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**DOI**
10.1016/j.trpro.2023.11.017

**Publication date**
2023

**Document Version**
Final published version

**Published in**
Transportation Research Procedia

**Citation (APA)**
Van Der Koogh, M., Chappin, E., Heller, R., & Lukszo, Z. (2023). A conceptual representation of short-term and long-term decision-making in the roll-out and exploitation of public EV charging infrastructure in Dutch neighborhoods. *Transportation Research Procedia*, *70*, 178-187. https://doi.org/10.1016/j.trpro.2023.11.017

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To cite this publication, please use the final published version (if applicable).
Please check the document version above.

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ScienceDirect

Transportation Research Procedia 70 (2023) 178–187

Transportation Research Procedia

www.elsevier.com/locate/procedia

8th International Electric Vehicle Conference (EVC 2023)

# A conceptual representation of short-term and long-term decision-making in the roll-out and exploitation of public EV charging infrastructure in Dutch neighborhoods

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**Abstract**

Charging infrastructure in neighborhoods is essential for inhabitants who use electric vehicles. The development of public charging infrastructure can be complex because of its dependency on local grid conditions, the responsibility to prepare for anticipated fleet growth policies, and the implicit biases that may occur with the allocation of charging resources. How can accessible EV charging be ensured in the future, regardless of energy infrastructure and socio-economic status of the neighborhood? This study aims to represent the decision-making in the allocation of public charging infrastructure and ensure that various key issues are accounted for in the short-term and long-term decision making. The paper first identifies these issues, then describes the decision-making process, and all of these are summarized in a visual overview describing the short-term and long-term decision loop considering various key indicators. A case study area is identified by comparing locally available data sources in the City of Amsterdam for future simulation.

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*Keywords:* Type your keywords here, separated by semicolons ;

## 1. Introduction

The Netherlands is one of the leading countries in public charging infrastructure, and they expect their electric vehicle (EV) fleet to grow to 1.9 million by 2030, which is translated into a need for up to 1.7 million charging points in the upcoming years (Netherlands Enterprise Agency, 2019). In the initial roll-out of Dutch public EV infrastructure,

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strategies were straightforward. Charging points were installed based on citizen requests, or spread out over an area to anticipate new adoption. In later stages, the data of existing charging points were used to determine effective expansions of the charging network. However, as more people adopt electric vehicles, it has become apparent that better planning is needed to ensure a robust charging network. Barriers such as limited electricity grid capacity, limited personnel and resources in the installment of charging points, and parking vs charging challenges could hamper this fast adoption. A long-term strategy is necessary to ensure comfortable charging for all citizens in the future.

*Technologies to manage grid conditions for public charging.*

There are various technologies that can be used to manage grid conditions for public charging (Das et al., 2023). For example, existing infrastructure can be equipped with smart charging, which takes into account the grid's current capacity and the number of other active charging connections. Alternatively, Vehicle-2-Grid can be used, which enables bidirectional charging between vehicles and the grid, and the car battery can be charged to buffer surplus electricity and discharged to compensate for moments of electricity scarcity. External batteries also buffer surplus electricity and help manage demand during peak hours. New charging infrastructure can be installed, and grids can be expanded. Grid expansions are considered expensive and time-consuming , and need to be planned far in advance. Although these technological solutions can help manage charging under various grid conditions, the scale-up of charging infrastructure also introduces other challenges. Charging demand will only grow, whereas resources and personnel are limited. Resources need to be divided across neighborhoods, and the combination of different intervention strategies needs to be evaluated for various circumstances (adoption rates, grid conditions, planned expansions). This is why new strategies to develop and prioritize areas should be investigated.

*Allocation of Charging Infrastructure*

Currently, the allocation of public charging infrastructure is mostly determined using one of the following strategies (Gemeente Amsterdam, 2020; Gemeente Rotterdam, 2015; Netherlands Enterprise Agency, 2019):
<u>Request-based:</u> EV drivers without the opportunity for private infrastructure request a new charging point, either directly through their municipality or through a charging point operator (CPO) who has a contract with the municipality.
<u>Strategic placement:</u> The municipality and/or the CPO selects locations where new charging demand is anticipated and strategically rolls out new infrastructure.
<u>Data-driven roll-out:</u> New charging points are determined by evaluating the performance and occupancy rates of current charging infrastructure, and by adding new infrastructure in locations with high demand.
<u>Citizen participation:</u> Citizens are sometimes asked by their municipality to participate in the allocation of charging infrastructure, for example with a voting system on potential locations using interactive online maps.

