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Stakeholder prioritizations for electric vehicle charging across time periods

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ABSTRACT

Electric vehicles have penetrated the Dutch market, which increases the potential for decreased local emissions, the use and storage of sustainable energy, and the roll-out and use of electric car-sharing business models. This development also raises new potential issues such as increased electricity demand, a lack of social acceptance, and infrastructural challenges in the built environment. Relevant stakeholders, such as policymakers and service providers, need to align their values and prioritize these aspects. Our study investigates the prioritization of 11 Dutch decision-makers in the field of public electric vehicle charging. These decision-makers prioritized different indicators related to measurements (e.g., EV adoption rates or charge point profitability), organization (such as fast- or smart-charging), and developments (e.g., the development of mobility-service markets) using the best-worst method. The indicators within these categories were prioritized for three different scenario's in time. The results reveal that priorities will shift from EV adoption and roll-out of infrastructure to managing peak demand, using more sustainable charging techniques (such as V2G), and using sustainable energy towards 2030. Technological advancements and autonomous charging techniques will become more relevant in a later time period, around 2040. Environmental indicators (e.g., local emissions) were consistently valued low, whereas mobility indicators were valued differently across participants, indicating a lack of consensus. Smart charging was consistently valued higher than other charging techniques, independent of time period. The results also revealed that there are some distinct differences between the priorities of policymakers and service providers. Having a systematic overview of what aspects matter supports the policy discussion around EVs in the built environment.

1. Introduction

Energy transition policy goals are ambitious but necessary to ensure a habitable planet for future generations. The energy transition will require massive change. It will affect our business models, means of travel, consumption habits, building designs, and so on. A substantial share of the required activities for the energy transition occurs within city boundaries. Therefore, this transition impacts urban planning: intensive coordination between a wide range of parties may be needed to adequately shape cities' transportation and energy infrastructure during the transition. This is particularly relevant because of the tensions between the city's short- and long-term (urban) developments, the allocation of budgets to various activities, developments in energy supply and storage infrastructure, expectations related to habitability, and developments in the area of mobility. Because all these elements interact within cities, coordination within cities is crucial for this transition to succeed. At the same time, cities should be able to fulfil the needs of their inhabitants. Changes and innovations should be harmonized with each other as well as with the local environment.

One key ingredient is the diffusion of electric vehicles, which are at the intersection of energy and mobility. Electric vehicles are crucial in obtaining climate goals (Delbeke et al., 2019). In the Netherlands, mobility was responsible for roughly 18–22% of the emissions in 2021 (Central Bureau of Statistics, 2021). The mobility and energy sectors are crucial for a functioning society, and transitioning to electric mobility can reduce their negative effects on the global and local climate. Electric vehicles allow us to store and transport electricity, use renewable energy effectively, match demand with supply, and drive a car without creating local emissions. Charging often takes place in public spaces, and markets (e.g., energy markets) are disrupted by the transition to electric mobility. The future development of petrol stations, parking spots, parking garages, driveways, and energy grids is also affected by this transition. Because of these complexities, there are many stakeholders involved in the transition to electric mobility. On a municipal level,

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there are implications for policymakers, environmental planners, charging point operators, citizens, grid operators, car manufacturers, energy, logistics, and transport industries. These stakeholders all play a role in the future development of charging infrastructure, and because of their roles, they may differ in opinion regarding the importance of various elements related to electric vehicle charging. Earlier research shows that stakeholders consider different things important when evaluating charging methods, in particular in the implementation of smart charging and fast charging (Wolbertus et al., 2020), (Bakker et al., 2014). Other potential conflicts of interest include governance, technical standards, roll-out strategies and policy management (Bakker et al., 2014). There may be a lack of alignment between and within organizations that focus on Dutch charging infrastructure that could be improved by co-learning and transparency (van Galen, 2015).

As mentioned before, coordination is very important in this transition. For this purpose, stakeholders will need to identify and compare their goals, address differences, and decide on a direction. In this study, we facilitate this process by interviewing important stakeholders in the field of electric mobility. Taking the interests of multiple stakeholders into account, we systematically determine and compare their prioritizations, identify the most important aspects of charging that need monitoring, and anticipate aspects of charging that will become important at a later point in the mobility transition.

The question for this study is as follows:

> “What are the most important issues, according to local decision-makers in the field of electric mobility? How do these change over time?”

In this study, we use the best-worst method (BWM) as a multi-criteria approach to identify stakeholder consensus and alignment in the future development of public EV charging infrastructure roll-out in municipalities, using a case study in the Netherlands. Multiple criteria decision making (MCDM) allows us to prioritize different aspects, taking into account different stakeholders (Serrano-Cinca et al., 2021). This method allows us to take individual assessments into account and find consensus, which can be useful when working with multiple stakeholders (Diaz-Balteiro et al., 2009). There have also been other studies using a multi-criteria approach in EV infrastructure stakeholder analysis. For example, one study identified critical factors for electric vehicle diffusion in China (technology level, policies and regulations, consumer acceptance, pricing and market structure) using multiple-criteria decision-making methods (Liu et al., 2017). Another study looked at three values for EV station deployment under different location scenarios, using a combination of multiple criteria analysis methods. They identified accessibility as the most important value, followed by traffic convenience and waiting times (Rouyendegh et al., 2019).

Our approach is to interview decision-makers involved in the roll-out of public charging infrastructure for electric vehicles (which includes service providers and local policymakers, among others). Decision-makers selected for this study are directly involved in the development of this public charging network, for example, because they are part of a market solution, they are involved in policymaking, or they are otherwise involved in developing charging in municipal areas. According to the BWM, we have had interviewees determine their prioritizations of various developments and topics in different time periods during the mobility transition. Details on the conceptualization of developments, time periods, and selection of stakeholders are in the Methods section.

We chose the Netherlands as our case study, where adoption is relatively high (over 1 out of 5 newly sold vehicles is electric (Netherlands Enterprise Agency, 2021)), there is a public charge network in the big cities, and explicit policy goals and pilot activities have been introduced to facilitate the energy transition and the adoption of electric vehicles. These policy goals include the development of an accessible charging network, the integration of renewable energy sources in charging, the electrification of traffic, interoperability standards, environmental zones, and traffic sectors (van der Koogh et al., 2021). Because the Netherlands includes some densely populated urban areas, regulations have been made to ensure charging opportunities for EV users: new buildings need to have charging points incorporated in their parking solutions, public parking spots that have a charging point installed cannot be used by conventional vehicles, and some municipalities have deadlines for their inner-city zones for professional traffic to transition into a clean transmission. The effectiveness of policy in the integration of EVs has been assessed by studies in the past. For example, in one study, charging comfort to reduce range anxiety was deemed more important than monetary compensation (Lieven, 2015). Other studies plea for a more integral policy rather than separate policies targeting either the vehicle or the infrastructure (van der Steen et al., 2015), argue that the acceptability of EV incentives differs across regions (Davies et al., 2016), and suggest that subsidizing research and development, as well as regulations (for manufacturers) to limit fuel consumption could improve the uptake of electric vehicles (Wu et al., 2021). Our study will also take into account the various policy instruments that have been introduced in local policy documents.

This paper is structured as follows: first, the selected methods and the set-up of the interviews are explained. After that, the most prominent results are discussed. We will end the paper with our conclusions and recommendations.

2. Methods

The following section contains a description of the methods used and the design of the experiment. The first subsection describes the multiple criteria analysis method. After, the selected criteria for the analysis are described. In the next subsection, the different time periods that were defined as inputs for the MCDM interviews are described. The last subsection explains the selection process of participants.

2.1. Multiple criteria analysis

We use the linear best-worst method (Rezaei, 2016) as our multiple-criteria analysis method. The method works as follows: the most and least important criterium is chosen from a set. Then, one set of weights is compared to the least important criterium, and one set of weights is compared to the most important criterium. This method is chosen because it’s less redundant than the analytical hierarchy process, as all indicators are only valued twice instead of $n \times n$. We adapted this method by adding three periods in time as scenarios. We also added a time-based comparison by calculating how indicator values change over time.

We will now illustrate the use of the best-worst method using the steps from Table 1. Steps 1 and 2 determine the context of the questionnaire. They are determined in the paragraphs below (see Tables 2

Table 1
Adapted method (adapted from Rezaei, 2016).

The original method for Linear best-worst Method	Adapted method (temporal comparisons)
Step 1: Determine the set of criteria	Step 1: Determine the set of criteria
Step 2: Determine the best and worst criterium	*Step 2: Determine the time periods*
Step 3: Determine best-to-others (BO) vector (1–9)	Step 3: Determine the best and worst criterium
Step 4: Determine worst-to-others (WO) vector (1–9)	Step 4: Determine best-to-others (BO) vector (1–9)
Step 5: Find the optimal weights by minimizing absolute differences	Step 5: Determine worst-to-others (WO) vector (1–9)
Step 6: Validate the consistency	Step 6: Find the optimal weights by minimizing absolute differences
	Step 7: Compare weights across time periods (within-subject)
	Step 8: Validate the consistency

and 3). To determine steps 3, 4, and 5, the participant is asked three questions:

> Q1: What is your favorite and least favorite option? (step 3)
> Q2: How much do you like your other options compared to your favorite (1 = just as much, 9 = nine times worse)? (step 4)
> Q3: How much do you dislike your other options compared to your least favorite (1 = just as much, 9 = nine times better)? (step 5)

This determines the set of weights compared to the best selection *[AB = (ab1, ab2, … abn)]* and the set of weights compared to the worst selection *[AW = (aw1, aw2, … awn)]*. For step 6, the min-max model is used to find the weights that have the smallest distance between both lists (see Fig. 1). This model can become more complicated when necessary (e.g., with a high number of criteria and multiple optima). As can be read from Fig. 1, the weights of all criteria in a set should sum up to 1. This means that if there are four criteria in a set and a participant ranks them all as equally important, each of these four criteria would have a weight of 0.25.

