

Amsterdam University of Applied Sciences

## **E-mobility** getting smart with data

CREATING TOMORROW

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# E-mobility

getting smart with data



## Preface

arly in 2012, our research team visited the policy-makers responsible for stimulating electric mobility in the city of Amsterdam. At the time, Amsterdam had recently installed several hundred public chargers, Car2Go was piloting with a small sharing program of electric smarts, and only a handful of (plugin) EVs were available on the market. Rather than being bright, the future of electric mobility was quite uncertain.

Nevertheless, the charging infrastructure grew, and with it the amount of data generated. However, there was limited knowledge about how to process and analyse such charging data. Would our research program be able to help?

This meeting proved to be the starting point for a long-term collaboration between our Urban Technology research program and the four main cities in the Netherlands. These cities were at the forefront of stimulating electric mobility and understood that applying data for monitoring and policy evaluation could make the difference.

Our research team took up the challenge and we set in motion a data-driven program around charging infrastructure. Based on the applied nature of our research, its agenda was largely based on questions from our professional partners. In parallel, connections with scientific disciplines were made to develop more generic findings valuable for the academic community. Additionally, the research also provided valuable case material for students to engage in applied research.

With this publication, we are proud to present a collection of the main research findings assembled from research projects carried in recent years. It includes key takeaways from data analysis on the topics of charging infrastructure performance, policies to stimulate effective roll-out, smart charging and segment studies such as electric taxis. With this publication, we hope to provide practical insights and tools that can support policy-makers in their quest to develop effective charging infrastructure.

Developments in electric mobility continue to accelerate, with batteries becoming cheaper, the range of electric vehicles increasing and charging becoming faster. In the meantime, the energy transition is rapidly evolving, bringing the energy and mobility sectors closer to each other. This provides major challenges for policy-makers on when to develop what type of infrastructure and where. As such, data-driven analysis is more urgent than ever. Rather than representing an end result, we hope that this publication forms the starting point for further applying datadriven methodologies to foster electric mobility.

Robert van den Hoed Lector Energy and Innovation Amsterdam University of Applied Science Research programme Urban Technology

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## INTRODUCTION

You are about to enter the world of electric mobility, more specifically the world of publiccharging infrastructure for electric mobility.

Over the past five years, we - researchers, teachers and students, together with municipalities, research institutes and companies - have gathered and analysed the charging data of public-charging infrastructure in the Netherlands. Together, we wanted to get smart, based on data, facts and figures. We have achieved this through experiments, evaluations of roll-out policies, and by developing computational models to simulate the future.

There are many ways to determine whether, where and what charging infrastructure to install. Demand-driven roll-out strategies have been applied next to the strategic placement of charging stations. Both regular and fast charging points have been installed and monitored. Stand-alone charging stations with two sockets, and charging hubs have been put in place. Smart-charging experiments have been executed at AC charging stations, and battery packs for solar energy storage have been installed.

Research results of the following research projects are presented in this book:

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## **Reading guide**

This book captures five years of research results on the roll-out of public-charging infrastructure. We don't expect you to read it from A to Z! In order to find the subject of your interest, we have developed the 4-5-6 system including icons for each charging infra category, policy field and user group.

Each article is marked with icons based on its content. If you want to read more about taxis, choose the articles with the taxi icon. Do you want to know more about charging hubs? Choose the articles with the icon for a charging hub. Colour codes direct you to the appropriate page, or select your articles for the contents overview.

Do you prefer an even quicker read? Take a look at the take-aways that come with almost each and every article. Are you interested in the full scientific background? Scan the QR code given in the article and access the scientific article or report directly on the web. Abbreviations used throughout the book are explained in the abbreviation table on page 160-161.

We hope that this book will inspire, make you a little smarter and well equipped to take the right decision regarding charging infrastructure roll-out, e-mobility or the renewable energy transition.

ategories of charging infrastructure	INFRA
AC chargers or regular chargers with alternating current	· _ <u>_</u>
DC chargers or fast chargers with direct current	DC
Smart-charging stations	Smart
Charging hubs	
Five fields of policy development	POLICY
f? Is it necessary to put public-charging infrastructure in place?	, 😧
What? How to determine what kind of charging infrastructure to put in place?	{ َ }
Where? How to select locations for public-charging infrastructure?	→ Ø Where?
Use: How to influence the usage of public-charging infrastructure?	Use
Adoption: How to promote the adoption of electric mobility?	Adoption
Six user groups	USERS
Visitors	Visitor
Residents	Resident
Commuters	Commuter

Shared fleets

PHEV versus BEV

Shared

9

## **Project Partner Network**



#### **Research Institutes**



## Companies and others





#### How are you involved in electric driving?

The Amsterdam University of Applied Sciences is increasingly becoming a knowledge institute. In addition to providing education, it is conducting applied research in close collaboration with the professional field. The Urban Technology research programme is investigating how companies and municipalities can prepare for the energy transition. In my research group, around fifteen researchers are exploring the development and roll-out of electric charging infrastructure for electric vehicles.

#### What specific things did you want to find out?

Research at the AUAS is demand-driven. Key questions from our partners mainly concern how to prepare for the future of electric driving: where, when, and what type of charging points should be used? The task of AUAS is to connect professional challenges with scientific disciplines. For example, we look at charging infrastructure as a complex system and use agent-based models to run simulations. We examine charging behaviour as a discrete choice model.

#### What will the future of charging look like?

There are three major challenges. First, in the coming years, new user groups such as taxis, shared cars and delivery vans will also shift to electric. Each group will have its own specific charging requirements. Second, not one design will dominate in terms of how we charge. In ten years' time, we'll probably charge our electric cars very differently than we do now, probably more quickly and partly inductive. Third, battery prices are coming down so fast that we will see exponential growth in the EV market. It will be an enormous challenge for municipalities and companies to ensure that sufficient charging infrastructure is in place in due time.

## **IDO-laad** Intelligent Data-Driven Optimisation of Charging Infrastructure

Amsterdam University

of Applied Sciences

VATTENFALL

UNIVERSITY

engie

OF AMSTERDAM

#### Duration

from 01-09-2015 till 31-08-2019

Project Objectives The goal of the IDO-laad research project was to develop mathematical models and tools to optimise the roll-out of EV charging infrastructure. The cities of Amsterdam, Rotterdam, the Hague and Utrecht provided the charging data of their public charging infrastructure.

Research questions How can professionals in the charging infrastructure chain be supported with concrete instruments to realise an [I] effective and [II] cost-efficient charging infrastructure?

**Outcomes** Our research comprised the iterative development of mathematical prediction and simulation models. Data science was the "engine" for executing [I] policy effect studies, [II] simulations of future scenarios, and [III] developing monitoring dashboards. Based on the results, professionals can proactively steer towards a more effective and efficient charging infrastructure.

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X Amsterdam

Among others, the effect of daytime charging in terms of reducing parking pressure was evaluated. Additionally, the effect of introducing car-sharing schemes in a city on EV-user convenience was studied. Dashboards to monitor the performance of existing charging infrastructure were implemented, offering insights into KPIs of charging infrastructure. These and other research results can be found elsewhere in this book.





INFRA

POLICY

Cities develop charging infrastructure to facilitate EV drivers, but not all EV drivers are alike. They may have different charging needs related to the starting time of a session, connection time, charging speed or frequency of charging. Some may be highly dependent on public chargers, whereas others may use charging infrastructure in a city irregularly as a visitor.

# Distinguishing User Groups

or cities, the challenge is to place sufficient charging infrastructure that matches charging demand, while considering that charging demand and behaviour differs geographically. Residential areas tend to have many overnight charging sessions, whereas office areas have more daytime charging sessions. Additionally, locations near specific points of interest and parking garages can expect more visitors.

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Optimising the use of charging infrastructure requires a better understanding of (i) how to distinguish user groups, (ii) establishing their user/ charging profile, and (iii) how this may differ geographically. Identifying user groups and their particular charging habits is also useful for simulating future charging demand in certain growth scenarios. For instance, what additional charging demand can we expect if 4,000 taxis become electric? In other words, studying charging behaviour of user groups helps to monitor, but also to plan ahead.

#### Private users

#### include residents, commuters and visitors:

 Residents represent only a small portion of RFIDs (13%) but they are responsible for more than 40% of all sessions and 53% of all KWh charged.

Similarly, commuters represent only 5% of all RFIDs, while contributing more than 14% of all sessions and 11% kWh charged.
 Visitors are by far the largest group (80% RFIDs), although they are only responsible for 39% of all sessions and 27% of all kWh charged.

Private users can drive a plug in hybrid or battery electric vehicle. In the database PHEVs are defined as EV-drivers with a battery capacity of less than 16kWh. BEVs have a battery capacity of 24kWh or more. Analysis on the charging behaviour of PHEVs versus BEVs are indicated by this icon:



### Commercial users

include fleets of taxis, shared vehicle programmes and (city) logistics vans. Due to voluntary agreements (taxis) and environmental zones in cities (city logistics), these fleets are increasingly electrified. Their charging habits present some striking results:

 At present, the 1,200 electric taxis in the database represent approximately
 1% of all RFIDs, although they contribute
 7% to all kWh charged. Apart from using public chargers, taxis are also much more reliant on fast-charging infrastructure, being one of the most frequent users of such chargers in the city of Amsterdam.
 Amsterdam and Utrecht have hosted

four e-car-sharing programmes. Overall, approximately 1% of all RFIDs participate, accounting for 2% of all sessions and energy charged. USERS

39%

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15

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## Managing charging infrastructure data: five issues to solve

Secure access to reliable historical charging data is very important to adapt quickly to changes in the electric mobility field as well as to reduce risks and costs. In terms of creating access to charging infrastructure data for research and monitoring purposes, we address five issues to solve regarding collecting the data, its quality and structure, adding contextual data and ensuring its secure access.

harging session data comprises chargepoint detail records (CDRs) and metre values (MVs) of kWh uptake at a charging station. Since 2014, AUAS has gathered data from every public charging station in Amsterdam, Rotterdam, the Hague and Utrecht and the metropolitan regions of Amsterdam and Rotterdam. Every month, the charging session data of the past month is added to the database.

