 26 KISLs as concerning mainly technological and urban planning, respectively (Bai et al., 2018; Giménez-Gaydou et al., 2016; Lucas et al., 2018).

To further investigate the relevance of the best KISLs, it would be useful to compare results by two additional ranking methods. The first method consists of a citation score, i.e., a count of how many times each indicator appears in the literature analysed (i.e., maximum once per article). The second consists of a bibliometric score, i.e., how many times the article that used each indicator has been cited. A ranking by H-index, SJR or quartile of the journal was also possible. However, there were almost zero variations from the bibliometric score. Therefore, this further classification was not discussed.

Commonalities among the adjusted ranking methods and the newly considered methods are in Fig. 3.

On the one hand, Fig. 3 shows that the counting and bibliometric rankings have many indicators in common (20 out of 32), as already verified in other transportation fields that have adopted the same ranking approach (Barabino et al., 2020). Probably, this similarity observed depends on the constant identification and selection of KISLs from previous literature. On the other hand, Fig. 3 shows that overlapping the AWKISLs<sub>i</sub> ranking, 5 KISLs common to all rankings were found. They appear in all three rankings in the first top 10 and regard technical aspects of charging stations, transport distribution of the EV fleet and existing charging stations and a facet of urban planning, i.e., population density. Moreover, there is still a sharp decrease in urban planning indicators favouring transport planning and the absence of any environmental indicators. These results are consistent with some studies, even though more indicators were considered. Huang and Kockelman (2020) considered 4 of the 5 common indicators, evaluating

elastic demand, congestion of stations and network equilibrium. Other authors have also considered 3 indicators (Funke et al., 2018; Giménez-Gaydou et al., 2016; Kang et al., 2021; Kaya et al., 2020; Lucas et al., 2018; Micari et al., 2017; Tian et al., 2018). Compared to the AWKISLs<sub>i</sub> ranking, previous studies included an average of 2-3 KISLs. Therefore, this study has enlarged the set of key indicators.

Our analysis further shows that a dichotomy emerges by critically comparing the different ranking methods, between the relevance of urban planning indicators in the AWKISLs<sub>i</sub> ranking, which was then replaced by those of transport planning in the Counting and Bibliometric rankings. However, this discrepancy represents a contradiction, probably highlighted by the sustainability perspective with which the indicators were selected in the AWKISLs<sub>i</sub> ranking. In this sense, the results reveal how sustainable solutions and strategies for developing the charging infrastructure in the urban environment should be identified in an integrated semi-compensatory framework between the interaction of charging systems and land use. Therefore, to be sustainable, the planning of EV charging station distribution will have to consider and balance the reasons for maximising demand, travel patterns and economic convenience with principles already well known in the literature. The planning will have to model the location according to a transfer-oriented modal structure with public transport and soft mobility whilst being integrated with the urban functions of shopping and public services according to a reduction in transit opportunities dictated by dual-use (Carra et al., 2022; Caselli et al., 2021). These principles, characterising accessibility planning, would contrast with the negative effects of an exponential increase in the use of private cars, which, although electric, would lead to a new car (electric)-centric model and to the consequent urban expansion and waterproofing of the territory to the detriment of rural areas (Orsi, 2021). However, the success of electric mobility and its positive effects seem to overlook fundamental facets of planning sustainable cities.

To summarise, although a careful comparison with previous studies was not possible because a similar study has not yet been performed, this research differs from what can be found in the current literature both in the approach developed and in the results of KISLs. Specifically, unlike all current studies, UA introduces an objective mechanism to select a compact and relevant set of KISLs, which is a prerequisite for driving (describing) the planning of public EV charging stations. Next, the results consolidate and enlarge previous relevant literature by comparing UA with two additional state-of-the-art ranking methods. Indeed, the result mines five KISLs that are common to all three ranking methods, thus increasing the size of the relevant pool of KISLs. Finally, unlike all previous research, our study selects KISLs by the perspectives of many stakeholders interested in EV charging station location.