Step 7 contains the delta analysis. The delta analysis works as follows: If a participant has a weight of 0.53 for indicator X at time A, we ask them to fill out the same question for time B. This time, the participant scores 0.3 on Indicator X. In that case, the Delta score of Indicator X is determined as *wj(T2) – wj(T1) = (X_Weight(Time B) – X_Weight(Time A) = - 0,23)*. The importance of indicator X is lowered over time by 0.23.

The last step is to determine the consistency ratio score, Ksi. This score is determined by looking at the differences between the values of the sets and the end value. The smaller the difference, the smaller the consistency ratio score.

2.2. Criteria

We looked at four different papers using indicators for EV and charging infrastructure in cities to determine the criteria for the interviews (Helmus and Van Den Hoed, 2016; Angelakoglou et al., 2020; di Martino et al., 2021; van der Hoogt et al., 2020). An overview of the selected criteria and related papers can be found in the Appendix (A1), and the definitions of the criteria can be found in Table 2. The criteria were split into three categories: measuring, organizing, and development indicators. The Measuring Indicators category contains nine different mobility and energy indicators that can be monitored for informed decision-making. The Organizing category contains seven different criteria related to the configuration of charging infrastructure. The Development category contains four relevant activities at the energy-mobility intersection.

Participants were also asked to select relevant policy instruments for each period in time. These instruments were not ranked, and participants were not limited in their number of selections for this category. The list of instruments includes: subsidy, knowledge exchange, restrictions (e.g., zero-emission zones), preferential treatment, voluntary agreements, technical and domain support, and ‘other’ (free text form).

2.3. Definition of time-based scenarios

We have added three consecutive periods in time as different phases in our interview study. These three time periods were introduced to the interviewees with a short description that we based on prognosis and policy goals in the Netherlands. Table 3 contains a translation of these descriptions.

2.4. Participants

Three participants were recruited through the consortium network of our RAAK-SIA-funded research project “Future Charging” (Amsterdam University of Applied Sciences/Urban Technology). These were policymakers from three of the four largest municipalities (Rotterdam, The

Table 2
Category, indicators, and description of indicators.

Category	Indicator	Description
Measuring	Car ownership	The number of vehicles in possession of inhabitants.
Measuring	EV Adoption	The number of sold EVs.
Measuring	Profitability of the business case	The extent to which the exploitation of charging infrastructure is profitable for the service provider/charge point owner.
Measuring	Public space	The space that is used for charging and parking.
Measuring	Peak demand	The peak in kW on the busiest charge moments.
Measuring	Use of sustainable energy	The extent to which sustainable energy is used in charging.
Measuring	Local emissions	The level of local emissions (e.g., CO_2 levels).
Measuring	Occupancy rate	The % of charge stations in a network that is occupied.
Measuring	User comfort	The level of comfort an EV driver experiences in finding and using a public charge point.
Organizing	The role of fast charging	Anything that isn’t slow charging. Includes DC quick & rapid charging, but does *not* include Level I/II AC charging (Botsford and Szczepanek, 2009).
Organizing	The role of V2G/energy storage in the car	Important technology in smart grid integration of renewable energy. High-performing batteries of electric vehicles can store renewable electricity and ensure grid stability (Ota et al., 2012).
Organizing	The role of smart charging	During smart charging, the charging behaviour of parked EVs is controlled by an aggregator based on available (renewable) energy, tariffs, and/or driver input about time and energy requirements. Smart charging can help reduce peak demand and charging fares (Daina et al., 2017).
Organizing	The role of induction (or autonomous-friendly) charging	Autonomous vehicles need induction charging or another intervention to be able to charge. Wireless Power Transfer (WPT) systems conduct energy without contact. Currently, this type of charging is not common due to misalignment risk and associated losses (inefficiency). Technological developments (Hwang et al., 2017) and developments in the mobility system might lead to more and improved WPT charging.
Organizing	The role of PV (solar) charging	Photovoltaic charge systems generate their electricity using light sources, and can be combined with smart charging (when), V2G (store) and, forecasting techniques (predict) for effective use of sustainable energy (Goli and Shireen, 2014)
Organizing	The role of charge locations and accessibilities (public, semi-public, private, work)	Exploring the potential role of locations given their difference in limitations on temporal and spatial availability (Philipsen et al., 2020).
Organizing	The roles of different user groups in the charging network	User types are distinguishable by charge behaviour. Observed user types with distinguishable behaviours include residents,

(*continued on next page*)

Table 2 (*continued*)

Category	Indicator	Description
		commuters, shared vehicles, logistics, and cab drivers (Helmus and van den Hoed, 2015).
Development	Developing the mobility service market	Examples of these development activities are: MaaS chains, shared vehicles, mobility budgets, and public transport expansions
Development	Activities in the Energy system	Examples of these energy activities are: grid expansions, peak shaving, and expansion of sustainable energy sources
Development	Roll-out of charging infrastructure	Examples are the roll-out of charging points and the construction of charging hubs.
Development	Stimulating technological developments	Examples of these developments are autonomous driving, battery developments, intelligent transport systems and hydrogen vehicles.

Table 3
Three time-based scenarios based on policy goals and prognoses in the Netherlands (van der Koogh et al., 2021), (Rijksoverheid, 2018; CityDeal-gemeenten, 2018; Rijksoverheid, 2019; Outlook, 2020; Gemeente Amsterdam, 2020; Rotterdam, 2015; Verslag et al., 2019; Ministerie van Infrastructuur en Waterstaat, 2019; PBL, 2019).

	Time period: Null (T1)	Time period: Near Future (T2)	Time period: Later Future (T3)
Timespan	2021–2025	2025–2030	2030–2040
Scenario	During this period, adoption rates of electric vehicles will increase (prognosis is that 16,4% to 42,7% new car sales are EVs), and we expect more variance in vehicle types. The 30–40 largest cities will work towards zero-emission logistics. The government set a goal of 50% electric cabs in 2025. Until 2025, private subsidies are available and road taxes are exempt. The 4 largest cities are also focusing on decreasing street parking, alternative mobility, and more efficient use of the public space.	After 2025, there will be zero-emission zones, and goals for sectors such as public transport, and zero-emission zones for logistics are compulsory for the 40 cities after 2026. Prognosis states that 29,6%–58% of new car sales are electric. When needed for sufficient CO2 reductions, additional rules will be made for emission-free construction vehicles. Larger cities will continue to develop alternative mobility, expand public transport, improve bike lanes, and migrate street parking.	This period is still very uncertain. The government's target is to exclusively sell new electric cars after 2030. City centers can install zero-emission zones that also require inhabitants to drive zero-emission. The focus will be on international mobility and European guidelines. Hydrogen vehicles, autonomous vehicles, and drones are expected to become more important. There will be a focus on creating more emission-free mobility sectors such as waterborne and aviation. The vision for inner cities is car-free streets, lots of green areas, recreation, and bike lanes.

$$
\begin{aligned}
&\min \max_{j} \left\{ \left| \frac{w_B}{w_j} - a_{Bj} \right|, \left| \frac{w_j}{w_W} - a_{jW} \right| \right\} \\
&\text{s.t.} \\
&\textstyle\sum_j w_j = 1 \\
&w_j \geq 0, \quad \text{for} \quad \text{all} \quad j
\end{aligned}
$$

Fig. 1. BWM min-max model to find the optimal weights, as described in (Rezaei, 2016).

Hague, and Utrecht). Input from these policymakers is valuable, since these larger municipalities have already installed public infrastructure and are familiar with some of the most important policy roadmaps since they take place in their areas of operation. Other participants were recruited online. The scope of our study is to determine the priorities of decision makers in the development of the public charging network. After filtering on focus (electric mobility and/or public charging) and decision-making (charging point operator/service provider, policymaker, municipal worker, market developer and/or involved in decision groups), 11 participants were left (see Table 4). Interviews were held in April 2021 (first rounds) and September 2021 (catch-up round for participants that were not available.

3. Results

The interviews were analysed with the use of MS Excel. Values of individual participants can be found in the Appendix (A2-A10). In the following sections, we will discuss three of our analyses. Table 6 contains the average weights, and Table 5 describes how this can be read.

3.1. *Analysis 3.1: summary for each time period*

3.1.1. *T1 time period: null (2021–2025)*

Measuring: For this period in time, EV adoption was selected most often as most important (4 out of 11 participants), among all participants 7 different criteria were chosen as 'Best'. 4 out of 11 participants chose Local emissions as 'Worst' (least important), while 3 others chose Car ownership as least important and 3 other criteria were chosen by others. The criterium use of Public Space was not selected by anyone as either 'Best' or 'Worst'. The rounded average KSI (consistency) score was 0,12. The full weighted table can be found in Appendix A2. *Organizing:* For this period in time, Accessibilities (of charge locations) were selected most often as most important (4 out of 11 participants), among all participants 5 different criteria were chosen as most important. A small majority (6 out of 11) chose Induction (or autonomous-friendly) as the least important criterium. The criteria User Groups and Induction (or autonomous-friendly) were never chosen as the 'Best' criterium in this time period. The criteria for Fast Charging and Smart Charging were never chosen as the 'Worst' criterium in this time period. The rounded average KSI consistency score was 0,14. The full weighted table can be found in Appendix A3. *Development*: 9 out of 11 participants found the Roll-out of infrastructure the most important. The other two found

Table 4
Participant list.

Role	Experience	Area of Operations
Service Provider, CPO	4 years	European
Policy Maker (Municipal)	15 years	Municipal (Rotterdam) & Regional
Policy Maker (Government)	29 years infra/2 years electric	National
Service Provider, CPO	12 years	International & Municipal
Interest Group Rep	6 years	National
Service Provider, CPO	30 years	Regional
Market developer	2 years	National
Market developer	3 years	Unspecified
Policy Maker (Municipal)	12 years	Municipal (Utrecht)
Service Provider, CPO	8 years	Municipal & Provincial
Policy Maker (Municipal)	1 year	Municipal (The Hague)

Table 5
Description table to read Table 6.