#### The G4 cities, MRA-E, and SGZH are the data owners Charging session and motro value data of public charges

- Charging session and metre value data of public charging points January 2014 - March 2019:
- Number of valid sessions : 9,484,156
- Total kWh charged: 82,417,880 kWh
- Total number of unique charging cards used: 161,580

Charging data Jan. 2014 – March 2019

Maximum number of used charging locations in 1 month: 5,882

## EV charging data regions, cities, state of the art



Figure 1. Each month AUAS collects and manages the charging data of the G4 cities', and the metropolitan regions' public charging infrastructure.

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Cleansing

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Switch of

Time

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chargers

Manual fixes

Mark session invalid

Mark session invalid

Manual fixes based on location

StartConnectionDateTime and

EndConnectionDateTime after

check with given Connection

connection time based on start

Check volume kWh and given

connection time; if valid

than calculate and repair

endconnectiondatetime

Mark session invalid

Mark session invalid

Mark session invalid, if

fastcharger=Y: session = valid

Under construction: chaining

broken sessions at non-fast

Mark second session invalid

Fix after calculation of

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## Data quality improvement

Type of error or

Any cell can be empty

Location errors: Region <> District

<> subdistrict <> subsubdistrict <>

kWh > 100 kWh or kWh < 0 kWh

Invalid date eg. date in the future

StartConnectionDateTime >

EndConnectionDateTime

Negative Connection Time

StartConnectionDateTime =

EndConnectionDateTime

Double rows within batch

Late arriving double rows

EndConnectionDateTime

Broken session (same RFID repetitively

connected within portion of an hour)

StartConnectionDateTime < previous

chargepointID <> Region <> District

<> SubDistrict <> SubSubDistrict <>

inconsistency

Location Address

Missing data

Inconsistencies

Errors

## Collecting the data

Data exchange between the electric vehicle and the charging station, the CPO, eMSPs and DSO is targeted at the authorisation, control and billing of the EV charging services delivered. However, certain problems emerge when gathering charging data for research purposes. For example, sources and channels through which the charging data is delivered vary, and data formats also vary. Until recently, the collection of data was a very labour-intensive process. The OCPI protocol for data exchange has recently been implemented in the Netherlands, and we tested this protocol in Q4 2018. The OCPI protocol standardises file formats and API calls, strongly reducing the data collection effort involved.

#### Data quality

Missing, incorrect or inconsistent data can lead to false research results or incorrect interpretations of EV charging infrastructure performance. These errors and inconsistencies are mainly caused by human entry errors or corruption in transmission or storage. Although the OCPI protocol automates the collection process, data quality is not being improved per se. CPOs and eMSPs are free to choose how to format data entries; for example, socketIDs. As the current version of the OCPI protocol does not prescribe the format of each entry in detail, differences between eMSP occur.

AUAS data engineers developed SISS packages to process errors and inconsistencies. Furthermore, manual corrections are being made. Table 1 lists the result of cleansing for each type of error or inconsistency. The cleansing code developed can be provided by AUAS upon request.

Location Address

E-mobility | getting smart with data

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#### Structuring charging data

Data scientists need to combine and compare data in new ways to execute complex statistical analysis and develop simulation models. Flat files like Excel sheets cannot process the large amount of charging data and do not provide the flexibility that data scientists need.

A relational database provides the necessary flexibility for data scientists to work with the data. AUAS selected MS SQL Server, a software package to store and retrieve data. MS SQL Server is a relational database management system providing high capacity and performance.

#### Combining charging data

Municipalities focus on stimulating the roll out of charging infrastructure. Back in 2014, policies targeted improving air quality and facilitating the adoption of EVs. In 2019, research focuses on how to manage the impact on energy grids and facilitate specific user groups like taxis, freight and car-sharing programmes with

## Relevant contextual data

	Contextual data	
Location	Charging location geo-coordinates	
	District, subdistrict and sub-subdistrict markers per charging location	
Technological specs	Fast charger Y/N	
	Number of charging points available at charging location	
	Maximum available charging power at charging location	
Specific user groups	User group labels (e.g. taxi, car-sharing programme)	
	Taxi stand entry and exit point registration	
Energy transition	Weather data	
	Renewable energy production data	
	Smart charging experiment indicators per charging location	
	Energy pricing data (APX)	
	Energy grid data	

Table 2. Contextual data to combine with charging data analysis.

smart roll-out strategies. These new research topics lead to research questions that require more information than charging data per se. For instance, other data such as the layout of electricity grids, renewable energy production and travel patterns of particular target groups are becoming increasingly important.

#### Data access

Charging data contains business and privacy sensitive information like the volume of kWh charged per charging station and charging card identification codes referring to an individual. Access to the data has to be secured properly to protect partners' and individuals' interests.

Data scientists can request access to charging data by following the data-sharing protocol developed by the municipalities and AUAS. Access to charging data is secured by personal accounts including a three-step authorisation. Each data scientist only gains access to a personalised data set based on the research question that he/she is trying to solve. All data scientists work in a protected R-studio environment using computational servers hosted by AUAS.

#### Take-aways

► This unique set of historical and up-to-date EV charging data of metropolitan and regional areas in the Netherlands provides the opportunity to monitor the adoption of electric mobility, and facilitates data-driven policy development for charging infrastructure roll-out.

• Bringing together data from various stakeholders requires the willingness or agreement of the stakeholders to provide the data.

The Dutch municipalities and regions included the requirement to make the charging data available for research purposes in the concession agreement.
Data science requires structuring the data. Accordingly, a data warehouse structure for charging data has been developed facilitating: [i] monitoring of charging infrastructure performance, [ii] scientific research, [iii] access for third parties.



# Charging infrastructure definitions

Charging infrastructure for electric cars comes in many shapes and sizes. What makes one charging station different from another? For example, what is the difference between a charging station and a charging point? This article describes the most commonly-used definitions as applied in this book. The definitions are the same as those laid down by the Netherlands Enterprise Agency and the EU Sustainable Transport Forum.

he availability of charging stations varies. Anyone can use publicly-accessible charging stations and they often have to be activated with a charging card with a radio-frequency identification (RFID) tag. By using the RFID tag, the charge point operator (CPO) can send the bill to the right person. The CPO is the manager and operator of the charging station. Users request the charging card from a mobility service provider (MSP), which takes care of the financial admin for the user and ensures that the user has access to the charging stations managed by various CPOs. In addition to publicly-accessible charging stations, there are also semi-public charging stations that are available to everyone but are located in places where there are restrictions in terms of opening hours – for example – or payment for access such as car parks. People may also have a private charging station on their driveway or in their garage at home – for example – or at their place of work. Only the owner is able to use this.

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#### AC charging

AC stands for alternating current. However, car batteries run on DC (direct current). AC charging is used to charge cars, and an inverter in the car converts this into DC. AC charging usually means regular charging at a speed of up to 22kW. In practice public charging stations usually have a capacity of 3 to 22kW. Fast charging with more than 22kW is possible with AC, although only a few cars are fitted with an inverter that can handle faster charging speeds. In this book,

### AC charging station With 2 charging points



#### DC charging

In practice, DC charging – on direct current – is mainly used for fast charging, defined as charging with a capacity of 50kW and above. With DC charging, the conversion from AC to DC takes place in the charging station. In practice, DC charging capacity is often between 50 and 175kW. The cable at DC stations is almost always attached to the charge point. This is in contrast to AC charging in Europe, where the user is expected to bring his/ her own cable.



#### **Smart charging**

Unlike a regular charging station, at a smart charging station the delivered capacity can be adjusted externally. This enables faster charging at times when there is for example a surplus of renewable energy. Available capacity can be lowered at times when the local electricity grid is overloaded. Lower capacity resulting in slower charging or no charging at all.

Vehicle-to-grid (V2G) is a more advanced method of smart charging: managing charging capacity whereby electricity can also be returned to the grid. The car battery is used as an energy buffer. This requires both vehicles and charging stations that support bi-directional charging.

### Smart charging station With 2 charging points



#### **Charging hub**

The Netherlands Enterprise Agency defines a charging hub as a charging location with several charging stations connected to a single mains connection. The charging stations at a charging hub may be equipped with several charging points. One charging point can have several types of sockets to support different charging standards for charging cables. One electric car at a time can be charged at one charging point. The charging hub example below demonstrates a charging hub with three charging stations equiped with two charging points each and one type op socket per charging point.

> AC charging hub With 6 charging points



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## INFRA AC DC Smart

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> 640 BEV I PHEV

Stimulating electric mobility

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Structured planning on how to stimulate electric mobility in the Netherlands dates back to 2011, when the first plan of action for E-mobility was presented. A set of governmental instruments were set in place aiming to realise 1 million EVs by 2025, most prominently including:

- fiscal/financial incentives for purchasing and/or leasing EVs;
- 2. support for the roll-out of charging infrastructure;
- 3. and demonstration programmes for particular target groups including commercial and commuter traffic, logistics, taxis and government vehicles. Lease car drivers were particularly supported with tax measures, given their relatively high mileage and kilometres driven in urban areas.

In recent years, the ambitions for EV sales have increased to the previously-mentioned targets of 50% of all car sales being electric by 2025 and 100% by 2030. Financial incentives play a major role in driving the sales of (PH)EVs. Moreover, the rollout of a dense, accessible and interoperable charging infrastructure has strongly contributed to the success of EVs in the Netherlands. Municipalities and particularly the large four cities and the metropolitan region of Amsterdam (MRA) have played a significant role in facilitating charging, as one of the most dense charging networks worldwide.