*User Demographics & Equity*

A significant portion of the current EV fleet in the Netherlands comes from (private and corporate) lease (Vereniging Nederlandse Autoleasemaatschappijen, 2021). The demographic of EV drivers are predominantly white, male, with relatively high income, and a high level of education (Hardman et al., 2021; Netherlands Enterprise Agency, 2021) . The design of subsidies, incentives and tax structures have contributed to this demographic (Hardman et al., 2021; Hoekstra & Refa, 2017). They are also likely to be middle-aged and are more likely to own their own driveways and solar panels (Hardman et al., 2021; Netherlands Enterprise Agency, 2021). It is not surprising that the distribution of charging points is skewed against low-income areas (Hardman et al., 2021). The irony of this bias is that access to infrastructure can actually lead to a decrease of income inequality, according to a study assessing infrastructure and income in 100 countries over 40 years (Calderón & Servén, 2004). Another aspect to take into account is the quality of the infrastructure across different areas. Institutional and technical solutions may be applied with the best intentions to manage charging under various conditions, but what if this leads to higher consumer costs or increased charging times? Equity should be taken into account when allocating crucial infrastructure related to transport: if some neighborhoods have better capacities than others, that is an undesirable outcome.

Charging point operators and municipalities have catered to current EV users to satisfy the charging demand. This has led to an analysis of charging behaviors and suggestions of charging profiles that were based on a skewed demographic. The European Union has banned sales of new fossil vehicles from 2035 (the Netherlands aims for 2030). This will lead to a larger, more diverse demographic of EV drivers who may not share the same charging behaviors or charging needs. Charging demands are expected to exceed current grid capacities which makes smart charging an important part of the strategy to ensure fair access (Michal van der Toorn, 2022; Xylia & Joshi, 2022). Technical solutions can enable and manage charging in a scale-up. But it is important to avoid undesirable outcomes, such as grid overload, inequal access, stranded assets, bad investments and missed opportunities.

In this study, we conceptualize a decision-making mechanism for the future roll-out of EV charging infrastructure, the main question being *'How can the decision landscape of EV infrastructure roll-out be represented to manage charging in neighborhoods with varying conditions?'*

The goal of the study is to conceptualize a potential decision-making method in the roll-out of charging infrastructure, using four different intervention strategies (roll-out of infrastructure, smart charging, Vehicle-2-Grid, and an external battery buffer), while taking into account current grid conditions, the planned grid expansions of the grid operator and the expected growth in adoption (derived from planned policy and neighborhood characteristics). This conceptualization can then be used in future studies to experiment with different interventions to work towards an adequate (in terms of charging comfort and grid integration) and fair (e.g. by prioritizing underdeveloped areas in the roll-out) distribution of resources.

The work that is about to be presented, is an intermittent result where issues are identified, the decision-making method is designed, available data sources are compared and a potential case study is suggested. In later work, the results of this intermittent work will be applied to the selected case study in an agent-based model, using Rstudio for charging point analysis and socio-economic analysis, and using the NETLOGO software to simulate the decision-making mechanisms under various scenario's. This will enable an assessment of the emerging patterns, such as charging satisfaction, spillover effects, and neighborhood equity. The ultimate goal of this simulation will be to determine how the prioritization of different indicators and issues under various (grid- and adoption) circumstances affect the development of charging infrastructure in neighborhoods with diverse backgrounds.

## 2. Methods

The research process of this study consists of five steps. Step 1 takes advantage of a literature study, step 2 & 3 elaborate on the findings in an unstructured fashion, step 4 uses the diagram style of a decision tree while also summarizing relevant aspects of a problem analysis (stakeholders, owners, performance indicators), and in step 5 data sources are identified. A geographical scope and geo-analysis are used to find geographical overlap between the available data sources. A short description of each step can be found below.