Despite these results and reflections, some limitations of the present study also emerged. The coexisting relevance of indicators among different types of recharging (i.e., slow, fast and ultra-fast), between different types of vehicles (i.e., BEV, PHEV) or between different recharging station types was not assessed. However, these insights were not considered based on the literature, which showed a preference for generic EVs and plug-in charging systems. Moreover, although we believe they are still few and far between, evaluating further variations in swapping or wireless/contactless charging types could be interesting (Bai et al., 2018; Yang et al., 2017).

Furthermore, the study does not presume to claim the best and universal KISL list, applicable everywhere. Indeed, the relevance of indicators can differ among places. For instance, some indicators could be measured according to different indices that depend on local data available (for instance, relevant attractors, degree of attractiveness of the site, or meters of proximity to certain services). However, the results

constitute a general compromise determined by: (i) territorial heterogeneity of the sample of experts considered, (ii) dynamic iteration between sustainable objectives and perspectives of a different nature, (iii) the importance of different criteria and attributes. Moreover, they do meet the aim of this study, i.e., to find a restricted set of indicators as a planning guideline to be used by any organization worldwide. Therefore, a multiscale level of local conditions (e.g., continental, national, between big, medium, and small cities) on data characterisation and EV adoption challenges is here quite generalizable as an objective of general norms. However, future developments will define how local conditions can be reflected in the choice of indicators, as well as what differences will be achieved in terms of charging station distribution and operation measurements.

## 6. Conclusions and research perspectives

The positioning of public charging infrastructure for electric vehicles (EVs) is a relevant and crucial issue. It is currently being addressed both in national and international policies in the form of guidelines and objectives and in the academic field through increasingly complex localisation methodologies. In this domain, attention to key indicators of sustainable locations (KISLs) depends on their ability to provide informative signals to point out superiorities and criticalities in the position of EV charging stations. Therefore, selecting suitable KISLs is crucial to planning a suitable charging station network. However, previous research has shown much fragmentation in those papers where indicators could be identified whilst largely considering few indicators based on the perspective of one stakeholder. Moreover, most importantly, the literature has generally focused more on “how to evaluate KISL” instead of “what KISL to measure”. Therefore, to account for these gaps properly, this study is attempting to contribute to the growing literature on the EV charging stations in a fourfold manner:

- An initial long list of 102 indicators was generated and collected from previous literature and further verified in the field by web survey. To date and as far the authors know, this is the most comprehensive list of indicators describing the EV charging station location issue.
- The identification of KISLs towards a *tout court* sustainable perspective, which is representative of the multidisciplinary and multi-perspective dimension of the EV charging station location issue. Therefore, this study balances compromises between (possible) competing objectives, e.g., the economic *versus* the environment.
- A novel and unified approach, (UA) is proposed for the selection of a concise (and representative) set of KISLs for EVs. This approach selects the best KISLs by integrating proper methodologies starting from the original list. Specifically, UA retrieves data based on the importance of the criteria, the attributes, and indicator scores, using a web survey, by querying international academics and practitioners with specific skills in locating charging stations. Next, UA evaluates these indicators by using AHP and an algorithm, which aggregates weight and marks. Finally, UA adjusts these indicators using Monte Carlo simulations and returns the most auspicious set. As far the authors know, no study has returned such a concise set of KISLs using an equally objective method.
- Results obtained according to UA are compared with two state-of-the-art ranking approaches. A restricted and relevant set of five common KISLs is identified and considered of primary importance. Therefore, the approach developed in the article extends existing knowledge by merging different ranking methods.

The main implications of this study are:

- The identification of many KISLs may help stakeholders collect KISLs data in detail and for benchmark purposes.
- The high degree of applicability of the UA is not strictly linked to the planning of EV charging stations but could be generalised for application to other transportation fields.
- The opportunity to assess the EV charging stations among cities according to a common set of KISLs, as normally proposed in technical norms of transport systems.