Rowname	Description
Best	The indicator that is selected as 'Best' by most participants for this time period (number of participants who made this selection). When more than 2 indicators have equal highest amount of selections, the result will be noted as 'Mixed'.
Highest avgW	The indicator that has the highest average weight of all rankings of this time period (average weight rounded to two decimals). Keep in mind that the average weights are scaled by the number of indicators in the category. This is why average weights can only be compared within their category. Averages of total (time-independent analysis) are calculated using participant levels (not average levels per time period).
Worst	The indicator that is selected as 'Worst' by most participants for this time period (number of participants who made this selection). When more than 2 indicators have equal highest amounts of selections, the result will be noted as 'Mixed'.
Lowest avgW	The indicator that has the lowest average weight over all rankings of this time period (average weight rounded to two decimals). Keep in mind that the average weights are scaled by the number of indicators in the category. This is why average weights can only be compared within their category. Averages of total (time-independent analysis) are calculated using participant levels (not average levels per time period).
SD	Standard deviation, which is the square root of the variance of the (mean) average weight.
KSI (rounded)	The average consistency ratio score (KSI) for this category and time period, rounded to two decimals. The lower the score, the more consistent individuals have been with their weights for this category and time.

Activities in the Energy System the most important. 6 out of 11 found Developing the mobility service market the least important. Out of the other five participants, four found Stimulating technological developments the least important. The rounded average KSI consistency score was 0,18. The full weighted table can be found in Appendix A4. *Policy Instruments:* 33 selections were made among 11 participants for 2021–2025. The policy instrument that was selected the most for this time period was the Subsidy (8), narrowly followed by Voluntary agreement (7). Knowledge exchange and Restrictions (e.g., zero-emission zones) were also selected by more than half of the participants (6). Other instruments were not or barely chosen (<3) for this period. The 'Other … ' button was used twice, with input 'Facilitation of market-based infrastructure roll-out' and 'Internal agreements between charging point operator and municipality'.

3.1.2. *T2 time period: near future (2025–2030)*

Measuring: The 'Best' selections were more mixed towards 2030. EV Adoption, Car ownership, Peak demand and Use of sustainable energy were all selected as most important by two participants. The other 3 participants selected Occupancy, Profitability and User Comfort. The criterium that was selected as 'Worst' the most was Car ownership (5 times). Another criterium that got selected three times as worst was the Local emissions. 2 participants selected User Comfort, and one Occupancy. The rounded average KSI consistency score was 0,11. The full weighted table can be found in Appendix A5. *Organizing:* Both Smart Charging, as well as V2G, got selected as 'Best' by four participants. The other participants selected Accessibility. Five participants found Induction (and autonomous-friendly) charging the 'Worst' (in 2025 this were 6). Among all participants 3 more criteria were selected as least important. The rounded average KSI consistency score was 0,16. The full weighted table can be found in Appendix A6. *Development:* The Roll-out of infrastructure was again most selected, but by only 4 participants. Others selected either Activities in the Energy System or Developing the Mobility service market. Five participants selected Stimulating Tech developments as 'Worst'. Others selected Developing the Mobility service market or the Roll-out of charging infrastructure. The rounded average KSI consistency score was 0,41. One of the participants had a score over 1, indicating an inconsistency. The full weighted table can be found in Appendix A7. *Policy Instruments:* 32 selections were made among 11 participants. Almost all participants selected Restrictions (e.g., zero-emission zones) for this time period (10). Voluntary agreements were also popular for this time period (8) and Knowledge exchange was selected by almost half of the participants (5). Other instruments were not or barely chosen (<3) for this period.

3.1.3. *T3 time period: later future (2030–2040)*

Measuring: The selection of 'Best' criteria was mixed among participants. The criteria EV adoption, Car ownership, Use of Sustainable energy and Peak demand were all selected as most important by two participants. The other 3 participants selected Public space, Profitability and Local Emissions. The criterium that was most selected as least important, or 'Worst', for this period was Car Ownership (4 times, while in 2030 it was 5 times). Local emissions and Occupancy were both selected twice, and the other results were mixed. The rounded average KSI consistency score was 0,12. The full weighted table can be found in Appendix A8. *Organizing:* All Organizing indicators except for PV and fast charging were selected as 'Best' at least once. All roles (no exceptions) were selected at least once as Worst for this period in time. The results were mixed. The rounded average KSI consistency score was 0,14. The full weighted table can be found in Appendix A9. *Development:* In this period, stimulating technological developments was the most popular as 'Best', as 5 participants selected it. The other participants either selected developing the mobility service market or activities in the energy system. Nobody selected the roll-out of infrastructure as most important in 2040. The criterium that was most selected as least important or 'Worst' in this period is the roll-out of infrastructure (4 times). The other participants selected a mix of all three other criteria. The rounded average KSI consistency score was 0,37. The full weighted table can be found in Appendix A10. *Policy Instruments:* 27 selections were made among 11 participants. For this period, both Voluntary agreements and Knowledge exchange were the most popular among participant selections (7). The only two other categories that had more than three selections were Technical & Domain support to parties (5) and Restrictions (e.g., zero-emission zones) (4). The 'Other … button' was used once, with the input 'Law and Regulation of autonomous driving'.

The colors of the figures correspond with the category of indicators: blue for measuring indicators, yellow for organizing indicators and red for development indicators.

3.1.4. *Time-independent analysis*

Measuring (Fig. 2, top): The most popular selection was EV adoption (8 times). All criteria were selected as 'Best' at least 1 time by 1 participant. The criteria that were selected only once were Local emissions and the use of Public Space. The criteria that address user experience, Occupancy and User Comfort, also scored low on 'Best' selection, as they were selected only twice. Car ownership, the use of sustainable energy, peak demand and profitability were more popular, with 4–5 selections. Peak demand was never selected as the 'Worst' indicator and therefore, only the 'Best' selections of Peak Demand can be observed in the graph (Fig. 2). Both Car Ownership and Local Emissions were often selected as 'Worst'. These criteria both focus on the local environment. The criteria that focus more on user experience (comfort, occupancy) were sometimes selected as the worst. EV adoption, the use of public space and profitability were selected as worst only by 1 participant for 1 period of time, and the use of sustainable energy was selected as the worst only two times. *Organizing (Fig. 2, down left):* Independent of time, the criteria Smart Charging, V2G and Accessibility were selected as 'Best' more often than the other criteria. All criteria were selected at least once. Independent of time, the criterium for induction charging was selected as 'Worst' or least important most often. However, Induction got selected as 'Best' more often than 3 other criteria. This is in line with the delta results, where almost all participants found Induction to

Table 6

Best, Highest average weights, Worst and Lowest average weights for all time periods and categories. It is recommended to read the description table (5).

T1: Null, Current 2021–2025	Measuring indicators	Organizing indicators	Development indicators	Policy instruments selected for this period (threshold >3)
Best	EV adoption (4)	Accessibility (4)	Roll-out of charging infra (9)	Subsidy (8) Voluntary agreements (7) Knowledge exchange (6) Restrictions (6)
Highest avgW	EV adoption (avgW = 0,16, SD = 0,08)	Smart Charging (avgW = 0,21, SD = 0,05)	Roll-out of charging infra (avgW = 0,40, SD = 0,08)	
Worst	Local emissions (4)	Autonomous/Induct (6)	Development of MaaS (6)	
Lowest avgW	Car ownership (avgw = 0,06, SD = 0,04)	Autonomous/Induct (avgW = 0,06, SD = 0,05)	Development of Maas (avgW = 0,14 SD = 0,09)	
KSI (rounded)	ξ = 0,12	ξ = 0,14	ξ = 0,18	
T2: Near Future 2025–2030	Measuring indicators	Organizing indicators	Development indicators	Policy instruments selected for this period (threshold >3)
Best	Mixed (4 optima).	V2G (4), Smart Charging (4)	Roll-out of charging infra (4)	Restrictions (10) Voluntary agreements (8) Knowledge exchange (5)
Highest avgW	Peak demand (avgW = 0,15, SD = 0,06)	Smart Charging (avgW = 0,21, SD = 0,06)	Activities Energy System (avgW = 0,31, SD = 0,09)	
Worst	Car ownership (5)	Autonomous/Induct (5)	Stimulate tech. dev. (5)	
Lowest avgW	Car ownership (avgW = 0,08, SD = 0,07)	Autonomous/Induct (avgW = 0,09, SD = 0,07)	Stimulate tech. dev. (avgW = 0,17, SD = 0,09)	
KSI (rounded)	ξ = 0,11	ξ = 0,16	ξ = 0,41 (one participant had >1)	
T3: Later Future 2030–2040	Measuring indicators	Organizing indicators	Development indicators	Policy instruments selected for this period (threshold >3)
Best	Mixed (4 optima)	Autonomous/Induct (3), V2G (3)	Stimulate tech dev. (5)	Voluntary agreements (7) Knowledge exchange (7) Technical/Domain support (5) Restrictions (4)
Highest avgW	Sustainable energy use (avgW = 0,16, SD = 0,08)	Smart Charging (avgw = 0,20, SD = 0,09)	Activities Energy System (avgW = 0,28, SD = 0,14)	
Worst	Car ownership (4)	Mixed (3 optima)	Roll-out of charging infra (4)	
Lowest avgW	Profitability (avgW = 0,08, SD = 0,04)	User Groups (avgW = 0,12, SD = 0,09)	Roll-out of charging infra (avgW = 0,23, SD = 0,09)	
KSI (rounded)	ξ = 0,12	ξ = 0,14	ξ = 0,37	
All time periods combined (avg)	Measuring indicators	Organizing indicators	Development indicators	Policy instruments selections summed over time (theoretical max = N x 3 = 33)
Best	EV adoption (8)	Smart Charging (9)	Roll-out of charging infra (14)	*Most selected* figur Voluntary agreements (22) Restrictions (20) *Least selected* Preferential treatment (6)
Highest avgW	Peak demand (avgW = 0,14, SD = 0,06)	Smart Charging (avgW = 0,21, SD = 0,07)	Roll-out of charging infra (avgW = 0,31, SD = 0,12)	
Worst	Car ownership (12)	Autonomous/Induct(13)	Development of MaaS (13)	
Lowest avgW	Car ownership (avgW = 0,09, SD = 0,06)	Autonomous/Induct (avgW = 0,10, SD = 0,09)	Stimulate tech dev. (avgW = 0,20 SD = 0,10)	
KSI (rounded)	ξ = 0,12	ξ = 0,15	ξ = 0,32	