1. *Identify (anticipated) issues in public charging in neighborhoods* (*Section 3.1*): Issues are identified through scientific literature and local policy literature, and the inventions are categorized as short or long-term. Table 1 describes the identified issues, and Table 2 categorizes the interventions.
2. *Determine the short-term application of interventions on existing charging points* (*Section 3.2*): After step 1, the interventions and issues in the short-term loop are used to determine the application of these interventions, and what is needed to deploy them. Various indicators are identified to collect on a neighborhood level, to make short-term decisions (e.g. the available grid capacity), and tracking of these indicators over time is essential to determine the performance in the long-term decision making (step 3). These indicators are described in Table 3.
3. *Determine the decision mechanism for long-term interventions and resource allocation (Section 3.3):* After step 2, and after a prolonged period of applying short-term interventions, the performance of each neighborhood is evaluated using the collected indicators. A pool of resources (long-term interventions) can then be divided using the performance indicators, taking into various aspects of the neighborhood performance (e.g. grid conditions and equity compared to other neighborhoods) for resource allocation. A stepwise comparison is made to determine the distribution of interventions between neigborhoods. This includes potentially updating infrastructure so that more short-term interventions can be deployed in the future.

4. *Make a decision tree of the conceptualization (Section 3.4):* The insights of step 1-3 are combined to design a decision tree as conceptualization, taking into account grid conditions, neighborhood characteristics, and planned policy.
5. *Identify a potential case study area by comparing available data sources and projects (See Section 4):* In order to test decision making under various circumstances, a simulation will be made by initializing parameters of real neighborhoods where charging takes place and considering decision making under realistic (grid- and charging) infrastructure. Such a simulation therefore requires a case study area of which multiple elements of charging can be quantified (e.g. charging points, grid conditions, socio-economic conditions). In Section 4, a potential case study is identified by comparing various local data sources.

## 3. Conceptualization

### *3.1 Issues in public charging in neighborhoods*

Section 1 introduced and explained charging management techniques and potential neighborhood charging issues. After this first exploration of neighborhood charging issues and charging management techniques, we consulted literature and media outlets to determine the relationship between our selected management techniques and the concerns of stakeholders in neighborhood charging (see Table 1).

Table 1. Mapping socio-technical concerns of neighborhood charging under various grid conditions with potential management techniques

| | **Concerns** | | **Charging management techniques** |
|---|---|---|---|
| | *Social* | *Technical* | |
| **Access to charging** | Walking distance<br>Availability<br>Cost of charging<br>(Glombek & Helmus, 2018; Khan et al., 2022) | Grid connection<br>Supply chain<br>Personnel<br>(Liander, 2022a; Michal van der Toorn, 2022) | Install new infrastructure<br>Market regulation<br>Update existing infrastructure (smart charging/Vehicle-2-Grid)<br>Grid expansions (mid-voltage, high-voltage) |
| **Quality of charging** | Waiting times<br>Failed sessions | Charging speed<br>Performance<br>Interoperability | Update existing infrastructure (higher capacity)<br>Maintenance/Support<br>Technical standards |
| **Energy Security** | Network tariff<br>Power outage<br>(Silva et al., 2021) | Grid overload (Liander, 2022b) | Enable Vehicle-to-grid<br>Install an External Battery (mid-voltage station)<br>Grid expansions (mid-voltage, high-voltage) |

Table 2. The short-term and long-term decision loop in the roll-out and management of charging infrastructure

| Short-term (daily loop) | Long-term (policy loop) |
|---|---|
| Smart charging, Vehicle-to-Grid, | Update Charging Protocols, Increase Capacity, Roll-out of points |
| Use external battery, DC / Fast charging | Install external battery |
| Reject session (occupancy- or grid-based) | Do Nothing |

Sometimes technology or institutions can alleviate some of the concerns of Table 1. The proposed management techniques are owned by different stakeholders (for example: *Policymaker, Charging Point Operator, Service Provider, Electricity Provider, Traffic Planner or Network Operator*). The way that public charging is organized and the lawmaking that surrounds it differs between countries. For example, differences exist between who gets to exploit the charging infrastructure, how prices are determined, whether the charging point is publicly owned and how subsidies are used (LaMonaca & Ryan, 2022). This is why we represent the decision-making using a neighborhood manager: each neighborhood gets a decision-maker who in reality consists of many other actors and stakeholders, depending on the state regulations and market design. This makes the representation generalizable beyond the Dutch case of public charging markets, and enables exploration of the mechanisms of prioritizing different neighborhoods in a city based on activities and needs. An exception to the list of decision-makers is the DSO and their planning for the grid expansions: these plans are made far in advance, and have to take into account other electricity growth activities (e.g. from households or industries). Therefore, the DSO planning of the local environment should be consulted in advance to reliably represent charging in the future.

