

Performance of EV Charging Infrastructure: a decision support tool based on charging data.

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Summary

Developers of charging infrastructure, be it public or private parties, are highly dependent on accurate utilization data in order to make informed decisions where and when to expand charging points. The Amsterdam The Amsterdam University of Applied Sciences in close cooperation with the municipalities of Amsterdam, Rotterdam, The Hague, Utrecht and the metropolitan region of Amsterdam developed both the back- and front-end of a decision support tool. This paper describes the design of the decision support tool and its DataWareHouse architecture. The back-end is based on a monthly update of charging data with Charge point Detail Records and Meter Values enriched with location specific data. The design of the front-end is based on Key Performance Indicators used in the decision process for charging infrastructure roll-out. Implementing this design and DataWareHouse architecture allows all kinds of EV related companies and cities to start monitoring their charging infrastructure. It provides an overview of how the most important KPIs are being monitored and represented in the decision support tool based on regular interviews and decision processes followed by four major cities and a metropolitan region in the Netherlands.

Keywords: charging, simulation, user behaviour, infrastructure, municipal government.

1 Introduction

At the start of charging infrastructure roll-out back in 2010-2011 until recently a mainly demand driven roll-out strategy [5] for public charging infrastructure was applied by the major cities in the Netherlands: Amsterdam, Rotterdam, the Hague and Utrecht. This has led to one of the most dense networks of public charging infrastructure worldwide: in December 2016 in Amsterdam 2030 public charging points were operational, resulting in a density of 12 charging points per km². The electrification of vehicles combined with the lack of private parking space in highly urbanized areas now creates the need for other approaches to charging infrastructure roll-out. Although estimates and forecasts have been made for charging infrastructure need to fulfill user demand, it is also stated that “an explicit statement on the number of charging stations needed on large scale ... is difficult to make on the basis of (local) user demand” [1]. Deciding where to expand the already dense public infrastructure now not only depends on whether a new EV-driver has requested a charging point, but also on how the existing charging infrastructure is being used. Performance measurement of charging infrastructure becomes more and more essential for effective roll-out and operation of charging infrastructure [2] illustrating the need for (near) real time data [4]. This paper describes the

architecture of how the large amount of charging data generated by the charging infrastructure are being filed and updated in a Data Warehouse environment and how the data is being transformed and presented to decision makers at municipalities and Charge Point Operators (CPOs). A number of Key Performance Indicators derived from the decision making process are visualized in a web-based decision support tool facilitating location selection. This paper describes an approach designed to handle large amounts of (charging) data, the process of location selection based key performance indicators the identification of issues at specific locations and the execution of location specific analyses. The combination of back-end, periodical update of data and the decision support tool can be implemented to any region or city, thus creating the opportunity for parties involved in the roll-out of charging infrastructure to monitor the performance of charging infrastructure and to take informed decisions on where to install new charging infrastructure. [3].

2 Data Warehouse for charging data

Periodically the transaction files consisting of Charge point Detail Records and Meter Values of every public charging location in the major four cities of the Netherlands and the metropolitan region of Amsterdam are filed in a back-end or Data Warehouse developed by Amsterdam University of Applied Sciences (AUAS).

SSIS packages extract, transform and import (ETL) these transaction files into the Data Warehouse [Fig. 1]. The data behind the transactions of a charging session nevertheless can be highly volatile. Errors vary from locations spelled differently to improbable session durations, impossible dates or extreme high kWh charged. In order to diminish error effects on final reports or visualizations, it is important to distinguish the factual data as being provided by the CPO from the data on which the reports and visualizations are being based. The factual data, “FACT_CHARGESESSION” in Fig. 1, contains the data that is being provided by the CPOs. This includes variables such as the connection time, the charge point ID, kWh, start- and end-connection etc. After filtering and correcting, the clean data are filed in so called “Dimension tables” (DIM). For example the “DIM_LOCATION” table contains the locations of the charge points: address, postal code and city based on the charge point detail records and enriched with data such as geo coordinates and district classifications.

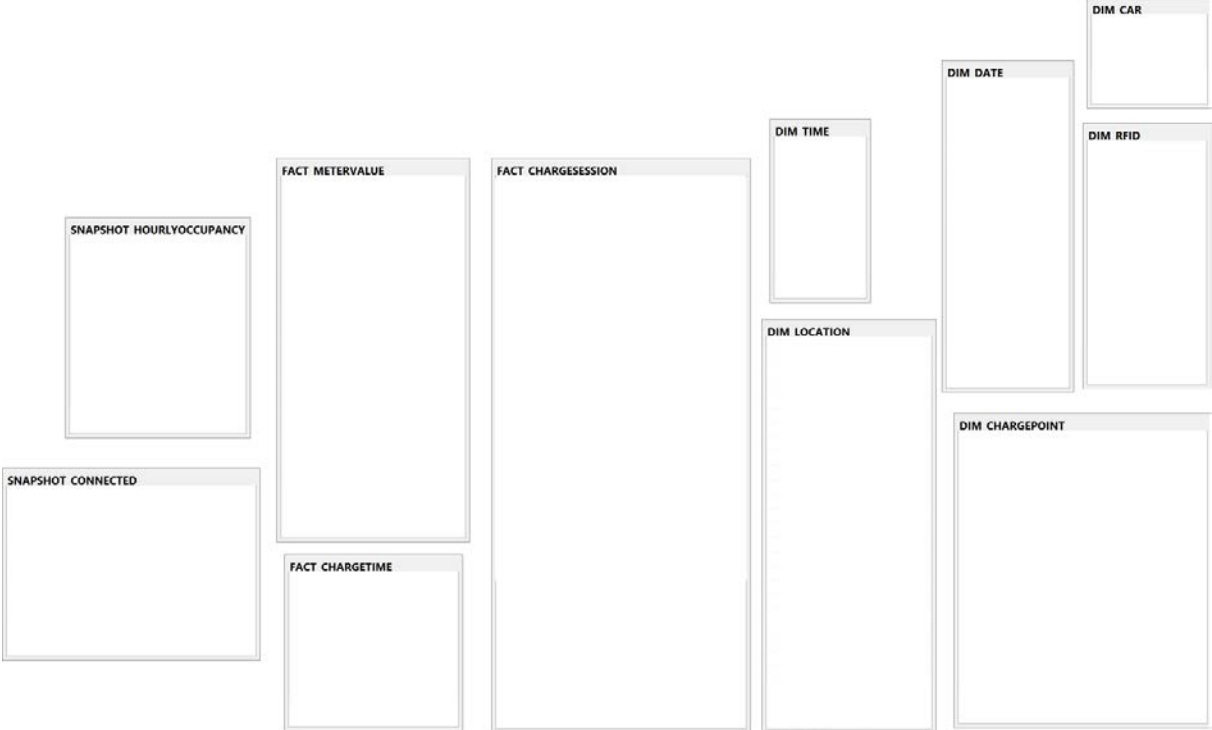


Figure 1: Data Warehouse architecture providing access to charging data.