be more important towards 2040. The second criterium that got selected as 'Worst' the most was User Groups, we've seen in the Measuring Indicator graphs that user experience criteria also was not selected as 'Best' often. Fast charging was not selected a lot as either 'Best' or 'Worst', despite becoming less important over time (towards 2030 as well as 2040). *Development (Fig. 2, down right):* The roll-out of infrastructure came out as most selected as 'Best' (14 times), but also is represented in 'Worst' selections (6 times). This further underlines the results in the delta analysis, where the roll-out became more unimportant for more than half of the participants over time. We see an inverse of this phenomenon for the stimulation of technological developments, which becomes more important, but time-independently is the least often chosen as 'Best' (5 times). Activities in the Energy System were the least selected as 'Worst' (3 times), implying a more stable relative importance over all time periods. Developing the mobility service market was selected the most often as 'Worst' (13 times), but policy-makers found it more important over time and it ended up also being selected as 'Best' sometimes (6 times). *Policy instruments:* Policy instrument selections of all time periods summed (92 selections): The use of voluntary agreements was the most selected instrument (22 selections), followed by Restrictions (e.g. Zero-emission zones) (20 selections). Preferential treatment was the least selected instrument (6).

3.2. *Average weights over time*

Below, we discuss the average weight per indicator across time periods. The average weights consider the inputs of each participant equally. However, the scores of individual participants may differ substantially from these averages. This is why we also analyse the standard deviation (see Tables 7–9), as well as the individual changes in scores over time (see Section 3.3).

3.2.1. *Measuring indicators*

Some indicators grow in average importance over time: *Car*

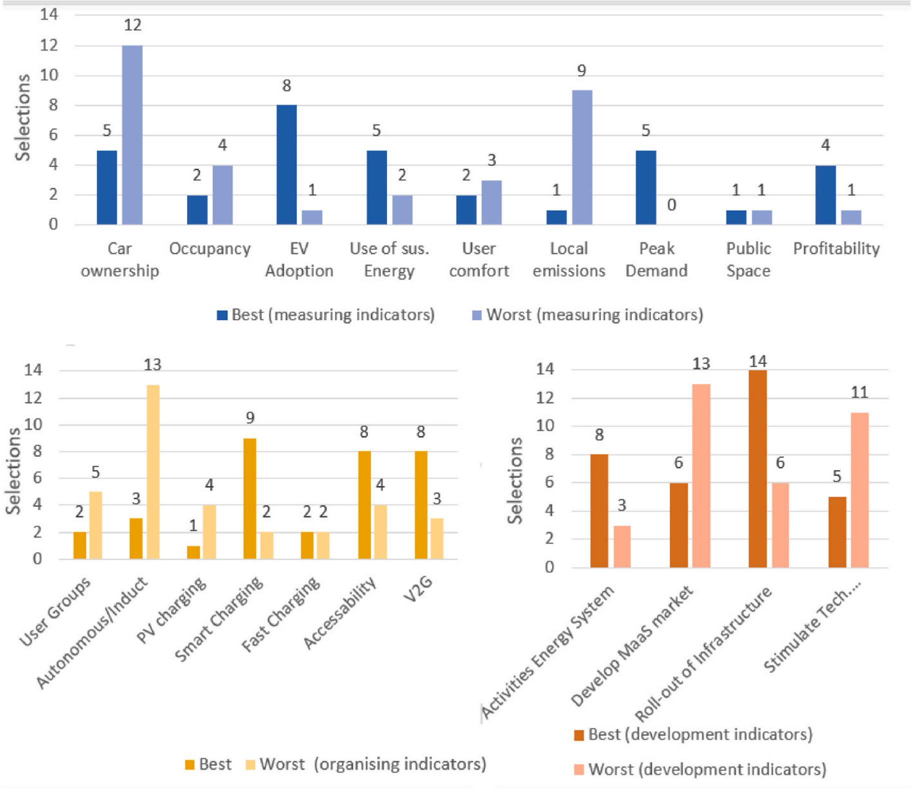

Fig. 2. Time-independent summation of Best and Worst selection for Measuring Indicators (top), Organizing Indicators (down, left) and Development indicators (down, right).

Table 7
Average weights and standard deviation of measuring indicators per time period.

	Car owner-ship	EV Adoption	Profita-bility	Public space	Peak demand	Sus. Energy use	Local emissions	Occupancy	User comfort
2025: T1 (SD)	0,060 (0,038)	0,156 (0,081)	0,114 (0,081)	0,107 (0,040)	0,137 (0,066)	0,102 (0,060)	0,092 (0,058)	0,098 (0,070)	0,134 (0,060)
2030: T2 (SD)	0,085 (0,067)	0,134 (0,034)	0,117 (0,048)	0,105 (0,050)	0,148 (0,061)	0,122 (0,060)	0,088 (0,054)	0,10 (0,060)	0,101 (0,061)
2040: T4 (SD)	0,088 (0,07)	0,117 (0,064)	0,079 (0,039)	0,112 (0,053)	0,145 (0,063)	0,155 (0,074)	0,102 (0,071)	0,091 (0,040)	0,112 (0,058)

Table 8
Average weights and standard deviation of organizing indicators per time period.

	Fast charging	V2G	Smart charging	Inductive charging	PV charging	Accessibility	User groups
2025: T1 *(SD)*	0,192 (0,079)	0,124 (0,065)	0,209 (0,048)	0,061 (0,046)	0,101 (0,061)	0,188 (0,103)	0,126 (0,055)
2030: T2 *(SD)*	0,156 (0,037)	0,182 (0,082)	0,207 (0,058)	0,088 (0,074)	0,097 (0,047)	0,150 (0,102)	0,120 (0,073)
2040: T3 *(SD)*	0,129 (0,073)	0,161 (0,083)	0,201 (0,091)	0,141 (0,130)	0,121 (0,048)	0,127 (0,065)	0,120 (0,086)

Table 9
Average weights and and standard deviation of development indicators per time period.

	Develop Maas	Energy System	Roll-out of Infra	Stimulate new tech
2025: T1 *(SD)*	0,136 (0,090)	0,299 (0,117)	0,399 (0,089)	0,166 (0,059)
2030: T2 *(SD)*	0,226 (0,160)	0,309 (0,090)	0,298 (0,130)	0,167 (0,093)
2040: T3 *(SD)*	0,235 (0,119)	0,277 (0,142)	0,230 (0,090)	0,258 (0,127)

ownership, Peak demand and *The use of sustainable energy* (see Table 7). The use of sustainable energy grows the most in average importance over time. There seems to be low consensus across participants for car ownership: the standard deviation is almost as high as the score itself in T2 and T3, and this standard deviation increases over time. Other indicators become less important over time: *EV Adoption* and *Profitability*. In the case of EV adoption, the relative average importance is not specifically low, it had the highest score for the first time period (T1), and lowered then. Some indicators stay similarly important on average across time periods: *Occupancy* and *Public space*. *Local emissions* and *Peak demand* averages did not change much over time either, however, their standard deviation is relatively higher than the other two indicators (See Table 7).

3.2.2. Organizing indicators

Smart charging has a relatively stable and high average weight. The spread is larger in T3. For *Fast charging*, the indicator seems to lose a bit of average importance, and also gains more spread in T3, indicating a temporary lack of consensus between participants. *V2G* becomes more important on average in T2, but the effect stabilizes. *Inductive charging* starts out with a low average, but becomes much more important, with a very high spread, in T3, indicating a lack of consensus. *Accessibility* of charging becomes less important on average, with less spread, and *PV charging* becomes a little more important on average in T3 (See Table 8).

3.2.3. Development indicators

The roll-out of infrastructure becomes less important over time on average, whereas *Stimulating technological developments* becomes more important over time on average. *Activities in the Energy system* has a stable average weight across time periods, however, the spread increases in T3. *Development of the mobility-service market (MaaS)* is not valued highly on average, especially in the first time period. It also has a relatively high spread across participants, indicating a lack of consensus (see Table 9).

3.3. Delta analysis (differences over time on individual level)

For each participant, we calculated $\boldsymbol{\Delta = wj(T2) - wj(T1)}$ where T1 is the weight calculated for the first time period (null-2025) and T2 is the weight calculated for the near future (2030). We also calculated the deltas (differences calculated on the individual level) between the second and third time period. For each participant we calculated $\boldsymbol{\Delta = wj(T3) - wj(T2)}$ where T2 is the weight calculated for the second time period (2025–2030) and T3 is the weight calculated for the last time period (2030–2040). This shows if the importance is changing, and in which direction in time. Below, we discuss the most interesting results. A full table of the delta analysis for each comparison and category can be found in Appendix (A11-A16).

3.3.1. Measuring Indicators

For 9 out of 11 (82%) and all policymakers (N = 4), User comfort becomes less important between 2025 and 2030. A majority (7 out of 11) also finds that the use of sustainable energy becomes more important, and that EV adoption becomes less important. This majority also finds that local emissions become more unimportant. For the other criteria, the results are more mixed. Between 2030 and 2040, EV adoption and Profitability become less important for 9 out of 11 participants. The subgroup of CPO/Service providers (N = 4), as well as policymakers (N = 4) agree that Profitability becomes less important. Additionally, for all Service Providers, EV adoption becomes less important and the use of sustainable energy becomes more important (quite strongly, an average of 0,10). For 8 out of 11, including all policymakers, user comfort becomes a bit more important towards 2040.