### *3.2 Short-term application of interventions on existing charging points*

As explained in the previous Section (3.1), applying interventions in the form of charging management techniques such as the integration of charging protocols and grid compensations knows two challenges: (1) the roll-out and management of these interventions, and (2) the deployment of these interventions when a charging session takes place. We conceptualized the deployment of these charging protocols in a decision tree (see Figure 1). It is also important to collect the right information during sessions in order to make confident choices in the future roll-out of new infrastructure and in installing new protocols on existing infrastructure. In order to do that, decision-makers need to be aware of the current conditions and charging performance of the neighborhood. Important indicators to collect throughout the year include the number of failed sessions because of grid overload, the occupancy rates and the number of times all charging points were occupied, the charging behaviors (starttimes, chargetimes, stalling, charge load), and the available leftover grid capacity (Helmus & Van Den Hoed, 2016; van der Hoogt et al., 2020). We would like to add the development of the neighborhood so far (existing charging infrastructure, installed external batteries, etc.) to assess a fair distribution of charging infrastructure across neighborhoods. The parameters included in the conceptualization are described in Table 3. Some indicators are not parametrized, for example, the distribution of start times of charging sessions, since they can be initialized within a case study using population data (these would however be relevant to collect when, for example, institutional interventions would be added that could influence the start time distribution).

Table 3. Charging indicators: neighborhood level parameters

| Parameter | Description |
|---|---|
| Failed sessions | Goes up every time a failed session because of grid overload takes place |
| Maximally occupied | Goes up each day in which the max occupancy was reached |
| Grid capacity (%) | The grid capacity at each step (determined by stations, batteries and surplus) |
| # of chargepoints | Number of charging points in the neighborhood |
| # of batteries | Available external batteries in the neighborhood |
| % of occupied chargepoints | Occupancy rate of charging points |
| Chargetime (hr) | The time it takes to fully charge a vehicle |
| Charge load (kWh) | The charging demand expressed in kWh |
| Distance (Passover) | The distance between the original charging request and the selected charging point (0 when the preferred point is available). |

### *3.3 Long-term interventions and resource allocation*

The next step to conceptualize is the decision-making mechanism that we want to suggest for rolling out new interventions to manage the occupancy rates and grid needs of public charging. The decision is made with the use of a weight set of parameters that is collected throughout the charging loops that take place within the timespan of a year (see Table 3). After 1 year, the evaluation round of the administrators in an area can take place. The evaluation round consists of the following steps:

1. *Check if there are any newly planned grid expansions for this year, according to the DSO timeline.*
2. *Assess the current charging and social conditions in the neighborhood to determine allocation of new infrastructure*

The future charging needs need to be determined for each neighborhood, for example by assessing how many times sessions failed because of missing infrastructure, the occupancy rates, the socio-economic predictors, the policy planning and the current distribution of charging point locations. To determine if connections are possible, the grid capacity should be assessed. The new charging points will be assigned to neighborhoods, and neighborhoods with higher charging needs, high prognosis or limited development are prioritized. When there is space to realize the connection, and if there are resources left in that year, neighborhoods will receive new infrastructure based on their priority level. Resources are not infinite, and personnel as well as technical components are in high demand, especially in large cities (Liander, 2022a)

3. *Assess the current grid conditions in the neighborhood to determine allocation of other interventions*

The existing infrastructure may be outdated, slow, or may not have protocols installed to use the smart charging or Vehicle-2-Grid interventions. Therefore, the potential to update infrastructure should be considered when managing charging infrastructure in neighborhoods. Especially the update to smart charging can be helpful when charging needs exceed grid capacity in neighborhoods, which is something that DSO's foresee happening in the near future (Michal van der Toorn, 2022). When neighborhoods struggle with grid conditions, and new expansions are not planned or still far away, an external battery could be considered to compensate for the excess charging load. The neighborhood should have designated space for the battery, and a need for the battery. The size of the battery is determined by the expected load, for which the maximum number of overlapping failed sessions could serve as an estimate.

### *3.4 Conceptualization Overview (Decision tree)*

Figure 1 is a decision tree that illustrates the short- and long-term decision loops in the roll-out of charging infrastructure, taking into account grid conditions. On the top left, the necessary inputs to determine charging management techniques in the short-term loop are defined. In the middle, there is a decision tree indicating the decision process in selecting the right charging protocol, given the current conditions. The top left bar shows the relevant outputs of this decision-making loop. These outputs, combined with case study specific information (such as grid planning and neighborhood parameters), then serve as inputs (bottom left) for the strategic decision making in the roll-out and allocation of charging and grid interventions.