The intermediate software to produce reports in the Shiny web application is R Studio. Based on user-account access authorization, stored procedures extract reports from the Data Warehouse into R Studio. R-functions are programmed to plot the data in Shiny, the front-end web application which the EV-infrastructure professional has access to.

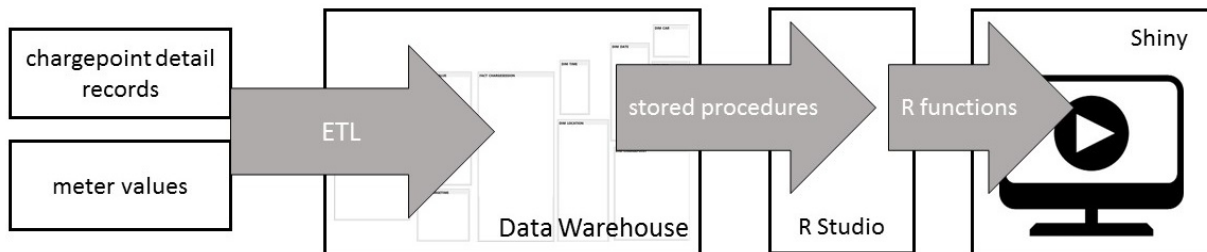


Figure 2: Charging Data transformation process.

3 Roll-out process

The roll-out process for public charging infrastructure starts with the political decision to facilitate public charging of electric vehicles. Thus leading to the question where to install charging infrastructure taking into account the interest of both EV-drivers, non-EV-drivers, other users of public space and the market potential [2]. From a decision process point of view three instigating events are defined based on interviews with infrastructure roll-out practitioners: 1. an external request (demand driven roll-out), 2. roll-out strategy based on forecasts, future scenarios or simulations, 3. detection of bottlenecks in the performance of existing infrastructure. The roll-out process distinguishes three phases: preparation, realisation and exploitation. The preparation phase includes the following activities: judgement of a request, location selection and assessment, informing citizens including objection procedure. See figure 3. The decision support tool presented in this paper focusses on assessment of performance and decision making on where to expand the existing charging infrastructure based on the charging data of the existing network. Exports of KPIs represented in lists, graphs or visualized on a map are being used to inform both citizens and other stakeholders involved in the roll-out process. The boxes “prepare location proposal ch X” in figure 3 refer to the chapters in this paper explaining the detailed approach of decision making using the decision support tool.

Based on interviews with roll-out practitioners the following requirements were set as the most important for the decision support tool:

- Easy to find addresses on map.
- Selection of a number of charging locations within walking distance from a certain spot.
- Selection of charging locations used by specific user groups.
- Graph representation of KPIs of selected charging locations.
- Graph representation of KPIs aggregated on municipal, district and sub-district level.
- Export of both map and KPI graphs for external documentation/communication.
- Integration of bottleneck assessment
- Downloadable KPI tables in order to integrate KPIs per location in other back-offices.

Based on these requirements the decision support tool has been developed to support the preparation phase of the roll-out process.

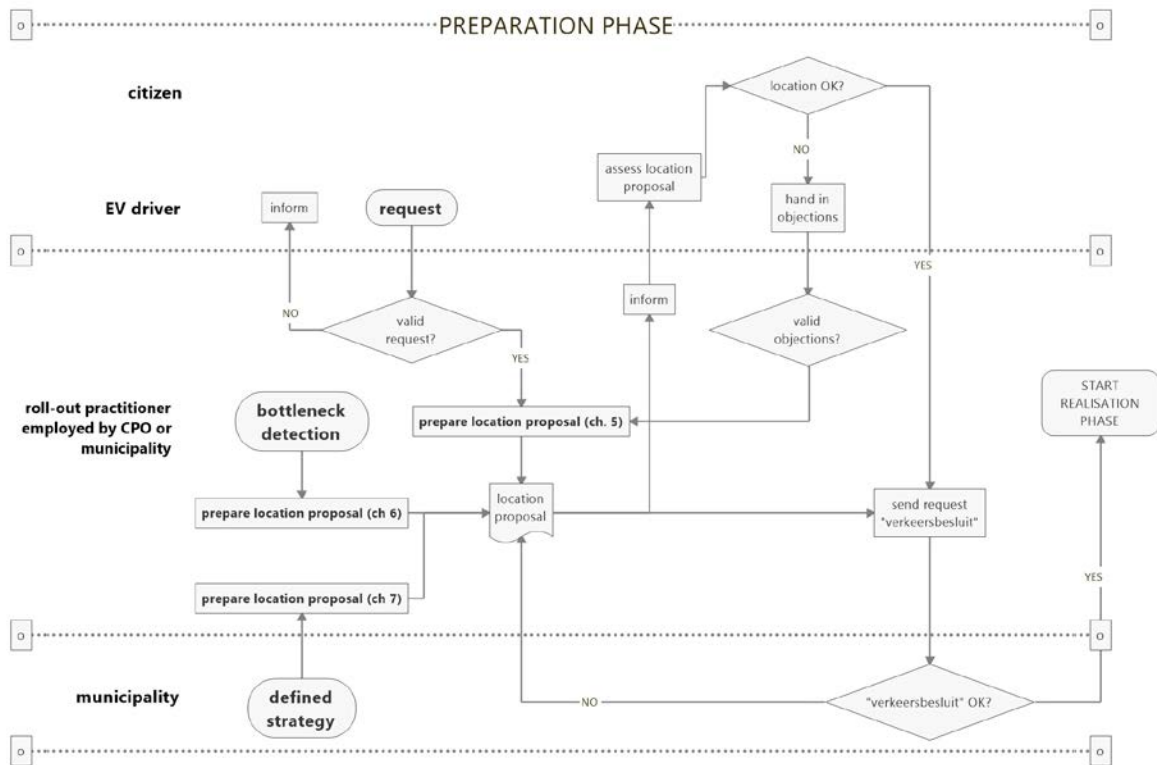


Figure 3: Preparation phase of the EV-infrastructure roll-out process.