## Roll-out of charging infrastructure

An estimated 65% of households in the Netherlands do not have a dedicated parking space where they can charge. Consequently, range anxiety is generally seen as one of the main barriers for electric mobility. Accordingly, enabling public charging infrastructure is one of the priorities of Dutch EV policy. At the national level, financial support was given to a programme set up in 2009 by joint grid operators (ELaadNL) to develop a public charging network of 10,000 charging points nationwide. This was complemented by municipal initiatives to develop public chargers through public tenders in the four major cities in the Netherlands. By 2018, the Netherlands has one of the most dense public charging infrastructures worldwide, with almost 12,000 public charging points installed. Indeed, this corresponds to nearly one public charger for every seven electric vehicles. Having such a dense charging infrastructure is generally seen as one of the success factors in overcoming the first

hurdles for purchasing electric vehicles.

In the early stages of the rollout of charging infrastructure, the main focus was on placing charging stations in strategic locations such as city centres. However, as EV adoption also started to take off among those who previously relied on on-street parking facilities, the focus shifted to a more demand-driven roll-out. EV drivers could request a charging station to be placed near their home while these charging stations remained publicly accessible. When few electric vehicles were on the road, this also meant that such drivers also created a private parking spot for themselves as the accompanying parking area was exclusively accessible to electric vehicles. In areas

## Development of charging stations



Figure 1. Number of public charging stations (grey) and ratio between "number of unique users" and "public charging stations" (red) in the four major cities and the metropolitan region Amsterdam in the Netherlands.

with high parking pressure, this served as an additional incentive for potential buyers.

Due to the demand-driven roll-out strategy, the ratio between the number of electric vehicles and public chargers has remained relatively stable and is one of the lowest in the world. Figure 2 offers an overview of the number of public chargers in the four major municipalities, as well as the EV-to-charger ratio for this public charging infrastructure. The latter is calculated based on the number of EV drivers actually using the infrastructure.

Apart from the steady growth in the number of charging stations, the figure shows how higher EV sales at the

> successful in providing sufficient accessibility for charging in the initial stages of development. It has also guaranteed that regular users utilise the charging stations, thereby reducing the number of non-used chargers and increasing the business case. Pushing interoperable standards has been essential for seamless charging for users with one charging card (through the so-called **Open Charge Point** Protocol (OCPP)).

end of 2015 and 2016

led to peaks in the EV-to-

periods. Near the end of

2016, when the highest

number of EVs was sold,

stations increased from

charging infrastructure

required to support EV

infrequently use public

chargers and thus mainly

Take-aways

A demand-driven roll

out strategy has been

rely on private charging

infrastructure.

around 5.5 to 7. The ratio

indicates the level of public

adoption, considering that

a large number of EVs only

the ratio of EVs to charging

charger ratio during these

E-mobility | getting smart with data

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Fiscal incentives have played a major role in stimulating EV sales in the Netherlands. Generous fiscal incentives were put in place in 2012, which spurred sales especially for PHEVs. Since then, fiscal incentives have been reduced step by step. This chapter provides an overview of fiscal incentives and demonstrates their effectiveness in stimulating sales of EVs and PHEVs in particular.

# Fiscal incentives and their effect on EV sales in the Netherlands

iscal/financial incentive schemes have been used as a policy instrument to steer and stimulate desired innovations. A relevant question is always whether or not the incentives are effective or lead to undesired consequences. In the Netherlands, the Dutch government has set up a scheme of four main measures to stimulate sales of (PH)EVs:

### Addition tax for the private use of a leased car

Company cars (leased) that are used privately are taxed in a scheme called 'addition for the private use of a company car' ("bijtelling" or "addition"). The "addition" to the income level is calculated based on the retail price of the new car. Depending on the vehicle's CO2 emissions, 0% to 25% of the new car value is added to the annual taxable income. Policy-makers have used the "addition" tax in recent years to steer company car users towards lower CO2 emitting vehicles. An overview of the changes in this tax since 2012 is provided in table 1. Notable changes can be seen in 2013 where both battery EVs and PHEVs were strongly favoured through 0% "addition" tax and increases in "addition" tax in subsequent years particularly for the 0-50 gram category, making PHEVs increasingly less favourable.

# Historic development of addition tax

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from 2013 to 2019

Year	0 grams CO2 emission (FEVs only)	0-50 grams CO2 emission (PHEVs)	>50 grams CO2 emission (non-EVs)
Pre-2012	0%	14%	14-25%
2012	0%	0%	14-25%
2013	0%	0%	14-25%
2014	4%	7%	14-25%
2015	4%	7%	14-25%
2016	4%	15%	14-25%
2017	4%	22%	22%
2018	4%	22%	22%
2019	4%<€50,000	22%	22%
	22%>€50,000		

Table 1. Addition tax for leased vehicles per CO2 emission category

#### Purchase tax:

Direct purchase incentives are in place for EVs through a CO2-based purchase tax, with higher taxes for higher CO2 emissions of a vehicle (based on NEDC test cycles). Differences can be substantial, from  $\in$ 365 (EVs) to more than  $\in$ 12,000 (diesel/gasoline cars with over 162 gr CO2/km).

#### Annual vehicle tax:

Zero-emission vehicles are exempt from annual vehicle taxes. For mid-size passenger cars, these taxes are in the range of €800-€1,500 per year

INFRA

POLICY

Adoption

USERS

600

Visitor

Resident

Commute

31

INFRA

POLICY

Adoption

USERS

672

Visitor

Resident

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Commuter

#### **Environmental investment deduction (EID)**

Besides a reduction in addition tax, the Dutch government has also offered businesses a tax reduction on yearly depreciation costs. This reduction is 36% from the depreciation costs, capped at €50,000. The EID particularly favours entrepreneurs and freelancers with their own businesses, given their opportunity to deduce company car depreciation costs as an environmental investment. The above incentives target different vehicle owners and powertrain types in different ways. The purchase tax and annual vehicle tax incentives mainly benefit private car owners. Although the vehicle purchase tax could build up to a significant amount, it only compensates for a part of the higher EV prices generally observed in the market. The annual vehicle tax only provides a relatively small additional incentive.

### EV Sales in the Netherlands 2012-2019

Source: Dutch Road Authority



Figure 1. EV Sales in the Netherlands 2012-2018, separated in FEV and PHEV (coloured bars). Share of total vehicle sales per month (black line), based on car registration data of the Dutch road authority. As can be seen, EV sales took off in 2012 and initially spiked at the end of 2013 when the "addition" tax for PHEVs was raised from 0% to 7%. Altogether, EVs had a market share over 15% of newly-sold vehicles in December 2013.

#### By the end of 2018, more than 85% of all (PH)EV sold were (leased) company cars. This can be mainly explained by the "addition" measure, aimed at the company/lease market. Over the lifetime of the lease contract, the addition tax

largely compensates the price premium for EVs, which thereby enables driving electric at similar costs to gasoline cars. Figure 1 demonstrates how the changes in the 'addition' measure have had a major effect on (PH)EV sales.

Even higher market shares followed in the December months of 2015 and 2016. This was also facilitated by the rising number of available EV models on the market, particularly PHEVs such as the Mitsubishi Outlander, which sold nearly 10,000 vehicles in those two years. By the end of 2016, just before taxes for PHEVs were to be raised to 15%, more than 20% of all new vehicles sales were PHEVs and FEVs.

A last spike in PHEV sales occurred in late 2016 when taxes for PHEVs were raised to a level equal to gasoline and diesel cars. PHEV sales have since fallen flat and the number of vehicles on the road has slightly decreased due to exports. Despite enjoying much of the same or better benefits as PHEVs, FEVs remained at a slow but steady pace until late 2016. After the subsidies for PHEVs were cut at the end of 2016, lease drivers turned to FEVs. FEV sales have steadily increased since early 2017, accounting for 3-4% of all sales in the first months of 2018.

### Conclusions

Overall, the set of incentives put in place provides a scheme that particularly favours company cars and small business owners. In particular, it can explain the unforeseen surge of PHEVs, making the Netherlands the country with the highest market share of PHEVs. The policy focus to stimulate EVs for company cars has been effective. Close to 50% of all new vehicles sold are company lease cars, while the average purchase price for company cars is much higher than for the private market. Given that around 2010-2015 only EV models in the higher price segment were available, targeting this company car segment has therefore been very effective.

#### Take-aways

 Focus on company cars as the most attractive first-mover market.
 For PHEVs, consider financial incentives related to charging; for instance reduce charging tariffs in order to stimulate electric driving, rather than purchase subsidies.

#### X City of Amsterdam

www.amsterdam.nl/parkeren-verkeer/amsterdam-elektrisch/
 Philipp Renard | Programme manager Charging Infrastructure

#### ▹ How are you involved in electric driving?

Within the Smart Mobility Programme and the Amsterdam Electric program, we conduct experiments together with partners on the impact of new, electric, technologies on mobility. Amsterdam is well known for its extensive charging infrastructure network, with almost 1,500 public charging stations (3,000 charging points) applying a demand-driven approach. Almost 1.000 of the 6.000 taxis that drive around the streets of Amsterdam are already driving fully electric. The city of Amsterdam also takes measures to improve air quality, including environmental zones, subsidies for purchasing electric cars, privileges such as shorter waiting times for a parking permit for emission-free cars, and a communication campaign aimed at influencing people's behaviour when taking decisions influencing

air quality and CO2 emissions. The combination of push (regulatory measures, e.g. environmental zones) and pull (stimulating and supporting measures, e.g. subsidies and public charging infrastructure) factors works to realise the transition to emission-free mobility.