This study represents an original steering tool for research, policy, and practice. It constitutes a starting point that defines the planning standard of a dense charging infrastructure according to sustainability goals and the coexistence of perspectives of stakeholders involved in the process. The results of this study are relevant for sustainable cities and societies because they provide important contributions to the development of electric mobility in urban contexts from a planning perspective. Identifying and selecting a compact set of KISLs will provide a tool to plan sustainable positioning of EV charging stations in cities. The proposal of a unified approach that adopts modelling tools (AHP and algorithms) and simulation (Montecarlo) will help provide a concise list of KISLs. This list would then be able to provide a driver-oriented tool to the sustainable planning and design of urban environments focused on the development of an EV charging station network. Thus, it can orient urban planning and ‘design’ from the perspective of viable insertion of EV charging stations in urban environments that move towards liveable urban spaces (e.g., safety, health, wellbeing, comfort, low carbon/zero carbon emissions, functional and habit compatibility), economic efficiency, social and spatial equity as well as environmental protection and improvement. Hence, mobility and accessibility could be guaranteed to the greatest possible number of people.

Finally, besides the previous limitations, this study did select a set of KISLs, but it did not face the issue of how to determine if an area of a city requires the implementation of an EV charging station, according to the value returned by the KISLs. Therefore, a more detailed analysis would be required for this purpose. Future studies should address these limitations which are relevant to building smart(er) and more sustainable cities.

## CRedit authorship contribution statement

**Martina Carra:** Conceptualization, Data curation, Formal analysis, Visualization, Writing – original draft, Writing – review & editing. **Giulio Maternini:** Supervision, Funding acquisition. **Benedetto Barabino:** Conceptualization, Methodology, Funding acquisition, Supervision, Project administration, Writing – review & editing.

## Declaration of Competing Interest

The authors have no conflict of interest.

## Data availability

The data that has been used is confidential.

## Appendix A

**Table A1**  
The long-reasoned list of indicators for locating and monitoring EV charging stations.

Topic	Sub-topic	Indicator	N.	Sub-specifics	
<b>1. Environmental</b>	1.1. Impact	Destruction degree on vegetation and water	1.1.1	-	
		Waste discharge	1.1.2	-	
		Greenhouse gas (GHG) emission	1.1.3	-	
		Fine particulate matter emission	1.1.4	-	
		Renewable market penetration	1.1.5	-	
		EV market penetration	1.1.6	-	
		LCA emission	1.1.7	-	
		CO <sup>2</sup> emission	1.1.8	-	
<b>2. Economic-financial</b>	2.1. Company or commercial parties' costs	Construction costs	2.1.1	Land cost, charging piles cost, Cost of infrastructure investment, Unit battery cost, Unit cost of building the charging capacity, Charger cost, Installation cost, Cost of contamination controlling for production of kWh, Electrification cost, Auxiliary devices cost, Penalty cost	
		Operating costs	2.1.2	Cost of electricity, Repair cost, Maintenance cost, Idle rate, administrative cost	
		Investment payback period	2.1.3	-	
		Budget limit	2.1.4	-	
	2.2. User costs	Annual time taken to reach the charging stations	2.2.1	-	
		Time spent to access of the charging service	2.2.2	-	
		Reservation service	2.2.3	-	
		Time spent charging	2.2.4	-	
		Service fee	2.2.5	-	
		Average cost per kilometre for the user	2.2.6	-	
2.3. Municipality costs	Costs for mitigated emission	2.3.1	-		
	Incentives	2.3.2	-		
<b>3. Socio-demographic and behaviour</b>	3.1. Population characteristics	Average income	3.1.1	-	
		People who cannot and will not be able to charge at home and/or at work	3.1.2	-	
		Family size	3.1.3	-	
		Average age	3.1.4	-	
		Level of education	3.1.5	-	
		Employment	3.1.6	-	
		Number of families	3.1.7	-	
		Number of vehicles per families	3.1.8	-	
	3.2. Impact on people's lives	Improvement of employment	3.2.1	-	
		Autonomy anxiety factor	3.2.2	-	
		Habit compatibility	3.2.3	-	
		Residents' acceptance	3.2.4	EV or non-EV	
		Reliability of the electrical system	4.1.1	-	
		Local demand of energy	4.1.2	-	
<b>4. Technological</b>	4.1. Electricity grid	Impact on grid stability	4.1.3	-	
		Voltage limit	4.1.4	-	
		Electricity consumption	4.1.5	-	
		Energy efficiency	4.1.6	-	
		4.2. Vehicle	Vehicle type	4.2.1	-
			Vehicle miles travelled	4.2.2	-
	4.3. Charging station	Battery	4.2.3	Consumption, Size, Performance, Autonomy	
		State of charge	4.2.4	Initial, Final	
		Charging power	4.3.1	-	
		Energy charged	4.3.2	-	
		Charge for multiple types of vehicles	4.3.3	-	
		Charging model	4.3.4	-	
		Charging process type	4.3.5	Plug-in, swapping, wireless or contactless	
		Average duration of charging	4.3.6	-	
Number of connectors		4.3.7	-		
Connector type		4.3.8	-		
Service capacity		4.3.9	-		
Service availability		4.3.10	Operating hour, probability that connectors are not available		
Charging efficiency	4.3.11	-			
Service quality	4.3.12	-			
Smart charging options	4.3.13	-			
Use of sustainable energy source of supply	4.3.14	Solar, wind, etc.			