4 Decision support tool

The decision support tool is a web based application built in the open source R package “Shiny”. Shiny provides a web framework for building web applications using programming language “R”. The version presented in this paper consists of three webpages: a map and two KPI tables. In addition to this, four assessment tools have been developed and implemented. These assessment tools provide the opportunity to assess the complete infrastructure visualizing the charging locations in various colors depending on the thresholds determined by the user.

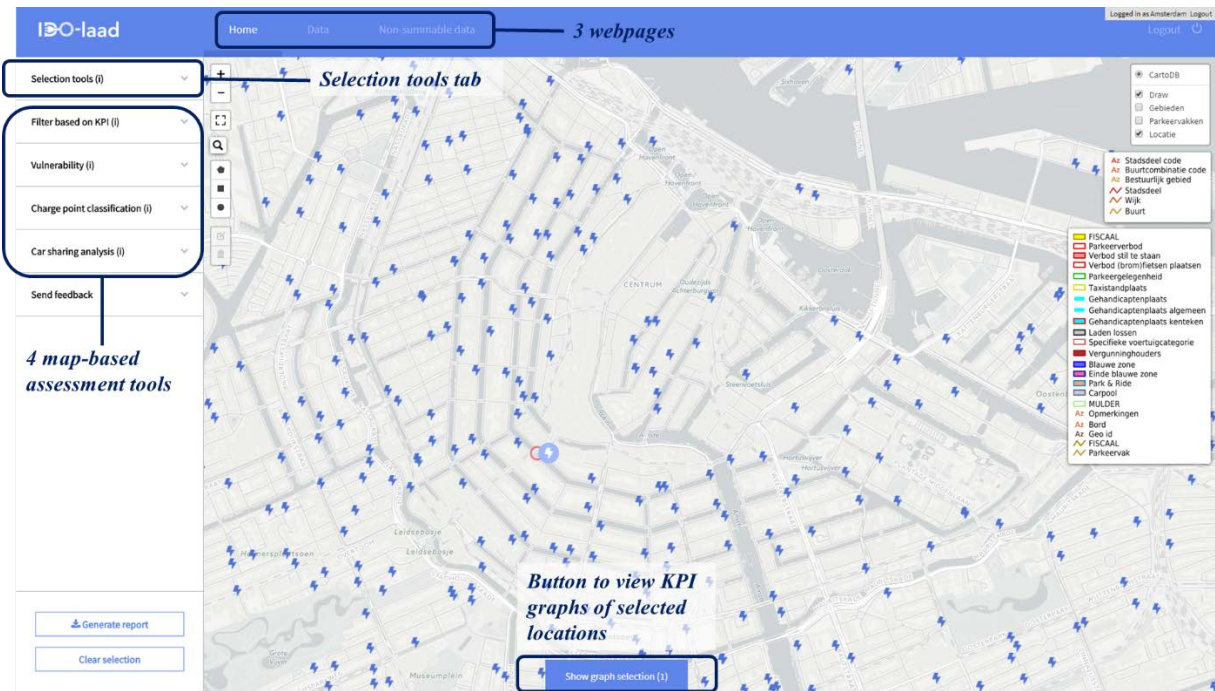


Figure 4: homepage including explanatory textboxes

4.1 KPI tables

The KPI tables are divided into one table showing summable KPIs (kWh, connection time, charging time, number of sessions) and one table showing non-summable KPIs (number of unique users per month, average occupancy). KPIs are represented per charging location and per month. By selecting the required time period (year, month) and required location (city, district, neighbourhood or address/postal code), a user can compose and export or download specific KPI lists.

The screenshot shows a data table with the following columns: Address, Chargepoint_key, ChargePoint_ID, SubDistrict, District, City, PostalCode, Jaar, Maand, SomConnectieTijd, SomLaadTijd, Som kWh, and Aantal Sessies. The table contains 23 rows of data for various charging points in Amsterdam.

Address	Chargepoint_key	ChargePoint_ID	SubDistrict	District	City	PostalCode	Jaar	Maand	SomConnectieTijd	SomLaadTijd	Som kWh	Aantal Sessies
1 Lekstraat 170	4349	EVB-P1552065	Schinkelbuurt	Zuid	Amsterdam	1075TR	2017	3	68.02	0	88.21	7
2 Lekstraat 170	4349	EVB-P1552065	Schinkelbuurt	Zuid	Amsterdam	1075TR	2017	3	769.87	0	516.74	38
3 Henri Zagvijnstraat 10	758	EVB-P1541213	Prinses Irenebuurt o.o.	Zuid	Amsterdam	1077XR	2017	3	25.21	0	37.09	4
4 Henri Zagvijnstraat 10	198	EVB-P1541213	Prinses Irenebuurt o.o.	Zuid	Amsterdam	1077XR	2017	3	255.62	0	417.38	59
5 Jan Puntstraat 4	416	EVB-P1532055	Slotenvaart Zuid	Nieuw West	Amsterdam	1066RH	2017	3	704.58	0	308.1	32
6 Jan Puntstraat 4	416	EVB-P1532055	Slotenvaart Zuid	Nieuw West	Amsterdam	1066RH	2017	3	70.53	0	131.3	20
7 Zeeburgerkade 10	1401	EVB-P1542191	Oostelijk Havengebied	Oost	Amsterdam	1013HA	2017	3	46.97	0	52.61	5
8 Zeeburgerkade 10	1401	EVB-P1542191	Oostelijk Havengebied	Oost	Amsterdam	1013HA	2017	3	888.13	0	354.67	41
9 Aukhof 2	257	EVB-P1450091	Banne Buksloot	Noord	Amsterdam	1034HD	2017	3	115.67	0	217.65	19
10 Aukhof 2	257	EVB-P1450091	Banne Buksloot	Noord	Amsterdam	1034HD	2017	3	124.94	0	196.64	23
11 Willem Heselaarsstraat 70	5403	EVB-P1552225	Odorp Midden	Nieuw West	Amsterdam	1063NA	2017	3	731.31	0	420.59	71
12 Willem Heselaarsstraat 70	5403	EVB-P1552225	Odorp Midden	Nieuw West	Amsterdam	1063NA	2017	3	36.72	0	71	4
13 Simonshavenstraat 55	424	EVB-P1520073	Hulendrecht Reigersdo	Zuidoost	Amsterdam	1107NA	2017	3	48.11	0	26.93	9
14 Ouberg 7	1479	EVB-P1552131	Buitenverdiert Oost	Zuid	Amsterdam	1083AE	2017	3	16.91	0	16.62	5
15 Moreelsestraat 33	5767	EVB-P1507151	Vaasumkaarter	Zuid	Amsterdam	1071LJ	2017	3	1171.39	0	687.53	72
16 Postjeskade 140	895	EVB-P1539589	Westerlandsche Buurt	West	Amsterdam	1054DN	2017	3	38.09	0	56.69	4
17 Postjeskade 140	895	EVB-P1539589	Westerlandsche Buurt	West	Amsterdam	1054DN	2017	3	442.51	0	200.11	31
18 Jan Voermanstraat 5	233	EVB-P1450063	Odorp Midden	Nieuw West	Amsterdam	1063ZH	2017	3	9.29	0	17.55	3
19 Jan Voermanstraat 3	233	EVB-P1450063	Odorp Midden	Nieuw West	Amsterdam	1063ZH	2017	3	7.81	0	24.10	3
20 J.F. van Hengelstraat 1	1454	EVB-P1552078	Oostelijk Havengebied	Oost	Amsterdam	1013FB	2017	3	672.56	0	353.45	49
21 Van Tuyl van Serooskerkenweg 15	429	EVB-P1539218	Stadionbuurt	Zuid	Amsterdam	1076JA	2017	3	116.96	0	25.72	4
22 Van Tuyl van Serooskerkenweg 15	5768	EVB-P1507153	Stadionbuurt	Zuid	Amsterdam	1076JA	2017	3	22.52	0	38.18	5
23 Van Tuyl van Serooskerkenweg 15	5768	EVB-P1507153	Stadionbuurt	Zuid	Amsterdam	1076JA	2017	3	1043.35	0	633.99	89