#### What specific things did you want to find out?

Back in 2014 when the first research project started, my colleagues Bart Vertelman and Doede Bardok oversaw the roll-out of charging infrastructure through developing and implementing new roll-out strategies. The primary question was whether and how these strategies would work out.



▶ What will the future of charging look like?

Amsterdam will have to scale up the roll-out of (fast) charging infrastructure to match the increasing pace of EV, in public spaces, parking garages and within city development projects (private garages). This is linked with further exploring smart charging solutions to minimise the impact on the electricity network and increase the use of renewable energy for charging. The city of Amsterdam is currently working on a new policy for charging infrastructure, setting a suitable and clear framework for all related topics for the next 5-10 years.

Many early adopters of electric mobility do not have their own driveway and rely on on-street parking. This is particularly the case for those who live in multiunit dwellings or dense urban areas, as is the case in the four largest cities in the Netherlands: Amsterdam, Rotterdam, The Hague and Utrecht. The availability of public charging infrastructure for EV drivers is vital. But just how urgent is charging infrastructure for EV users, and more importantly: to what extent can accessible charging infrastructure incentivise inhabitants to buy an electric vehicle? An experiment carried out in 2017 provides interesting insights.

# **Charging infrastructure** *as enabler for buying EVs*

harging transactions on the public charging infrastructure in the G4 cities show that 80% of these sessions can be labeld as "home charging sessions", i.e. executed during the night. This is partly a result of the demand-driven rollout strategy these cities have chosen: new stations are placed upon demand of candidate EV drivers. These users rely on public charging infrastructure for recharging their car on a daily basis. For policy makers the challenge is to facilitate electric mobility by placing charging statons, but in the meantime not placing too many, at suboptimal locations that lowers the business case and uses scare public space. INFRA

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Back in 2017 we carried out an experiment to estimate how big a factor charging infrastructure availability is in the decision to purchase an electric vehicle. We solely focused on those persons that would rely on public charging stations for home charging. The experiment also provided the opportunity to investigate the effect of related parking strategies, including [i] exclusivity of parking spots for charging, and [ii] reduced parking fees for EVs.

149 respondents chose among three types of vehicles (BEV, PHEV and Conventional (ICEV)), each with a certain price and driving range. Each choice was made under a different policy setting, varying with regard to the exclusivity of the parking spot and free parking policy, as well as the placement strategy of the municipality. This so-called discrete choice experiment allows to assess the effects of different incentives independently on the purchase intention of a set of users.

#### Key role for charging accessibility

The results of the experiment show that the placement strategy of charging stations has the strongest effect on the intention to purchase an electric vehicle. Providing accessibility to charging was a much stronger incentive than lower parking fees or exclusivity of charging spots. Having to share a public charging station with more owners has a negative impact on BEV and PHEV purchase intention. This effect was found to be twice as high for BEVs than PHEVs. This makes sense, as certainty about the availability of a charging station at home is less important for PHEVs, as they have a gasoline back-up. However simply placing these charging stations is not enough. The parking spots next to the charging stations should be available exclusively for EVs. Restricting this exclusivity by implementing daytime charging or allowing ICEVs to park at charging stations reduces the purchase intention for BEVs. Such an effect is not found for PHEVs, which again could be explained by the fact that PHEVs have a back-up option if the charging station is not available. Reducing the parking fee for those electric vehicles could also help in stimulating consumers to choose for an EV. The effect of the parking fee however was found to be much smaller than providing the necessary charging opportunities.

## Conclusions and take-aways

Infrastructure proves to have a significant positive influence on the purchase intention of prospective EV buyers.

Providing charging infrastructure is of major importance for those who rely on public charging at home.

 Certainty about home charging is especially important for those considering buying a BEV, and to a lesser extent for PHEVs.

Policy makers can also consider to reserve parking spots exclusively for EVs or to offer free parking to prospective EV buyers in order to incentivise the purchase of EVs. The influence of reserving parking spots exclusively for EVs or offering free parking to prospective EV buyers nevertheless is less strong than the actual placement of charging stations close to where prospective EV buyers live.

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#### Type of policy

#### Variations in experiment

Placement strategy	1 new EV
Place new charging station for every	2 new EVs
X number of EVs	4 new EVs
Parking fee	<ul> <li>Free parking across the city</li> </ul>
	<ul> <li>Free parking at charging stations only</li> </ul>
	<ul> <li>Regular parking fee</li> </ul>
Availability of parking spots at	<ul> <li>Exclusively available for EVs</li> </ul>
charging station	<ul> <li>Exclusively available for EVs between</li> </ul>
	8:00 and 22:00
	Also available for gasoline-driven vehicles

#### Example of a choice set for respondents

<b>.</b>				
Placement strategy: Parking tariff:	: The municipality places a charging station per new EV Free parking is offered when charging			
Availability:	Parking spot at charging station is exclusively for EV			
	Electric Vehicle	Plug-in Hybrid Vehicle	Convention	
Retail Price	€20.000	€20.000	€20.000	
Electric range	500 km	50 km	-	

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www.evbox.com 

Joke van der Eerden | Commercial Director Netherlands

Daniël Geerts | Partner Manager Utility (Energy)

#### ▹ How are you involved in electric driving?

The Dutch sales team at EVBox offers our charging solutions to several customers in different segments. We offer charging stations with various capacities, from 3.7 to 350 kW. Thanks to our product range, we have charging solutions to suit every home, semipublic and public situation. In addition to our charging stations, we also offer an intelligent back-office system on which the charging stations run and from which they can be controlled. Our work is closely connected with e-mobility and its developments.

What specific things did you want to find out? How exactly do the research projects contribute to your work?

It is particularly important for EVBox to gain more insights into charging statistics and charging behaviour. We can use these insights to offer e-drivers a better charging experience. We also consider it beneficial to look at the installation process for public charging stations, whether ad hoc or strategic and proactive. We believe that it is essential to have sufficient charging infrastructure in public spaces, as this will have a major impact on people's willingness to make the switch to electric driving.

#### ▹ What will the future of charging look like?

Electric driving will rapidly develop in the coming years because electric cars will simply be a better, cleaner and cheaper alternative to the current petrol and diesel cars. This will require many developments in terms of charging infrastructure and energy supply. We anticipate a sharp increase in demand for fast chargers in public and semi-public areas and we also expect that charging infrastructure will have to become more intelligent and connected to other systems. We will respond to this by providing smart charging solutions in these areas and connecting them to our intelligent and open backoffice system, which enables integration with other platforms.

# KEY PERFORMANCE INDICATORS

Data on charging transactions is crucial for policy-makers to monitor the performance of charging infrastructure. What do they actually need to monitor? In this section, we present a framework for key performance indicators (KPIs) for charging infrastructure. The KPIs form the backbone for a set of dashboards used by policy-makers to monitor how charging infrastructure is utilised. Moreover, the data warehouse where all charging transactions are stored is described.

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•	EVdata.nl: Portal with up-to-date information on electric charging in the Netherlands	43-46
•	Utilisation rates of charging infrastructure: A balancing act for policy-makers	47-50
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## Key Performance Indicators of Charging Infrastructure

Municipalities play an instrumental role in the roll-out of public charging infrastructure. But how does a policy-maker establish whether the charging infrastructure is performing well? What are the relevant key performance indicators (KPIs) for charging infrastructure? Most importantly, what measures can a policymaker take to increase performance?

Policy-makers want to provide sufficient charging infrastructure for the growing number of EV drivers. In addition, they also need to manage scarce parking resources, complaints of non-EV drivers about privileged EV drivers or empty parking lots, and the impact of EV charging on the electricity grid.

Back in 2016, the AUAS presented result and performance indicators at EVS 29. These can help to optimise the roll-out and improvement of public charging infrastructure. Researchers applied a structured approach to identify the KPIs.

### A structured approach towards performance indicators

Step 1. Identify the interests of the most important stakeholders. We identified the following five stakeholders: [I] the municipality, [II] EV users, [III] residents, [IV] CPOs and [V] grid operators.

Step 2. Translate stakeholders' interests into objectives and measurable results indicators. Result indicators tell organisations how they have performed in relation to their objectives.

Step 3. Translate the result indicators into performance indicators, which provide guidance on what to monitor on a regular basis. Performance indicators help to identify measures to improve performance.

### From stakeholder interests to result indicators

Table 1 provides an overview of [I] the five main stakeholders, [II] the objectives that policy-makers have to align the stakeholders' interest and [III] how this translates into measurable result indicators.

For instance, the **municipality** has particular sustainability goals such as improving air quality or climate goals, which led to investments in public charging infrastructure. In order to legitimise these investments, it is important to account for the contribution of these investments to sustainability goals. Result indicators thus include emissions reduced due to facilitated electric driving as well as the *cost effectiveness* of the measures.

Result indicators have also been derived for the other stakeholders:

For both prospective and existing **EV users**, accessibility of on-street charging infrastructure is an urgent need. Providing accessibility of charging stations is thus a major objective, with *infrastructure accessibility* and the number of *EV users* facilitated as result indictors.

The loss of parking facilities due to parking lots being assigned for EV charging can lead to frustration among residents, particularly if these charging spots are seldom used. Therefore, the

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structural under-utilisation of charging stations should be prevented, with utilisation as an important result indicator. Note that high utilisation for residents can conflict with the result indicator accessibility to charging stations for EV users. Indeed, this illustrates the balancing act for policymakers to prevent both under- and over-utilisation.

**CPOs** require a long-term commercial perspective on public charging infrastructure with an attractive

business case. The related result indicators include reduced costs and increased benefits of public charging infrastructure.

Policy-makers need to manage roll-out ambitions to include concerns of **grid operators** for grid stability and smart charging. Result indicators include reduced risks of power outages and the level of smart charging options facilitated by the municipality.