(continued on next page)

Table A1 (continued)

Topic	Sub-topic	Indicator	N.	Sub-specifics
<b>5. Transportation planning</b>	5.1. Demand	Shelf life	4.3.15	-
		Road Traffic flow	5.1.1	Peak hour, Off peak hour, Incoming and outgoing flows from a node, Average flow
		EV fleet distribution	5.1.2	EV, non-EV and hybrid
		Rate of long-distance traffic	5.1.3	-
		Expected charging per day	5.1.4	-
		Average trip frequency	5.1.5	-
		Moving habits	5.1.6	Departure and arrival times
		Travelled distance	5.1.7	-
		Driving patterns	5.1.8	-
		Charging demand	5.1.9	Day-time, night-time
	Parking demand	5.1.10	-	
	5.2. Supply	Road intersections rate	5.2.1	-
		Length of roadway	5.2.2	-
		Average speed along corridors	5.2.3	-
		Road class	5.2.4	-
		Distance after charging	5.2.5	-
		Road slope	5.2.6	-
		Existing charging station locations	5.2.7	Numbers, points, yes/none
		Existing private charging stations	5.2.8	-
Parking time		5.2.9	-	
<b>6. Urban planning</b>	6.1. Land use	Parking capacity	5.2.10	-
		Safety	5.2.11	Car, passengers, drivers
		Number of TAZ served	5.2.12	-
		Types of parking	5.2.13	Parking area, Street parking, Garage parking
		Number of relevant attractors (in proximity)	6.1.1	Shopping malls, public transport stations, Petrol stations, Parks, Shops, Hospitals, Recreation, Home, School, Workplaces, Supermarket, Public office, Post office, Bank, Parking, Cultural tourist facility, Tourist sports facility
		Functional mix	6.1.2	-
		Residential building types	6.1.3	Single-family detached, Single-family attached, large multi-family
		Territorial zone type	6.1.4	Landslide risk, Seismic risk, Flatlands, Green areas, Archaeological risks, Environmental risks
		Population density	6.1.5	-
		Build-up density	6.1.6	-
	Existing gas stations	6.1.7	-	
	Site attractiveness	6.1.8	-	
	Spatial availability for other structure/site services	6.1.9	-	
	Future expansion prevision	6.1.10	Urban planning, regional planning, urban mobility plans, etc.	
	6.2. Accessibility	Number and types of stops/stations	6.2.1	-
		Number of vehicles served	6.2.2	-
		Proximity to pedestrian and cycle paths	6.2.3	-
Accessibility by car		6.2.4	-	
Proximity to sub-station services		6.2.5	-	
Visibility of charging stations		6.2.6	-	
Distances from public transport stops		6.2.7	-	
Distances from attractors		6.2.8	-	
Distances from vegetation	6.2.9	-		
Distances from water resources	6.2.10	-		
Proximity to travel corridors	6.2.11	Proximity of intersections, proximity main roads		
Distance between charging stations	6.2.12	Minimum, medium, maximum		

**Appendix B**

Examples of questionnaires adopted for Stages 1 and 2 of the international survey

**If you were asked to choose an indicator for locating and monitoring an EV charging station based on its Methodological quality or its Sustainability relevance which of the two criteria would you deem more important to your selection and how strongly so? \***

Please mark the appropriate number (1 = equal importance; 3 = moderate importance of one item over another; 5 = essential or strong importance of one item over another; 7 = Very strong importance of one item; 9 = Extreme importance of one item; 2,4,6,8 = Intermediate values between the two adjacent)