*Decision-making:* The decision-making is represented in the decision tree that can be found in the middle of the bottom row of Figure 1. The decisions can be categorized as the updating of charging points (protocol or capacity), the allocation of new charging points and the introduction of external batteries. Decisions take place in both the short-term as well as the long-term loop. For the short-term loop, the grid capacity, occupancy and type of charging point play an important role in selecting interventions. In the long-term loop, grid performance and charging point performance important for battery allocation and infrastructure upgrades. Upgrades are determined by grid conditions and charging needs, whereas external batteries are only considered when grid capacity is dangerously low and there is space available for a battery. For the allocation of new charging points, the performance of the infrastructure, as well as other factors (such as socio-economic or policy planning) are considered using a prognosis.

*Prognosis:* Some researchers and consultants have looked into a variety of indicators to determine the charging potential for on-street public charging at Dutch neighborhoods. Dutch researchers and consultants identified car ownership, driveways, population density, rental houses, proximity to schools and hospitals, age, employment, income, and voting behavior of neighborhoods as neighborhood indicators for future charging needs (ElaadNL, 2020; Koopman, 2023). The exact conceptualization of a prognosis will be dependent on the location of the roll-out, but important elements include the occupancy rates (*what is the current charging demand?),* socio-economic predictors (*which neighborhoods are more likely to experience growth in EV fleets?),* desirable effects (*where do we want to make EV purchases more attractive?*), feasibility (*how many new points can we facilitate under current space and grid conditions?),* and special circumstances, for example, the introduction of policies that may increase adoption rates, or new contracts for shared electric vehicles. This prognosis will vary per use case, to ensure applicability.

*Applicability:* Other countries than the Netherlands may differ in their challenges and needs and may therefore use other indicators to determine allocation. For example, Asian cities are often more densely built and facilities are more likely to be government-owned, which makes charging hubs at community areas a fitting solution for allocation (He et al., 2022), whereas in Sweden, populations are less dense and private charging is more widely adopted (Xylia & Joshi, 2022). Therefore, the conceptualization considers both the current level of infrastructure development (to ensure a fair distribution), as well as a prognosis, which can be specified within the use case, to determine the priority of new charging points in neighborhoods.