#### Objectives and result indicators

Stakeholder	Objectives for municipality	Result indicators
Municipality	Achieve sustainability goals	Air quality improvements due to CI
	in a cost-effective way	Climate change improvements due to Cl
		Achieved cost effectiveness of CI
EV users	Stimulate electric mobility by	Increased accessibility of CI
	enabling charging	Growth in number of users of CI
Residents	Optimise utilisation of CI and	Increased level of utilisation of CI
	manage parking pressure	
CPOs	Facilitate a positive business	CI-costs reduced
	case	CI-benefits increased
		Business case CI improved
Grid operators	Safeguard grid quality	Risks of power outage/grid congestion
		reduced.
		Smart charging options facilitated

E-mobility | getting smart with data

Table 1. Stakeholder objectives and result indicators

#### Take-aways

 Performance indicators are key to assess how to measure performance, but also to identify interventions.
 Overall, eleven result indicators and thirteen performance indicators were identified as most relevant monitoring instruments for policy-makers engaged in the roll-out of public charging infrastructure.

#### From result indicators and performance indicators to possible interventions

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The result indicators identified for each stakeholder need to be translated into measurable performance indicators. To illustrate, the sustainability-related result indicators for the municipality translate into two performance indicators: [I] amount of electricity (kWh) charged, and [II] effectiveness of government investments (euros per emissions mitigated). Possible interventions may then include maintaining a demand-driven roll-out strategy that guarantees basic demand on each charging station, investing in knowledge and predictability on attractive charging locations and/ or developing incentive systems for shorter connection times, thus allowing other EV drivers to charge.

For residents, reducing the percentage of low-utilised stations is key. Possible interventions may include removing low-performing charging stations or allowing parking by non-EV vehicles during particular periods. As such, this enables managing the concerns of all types of stakeholders related to charging infrastructure in a structured fashion.

(Table 2. on next page)

### Key result and performance indicators

Goals	Result indicators	Performance indicators	Possible interventions
Achieve sustainability goals in a cost- effective way	<ul> <li>Air quality improved</li> <li>CO2 emission reductions</li> <li>Costs for mitigated emission</li> </ul>	► ∑kWh charged	<ul> <li>Add(/remove) charging stations</li> <li>Incentives for re-parking</li> <li>Purchase subsidy for EV candidates</li> <li>Incentivize larger charge sessions</li> </ul>
Stimulate electric mobility	<ul> <li>Accessibility of CI</li> <li>Growth in #users of C</li> </ul>	<ul> <li>Growth in capacity utilization</li> <li>CP Convenience</li> <li>#frequent users/ charging station</li> <li>% long chargers</li> <li>Charge time ratio</li> </ul>	<ul> <li>Add charging stations</li> <li>Incentives to reduce long charging</li> <li>Increase number of sockets of CPs</li> <li>Smart rerouting of EV users</li> </ul>
Optimize utilization of CI and manage parking pressure	► Level of utilization Cl.	► % of low utilized stations (incl. peak times)	<ul> <li>Remove charging stations.</li> <li>Allow regular parking during low-peak times (non-EV windows).</li> </ul>
Enable market takeover of Cl / Facilitate a positive business case	<ul> <li>Costs decreased</li> <li>Benefits increased</li> <li>Over-capacity</li> <li>reduced</li> </ul>	<ul> <li>Costs/benefits-ratio</li> <li>% of charging points with positive BC (incl. trendline)</li> <li>Shelf life of Cl</li> <li>∑kWh charged/∑potential kWh charged</li> </ul>	<ul> <li>Lower grid costs (e.g. change in capacity, master-hub systems).</li> <li>Reduce energy costs (e.g. taxes).</li> <li>Lowering parking tariffs.</li> <li>Stimulate more users, sessions and electricity charged (see above)</li> <li>Enabling income streams (e.g. hourly/starting tariffs).</li> </ul>
Safeguard grid quality	<ul> <li>Reduced risk of power outage.</li> <li>Smart charging facilities</li> </ul>	<ul> <li>Peak power level</li> <li>Peak shaving potential</li> <li>% charging points with smart charging</li> </ul>	<ul> <li>Enable delayed charging.</li> <li>Enable different flexible power capacities.</li> <li>Create incentives for smart charging.</li> </ul>

Table 2. 11 result indicators, 13 performance indicators, and intervention opportunities

## **EVdata.nl** *Portal with up-todate information on electric charging in the Netherlands*

The G4 cities, MRA-Elektrisch and the AUAS regularly receive requests to share data. These are often relatively simple figures, such as how many charging sessions take place per station, or how many kWhs are charged per session. In order to simplify these data requests, G4/MRA-e has set up the EVdata.nl portal.

he site shows the development and current status of electric charging in the Netherlands, based on hard data from more than 11,000 public charging points. It is a useful tool to monitor and manage the development of electric driving. As part of the MRA-Elektrisch project, municipalities in Noord-Holland, Flevoland and Utrecht are building a network of public charging stations. The G4 cities are doing this in Amsterdam, the Hague, Utrecht and Rotterdam. Added together, these stations account for at least 65% of all public charging stations in our country. The Amsterdam University of Applied Sciences collects and analyses the data generated by the stations. The results were first published on evdata.nl on 14<sup>th</sup> February 2019, and they are updated monthly. 43

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### Major demand for charging data

In addition to the roll-out of the public charging network, the website shows – among other things – how many unique users visit the charging stations and how many kWhs are charged per station and per session. In this way, the G4 cities and MRA-Electrisch are able to meet the high demand for up-to-date charging data. All of the figures show that electric driving is becoming increasingly popular. In 2017, 19,075,529 kWh were charged, which amounts to more than 95 million clean kilometres and reflects an increase of 24% compared with 2016.

With evdata.nl, for the very first time a website enables closely monitoring the roll-out and use of the public charging network in the Netherlands based on objective, reliable and representative indicators. Thanks to this ongoing research, we are able to monitor the developments in electric charging exceptionally well. This makes evdata.nl a useful tool for policy-makers in municipalities and provinces and climate committees, for example. There is also interest from the market, scientists, journalists and from abroad.

#### Take-aways

► Since 2015, the G4/MRA-e charging network has grown by almost 1,500 charging points per year (with an annual growth rate of ~25%).

- ► In 2018, 2.8 million charging sessions took place on the G4/MRA-e network. It was used by more than 100,000 unique users.
- ► The amount of electricity charged per session (kWh/session) has considerably increased since 2018, from approximately 8kWh/session to well above 10kWh/session. This seems to have been caused by the increased share of fully electric vehicles on the market.

► The amount of electricity charged per charging station has also increased: in the G4/MRA-e network, this is often by more than 25%. The increasing popularity of fully electric vehicles has also had a positive effect on the business case for charging points.

Aggregated data is shared with third parties on evdata.nl, which helps to further develop electric driving while ensuring the privacy of users and the businesssensitive information of the charging station operators. In the future, relevant research results and additional indicators will also be published on the portal.

## Utilisation rates of charging infrastructure: A balancing act for policy-makers

Performance indicators for charging infrastructure enable policy-makers to monitor and assess how charging infrastructure is being used. Here, we describe performance indicators at the charging point level indicating how busy a charging point is. Is the current charging infrastructure available for new EV drivers? For how much time are stations not occupied? Two utilisation rates are generated based on charging data: the average utilisation rate and the utilisation rate per hour. For policy-makers, it seems even relevant to distinguish this hourly utilisation rate per day of the week.

> or most policy-makers, placing a new charging station forms a balancing act between providing sufficient charging infrastructure for EV drivers and preventing empty parking spots at charging stations in areas with high parking pressure.

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### Hourly utilisation rate









continuously, while others have an occupancy of less than 5%. By monitoring the occupancy of individual and surrounding charging stations, policy-makers in the G4/MRA-e cities can take informed decisions about adding or removing charging stations locally, as well as managing charging infrastructure accessibility.

#### Utilisation rate per hour of the day

Figure 2 provides an overview of utilisation rates of two exemplary charging stations over 24 hours, based on the charging sessions executed at these stations in March 2018. This includes both weekdays as well as weekends. The figure illustrates how two charging stations in the city of Rotterdam differ in daily charging profiles. While both charging stations have an average utilisation rate of about 50%, their usage profiles completely differ between a night-charger profile (Breitnersingel) to an office charger profile (Geyssendorfferweg). For example, charging profiles can significantly differ depending on the type of neighbourhood (residential versus office).

#### Average utilisation rate



Figure 1. Historic development of average utilisation rate across several cities (January 2014 - March 2019)

#### Average utilisation rate

An important performance indicator for policy-makers is the average utilisation rate or average occupancy, defined as the amount of time that a charging point is occupied divided by the total available time within a set timeframe, e.g. a month. 100% indicates that a particular point is continuously occupied, while 0% indicates that no one has used the charging point during that timeframe.

Figure 1 shows the historic development of average utilisation rates in the four major cities and the metropolitan region of Amsterdam (2014-2019). The figure shows that the extent to which the charging infrastructure is occupied

the utilisation rates show an upward trend, indicating that the utilisation of charging infrastructure is steadily increasing each year. While an occupancy of 30-40% may seem low, policy-makers

do not strive for 100% as this would limit accessibility for new EV drivers. Dutch policymakers regard an average utilisation rate of 50-60% as high, and a legitimate percentage at which to consider adding charging points in that neighbourhood.

varies from around 20-30%

and Utrecht. It also shows

seasonal effects, with lower

utilisation rates in summer

in the Hague, Rotterdam and

MRA to 35-40% in Amsterdam

vacation periods. In all regions,

From the charging data, there are evidently large differences in average utilisation rates between neighbourhoods, although the occupancy of a charging station can also strongly vary per hour of the day, and day of the week. While the average utilisation rate may be around 20-25% for all charging stations in a city, a significant share of charging stations might be occupied 40-60% of the time. Some charging stations might even be occupied almost

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Utilisation rates may thus differ beween stations, as well as based on the hour of the day and between weekdays and weekdays. As a result, there may be charging stations that are relatively under-utilised, with a negative impact on the business case and parking pressure. On the other hand, there are charging stations that tend to be over-utilised, possibly with frustrating effects for EV drivers who are dependent on on-street charging.