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
<b>Methodological Quality</b> what is this? (i.e. Measurability, Easy Availability, Fast Availability, Interpretability)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<b>Sustainability Relevance</b> what is this? (i.e. Economic growth and efficiency, Environment protection and improvement, Social (and spatial) equity and security, Liveable of cities and neighbourhoods)

**In deciding an indicator of 'EV Charging Location and Monitoring', which of the following attributes would you deem more important for indicator choice and how strongly? \***

Please mark the appropriate number (1 = equal importance; 3 = moderate importance of one item over another; 5 = essential or strong importance of one item over another; 7 = Very strong importance of one item; 9 = Extreme importance of one item; 2,4,6,8 = Intermediate values between the two adjacent)

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
<b>Measurability</b> what is this?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<b>Easy Availability</b> what is this?
<b>Fast Availability</b> what is this?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<b>Measurability</b> what is this?
<b>Interpretability</b> what is this?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<b>Fast Availability</b> what is this?
<b>Easy Availability</b> what is this?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<b>Interpretability</b> what is this?
<b>Interpretability</b> what is this?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<b>Measurability</b> what is this?
<b>Fast Availability</b> what is this?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<b>Easy Availability</b> what is this?
<b>Economic growth and efficiency</b> what is this?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<b>Environment protection and improvement</b> what is this?
<b>Environment protection and improvement</b> what is this?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<b>Social (and spatial) equity and security</b> what is this?
<b>Social (and spatial) equity and security</b> what is this?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<b>Economic growth and efficiency</b> what is this?
<b>Liveable of cities and neighbourhoods</b> what is this?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<b>Environment protection and improvement</b> what is this?
<b>Economic growth and efficiency</b> what is this?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<b>Liveable of cities and neighbourhoods</b> what is this?
<b>Liveable of cities and neighbourhoods</b> what is this?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<b>Social (and spatial) equity and security</b> what is this?

Figure B1. Example of the questionnaire for stage 1 of pairwise comparisons between criteria and attributes. Source: Elaborated from the authors.

	Measurability what is this?	Ease of Availability what is this?	Fast Availability what is this?	Interpretability what is this?	Economic growth and efficiency what is this?	Environment protection and improvement what is this?	Social (and spatial) equity and security what is this?	Liveable of cities and neighbourhoods what is this?
Road Traffic flow	1-10	1-10	1-10	1-10	1-10	1-10	1-10	1-10
EV fleet distribution	1-10	1-10	1-10	1-10	1-10	1-10	1-10	1-10
Rate of long-distance traffic	1-10	1-10	1-10	1-10	1-10	1-10	1-10	1-10
Expected charging per day	1-10	1-10	1-10	1-10	1-10	1-10	1-10	1-10
Average trip frequency	1-10	1-10	1-10	1-10	1-10	1-10	1-10	1-10
Moving habits	1-10	1-10	1-10	1-10	1-10	1-10	1-10	1-10

Figure B2. Example of the questionnaire for stage 2 on evaluating KISLs for each attribute. Source: Elaborated from the authors.

Appendix C

Table C1

Preliminary ranking of Weighted Key Indicators Score.