3.3.2. Organizing indicators

For most participants (82%), Vehicle-to-Grid becomes more important between null and 2030. Also, 82% of participants, including all Service providers (subgroup, N = 4) found Accessibility to become less important between null and 2030. PV charging becomes more important for 8 out of 11 participants, including all policymakers (subgroup, N = 4), while fast charging becomes less important for 8 out of 11 participants, including all policymakers. The delta of Organizing indicators between 2030 and 2040 differs in direction between participants. The highest overlap in direction is on the role of fast charging (73% or 8 out of 11 participants think it becomes less important over time). 1 participant gave identical ratings and distances for 2030 and 2040, which makes the delta 0. All policymakers (N = 4) find that PV charging becomes more important in 2040, while fast charging becomes less important.

3.3.3. Development indicators

8 out of 11 participants find that the roll-out of infrastructure becomes less important after 2030. All policymakers (N = 4) find that Activities in the Energy System will become more important. Participant 7 (P7) had a consistency ratio score for this question that exceeded the threshold of 1. They did not belong to the subgroup service provider or policymaker. The error was nominally small (1–2 points out of 9) and the entry is annotated with an Asterix in the table. Stimulating technological developments becomes equally or more important over time for 8 out of 11 participants (73%), while activities in the energy system become equally or less important for 8 out of 11 participants. For all policymakers (N = 4), the development of the mobility-as-a-service market is equally or more important between 2030 and 2040. 1 participant gave identical ratings and distances for 2030 and 2040. Another participant had a consistency score that was deemed too high.

3.4. Subgroup analysis

3.4.1. Subgroup consensus: policymakers

The level of subgroup consensus becomes more apparent when we plot individual weights over time and draw a line to determine the change direction (more- or less important). Below, the most prominent cases are illustrated in Figs. 3–5. The y-axis is not standardized. The colors of the figures correspond with the category of indicators: blue for measuring indicators, yellow for organizing indicators and red for development indicators.

As can be seen in Fig. 3, not only do policymakers have some identical trend directions (more- or less important). In some cases, the distance between the weights is minimized and the level of consensus of the importance seems similar. There seems to be an agreement of decreasing importance of the measuring indicator Profitability towards 2040, despite different starting points. The importance of Public Space in 2040 is also ranked more similarly, as well as the importance of the organizing indicator Fast Charging, where the weight difference is minimized in 2030. In contrast, the level of consensus for the car ownership indicator is low. The weights, as well as the trend patterns, differ between policymakers.

3.4.2. Subgroup consensus: service providers

Fig. 4 highlights some consensus patterns for the service provider subgroup. Whereas the measuring indicator for Profitability, EV Adoption, and the Organizing indicator Accessibility start out being valued differently across service providers, the importance lowers over time and service providers rank these indicators more similarly towards 2040 (T3). The level of consensus for these values increases towards later time periods. For the Organizing indicator of different User Groups, the opposite happens: the service providers value it similarly (low) in the 'now' period (T1), but they end up being differently valued at T3: some service providers find that the importance increases, and others don't.

3.4.3. Differences between subgroups

As can be seen in Fig. 5, in some cases, subgroups have distinct patterns for specific indicators. For the development indicator that addresses the mobility-service-market, the importance increases towards 2040 for policymakers, whereas the importance peaks in 2030 for service providers, and decreases after. The importance of considering different user groups (one of the organizing indicators) has lower overall consensus, as we established in the previous section: importance increases but consensus decreases over time for service providers. We see an inverse between the two subgroups: for policymakers, the importance decreases towards 2040, whereas the level of consensus increases.

3.5. Discussion

Based on these results, four important observations are discussed: current priorities (2025), priorities in the near future (2030) and the later future (2040), as well as indicators with low priority. Fig. 6 summarizes these priorities in a timeline.

In the near future, prioritizations will shift from adoption and roll-out based indicators to sustainability indicators. EV Adoption, Roll-out of infrastructure and Accessibility of charging are considered

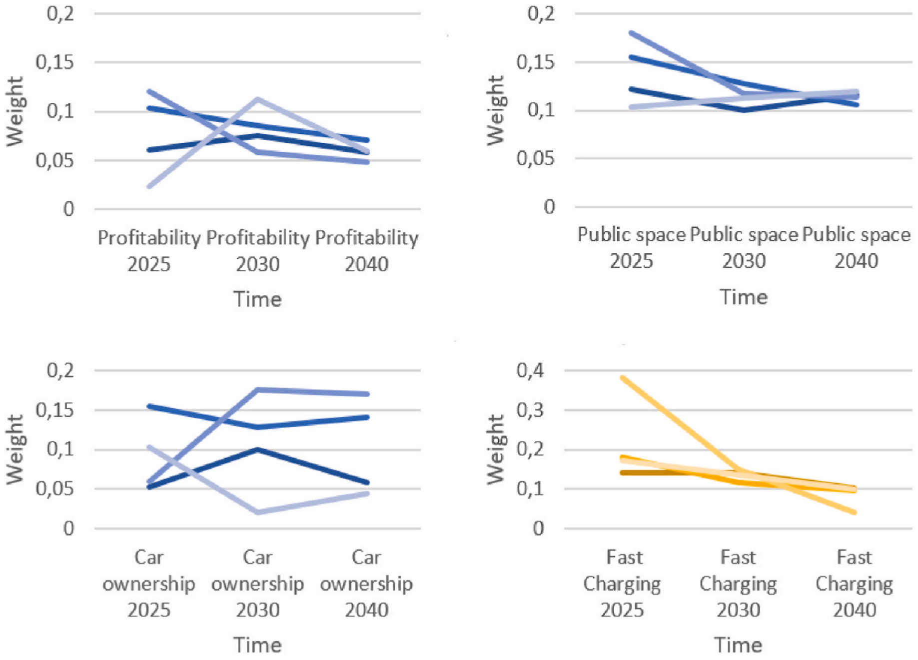

Fig. 3. Policymaker subgroup plots with interesting consensus patterns in weights (y-axis) over time (x-axis).

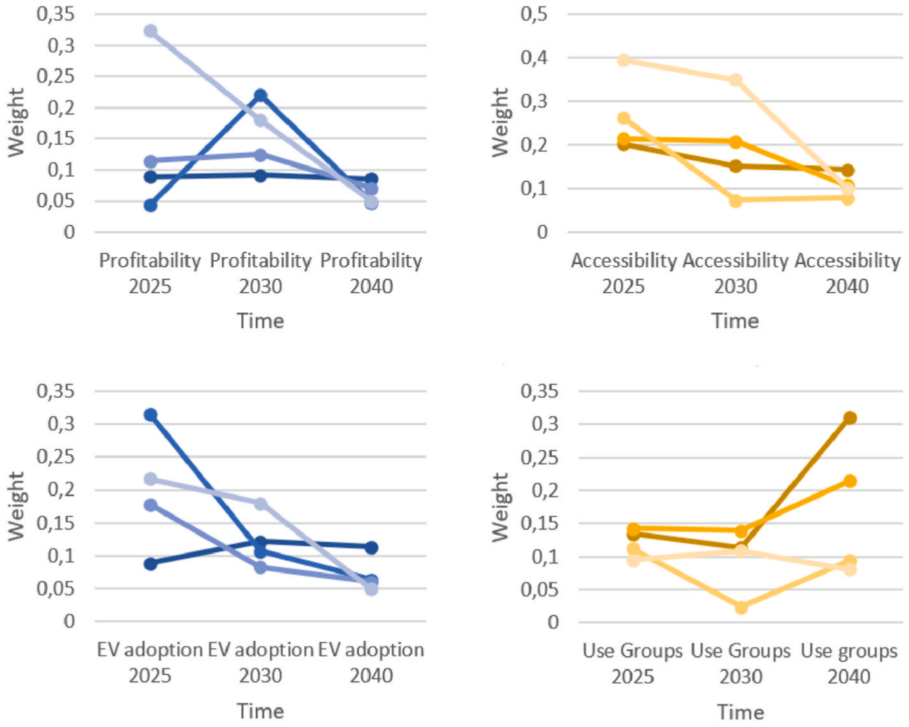

Fig. 4. Service providers subgroup plot with interesting consensus patterns in weights (y-axis) over time (x-axis).

important right now. Looking at the firsfit time period (up to 2025), the indicators EV adoption (avgW = 0,16) and Roll-out (avgW = 0,4) had the highest average weights in their category, and were both chosen most often as ‘Best’ within their category. Accessibility to charging points did not have the highest average weight (Smart charging was higher), but was chosen most often as ‘Best’. These results indicate that the current emphasis is on adoption, sector electrification, roll-out, and access.

Sustainable charging becomes more important over time. 82% of participants found that V2G becomes more important between 2025 and 2030. All policymakers (N = 4) found that the importance of PV/ solar charging increased between 2025 and 2030. The policymakers also find that fast charging becomes less important over time. Service providers find that the use of sustainable energy in charging becomes more important between 2030 and 2040. The exception here is smart charging, a technique that is chosen as ‘Best’ most often, independent of

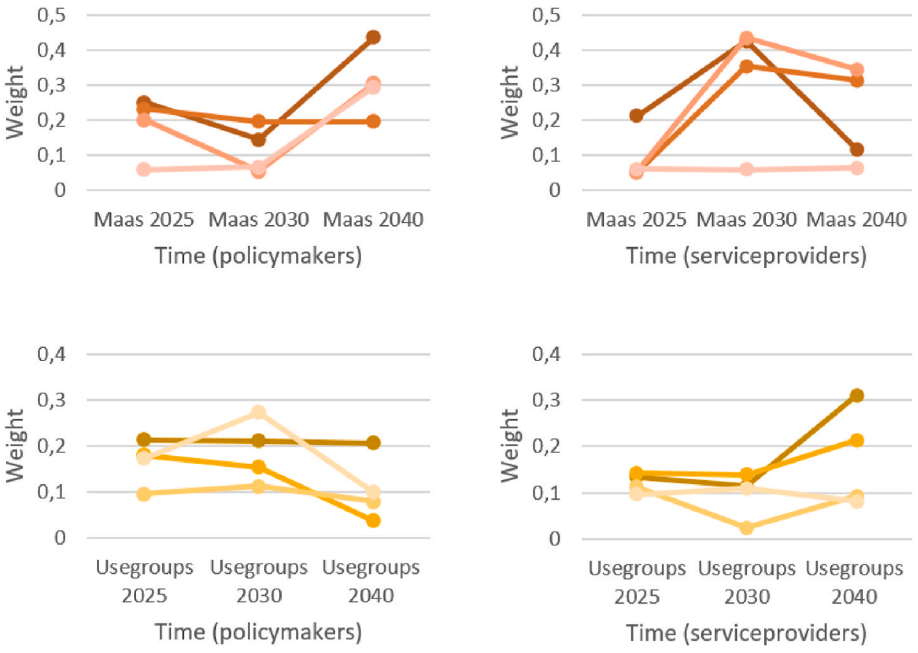

Fig. 5. Comparing indicator scores of Policymakers (left) and Serviceproviders (right).