Reducing both over- and under-utilisation are major concerns for policy-makers, who can take the following measures to avoid or reduce under-utilisation:

(I) Applying window times at charging stations by making charging spots available to non-EVs after a certain time in the evening (see the "Using daytime charging to reduce parking pressure" chapter).
(II) Attracting user groups with complementary charging profiles such as electric taxis and/or electric car sharing schemes.

(III) Placing charging
 infrastructure in neighbour hoods with different
 functions, where it is likely
 that a combination of
 residents (residential area),
 commuters (office buildings)
 and/or visitors (shopping areas,
 POI) will park and charge.

In order to reduce overutilisation of charging points, policy-makers may consider the following measures:

 (I) Continue on-demand placement of charging points.
 This strategy guarantees regular utilisation by at least one EV user.

 (II) Extending individual charging stations to charging hubs, in case a certain threshold in utilisation is reached for this location.
 Extending to hubs may be worthwhile if other stations can also connect to the same grid connection, thereby reducing grid connection costs.

(III) Considering tariff structures that stimulate EV users with long connections to re-park their car earlier, thereby providing spaces for new EV drivers (see also the "Charging Station Hogging: Is it a problem?" chapter). This option only makes sense if the charging station is indeed occupied, otherwise it may simply increase parking pressure while not providing more accessibility to other EV drivers.

#### Take-aways

► The average utilisation rate offers an overall impression on how occupied charging infrastructure in a certain area is. This can be calculated at various levels, namely the region, city, district, neighbourhood and charging station level. ► The utilisation rate per hour of the day is an important KPI for policymakers to assess the local availability of existing charging infrastructure and whether new EV drivers can find a spot to charge. ► The utilisation rate per hour of the day per weekday creates an even

weekday creates an even more detailed view on the local availability of charging infrastructure. This is interesting for both policy-makers dealing with the roll-out of charging infrastructure as well as EV drivers and people who are considering buying an EV.

# Charging infrastructure assessment platform

**=** Contents

In close cooperation with the cities of Amsterdam, Rotterdam, the Hague and Utrecht, AUAS developed a charging infrastructure (CI) assessment platform based on real-life charging data. INFRA

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The charging infrastructure assessment platform is an online dashboard representing five KPIs for each public charging station and two tools representing potential bottlenecks in CI availability. The dashboard allows roll-out practitioners to take informed decisions on where and how to expand the existing CI.

When receiving a request for a new charging point, a roll-out practitioner wants to know how the charging stations are being used close to the address of the EV driver who filed the request. The address can be looked up on a map showing the existing charging stations. After selecting the surrounding charging stations, the following five KPIs are shown per month for each selected charging station: kWh charged, average occupancy, hourly occupancy, number of sessions, and number of unique users. The vulnerability tool and the charge point classification tool offer a more general impression of where bottlenecks in CI availability might arise in the near future.

The software packages R Studio and R Shiny were used to build the dashboard. These packages offer the advantage of controlling access to parts of the CI information based on personal authorisation. In the chapter "Managing charging infrastructure data: five issues to solve", we describe the processing and storage of the charging data, as an important prerequisite for building the dashboard.

## Assessing CI performance for demand driven expansion

EV drivers located in Amsterdam, Rotterdam and Utrecht could send a request for a public charging point to their municipality. Once the request was received and validated, two main questions had to be answered: [I] Is CI present or planned within a radius of – for example – 300 m metre from the requester's address? [II] Does the performance of the nearby infrastructure justify an expansion of the infrastructure? Figures 1-3 illustrate the use of the dashboard.

## Selecting charging stations



Figure 1. Select charging stations within a 300 m radius from the requester's address.



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## Detecting bottlenecks in CI performance

In order to anticipate and keep the roll-out of CI in pace with the growing need, rollout practitioners aimed to assess the existing CI at potential bottlenecks.

Having checked the performance results as shown in figures 1-3, the practitioner balances the various KPIs and either proposes a new location to the various

stakeholders or declines the request. Downloads can be made by clicking either the

**Charge Point Classification Tool** 

"generate report" or "export graph" button.

This tool indicates the level of average occupation during the day or night by colour. Red highlighted charging locations have an hourly occupancy rate of over 50% during both the day and night. The threshold of 50% was set by the practitioners. Once the red locations had been detected (figure 4), the roll-out practitioner started to evaluate single locations by checking their number of unique users, kWh charged, etc. Based on this assessment, a practitioner could decide to expand the CI even without a new EV driver requesting a charging point.

Charge point classification based on hourly occupation



Figure 4: Colours indicating average occupation rates of charging locations: above or below 50 % during the day, night or both.





Figure 2. For each hour of the day, the occupation rate of the selected charging stations is shown. E.g. between 8pm and 9pm, the occupation rate of "Rochussenstraat 20" station is 70%.

#### Number of unique users

54



Figure 3. Checking the development of the number of unique users over time.

#### Vulnerability Tool

Using the principle of cascading failure, this assessment tool measures the effect of "competition" for usage of a charging location by EV users. Details about how this tool works can be read in the chapter "Vulnerability of charging infrastructure". At vulnerable charging locations, expansion might be considered depending on the number of affected users in case a new user utilises the infrastructure.

#### Vulnerability tool: Inconvenience.



Figure 5. Inconvenience of CI. The charging locations at which more than ten unique users could be affected by adding one user to that location are shown in red.

#### Take-aways

► The online dashboard has significantly reduced the lead time for realisation of a new charging point following a request.

► Assessing KPIs along the roll-out process promotes the efficient utilisation of charging infrastructure.

► The presented dashboard can be copied and implemented for both public and semi-public charging infrastructure across the world, as long as the charging session data is available in CDR format.



We are Over Morgen! If we want our cities to remain liveable and accessible, the way in which we travel from A to B must become cleaner and quite different. Technological innovations such as electric transport, smart charging facilities, mobility as a service and autonomous transport are the building blocks for the mobility of the future. How can we ensure that this new mobility also contributes to the sustainability of our energy supply? What impact will this have when redesigning a city or (re)designing a future or existing residential area?

#### How are you involved in electric driving?

Over Morgen advises most municipalities in the Netherlands on how to roll-out their charging infrastructure. The system of parties applying for individual charging stations is simply no longer fit for purpose, whereas instead upscaling has to take place in a systematic way. In addition to issuing advice, we also play an active role in the roll-out of charging infrastructure. With our company PARKnCHARGE, we invest in and operate charging stations. Social charging makes it possible to share charging stations efficiently with other e-drivers.

#### What specific things did you want to find out? How exactly do the research projects contribute to your work?

Over the years, our questions have evolved from basic issues such as "what impact does a parking time limit have on charging infrastructure?" to those about the future of charging with larger batteries and the influence of shared mobility.

#### What will the future of charging look like?

Self-driving cars will be the major game-changer for charging. Until selfdriving cars truly make a breakthrough, we will need to keep installing charging infrastructure for one or more individual users. Autonomous vehicles can use centralised charging infrastructure en masse. I'm very intrigued by what will happen in the future.



# EVALUATING POLICY MEASURES

Data analysis provides a powerful tool for policy-makers to monitor and evaluate policy effectiveness. Here, we present the results of different effect studies related to charging infrastructure. We evaluate demand-driven and strategic placement strategies, effects of different tariff structures on charging behaviour as well as the effect of window times on the utilisation of chargers. Furthermore, data analysis related to 'hot topics' such as plugins (do they charge?) and long charge sessions ("station hogging") is presented.

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Roll-out strategies: Demanddriven versus Strategic

Dutch policy makers have essentially followed two roll-out strategies for charging infrastructure: [I] demand-driven roll-out, where charging stations are placed upon the request of candidate EV drivers, and [II] strategic roll-out, where charging stations are placed at "strategic" locations where many visitors are expected. The question is how these strategies compare. Researchers of AUAS and ElaadNL explored performance differences between the two. INFRA

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attractive to visitors. At shopping

points of interest, charging sessions

are relatively short. The duration of overnight charging sessions by

residents or sessions during the day

longer, leading to a lower charging

while at work are logically significantly

ratio (ratio between charging time and connection time) compared with demand-driven stations. This confirms that the demand-driven stations are mainly used by residents for overnight charging, whereas strategic ones are and leisure areas, public facilities and

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driven strategy has been dominant. By placing a charging point for an EV driver filing a request, the utilisation of the charging point is guaranteed to a certain extent. Charge point operator EVNetNL chose to apply both strategies in the early years of infrastructure roll-out. Between 2011 and 2016, EVnetNL installed around 1,742 public charging stations, 1011 of which were labelled as "strategic" and 731 as "demanddriven". As such, this roll-out formed a perfect experimental setup to assess differences in utilisation.

## Strategic versus demand-driven



Figure 1. Public charging station roll-out in the Netherlands between 2010 and 2015

#### **Results: Differences** in Utilisation

The results show that demand-driven charging stations have a significantly higher energy transfer (daily kWh charged) than strategic charging points (see figure 2). This is particularly the case for the period up to 2014, when twice as much was charged at demanddriven stations compared with strategic charging stations. With the fast growth of EVs in the Netherlands, at the end of 2013 the difference between energy transfer at demand-driven stations compared with strategic stations was significantly reduced. When looking at energy transfer - and relatedly the business case for charging stations - a

demand-driven strategy makes sense in less mature EV markets. In a more mature EV market, these differences seem to straighten out, suggesting that both strategies may well complement each other in time.