Figure 5: example of KPI list.

4.2 Map

4.2.1 Map-based selection of charging locations

The map provides an intuitive interface for selecting the desired charging locations quickly and assess and compare performance. The search field facilitates zooming in on the map based on address. Using polygons, circles, rectangles and mouse-clicks, surrounding charging locations can be selected. Once a charging location has been selected the “show graph selection” button appears in the center bottom of the map. Clicking this button the KPI graphs of the selected charging locations appear. The graphs are interactive: the number of selected charging locations can be adjusted by clicking the graph-legenda, the timeline can be adjusted using the month and year selection box or the zoom button in the top right corner of the graph, or simply by dragging a rectangle using the mouse. Once adjusted all KPI graphs adapt to the adjusted values. KPI values for a certain month pop-up once moving the mouse-pointer over the graph.

4.2.2 Selection tools

The selection tools tab in the left top corner contains six choices for selecting clusters of charging locations. It sets on which location-level you want to calculate KPIs and which part of the charging infrastructure you want to see on the map based on 1. location-level (address, neighbourhood/sub-district district, or city), 2. project (shows all charging locations part of a project/experiment), 3. Charge Point Provider (shows all charging locations of the selected CPO), 4. Use type (shows all charging locations used by the selected usergroup), 5. Fastcharger (shows only fastchargers on the map), 6. Chargehub (shows only chargehubs – e.g. a clusters of charging points - on the map). After selecting a level in 1. “location level”, KPIs will be calculated based on all charging locations in the cluster, eg. the district, subdistrict or city in which a selected charging location is situated.

4.2.3 Assessment tools

“Filter based on KPI”: Changes color of the charging location-markers in the map based on the selected KPI, year, month and KPI thresholds. Having set the KPI thresholds the charging locations performing below the minimum threshold color green, orange if the performance of a location fits the installed range and red if the location performs above the maximum threshold of the installed range.

“Vulnerability”: Using the principle of cascading failure the effect of ‘competition’ for usage of a charging location by EV users is measured by this assessment tool. If a charging location is not available (out-of service or occupied) regular sessions cannot be fulfilled at the desired location. Users search for an alternative location within a certain walking distance. Based on the historic charging data of a selected month, the vulnerability tool calculates two indicators: service failure and inconvenience.

Service failure indicates the fraction of regular sessions of a charging location during the set year and month that cannot be transferred to other charging locations within the set radius. *Inconvenience* counts the number of charging sessions having to transfer to an alternative location within the set radius during the set year and month. The more charging sessions have to be transferred the more users are being affected.

“Car sharing”: Indicates locations highly occupied by vehicles part of a free floating car sharing scheme. Depending on the set thresholds for minimum and maximum occupancy rate caused by free floating car sharing at a charging location, the charging locations in the map color green, yellow or red.

“Charge Point Classification”: Changes color of the charging location-markers in the map based on the following rules:

- Green = hourly occupancy at the charging location is less than 50% both during the day and night
- Red = hourly occupancy at the charging location is larger than 50% both during the day and night
- Blue = “Day location”: hourly occupancy during the day is more than 50%, whereas hourly occupancy during the night is less or equal to 50%.
- Yellow = “Night location”: hourly occupancy during the night is larger than 50%, hourly occupancy during the day less or equal to 50%.

5 Roll-out: Demand driven expansion of the charging infrastructure

Citizens and companies living or located in Amsterdam, Rotterdam and Utrecht can send a request for a public charging point to their municipality. Once a request is received and validated two main questions have to be answered: 1. Is charging infrastructure present or planned within a radius of X (in most cases a radius of 250 to 300 m meter from the requester's address is taken into account) 2. Does the performance of the nearby infrastructure justify expansion of the infrastructure? The pictures below illustrate how the decision support tool is being used by the roll-out practitioner.