N.	Topic	Sub-topic	Indicator	Value
1	Urban planning	Accessibility	Distance between charging stations	7.759
2	Urban planning	Accessibility	Distances from public transport stops	7.451
3	Technological	Charging station	Charging power	6.892
4	Urban planning	Accessibility	Distances from activities	6.789
5	Economic-financial	User costs	Average cost per kilometre for the user	6.757
6	Transportation planning	Supply	Existing charging station locations	6.726
7	Urban planning	Accessibility	Accessibility by car	6.654
8	Urban planning	Land use	Existing gas stations	6.603
9	Technological	Charging station	Charge for multiple types of vehicles	6.575
10	Economic-financial	User costs	Annual time taken to reach the charging stations	6.556
11	Urban planning	Land use	Build-up density	6.537
12	Transportation planning	Demand	EV fleet distribution	6.517
13	Technological	Charging station	Average duration of charging	6.484
14	Technological	Charging station	Charging efficiency	6.478
15	Technological	Charging station	Energy charged	6.466
16	Socio demographic and behaviour	Population characteristics	Average age	6.446
17	Technological	Charging station	Connector type	6.426
18	Urban planning	Accessibility	Number of vehicles served	6.397
19	Technological	Charging station	Charging process type	6.370
20	Technological	Charging station	Number of connectors	6.348
21	Socio demographic and behaviour	Population characteristics	Average income	6.333
22	Economic-financial	Company or commercial parties' costs	Budget limit	6.229
23	Socio demographic and behaviour	Population characteristics	Family size	6.215
24	Technological	Electricity grid	Electricity consumption	6.206
25	Transportation planning	Demand	Charging demand	6.173
26	Urban planning	Accessibility	Distances from vegetation	6.169
27	Technological	Vehicle	Battery	6.154
28	Economic-financial	Company or commercial parties' costs	Construction costs	6.139
29	Urban planning	Accessibility	Distances from water resources	6.125
30	Urban planning	Accessibility	Number and types of stops/stations	6.122
31	Environmental	Impact	Fine particulate matter emission	6.070
32	Urban planning	Accessibility	Proximity to travel corridors	6.061
33	Technological	Electricity grid	Impact on grid stability	6.023
34	Transportation planning	Supply	Average speed along corridors	6.018
35	Urban planning	Land use	Population density	6.012
36	Urban planning	Land use	Functional mix	5.996
37	Environmental	Impact	Greenhouse gas (GHG) emission	5.958
38	Technological	Electricity grid	Energy efficiency	5.954
39	Urban planning	Accessibility	Proximity to pedestrian and cycle paths	5.953
40	Technological	Charging station	Use of sustainable energy source of supply	5.924
41	Socio demographic and behaviour	Population characteristics	Employment	5.907
42	Transportation planning	Supply	Existing private charging stations	5.888
43	Technological	Charging station	Service quality	5.869
44	Transportation planning	Supply	Length of roadway	5.857
45	Economic-financial	User costs	Time spent charging	5.818

(continued on next page)

Table C1 (continued)

N.	Topic	Sub-topic	Indicator	Value
46	Transportation planning	Supply	Parking capacity	5.759
47	Environmental	Impact	CO2 emission	5.744
48	Economic-financial	Municipality costs	Costs for mitigated emission	5.737
49	Economic-financial	Municipality costs	Incentives	5.718
50	Technological	Demand	Service availability	5.697
51	Transportation planning	Supply	Road intersections rate	5.648
52	Urban planning	Land use	Future expansion	5.627
53	Economic-financial	User costs	Service fee	5.597
54	Transportation planning	Supply	Road class	5.591
55	Socio demographic and behaviour	Impact on people's lives	Autonomy anxiety factor	5.479
56	Transportation planning	Demand	Road Traffic flow	5.471
57	Economic-financial	User costs	Time spent to access of charging service	5.410
58	Transportation planning	Demand	Driving patterns	5.403
59	Transportation planning	Supply	Safety	5.355
60	Technological	Charging station	Smart charging options	5.349
61	Urban planning	Land use	Number of relevant attractors	5.305
62	Transportation planning	Demand	Travelled distance	5.286
63	Economic-financial	Company or commercial parties' costs	Operating costs	5.283
64	Urban planning	Land use	Territorial zones	5.263
65	Technological	Vehicle	Vehicle miles travelled	5.253
66	Technological	Charging station	Service capacity	5.252
67	Technological	Vehicle	Vehicle type	5.224
68	Transportation planning	Supply	Parking time	5.221
69	Environmental	Impact	EV market penetration	5.210
70	Transportation planning	Supply	Types of parking	5.192
71	Environmental	Impact	Destruction degree on vegetation and water	5.175
72	Socio demographic and behaviour	Population characteristics	Level of education	5.171
73	Socio demographic and behaviour	Population characteristics	Number of vehicles per families	5.154
74	Transportation planning	Supply	Distance after charging	5.128
75	Transportation planning	Demand	Moving habits	5.123
76	Socio demographic and behaviour	Population characteristics	People who cannot and will not be able to charge at home and/or at work	5.107
77	Economic-financial	User costs	Reservation service	5.095
78	Technological	Charging station	Charging model	5.090
79	Transportation planning	Demand	Expected charging per day	5.078
80	Urban planning	Accessibility	Proximity to sub-station	5.074
81	Socio demographic and behaviour	Population characteristics	Number of families	5.069
82	Transportation planning	Demand	Average trip frequency	5.064
83	Socio demographic and behaviour	Impact on people's lives	Habit compatibility	5.038
84	Technological	Charging station	Shelf life	4.987
85	Technological	Electricity grid	Local demand of energy	4.978
86	Transportation planning	Demand	Parking demand	4.960
87	Urban planning	Accessibility	Visibility of charging stations	4.946
88	Socio demographic and behaviour	Impact on people's lives	Improvement of employment	4.927
89	Economic-financial	Company or commercial parties' costs	Investment payback period	4.921
90	Urban planning	Land use	Residential building types	4.856
91	Transportation planning	Demand	Rate of long distance traffic	4.781
92	Technological	Electricity grid	Voltage limit	4.715
93	Technological	Electricity grid	Reliability of the electrical system	4.709
94	Environmental	Impact	Renewable market penetration	4.702
95	Environmental	Impact	LCA emission	4.699
96	Urban planning	Land use	Site attractiveness	4.627
97	Transportation planning	Supply	Road slope	4.622
98	Socio demographic and behaviour	Impact on people's lives	Residents' acceptance	4.610
99	Technological	Vehicle	State of charge	4.498
100	Transportation planning	Supply	Number of TAZ served	4.493
101	Urban planning	Land use	Physical availability for other structure/site services	4.369
102	Environmental	Impact	Waste discharge	4.356