Researchers also compared the number of unique users facilitated by the strategic versus demand-driven stations. In the 2014-2016 period, strategic charging stations facilitated 40-60% more unique users compared with their demand-driven counterparts (figure 3). Strategic charging stations also show a higher charging time

Average energy transfer at demanddriven and strategic charging stations

time ratio.



Figure 2. Average total energy transfer per week for the two roll-out strategies between 2012 and March 2016

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## Number of unique charging cards



Figure 3. Average number of unique charging cards per week per charging point between 2012 and March 2016.

#### Conclusions

Based on this analysis, one roll-out strategy cannot be deemed favourable over the other. Demand-driven stations show higher transaction volumes, while strategic stations perform better in terms of the number of unique users facilitated and the charging time ratio. Therefore, the choice of a particular roll-out strategy depends on the local context and specific objectives of a municipality or CPO.

Furthermore, the performance of both demand-driven and strategic stations has changed over time, which is likely related to the maturity of the EV market and the density of the charging network. In addition, we know that increasing battery size has an impact on charging behaviour in general. More about this effect can be read in the chapter "Simulating the transition from PHEV to large battery BEV."

### Take-aways

- ► Demand-driven roll-out strategies are likely to make sense in the first phases of infrastructure roll-out and immature EV markets as they guarantee a baseline utilisation by local EV users.
- Strategic roll-out is a favourable strategy particularly at points of interest and in cases where network density and EV adoption rates are high.

## How much will they charge? Charge tariffs in the Netherlands.

Charging at public charging stations in the Netherlands is rarely for free. But how much does the EV driver pay? Prices of charging are not straightforward and they strongly vary. With many different CPOs and eMSPs providing charge cards, it is difficult to determine the actual price to be paid in advance.

o understand the differences in charge tariffs, it is important to distinguish between commercial parties that install and maintain the charge stations – CPOs – and those offering charge cards that can be used at all public charge stations, namely eMSPs. In general, since June 2014 CPOs are free to determine the costs of charging at their charging infrastructure. These costs are billed to the eMSPs. Consequently, eMSPs charge the EV user to meet these costs and are free to add additional costs for their services (e.g. subscription fee). INFRA

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CPOs are not restricted to a single tariff but can vary, e.g. based on the charging location or the charge speed offered. Furthermore, pricing mechanisms also differ between CPOs. We found three main pricing mechanisms, billing based on: 1) the amount charged in kWh, 2) the time connected or 3) both the kWh charged and a certain "per-use" fee e.g. starting tariff. Additionally, the price per kWh or time can vary across the day, some CPOs have a subscription fee that offers lower rates and the three main pricing mechanisms can be combined. Overall, we found over fifteen different pricing mechanisms for charging in the Netherlands. On average, the per-use fee equals  $\in 0.42$  per session and the volume charged fee is  $\in 0.32$  per kWh.

Municipal policy is the most important cause of price differences. Municipalities in the Netherlands in general apply either the concession model or the open market model. The concession model gives the concession holder the right to place public charging infrastructure in a certain municipality. The price of charging is one of the requirements imposed by the municipality. The four largest cities in the Netherlands and the metropolitan region of Amsterdam want to guarantee the price of public charging to their EV drivers for a longer period. Many residents in these densely-populated areas do not have their own driveway and cannot install their own charging point. By applying the concession model, municipalities subsidise the installation of charging infrastructure and thus promote the adoption of electric driving. The open market model is more suitable for municipalities with less focus on promoting electric driving or little money to support the roll-out of public charging infrastructure. In this model, CPOs are free to choose a pricing strategy that suits the business case of public charging infrastructure. For example, a higher energy tariff can be charged, but also a starting tariff or an hourly rate.

In addition to the costs that the CPO charges, the consumer also pays for using the eMSP charge card. Indeed, there are largely differences between the fees charged. The eMSP can charge the consumer costs for purchasing a charging card, monthly subscription costs, pay per use, an increment per kWh charged or a fixed tariff (volume or time based). This means that charging at a similar station can vary in price by several Euros depending on which charging card is being used. This is often not communicated at the charging station. Identifying that transparency is key we formulated a number of suggestions.

#### Take-aways

CPOs and eMSPs: Make prices on websites transparent so that users can make smarter choices.

 CPOs: Display the price being charged to the eMSP at the charging station. This makes the EV driver less reliant on several internet services and apps that are not entirely reliable.

▶ eMSPs: Make the bill transparent by providing information on the different cost elements (e.g. price per kWh, starting tariff and time-based fees).

► Web developers: Develop easy-to-use comparison websites offering personal advice to EV drivers. Given that most EV drivers use fewer than five different charging stations per month, advice on which eMSPs card to use at those locations would be valuable.

► EV drivers: Use the information available in apps about prices at the charging stations that you most commonly use. Make use of websites that compare prices of CPOs and eMSPs.

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**Charging Station** Hogging: Is it a problem?

The Dutch word "laadpaalklever" – or "charging station hogger" - was announced as the word of the year for 2018. This term reflects someone who leaves his/her electric vehicle unnecessarily long at a charging station without actually charging. But how can we define 'unnecessarily long' and how does such a definition vary in different contexts?

he problem of charging station hogging arises when another EV driver would like to charge at an occupied charging station. This strongly depends on the actual situation, including location characteristics, the duration of the session, time of the day, day of the week, and type of charging station.

#### **Connected** with a fully charged battery?! Are you a hogger?

As soon as a vehicle is fully charged, one can speak of charging station hogging, namely being "unnecessarily connected". Of all charging sessions on AC charging stations only 2% charge all the time while being connected. Nevertheless, in practice AC public charging stations are often built for EV drivers relying on on-street parking at home or the office. Drivers are

expected to park at charging stations, including overnight, for example. About 50 percent of the charging sessions at public charging stations in the G4 cities and the metropolitan region of Amsterdam take 8 hours or more. By contrast, 5 percent of the charging sessions take longer than 24 hours, and less than 1 percent have a duration of 48 hours or longer. Therefore, charging sessions are much shorter than the parking duration of fossil fuel cars on average.

Most sessions of more than 24 hours take place during the night or weekend, when demand at most public charging locations is lower. In addition, most charging locations offer at least two charging points. During almost 50 percent of the charging sessions of more than 24 hours, the other charging point at the charging location remains available.

At busy fast-charging stations, occupying the charging station after the vehicle has been fully charged is highly inconvenient for other EV drivers and it immediately reduces the business case for the CPO. Policies forcing EV drivers move their car as soon as the battery is fully charged during busy times of the day or at fast-charging stations might help.

### Charging station hogging a problem or not?

Charging station hogging is only problematic when another EV driver would like to charge at an occupied charging station. It is however not yet possible to measure unfulfilled demand but is possible to give some indications.

Most sessions of longer than 16 hours take place during the night or weekend, when demand at most public charging locations is lower. It is therefore not very likely that hogging during these hours is problematic. In addition, most charging locations offer at least two charging points. During almost 50 percent of the charging sessions of more than 24 hours, the other charging point at the charging location remains available.

It therefore seems that hogging is not very problematic at the moment due to the available number of charging sockets, and the fact that most hogging behavior takes place at times of low demand. If demand gets higher it is advised to look for potential solutions such as steering behaviour by a monetary fee (a so-called connection fee) or enhancing the social interaction between EV drivers.

#### Future developments With a growing number of electric vehicles on the road the ratio between number of EVs and number of charging

points is likely to increase as well, which might also increase the impact of charging station hogging on other EV users. On the other hand, battery

fee would be useful to validate the effect of such a measure. Data from the 'social charging' app could also provide knowledge about how to enhance social behaviour and to reduce charging station hogging. Take-aways Charging station hogging is not that common as sometimes claimed in media. 1 percent of the charging sessions last more than

48 hours.

sizes increase as well so in

general the duration of an

EV actually charging during

a session also increases. In

this light, it is interesting

to consider how to prevent

very long charging sessions.

Evaluating possible changes

in charging behaviour when

applying a connection

of the 24 hours + charging sessions, the other charging point at the charging station is available for charging. Possible interventions include connection fees and social charging. However stimulating EV drivers to repark their car once fully charged is likely to lead to higher parking pressure.

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#### ► How are you involved in electric driving?

Vattenfall wants to facilitate fossil-free lifestyles at home, at work and on the road. That's why we've been involved in electric transport for ten years now. We manage more than 7,000 charging points throughout the Netherlands. More than 100,000 charging sessions take place each month at our public charging points, which is more than 12 GWh of green electricity and more than 50 million emissionfree kilometres.

We also encourage our own employees to use electric vehicles. We want to switch our entire fleet to electric vehicles. In Sweden, the Netherlands and Germany, more than 3,500 passenger cars and commercial vehicles – of which 750 are in the Netherlands – will be replaced by electrical alternatives over a five-year period. What specific things did you want to find out? How exactly do the research projects contribute to your work?

The AUAS has supported us in the Flexpower pilot, which we are conducting with ElaadNL, Liander and the city of Amsterdam. In this pilot, we are testing the effect of smart charging on the grid load and the user. The most important questions for us were how smart charging affects our users and what changes we can detect on our charging objects in terms of consumption and use.  What will the future of charging look like?

In the coming years, the EV market will grow tremendously. This will place a lot of pressure on employers, car companies, governments and local authorities. It is important that we all learn from each other and copy each other's best practices to avoid delays in the implementation or dissatisfaction by using the charging infrastructure. Cars are parked more than 90% of the time, which provides the opportunity to overcome problems of limited range and long recharging times, even with currently available short-range vehicles. This requires installing (public) charging infrastructure at places where users park their cars, such as at home, work or public facilities such as shopping centres. Such parking behaviour also implies that vehicles stay connected longer than necessary for charging. Could time-based fees help to reduce session length with minimal inconvenience for the EV driver?