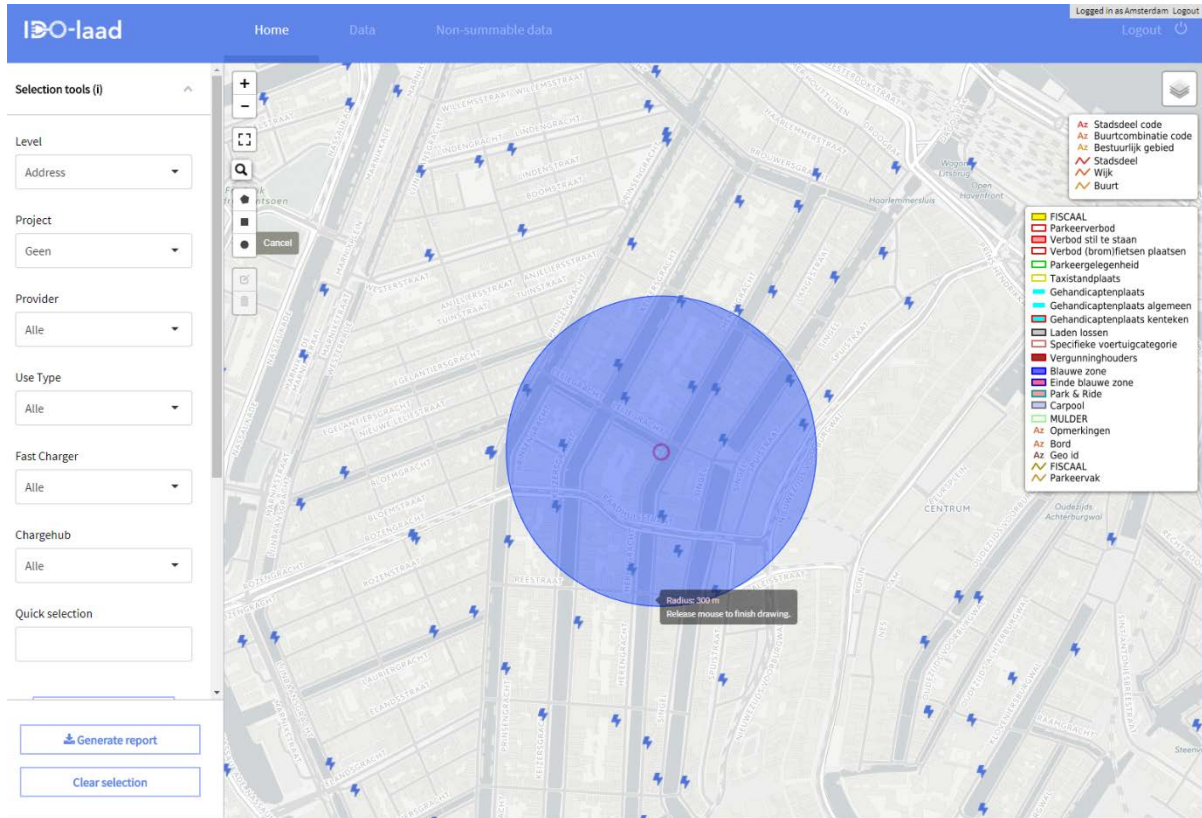


Figure 6: Select nearby infrastructure within 300 m radius from the requester's address.

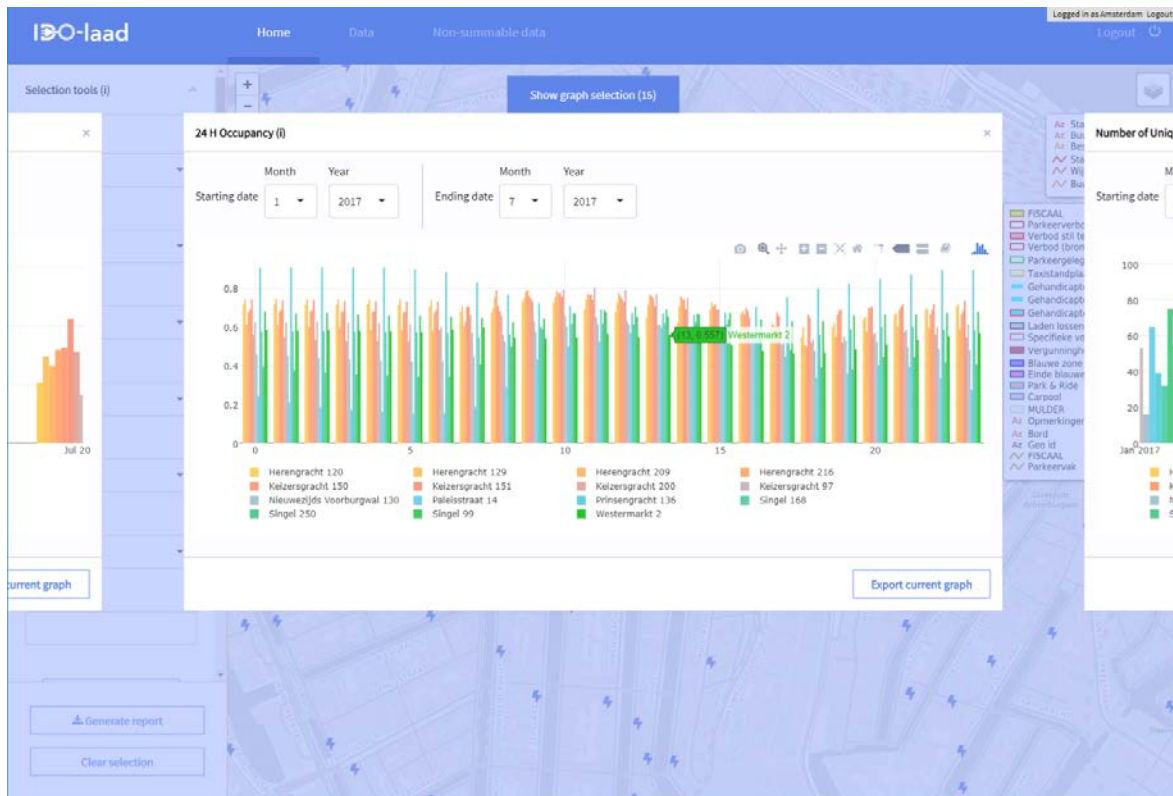


Figure 7: Check hourly occupancy of nearby charging points during the past 6 months. For each hour of the day, the occupation rate of the selected charging locations is shown. Eg. Between 5 and 6 am the occupation of location “Prinsengracht 136” is 90%.