**Table C2**  
Final ranking of Weighted Key Indicators Score.

N.	Topic	Sub-topic	Indicator	Value
1	Urban planning	Accessibility	Distance between charging stations	7.397
2	Urban planning	Accessibility	Distances from public transport stops	7.054
3	Urban planning	Accessibility	Distances from activities	6.737
4	Urban planning	Accessibility	Number and types of stops/stations	6.663
5	Technological	Charging station	Charging power	6.467
6	Urban planning	Accessibility	Number of vehicles served	6.455
7	Urban planning	Accessibility	Accessibility by car	6.411
8	Urban planning	Land use	Population density	6.383
9	Transportation planning	Supply	Existing charging station locations	6.347
10	Urban planning	Accessibility	Proximity to pedestrian and cycle paths	6.323
11	Economic-financial	User costs	Time spent charging	6.304
12	Economic-financial	User costs	Annual time taken to reach the charging stations	6.303
13	Urban planning	Land use	Existing gas stations	6.264
14	Economic-financial	User costs	Average cost per kilometre for the user	6.258
15	Urban planning	Land use	Build-up density	6.246
16	Transportation planning	Demand	EV fleet distribution	6.189
17	Technological	Charging station	Energy charged	6.136
18	Technological	Charging station	Connector type	6.118
19	Technological	Charging station	Average duration of charging	6.103
20	Technological	Charging station	Number of connectors	6.089
21	Socio demographic and behaviour	Population characteristics	Average age	6.058
22	Technological	Charging station	Charging efficiency	6.025
23	Transportation planning	Supply	Average speed along corridors	5.992
24	Socio demographic and behaviour	Population characteristics	Average income	5.990
25	Urban planning	Accessibility	Proximity to travel corridors	5.964
26	Technological	Charging station	Charge for multiple types of vehicles	5.961
27	Urban planning	Accessibility	Distances from vegetation	5.940
28	Technological	Charging station	Charging process type	5.932
29	Urban planning	Land use	Number of relevant attractors	5.908
30	Transportation planning	Demand	Charging demand	5.882
31	Economic-financial	User costs	Service fee	5.877
32	Urban planning	Land use	Functional mix	5.867
33	Transportation planning	Supply	Length of roadway	5.861
34	Technological	Charging station	Use of sustainable energy source of supply	5.854
35	Environmental	Impact	Fine particulate matter emission	5.843
36	Technological	Electricity grid	Electricity consumption	5.832
37	Technological	Vehicle	Battery	5.810
38	Transportation planning	Demand	Road Traffic flow	5.808
39	Economic-financial	Company or commercial parties' costs	Budget limit	5.806
40	Urban planning	Accessibility	Distances from water resources	5.806
41	Environmental	Impact	Greenhouse gas (GHG) emission	5.784
42	Socio demographic and behaviour	Population characteristics	Number of vehicles per families	5.783
43	Technological	Demand	Service availability	5.775
44	Socio demographic and behaviour	Population characteristics	Family size	5.768
45	Technological	Charging station	Service quality	5.745
46	Economic-financial	Company or commercial parties' costs	Construction costs	5.714
47	Economic-financial	User costs	Reservation service	5.714
48	Technological	Vehicle	Vehicle type	5.677
49	Technological	Electricity grid	Energy efficiency	5.674
50	Transportation planning	Supply	Existing private charging stations	5.641
51	Socio demographic and behaviour	Population characteristics	Employment	5.636
52	Environmental	Impact	CO <sub>2</sub> emission	5.602
53	Transportation planning	Supply	Parking capacity	5.569
54	Technological	Vehicle	Vehicle miles travelled	5.553
55	Economic-financial	Municipality costs	Costs for mitigated emission	5.542
56	Transportation planning	Supply	Safety	5.540
57	Socio demographic and behaviour	Population characteristics	Level of education	5.502
58	Economic-financial	User costs	Time spent to access of charging service	5.490
59	Transportation planning	Supply	Road class	5.485
60	Transportation planning	Demand	Travelled distance	5.465
61	Technological	Electricity grid	Impact on grid stability	5.443
62	Transportation planning	Supply	Road intersections rate	5.434
63	Economic-financial	Municipality costs	Incentives	5.414
64	Economic-financial	Company or commercial parties' costs	Operating costs	5.403
65	Socio demographic and behaviour	Population characteristics	People who cannot and will not be able to charge at home and/or at work	5.375
66	Urban planning	Land use	Residential building types	5.331
67	Technological	Charging station	Service capacity	5.325
68	Urban planning	Land use	Future expansion	5.311
69	Transportation planning	Supply	Parking time	5.310
70	Urban planning	Accessibility	Proximity to sub-station	5.302
71	Technological	Electricity grid	Reliability of the electrical system	5.293
72	Transportation planning	Supply	Types of parking	5.273
73	Socio demographic and behaviour	Population characteristics	Number of families	5.249
74	Technological	Charging station	Smart charging options	5.236