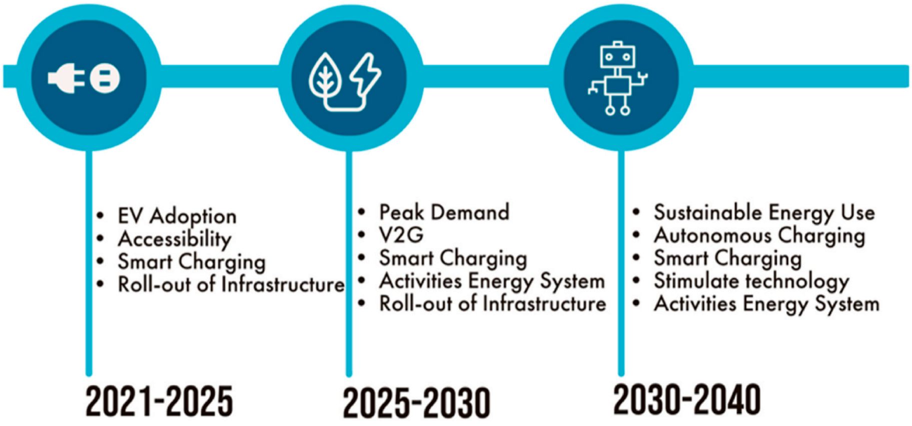

Fig. 6. Priority timeline based on the most popular selections (‘best’) and highest average weights.

time, and stays relevant throughout all periods.

The importance of technological developments and autonomous charging will increase at a much later time (2040). Autonomous charging and the stimulation of technological developments were not popular in the first two time periods. However, all service providers increased their importance for technological developments between 2030 and 2040. About half of the participants chose technological development as ‘Best’ activity in 2040. Autonomous charging becomes a bit more important towards 2040 (with high spread). The role of autonomous charging is therefore still uncertain.

Policy instruments are preferred as more supportive for the first time period and more restrictive for later time periods. Suggestions for different policy instruments were mainly suggested for the first time period. The instrument of voluntary agreements got more popular over time and is considered relevant for future scenarios, whereas the subsidy is popular now but phases out over time. Restrictions (with the given examples of zero emission zones and deadlines) were also often selected.

The role of alternative mobility in the EV transition is not prioritized by EV stakeholders.

The study examined indicators of alternative mobility and modal shift, such as car ownership and public space usage. Car ownership scored lowest in the time-independent analysis, while public space was of relatively low importance. Some participants did prioritize car ownership. The development indicator of the mobility service market scored low, but recovers by the last time period (T3: 2030–2040). Although it is not entirely clear how participants rank alternative mobility, it is not a priority on a group level.

Fig. 6 summarizes these priorities in a timeline. This timeline represents the priorities of the stakeholders, not taking into account the technical feasibility or the differences between subgroups or individual participants.

4. Conclusion & recommendation

4.1. Conclusions

This study addressed the question of which issues are most urgent in public electric vehicle charging, according to stakeholders, and how these priorities change over time. On the basis of stakeholder consultation, we were able to distinguish priorities for different time periods, as well as differences between specific stakeholders (with a focus on policymakers and service providers). We conclude that the short-term focus of key decision-makers lies with EV adoption, roll-out of infrastructure, and accessible charging. Smart charging is already important for most decision-makers, and sustainable charging becomes more and more important over time. In the later future, towards 2040, decision-makers find technological developments and autonomous charging more important, whereas the importance of the infrastructure and the adoption decreases.

Previous studies of stakeholders in the case study area, published in 2014 and 2019, stated that stakeholders find smart charging important (Wolbertus et al., 2020) (Bakker et al., 2014) and indicated a lack of consensus within indicators addressing charging methods, specifically the level of user control for smart charging and the importance of fast charging compared to regular charging (Wolbertus et al., 2020). We found that, although values differed across participants, smart charging was among the most prioritized indicators by most participants and was selected as ‘Best’ by most participants, confirming the importance found in previous studies (see Table 6). Table 8 also reveals that the standard deviation for smart charging was not particularly high compared to other indicators. The subgroup analysis illustrates how the subgroup of policymakers agrees on the importance of fast charging across time periods. Table 8 reveals that the standard deviations for fast charging were not very high in the first two time periods. The delta analysis (Section 3.2) shows how 73% of participants decrease the importance of fast charging over time (T2-T3). This study therefore found a higher level of consensus (and lower long-term importance) on the role of fast charging than previous studies had found. The case study of 2019 found that the type of stakeholder did not predict the type of perspective, except for one of the perspectives, where local policymakers were overrepresented. We also found some distinct patterns for policymakers and identified new patterns that were specific to service providers, whereas in the 2019 study, perspectives differed across that subgroup. Policy instruments were also selected for each period. User subsidies were selected the most for the first time period, which users valued lower than comfort and ensured charging, according to Lieven et al. (Lieven, 2015). Another study stresses the importance of research and development (Wu et al., 2021), whereas our similar instrument “technology and domain support" was only selected a few times for the last period.

In time period T1 (2021–2025) and time period T2 (2025–2030), the indicators public space, user comfort, technology developments and autonomous charging are not valued highly. However, peak demand and the use of sustainable energy are considered important for time period 2, and the technology of smart charging is valued highly for every period in time. Applying these results to the real world could lead to challenges in the demand: The exponential growth in EV adoption will lead to higher demand, not just from the electricity grid. The number of charging points will also need to grow so that drivers can park and charge their vehicles. This will require many resources beyond electricity such as traffic decision-makers, public space, parking spots, charge point installers, grid connections and service providers. The stress during peak hours could increase a lot, whereas most of the infrastructure would not be used during most of the day. In Section 4.2, we will discuss some strategies for handling this high demand.

4.2. *Policy implications*

The results on short-term prioritizations imply that creating and satisfying charging demand are the most urgent priorities for decision-makers. The increase in charging demand can be addressed from different perspectives. Various social, local and environmental trade-offs are at play which further complicates the roll-out of urban charging infrastructure (Hensley et al., 2018), (van der Kam et al., 2020). Below, we discuss two strategies decision-makers can use in future roll-out of infrastructure, and discuss these strategies and their drawbacks in the context of the results of this study.

4.2.1. *Strategy A: roll-out of charging resources with protocols to limit grid strain*

Facilitate many connections during the same point in time, using smart charging techniques to migrate grid demand, but the demand for other resources (installers, operators, public space, and so on) will be high. This option helps to avoid peak grid overload, and increases user comfort by installing an abundance of charge points. Smart charging can help in scaling up the roll-out of public charging infrastructure, because a significant number of Dutch neighbourhoods don’t have enough grid capacity to fulfil the anticipated charging demand without interventions (van der Toorn, 2022). In an Amsterdam smart charging pilot, no significant increases in charging speeds were observed (Bons et al., 2020), although this may differ in a scaled-up scenario. In the future, this setup could be enriched with V2G protocols and techniques to make balancing the grid possible. This would require intensive cooperation between manufacturers, policymakers and installers.

4.2.2. *Strategy B: sharing of charging resources to limit resource strain*

This strategy migrates the connection times of EVs by using new technologies (autonomous charging, snake arms, automatic clutch release, induction rotation), user incentives (social charging, tariffs) and introducing alternative mobility (reducing the number of owned vehicles). Car sharers drive up to 20% less than personal vehicle owner (Nijland et al., 2015), (Nijland and van Meerkerk, 2017). Intensive sharing of vehicles reduces the need for parking space (Hensher, 2017). *Strategy B* could not only avoid peak overload of the grid, but could also lead to sharing of other resources. When a charging point is used by more users throughout the day, this could improve the business case. Autonomous charging technologies could also be considered future-proof because some technologies allow the vehicle to charge and discharge without driver intervention. This allows for one charging point to be used on multiple vehicles sequentially without user intervention. This option could also be enhanced by V2G in the future, and combinations of technologies (e.g. autonomous V2G balancing fleets) could potentially revolutionize the way we handle electricity demand in municipalities.

The study found that decision makers prioritize roll-out, adoption, and smart charging over car ownership and public space. *Strategy A*, which facilitates connections and uses smart charging techniques, is crucial for successful transitions. However, it has drawbacks, such as increased charging point usage, increased demand for installers and resources, and less profitability for charging point operators with fewer customers per resource. High flexibility without compensating comfort requires more charging points than actively used, requiring more parking space and resources. These resources are already in great demand and their efforts might be more worthwhile in areas that are underdeveloped in terms of charging.

It is undeniable that the future roll-out of charging infrastructure under current grid conditions can only be achieved with the help of smart charging. Nevertheless, other initiatives are necessary too in order to limit the strain on product chains, installers, and public space, and to better connect with other mobility goals, such as modal shift or reduced parking. *Strategy A* can be used to scale up the roll-out of infrastructure that is necessary to ensure charging, and elements of *Strategy B* can be used to limit the charging demand (and therefore, necessary resources) in a spatial area, allowing for more adoption under current grid conditions and a more efficient use of resources. We would like to encourage decision-makers to consider interventions of both strategies before the third time period to ensure a positive business case and a future-proof design.