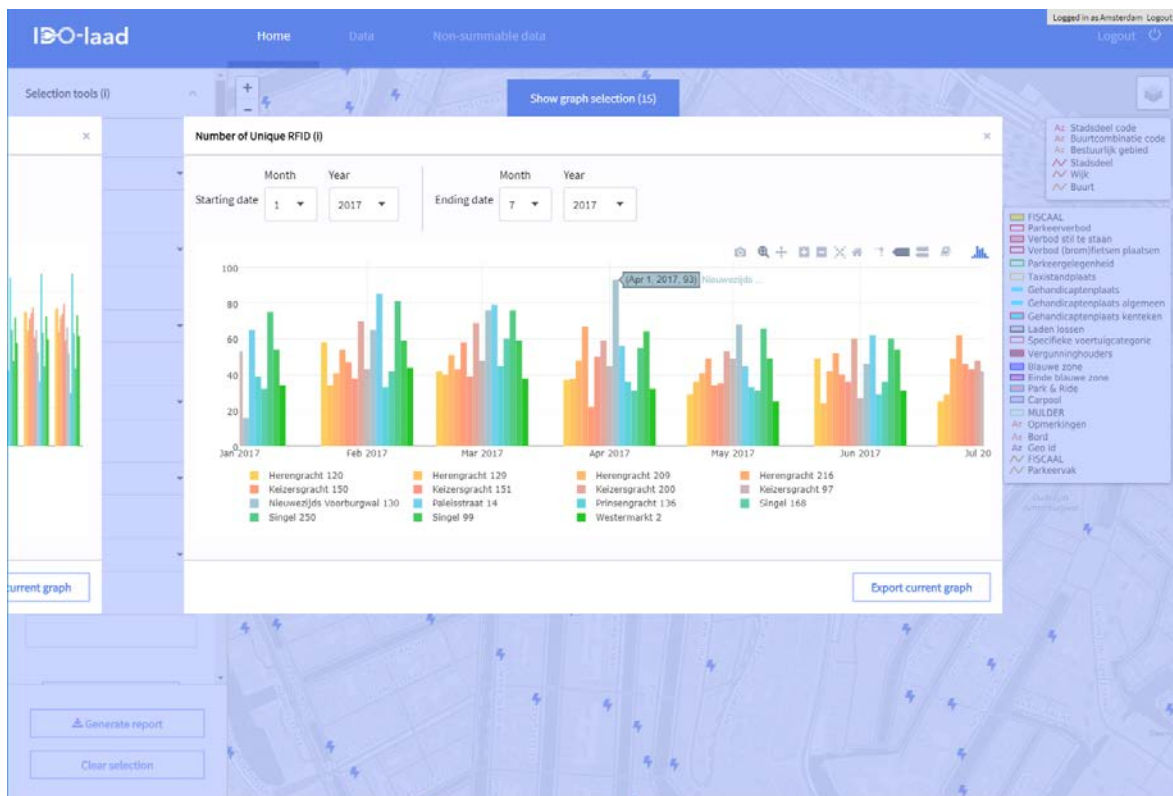


Figure 8: Check development of number of unique users during the past 6 months.

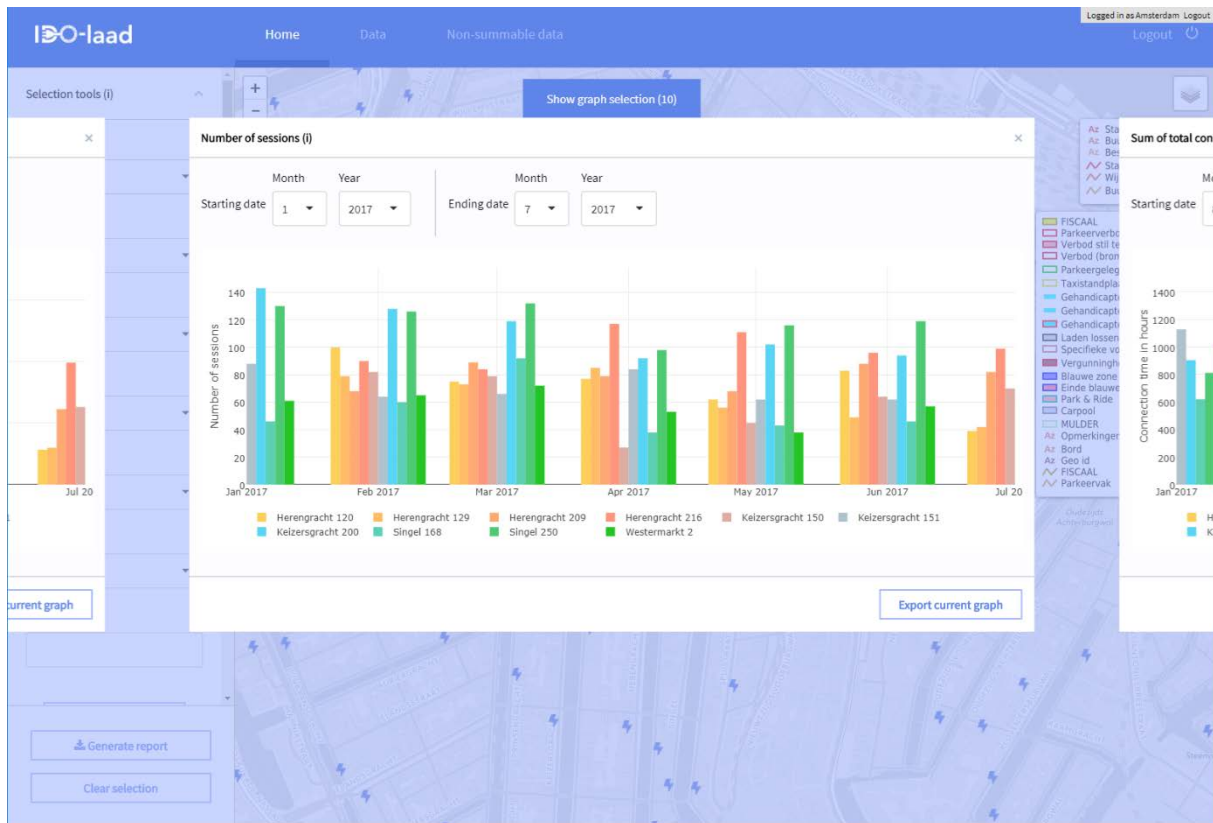


Figure 9: Check number of sessions during the past 6 months.

After having checked the performance results as shown in the above figures, the practitioner balances the various KPIs and either proposes a new location to the various stakeholders or declines the request. In both cases KPI reports and maps provide important information supporting the decision and convincing the stakeholders. Downloads can be made either by clicking the “generate report” button or using the “export graph” button in graph mode. If stakeholders do not approve the proposed expansion, iterations take place assessing the infrastructure performance and gathering arguments based on the charging data represented in the decision support tool.

6 Roll-out: Detection of infrastructure bottlenecks

With a dense charging infrastructure in place and a growing numbers of electric vehicles on the road, it has become crucial the roll-out professional to regularly assess the charging infrastructure on potential bottlenecks. This in order to be able to anticipate and keep the roll-out of charging infrastructure in pace with the growing need for it.

6.1 Vulnerability tool

The vulnerability tool as described in paragraph 4.2.3 provides the opportunity to assess the performance of the infrastructure adding new users or in case charging locations are out of service. At vulnerable charging locations expansion might be considered depending on the number of affected users in case of service failure or a new user entering the infrastructure or the fraction of sessions which cannot be fulfilled by the infrastructure. Further development of the algorithms behind the tool are being considered by the developers: eg. creating the opportunity to add charging location in the tool manually and test the effect on the vulnerability scores.