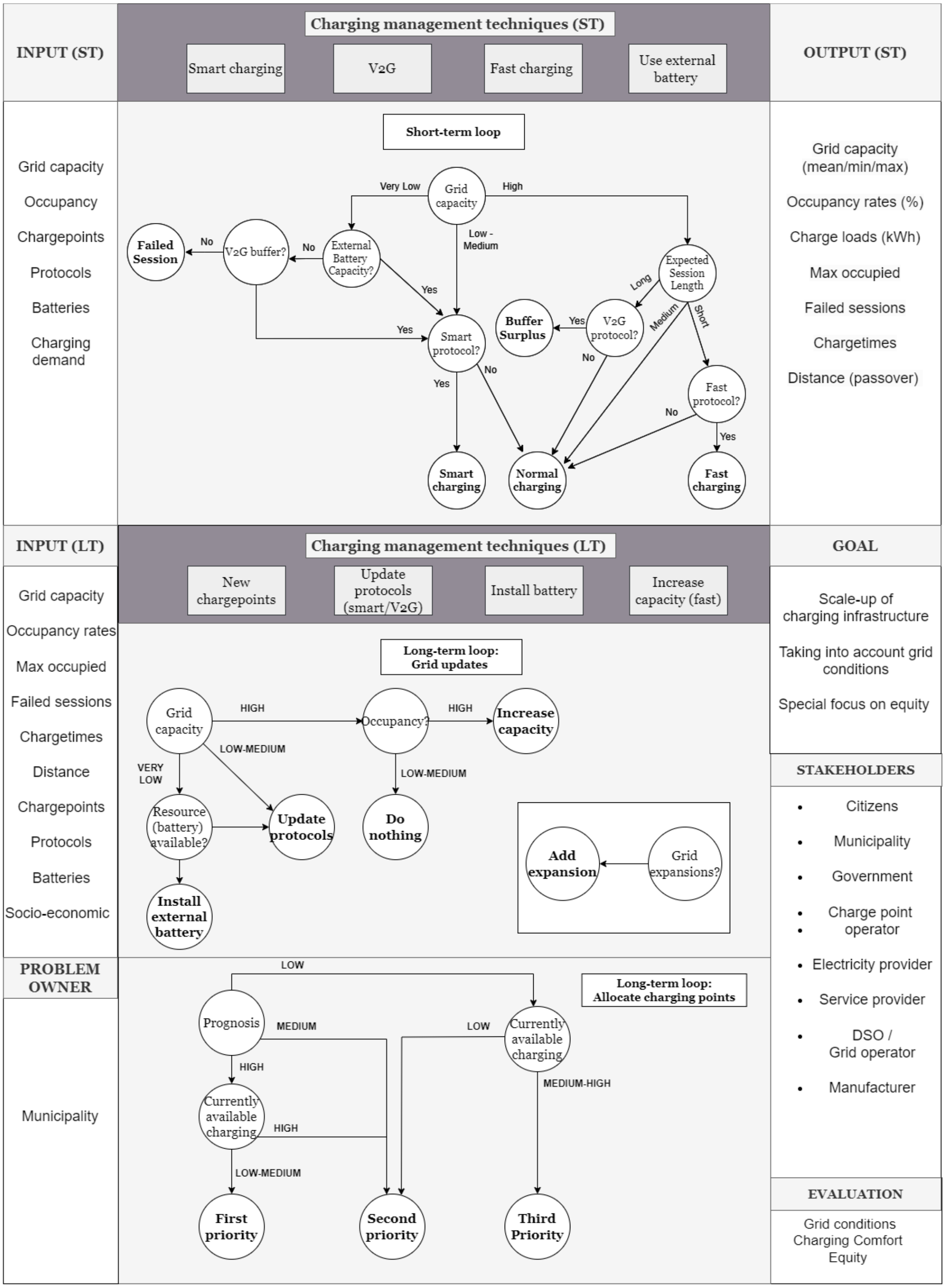


Figure 1: Conceptualization of the short- and long-term decision making in public EV charging across neighborhoods, taking into account grid conditions and equity.

## 4. Case Study

One potentially interesting area the Netherlands is the city of Amsterdam. The available data for this geographical area make an interesting opportunity to investigate potential allocation of infrastructure and interventions. The city of Amsterdam has a high penetration of electric vehicles, and because of the high population density with limited private parking facilities, EV drivers in this city are often dependent on public charging infrastructure. The city also knowns more inequality between neighborhoods than most Dutch cities (Modai-Snir & van Ham, 2020). Amsterdam-based institutions have different projects working on electrification in the city, and this enables access to the following information:

- Charging point data of over 3,000 public charging points in the City of Amsterdam (internal institute database)
- Municipal planning by the medium-voltage grid operator of which stations will be expanded in Amsterdam (Gemeente Amsterdam et al., 2022; Liander & Gemeente Amsterdam, 2021),
- Charging point data of charging points that include the smart charging protocol in Amsterdam (Buatois et al., 2019; Ligthart et al., 2020),
- Simulated and empirical data of a pilot that uses an external battery to buffer surplus renewable energy for charging in an Amsterdam parking garage (Heath et al., 2023),
- Socio-economic neighborhood data from the Central Bureau of Statistics (Centraal Bureau Statistiek, n.d.)
- Local policy documents pertaining different electrification goals for commercial and passenger vehicles (van der Koogh et al., 2021). For example, incentives and electrification deadlines for logistics, shared mobility, cab drivers and, from 2030, emission-free zones for passenger vehicles (Gemeente Amsterdam, 2016, 2019; Rijksoverheid, 2018).

Table 4. Case Study Data

| Conceptualization components | Data from case study | Reference |
|---|---|---|
| Normal charging | Charging transaction data | (Maasse, S., van den Hoed, 2019) |
| Smart charging | Flexpower charging transaction data | (Bons et al., 2020) |
| Fast charging (not highway) | Charging transaction data (sample of fast chargers) | (Maasse, S., van den Hoed, 2019) |
| External battery for charging | Simulation, P&R garage pilot | (Heath et al., 2023) |
| Vehicle-to-grid | *No case study specific data* | |
| Socio-economic neighborhood factors | Income, gender, population density, urbanization, cars/household | (Centraal Bureau Statistiek, n.d.) |
| Grid capacity | Transport capacity maps (national, regional, Amsterdam) | (Liander, 2022b) |
| Grid expansions | Timeline of expansions and expected increase of capacity in the city of Amsterdam | (Gemeente Amsterdam et al., 2022; Liander & Gemeente Amsterdam, 2021) |