4.3. *Limitations*

We aimed to include policymakers from all four large municipalities and a national policymaker. One of these municipalities was not available, and therefore, the perspective of only three of the largest municipalities in the Netherlands are included. Additionally, the perspective of rural policymakers is missing. Rural areas in the Netherlands are less developed in terms of public infrastructure, partially because inhabitants are more likely to have their own driveway. However, the importance of public infrastructure will grow over time and therefore it is important to consider the rural perspective in future studies. The service providers that were interviewed are employed by different companies. Together they represent a significant portion of the current charging market in the Netherlands. Future work should also consider the perspective of the grid operator, which was not included here. This may give insight into the steps needed to align the perspectives of policymakers, grid operators and service providers. Future work in other countries should be finetuned to their local context because the stakeholders and issues involved may differ. Since this study focuses on key decision-makers regarding the charging infrastructure, the outcomes do not represent the values or opinions of the users of the charging infrastructure. To generalize the results beyond the case study, additional research with a larger pool of stakeholders is recommended. The best-worst method should only be trusted when the consistency ratio of the outcomes is low enough. This is because pairwise comparison methods do not guarantee a global optimum. Besides that, if participants are asymmetrical in valuing their best- and worst-sets, the consistency ratio is likely to grow since the distance between the outcome weight and sets will be greater. The consistency ratio of the answers overall was acceptable. In the development indicators, Ksi scores were higher in some individual cases. Questionable ksi scores are found for one participant in T2 of the development indicators (1,78) and for two participants in T3 of the development indicators (0,87 and 0,94). We see no substantial effects on the conclusion. Two participants were not able to finish the questionnaire within the meeting; these participants completed the questionnaire within 16 h after the initial meeting. We did not observe inconsistencies in the data of these participants. When indicators lose priority over time, for example, the roll-out of an infrastructure indicator, there were some participant assumptions that the demand would be satisfied by then because of prior activities. An alternative approach to avoiding these assumptions in future work could be the use of thresholds rather than discrete time periods.

Statement

This research is funded through NWO's RAAK-PRO project Future Charging (RAAK.PRO03.128).

Data availability

The data that has been used is confidential.

Appendix

Table A1
Literature Derived Criteria Selection

Criteria selection from literature	Helmus and Van Den Hoed (2016)	van der Hoogt et al. (2020)	di Martino et al. (2021)	(Angelakoglou et al., 2020)
Perspective	EV charging infrastructure	Smart EV and renewable integration	Business model of green EV behaviour	Energy transition in smart cities
Indicator about car ownership, modal shift and/or use of alternative transport				X
Indicator about EV adoption and/or amount of EV users/drivers	X	X	X	X
Indicator about cost (benefits), pricing, profitability and/or business case	X	X	X	X
Indicator about the surface costs/use of public space for charging and/or parking	X			
Indicator about kWh, kW, energy use and/or peak demand	X	X	X	X
Indicator about the mix of sustainable energy, sustainable capabilities, peak shaving, V2G and/or smart use	X	X	X	X
Indicator about air quality, CO2 emissions and/or avoided emissions	X	X		X
Indicator about occupancy rates and/or utilization of the charging network	X		X	X
Indicator about user convenience, comfort accessibility and/or security	X			X

Table A2
Individual Weights for Measuring indicators T1: 2021–2025

Measuring indicators 2025	Car ownership	EV Adoption	Profitability	Public space	Peak demand	Sus. Energy use	Local emissions	Occupancy rates	User comfort	Consistency (KSI)
P1	0,022	0089	0,089	0089	0,222	0133	0,133	0089	0,133	0044
P2	0,052	0183	0,061	0122	0,061	0183	0,183	0061	0,092	0183
P3	0,155	0155	0,103	0155	0,078	0078	0,044	0077	0,155	0155
P4	0,056	0316	0,044	0132	0,197	0033	0,099	0066	0,057	0079
P5	0,038	0,15	0,1	0,1	0,075	0,1	0,1	0,15	0,188	0113
P6	0,038	0178	0,114	0076	0,229	0057	0,021	0057	0,229	0051
P7	0,049	0098	0,098	0073	0,146	0146	0,146	0098	0,146	0146
P8	0,035	0082	0,177	0035	0,207	0207	0,015	0035	0,207	0071
P9	0,060	0027	0,12	0,181	0,12	0,052	0,06	0,289	0,09	0,072
P10	0,054	0217	0,324	0109	0,072	0031	0,048	0072	0,072	0131
P11	0,103	0226	0,024	0104	0,104	0104	0,155	0078	0,104	0294

Table A3
Individual Weights for Organizing indicators T1:2021–2025

Roles 2025	Fast charging	V2G	Smart charging	Inductive charging	PV/Solar	Accessibility	User group roles	Consistency (KSI)
P1	0,202	0067	0,202	0058	0,135	0202	0,135	0202
P2	0,142	0106	0,213	0053	0,061	0213	0,213	0213
P3	0,18	0,18	0,135	0108	0,135	0081	0,18	0,459
P4	0,277	0042	0,214	0048	0,061	0214	0,143	0151
P5	0,156	0156	0,156	0031	0,063	0281	0,156	0031
P6	0,169	0084	0,262	0027	0,084	0262	0,112	0075
P7	0,176	0118	0,176	0176	0,235	0088	0,029	0118
P8	0,169	0269	0,269	0025	0,169	0042	0,056	0069
P9	0,382	0068	0,239	0036	0,06	0,119	0096	0,096
P10	0,079	0158	0,158	0079	0,035	0395	0,095	0,08
P11	0,173	0115	0,27	0,028	0069	0,173	0173	0,076

Table A4
Individual Weights for Development indicators T1:2021–2025

Development indicators 2025	Develop Maas	Energy Activities	Roll-out of Infra	Stimulate new tech	Consistency (KSI)
P1	0,211	0316	0,316	0158	0,316
P2	0,25	0,25	0,375	0125	0,375
P3	0,231	0077	0,462	0231	0,231
P4	0,05	0,275	0,45	0,225	0175
P5	0,064	0511	0,32	0,106	0128
P6	0,053	0474	0,32	0,158	0158
P7	0,07	0,296	0437	0,197	0155
P8	0,25	0,25	0,25	0,25	0
P9	0,2	0,3	0,45	0,05	0,15
P10	0,06	0,226	0546	0,169	0131
P11	0,058	0,32	0,466	0155	0,146

Table A5
Individual weights for measuring indicators T2:2025–2030

Measuring indicators 2030	Car ownership	EV Adoption	Profitability	Public space	Peak consumption	Sus. Energy use	Local emissions	Occupancy rates	User comfort	Consistency (KSI)
P1	0,052	0122	0,092	0061	0,122	0092	0,183	0092	0,183	0367
P2	0,1	0,15	0,075	0,1	0,1	0,15	0,15	0,1	0,075	0,15
P3	0,128	0128	0,085	0128	0,064	0128	0,085	0128	0,128	0128
P4	0,16	0,107	0,22	0,08	0,16	0,16	0,053	0,04	0,02	0,1
P5	0,026	0126	0,126	0126	0,178	0084	0,126	0084	0,126	0073
P6	0,188	0083	0,125	0229	0,083	0063	0,021	0083	0,125	0063
P7	0,02	0,18	0,08	0,08	0,12	0,24	0,12	0,08	0,08	0,06
P8	0,017	0135	0,135	0034	0,135	0195	0,045	0,09	0,213	0075
P9	0,175	0088	0,058	0117	0,175	0058	0,05	0,253	0026	0,097
P10	0,045	0,18	0,18	0,09	0,269	0,06	0,025	0,09	0,06	0,092
P11	0,02	0,174	0112	0,112	0225	0,112	0112	0,056	0075	0,051

Table A6
Individual Weights for Organizing indicators T2: 2025–2030

Roles 2030	Fast charging	V2G	Smart charging	Inductive charging	PV/Solar	Accessibility	User group roles	Consistency (KSI)
P1	0,227	0076	0,227	0114	0,091	0152	0,114	0227
P2	0,141	0141	0,211	0085	0,07	0,141	0211	0,423
P3	0,115	0092	0,154	0,04	0,154	0291	0,154	0,17
P4	0,209	0104	0,209	0,06	0,07	0,209	0139	0,209
P5	0,169	0169	0,27	0,025	0113	0,169	0085	0,068
P6	0,146	0,22	0,146	0293	0,098	0073	0,024	0073
P7	0,169	0311	0,254	0101	0,063	0029	0,072	0196
P8	0,103	0318	0,205	0068	0,205	0068	0,032	0093
P9	0,149	0223	0,315	0089	0,074	0037	0,112	0131
P10	0,145	0145	0,145	0073	0,033	0,35	0,109	0086
P11	0,136	0205	0,136	0023	0,091	0136	0,273	0068

Table A7
Individual weights for Development indicators T2: 2025–2030

Development indicators 2030	Develop Maas	Energy Activities	Roll-out of Infra	Stimulate new tech	Consistency (KSI)
P1	0,425	0,31	0,207	0057	0,195
P2	0,143	0286	0,429	0143	0,857
P3	0,195	0,26	0,39	0,156	0,39
P4	0,353	0294	0,294	0059	0,235
P5	0,061	0429	0,306	0204	0,184
P6	0,433	0,2	0,067	0,3	0,167
P7*	0,298	0223	0,223	0255	1787
P8	0,403	0273	0,273	0052	0,143
P9	0,053	0474	0,316	0158	0,158
P10	0,057	0,24	0,559	0144	0,16
P11	0,066	0412	0,209	0313	0,214

The asterix at P7 indicates consistency issues with this entry.