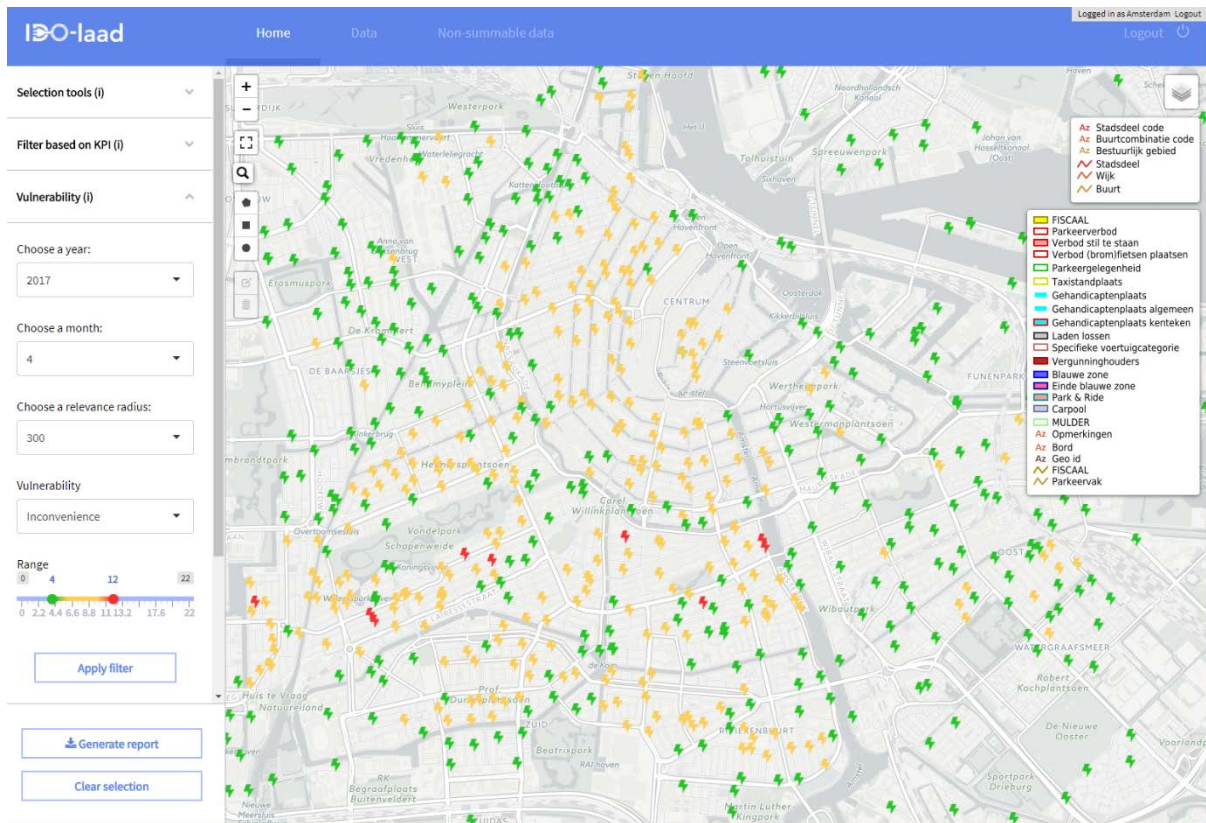


Figure 10: Inconvenience of the charging infrastructure May 2017. In red the charging locations at which more than 12 unique users are being affected by 1 user added to the network.

6.2 Charge Point Classification tool

Another tool used for the detection of potential bottlenecks in the infrastructure is the charge point classification tool. After selecting the desired year and month and clicking the “apply filter” button a visual overview is generated on the map indicating the level of occupation during the day and night of each charging location. Red highlighted charging locations have an hourly occupancy rate of over 50% both during the day and the night. Once the red locations have been detected, the roll-out practitioner can start to evaluate single locations checking their number of unique users, kWh charged etc. in order to take an informed decision whether or not to expand the charging infrastructure in order to avoid problems in the future.

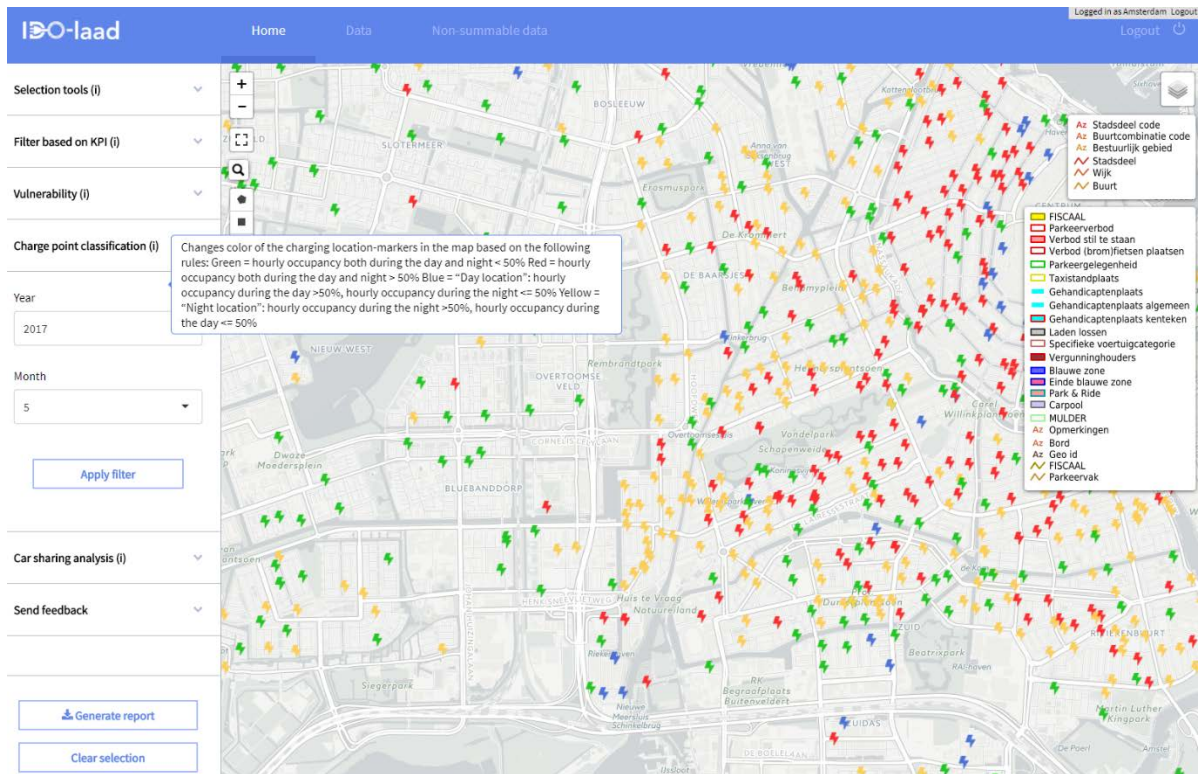


Figure 11: Charge point classification indicating high hourly occupied during the day, night or both.