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Table C2 (continued)

N.	Topic	Sub-topic	Indicator	Value
75	Transportation planning	Demand	Parking demand	5.163
76	Environmental	Impact	Charging model	5.150
77	Socio demographic and behaviour	Impact on people's lives	Autonomy anxiety factor	5.149
78	Transportation planning	Demand	Average trip frequency	5.127
79	Environmental	Impact	Destruction degree on vegetation and water	5.127
80	Economic-financial	Company or commercial parties' costs	Investment payback period	5.106
81	Technological	Electricity grid	Local demand of energy	5.072
82	Transportation planning	Demand	Moving habits	5.069
83	Technological	Electricity grid	Voltage limit	5.067
84	Technological	Charging station	Shelf life	5.050
85	Urban planning	Land use	Territorial zones	5.042
86	Transportation planning	Demand	Driving patterns	5.039
87	Environmental	Impact	EV market penetration	5.039
88	Transportation planning	Demand	Expected charging per day	5.018
89	Transportation planning	Supply	Distance after charging	5.016
90	Transportation planning	Supply	Number of TAZ served	4.953
91	Socio demographic and behaviour	Impact on people's lives	Improvement of employment	4.951
92	Socio demographic and behaviour	Impact on people's lives	Habit compatibility	4.915
93	Transportation planning	Supply	Road slope	4.849
94	Urban planning	Land use	Site attractiveness	4.814
95	Environmental	Impact	Waste discharge	4.787
96	Transportation planning	Demand	Rate of long distance traffic	4.774
97	Technological	Vehicle	State of charge	4.764
98	Urban planning	Accessibility	Visibility of charging stations	4.739
99	Environmental	Impact	LCA emission	4.738
100	Environmental	Impact	Renewable market penetration	4.697
101	Urban planning	Land use	Physical availability for other structure/site services	4.577
102	Socio demographic and behaviour	Impact on people's lives	Residents' acceptance	4.558

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