Interesting neighborhoods with widely available data were compared to ensure a rich representation of dynamics between charging and the electricity grid. This means that, in the context of the available data, a selected neighborhood cluster should have at least the following elements so that realistic parameters for behavior and interventions can be ensured:

1. A major residential function
2. Available charging data and available socio-economic data
3. Close proximity to a number of charging points with the smart protocol installed (if possible)
4. Interesting grid dynamics and close proximity to a neighborhood with planned grid expansions as determined by the planning of the DSO Liander).

The currently available smart charging data takes place in the following districts in Amsterdam: *Bos en Lommer, Grachtengordel west, Hoofddorppleinbuurt, Oostelijk havengebied, Oud-zuid* and *Rivierenbuurt.* The Bos en Lommer district contains smart charging pilots location. Liander has planned to expand the grid by adding a new underground station in 2024 (Nieuwpoortstraat), located at the bos en lommer area, because of other stations I neighborhoods with near proximity that are experiencing congestion and are nearly overloaded (Marnixstraat, Westzaanstraat). In 2035, Liander planned to expand Station Westzaanstraat for more capacity. These stations are located in neighbouring subdistricts of the Bos en Lommer area, making this expanded area of neighborhood clusters an interesting one to analyze. Figure 2 shows these points of interest on a map.

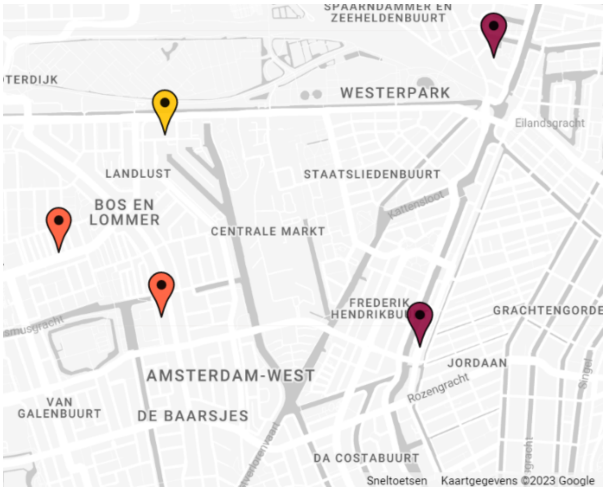

Figure 2. Potential Case Study Location (the yellow marker is a planned grid expansion, dark red markers are congested stations, orange markers are smart charging pilots).

## 5. Conclusion & Future Work

In this paper, some of the most prominent issues in neighborhood charging were identified (Section 3.1) and an approach was suggested for future roll-out of charging management strategies and charging infrastructure, taking into account various factors (grid conditions, socioeconomic factors, policy planning and the current charging behavior). A distinction was made between the short-term (Section 3.2) and long-term (section 3.3) allocation of interventions and the conceptualization was summarized in a decision tree (Section 3.4). A case study location was found (Section 4), by comparing available data sources to find an area that is interesting in terms of charging demand, grid challenges, existing infrastructure, existing pilots and policy planning. The next step will be the simulation of this decision-making, using data from the case study. Technical interventions will be improved and newly developed over time, and some technical interventions (e.g. inductive charging and battery swap) were not included in the suggested design because their readiness level in terms of legislation makes their implementation currently less accessible and more uncertain than the technologies now included. However, these technologies can play an important role in the future, for example for commercial fleets with a static location. In the future, the design could be expanded to include these new technologies. Another type of intervention could also be included in future designs. For example, institutional interventions and market regulations could be included to promote fair use and fair pricing. The design does not take into account compensation options for situations where some neighborhoods have an unfair advantage over others. Compensations such as charging discounts, public transport discounts could be used to compensate inhabitants of neighborhoods with lesser charging options. The suggested conceptualization could be expanded with other infrastructural challenges in urban planning across neighborhoods, for example, considering renewable electricity generation or challenges of the heat transition, by first exploring the management techniques and determining under which conditions (planning, comfort, grid, equity) they could be allocated (long-term loop) and/or deployed (short-term loop). This could create a more holistic insight of the future energy needs and opportunities of a neighborhood.

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