7 Roll-out: Strategic expansion of the charging infrastructure

Strategic expansion captures a wide range of possible strategies to develop and expand charging infrastructure. The current version of the decision support tool provides general knowledge to inform a chosen strategy. Assessment tools based on forecasting or simulation models/algorithms can be implemented in the web application on request. The car sharing tool is an example of a tool developed on request in order to evaluate a chosen strategy. The tool creates insight in at which locations vehicles part of a free floating car sharing scheme charge and to which extent they contribute to the occupation of the charging infrastructure.

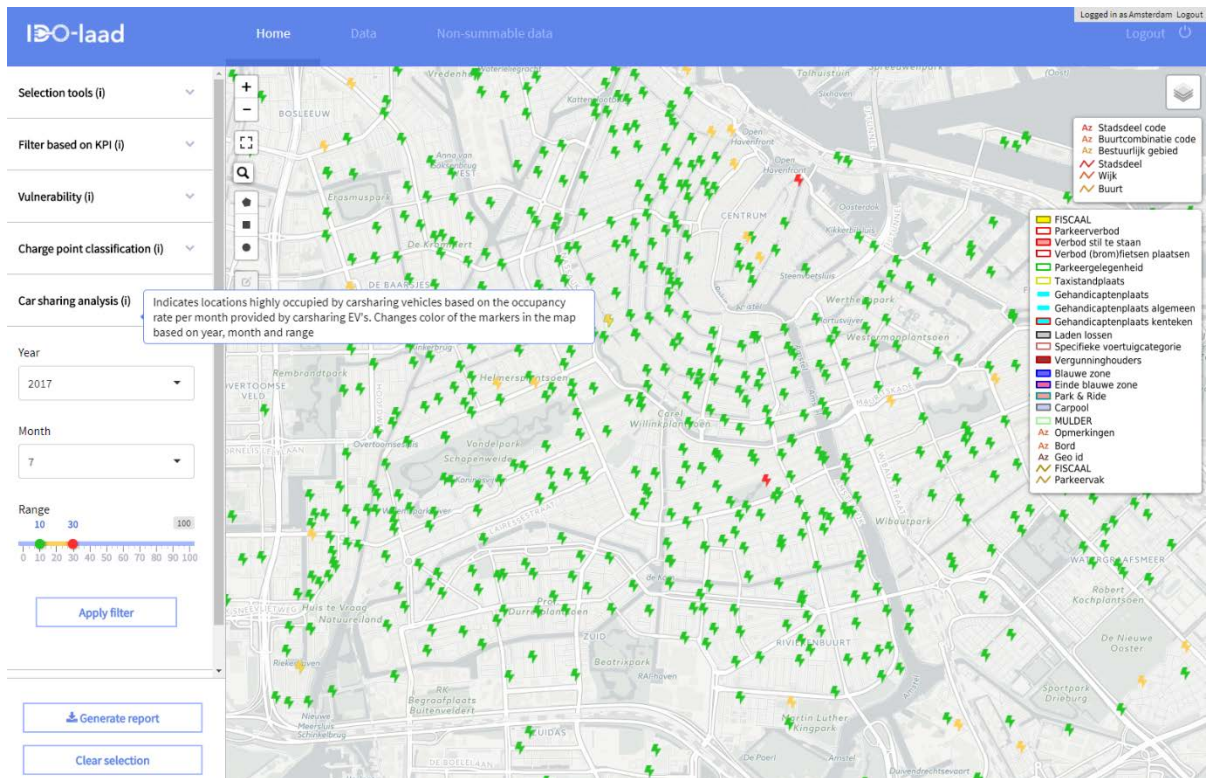


Figure 12: Car sharing analysis. Charging locations occupied for over 30% by fleet cars colour red. The threshold can be adjusted according to the practitioner's desire.

8 Conclusions

Big data provides infrastructure developers great opportunities to optimize the roll-out of charging infrastructure [3]. In this paper we describe an interactive tool including the architecture of a Data Warehouse structure which allows roll-out practitioners to work with big data in the field of EV charging infrastructure development. The front-end web application creates access to quantitative knowledge about the local performance of the charging infrastructure thus creating the opportunity to take informed decisions. This decision support tool covers the phase of evaluating the performance of existing charging infrastructure based on Key Performance Indicators. This evaluation results in a proposal for a new charging infrastructure location and includes plots of the performance of the existing charging infrastructure and a location-plot. Maps representing neighbourhood borders and parking lots provide location specific information. Nevertheless the tool does not integrate all location specific information required in the decision process such as the lay-out of the electricity grid, demographic information, spatial planning and information on current and planned roadworks. Future development and research will be aimed at the elaboration of the tool to cover a larger range of information used in the roll-out process. The combination of the Data Warehouse architecture, a continuous feed-in of most recent charging data and the web application can be implemented to any region or city, thus creating the opportunity for parties involved in the roll-out of charging infrastructure all over the world to monitor the performance of charging infrastructure based on big data.

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References

- [1] Funke S.A. et. al., *Addressing the Different Needs for Charging Infrastructure: An Analysis of Some Criteria for Charging Infrastructure Set-up*, in W. Leal Filho and R. Kotter (eds.), *E-Mobility in Europe, Green Energy and Technology*, DOI 10.1007/978-3-319-13194-8_4, Springer International Publishing Switzerland, 2015.
- [2] Helmus, J.R. et. al., *Key Performance Indicators of Charging Infrastructure*. EVS29 Symposium Montréal, Québec, Canada, June 19-22, 2016.
- [3] De Gennaro, M., Paffumi, E., & Martini, G.. *Big data for supporting low-carbon road transport policies in Europe: Applications, challenges and opportunities*. Big Data Research, Volume 6, December 2016, Pages 11-25. <https://doi.org/10.1016/j.bdr.2016.04.003>
- [4] Li-MinnAng, Kah PhooiSeng. (2015). *Big Sensor Data Applications in Urban Environments*. Big Data Research, Volume 4, June 2016, Pages 1-12. <https://doi.org/10.1016/j.bdr.2015.12.003>
- [5] Hoed van den, R. et al., *Data analysis on the public charge infrastructure in the city of Amsterdam*. EVS27 Symposium Barcelona, Spain, November 17-20, 2013.

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