Table A8
Individual Weights for Measuring indicators T3: 2030–2040

Measuring indicators 2040	Car ownership	EV Adoption	Profitability	Public space	Peak demand	Sus. Energy use	Local emissions	Occupancy rates	User comfort	Consistency (KSI)
P1	0,027	0113	0,085	0057	0,085	0264	0,17	0,085	0113	0,076
P2	0,058	0116	0,058	0116	0,078	0159	0,233	0022	0,159	0073
P3	0,14	0,211	0,07	0,105	0,07	0,07	0,018	0105	0,211	0,07
P4	0,055	0064	0,048	0127	0,267	0191	0,127	0095	0,025	0115
P5	0,178	0119	0,119	0119	0,178	0059	0,059	0119	0,051	0178
P6	0,211	0,06	0,07	0,141	0141	0,106	0,07	0,06	0,141	0211
P7	0,031	0088	0,088	0088	0,131	0225	0,131	0088	0,131	0038
P8	0,034	0,12	0,177	0014	0,12	0,177	0,06	0,12	0,177	0064
P9	0,17	0,257	0049	0,113	0113	0,049	0022	0,17	0,057	0083
P10	0,02	0,05	0,05	0,228	0228	0,228	0,05	0,074	0074	0,069
P11	0,045	0,09	0,06	0,119	0179	0,179	0179	0,06	0,09	0,358

Table A9
Individual Weights for Organizing indicators T3: 2030–2040

Roles 2040	Fast charging	V2G	Smart charging	Inductive charging	PV/Solar	Accessibility	User group roles	Consistency (KSI)
P1	0,216	0038	0,144	0062	0,086	0144	0,311	0121
P2	0,103	0206	0,206	0082	0,059	0137	0,206	0206
P3	0,095	0095	0,239	0,08	0,159	0295	0,037	0182
P4	0,214	0071	0,214	0107	0,071	0107	0,214	0214
P5	0,169	0169	0,27	0,025	0113	0,169	0085	0,068
P6	0,236	0118	0,047	0307	0,118	0079	0,094	0165
P7	0,152	0152	0,235	0152	0,152	0101	0,055	0069
P8	0,064	0292	0,317	0025	0,193	0055	0,055	0094
P9	0,042	0139	0,139	0444	0,079	0079	0,079	0111
P10	0,03	0,294	0324	0,068	0101	0,101	0081	0,111
P11	0,099	0197	0,079	0197	0,197	0132	0,099	0197

Table A10
Individual Weights for Development indicators T3: 2030–2040

Development indicators 2040	Develop Maas	Energy Activities	Roll-out of Infra	Stimulate new tech	Consistency (KSI)
P1	0,115	0288	0,192	0404	0,173
P2	0,435	0217	0,174	0174	0,87
P3	0,195	0,26	0,39	0,156	0,39
P4	0,313	0188	0,313	0188	0,938
P5	0,063	0579	0,239	0119	0,138
P6	0,345	0172	0,138	0345	0,345
P7	0,25	0,188	0188	0,375	0375
P8	0,209	0372	0,372	0047	0,163
P9	0,304	0063	0,203	0,43	0,177
P10	0,063	0,43	0,203	0304	0,177
P11	0,294	0294	0,118	0294	0,294

Table A11
Full deltas of measuring indicators (T1-T2)

2025-2030	Car Ownership	EV Adoption	Profitability	Public Space	Peak demand	Sus. Energy	Local emissions	Occupancy	User comfort
P1	0,03	0,033	0,003	-0,028	-0,1	-0,042	0,05	0,003	0,05
P2	0,048	-0,033	0,014	-0,022	0,039	-0,033	-0,033	0,039	-0,017
P3	-0,027	-0,027	-0,018	-0,027	-0,014	0,05	0,041	0,05	-0,027
P4	0,104	-0,209	0,176	-0,052	-0,037	0,126	-0,045	-0,026	-0,036
P5	-0,011	-0,024	0,026	0,026	0,103	-0,016	0,026	-0,066	-0,062
P6	0,149	-0,095	0,011	0,153	-0,145	0,005	0	0,026	-0,104
P7	-0,029	0,082	-0,018	0,007	-0,026	0,094	-0,026	-0,018	-0,066
P8	-0,018	0,053	-0,041	-0,001	-0,071	-0,011	0,03	0,055	0,006
P9	0,115	0,06	-0,062	-0,064	0,055	0,007	-0,01	-0,036	-0,064
P10	-0,009	-0,037	-0,144	-0,018	0,196	0,03	-0,023	0,018	-0,012
P11	-0,083	-0,052	0,089	0,009	0,121	0,009	-0,043	-0,021	-0,029

Note: the color implies the direction before rounding (green =positive, red = negative)

Table A12
Full deltas of organizing indicators (T1-T2)

2025-2030	**Fast charging**	**V2G**	**Smart charging**	**Induction charging**	**PV charging**	**Accessibility**	**User group roles**
P1	0,025	0,008	0,025	0,056	-0,044	-0,05	-0,021
P2	-0,001	0,035	-0,001	0,031	0,01	-0,072	-0,001
P3	-0,065	-0,088	0,019	-0,068	0,019	0,21	-0,027
P4	-0,068	0,062	-0,005	0,012	0,008	-0,005	-0,004
P5	0,013	0,013	0,114	-0,006	0,05	-0,112	-0,072
P6	-0,022	0,135	-0,115	0,266	0,013	-0,189	-0,088
P7	-0,007	0,194	0,077	-0,075	-0,172	-0,059	0,043
P8	-0,066	0,049	-0,064	0,043	0,036	0,026	-0,024
P9	-0,233	0,155	0,076	0,054	0,015	-0,083	0,016
P10	0,066	-0,013	-0,013	-0,007	-0,002	-0,045	0,014
P11	-0,036	0,089	-0,133	-0,005	0,022	-0,036	0,1

Table A13
Full deltas of development indicators (T1-T2)

2025-2030	**Develop MaaS**	**Energy Activities**	**Roll-out of Infrastructure**	**Stimulate new Technologies**
P1	0,215	-0,005	-0,109	-0,1
P2	-0,107	0,036	0,054	0,018
P3	-0,036	0,183	-0,072	-0,075
P4	0,303	0,019	-0,156	-0,166
P5	-0,003	-0,082	-0,013	0,098
P6	0,381	-0,274	-0,249	0,142
P7*	0,227	-0,072	-0,213	0,058
P8	0,153	0,023	0,023	-0,198
P9	-0,147	0,174	-0,134	0,108
P10	-0,002	0,014	0,013	-0,025
P11	0,008	0,092	-0,257	0,158

The asterix at P7 indicates consistency issues with this entry (consistency issue arised at Table A7)

Table A14
Full deltas of measuring indicators (T2-T3)

T2-T3 Delta	Car ownership	EV Adoption	Profitability	Public space	Peak demand	Sus. Energy	Local emissions	Occupancy	User comfort
P1	-0,026	-0,009	-0,007	-0,004	-0,037	0,172	-0,013	-0,007	-0,07
P2	-0,042	-0,034	-0,017	0,016	-0,022	0,009	0,083	-0,078	0,084
P3	0,013	0,083	-0,015	-0,022	0,006	-0,058	-0,068	-0,022	0,083
P4	-0,105	-0,043	-0,172	0,047	0,107	0,031	0,074	0,055	0,005
P5	0,152	-0,007	-0,007	-0,007	0	-0,024	-0,066	0,035	-0,075
P6	0,024	-0,023	-0,055	-0,088	0,057	0,043	0,05	-0,023	0,016
P7	0,011	-0,093	0,008	0,008	0,011	-0,015	0,011	0,008	0,051
P8	0,017	-0,015	0,041	-0,02	-0,015	-0,019	0,015	0,03	-0,036
P9	-0,005	0,17	-0,01	-0,003	-0,062	-0,01	-0,028	-0,083	0,031
P10	-0,025	-0,131	-0,131	0,138	-0,041	0,168	0,024	-0,016	0,014
P11	0,024	-0,084	-0,053	0,007	-0,046	0,067	0,067	0,003	0,015

Table A15
Full deltas of organizing indicators (T2-T3)

2030-2040	Fast charging	V2G	Smart charging	Induction charging	PV charging	Accessibility	User groups
P1	-0,026	-0,009	-0,007	-0,004	-0,037	0,172	-0,013
P2	-0,042	-0,034	-0,017	0,016	-0,022	0,009	0,083
P3	0,013	0,083	-0,015	-0,022	0,006	-0,058	-0,068
P4	-0,105	-0,043	-0,172	0,047	0,107	0,031	0,074
P5	0,152	-0,007	-0,007	-0,007	0	-0,024	-0,066
P6	0,024	-0,023	-0,055	-0,088	0,057	0,043	0,05
P7	0,011	-0,093	0,008	0,008	0,011	-0,015	0,011
P8	0,017	-0,015	0,041	-0,02	-0,015	-0,019	0,015
P9	-0,005	0,17	-0,01	-0,003	-0,062	-0,01	-0,028
P10	-0,025	-0,131	-0,131	0,138	-0,041	0,168	0,024
P11	0,024	-0,084	-0,053	0,007	-0,046	0,067	0,067

Table A16
Full deltas of development indicators (T2-T3)

2030-2040	Develop MaaS	Energy Activities	Roll-out of Infrastructure	Stimulate new Technologies
P1	-0,31	-0,022	-0,015	0,346
P2	0,292	-0,068	-0,255	0,031
P3	0	0	0	0
P4	-0,04	-0,107	0,018	0,129
P5	0,002	0,15	-0,067	-0,085
P6	-0,089	-0,028	0,071	0,045
P7	-0,048	-0,036	-0,036	0,12
P8	-0,193	0,099	0,099	-0,005
P9	0,251	-0,41	-0,113	0,272
P10	0,006	0,191	-0,357	0,16
P11	0,228	-0,118	-0,091	-0,019

The asterix at P7 indicates consistency issues with this entry (consistency issue arised at Table A7)

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