## Time-based fees to reduce session length

fficient use of the limited available charging stations is important in early adoption phases to ensure a positive experience for early adopters and reduce resistance among non-adopters. Effective usage creates a positive business case for CPOs. However, statistics show that efficiency at both slow and fast charging stations is not ideal. At AC public charging stations, vehicles are only charging during 20-40% of the time connected to the charging station.

Current business models are based on sales of the energy transferred. This does not provide an incentive for the driver to move the vehicle once it is fully charged. Therefore, CPOs have experimented with time-based fees to improve the efficiency and business case of their operations while providing equal or even better user experience. Parking studies show that the introduction of time-based fees can help to shorten parking duration and possibly maximise the use of charging station capacities. Consequently, vehicles spend less time at one charging station and thus more space is available for other vehicles.

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Applying a time-based fee might interfere with a 'charging is parking' regime, which is one of the advantages of EVs compared with fossil fuel cars. Moreover, there are large differences in how EV drivers use public charging infrastructure. Influencing factors include the location (e.g. home or work) and the time of day. Besides these circumstantial differences, drivers also differ in their parking and charging patterns. Such differences could also influence how time-based fees influence the behaviour of EV drivers. Additionally, users have to look for a new parking spot after moving their car once fully charged. Indeed, in areas with high parking pressure, this is problematic. Therefore, using a time-based fee while no other EV occupies the charging point might lead to additional unwanted parking pressure. Using these differences we presented several scenarios to EV drivers to see how they would respond to a time-based fee once their vehicle was fully charged.

The results of this study show that implementing a time-based fee could result in higher efficiency in charging station usage. Applying only a small fee during the daytime, to avoid frustrating EV drivers, could achieve a considerable improvement. In the final design of the fee, the CPOs would have to consider those drivers who experience severe parking pressure and are less open to a time-based fee because they are not willing or able to move their vehicle away from the charging station once fully charged. In such cases, the implementation of a fee is not effective. The design of the fee could focus on only preventing very long charging sessions (e.g. >24 hours). This would also prevent EV drivers from exploiting the system by setting the charging speed at a very low rate to extend the charging session. Another important factor when considering the implementation of a time-based fee is that the policy is only effective when the fee is communicated clearly. Accordingly, all costs related to the time-based fee must be at least specified in the transaction data and the bill, and preferably beforehand at the charging location.

## Take-aways

► Respondents indicate that time based fees can provide an incentive for EV drivers to repark connected EVs making occupied chargers available for other EV drivers.

- However, not all EV drivers are likely to be responsive to time based fees, while re-parking connected EVs may in fact increase parking pressure in some neighborhoods.
- ► A scheme that includes a time based fee should be carefully designed to include concerns of parking pressure, responsiveness of the target group and the threshold at which a time based fee start (e.g. >24hours).

# Charging Behaviour of PHEVs

Do plug-in EVs (PHEVs) drive electric or do they merely profit from favourable fiscal incentives without reducing carbon emissions? Back in 2017, this was a major debate in the Netherlands. AUAS calculated the portion of charging sessions and kWhs charged that can be assigned to PHEVs. The results show that although FEVs charge more kWh per session compared with PHEVs, the majority of charging sessions are executed by PHEVs.

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HEVs in the Netherlands tend to drive fewer electric kilometres than assumed in the NEDC cycle. A likely reason for this is that PHEV drivers are less inclined to charge on a daily basis, simply given that it does not prohibit their range (the gasoline engine will take over). The rise of PHEVs can be explained by financial support. An important question concerns the extent to which PHEVs in fact charge regularly INFRA

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(compared to EVs) and contribute to airquality goals. Using the public charging dataset, we were able to distinguish between EVs and PHEVs<sup>1</sup> and analyse their share in transactions and kWhs charged.

The results show that PHEVs use public charging station only slightly less than expected based on the number of vehicles on the road. Between 2014 and 2017, on average 85% of all EVs on Dutch roads were PHEVs. Figure 1 shows that in the same period on average PHEVs accounted for 70% of all charging sessions at public infrastructure networks in the four major cities. Only in 2018 was the share of transactions by PHEVs reduced to 55-60%, mainly due to the shift in the EV fleet composition towards BEVs. This suggests that the share of PHEV drivers who never charge may be limited and at least is not the norm.

### Charging sessions

Source: Data from G4 cities, MRA and SGZH region



Figure 1. Share of charging sessions by type of electric vehicle at public charging stations in the four major cities and the metropolitan region of Amsterdam in the Netherlands An 'unknown' category was added for RFIDs that could not be attributed to either the PHEV or BEV category. A significant share of PHEV drivers charge frequently, although some may skip charging sessions; for instance, if a convenient charging location is not accessible. A report by TNO found similar results, namely that nearly 25% of all PHEV drivers charge more than once a day.

Unsurprisingly, in terms of average electricity charged per session, PHEVs lag behind FEVs, given the latter's larger battery size. Figure 2 shows how PHEVs have been responsible for more than half of the total electricity charged by EVs in the four major cities until end 2017. Due to the changed fleet composition this share decreased to 35-40% end of 2018. In practice, PHEVs may drive less electric than expected based on the NEDC drive cycle, although the sheer size of the PHEV fleet in the Netherlands has contributed to a comparable number of electric kilometres driven in urban environments.

Accordingly, PHEVs have in fact contributed a significant amount to the number of electric kilometres driven, albeit with more cars, and thus against higher fiscal costs. As such, reducing the fiscal measures for PHEVs makes sense. However, the suggestion that PHEVs never charge and do not contribute is nuanced with the above analyses.

### Secondary effects

Apart from the direct contribution of PHEVs to the number of electric kilometres driven, it is possible to reflect upon possible secondary effects of PHEV sales in the Netherlands. For instance, PHEVs have contributed to EVs (vehicles with a plug) becoming a legitimate



Figure 2. kWh charged by type of electric vehicle in the four major cities and metropolitan region of Amsterdam in the Netherlands

alternative to gasoline vehicles for a fairly large public. The accumulated fleet of EVs still only reflects 1.5-2% of the total Dutch vehicle market but is beyond a small niche market and not limited to an elite group, but rather the relatively mainstream lease markets. As such, a large group of drivers have experienced driving electric, developed charging routines and are likely to make more informed decisions on the pros and cons of EVs. Similarly, sales of PHEVs have stimulated the development of public charging infrastructure to the extent that it is one of the densest charging networks worldwide. Indeed, this has helped to overcome the first chicken-egg problem for EVs.

### Take-aways

 Due to the changed fleet composition this share decreased to 35-40% end of 2018.
 PHEVs tend to charge less kWh per session than FEVs, and therefore contribute less to air-quality goals per vehicle. A differentiated fiscal incentive for FEVs versus PHEVs therefore seems fair.

► Fiscal measures to stimulate PHEV sales should incentivise electric driving (for instance, by reducing charging costs) rather than lease or purchase incentives. 73

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In urban areas where residents and commuters rely on on-street parking, it is necessary to balance the roll-out of public charging stations with high parking pressure for both EV and ICE drivers.

Not responding to high demand for charging points can lead to frustrations among EV drivers. Under-utilisation of charging stations can lead to increased public resistance to electric mobility due to empty parking spots at charging stations that cannot be used by ICE drivers. A possible solution is to allow ICE drivers to use charging spots within certain parking windows. This has been piloted in the city of The Hague.

# Using daytime charging to reduce parking pressure

unicipalities generally reserve the parking spots next to charging stations exclusively for EVs to ensure their availability. However, under-utilisation of these charging stations leads to increased parking pressure, especially during peak hours. Furthermore, in areas with high parking pressure this leads to complaints from local residents.

#### **Pilot: Daytime charging**

In this research, we analyse the implementation of a daytime charging scheme in The Hague. The municipality of The Hague implemented daytime charging in January 2013 at charging stations in neighbourhoods in which over 90% of parking spots were occupied during peak hours. During the daytime – defined as 10:00 to 19:00 – the parking spots adjacent to charging stations were exclusively reserved for EVs. Outside of these times, non-EVs could also park their car at these parking spots. A unique natural experiment was created in which charging stations within areas of similar parking pressure either had this scheme implemented or not.

Overall, 79 charging stations were selected. Due to an unknown error with the municipal services, 20 charging stations did not receive a daytime charging sign. This omission thereby created an experimental group (59 stations) and a comparable control group (20 stations) with full-day charging. Charging stations in areas with parking pressure below 90% (311 stations) remained exclusively available for EVs.

E-mobility | getting smart with data

In September 2015, the municipality expanded the time for exclusive EV charging to 10:00-22:00. They also put up road signs at the 20 charging stations that previously did not have this sign installed, thus putting the charging stations in comparable conditions again. In the research, we analysed the occupation rate of charging stations with or without daytime charging implemented. We also controlled both groups again after all charging stations had daytime charging after September 2015.

#### Effect on occupation rate

The main question was whether allowing non-EVs at charging spots would reduce accessibility for EV drivers, and how this translates into the occupation rates of charging stations. The results show that charging stations with daytime charging between 10:00 and 19:00 have a significantly lower occupation rate after 19:00 than those that do not have daytime charging implemented. At 23:00, this difference was nearly 8% occupation on average. It was therefore hypothesised that gasoline-driven vehicles were occupying the charging spots from 19:00 onwards, leading a significant share of EV drivers not being able to charge at these particular locations. After the daytime charging was implemented at all charging stations and expanded to 22:00, there no longer was a significant difference between the occupation rates.



Charging station occupation rate



Figure 1. Charging station occupancy throughout the day for daytime and no daytime charging from 2014- August 2015

Road sign to indicate daytime charging (10:00-19:00)

Take- ► Implementing daytime charging between 10:00 and 19:00 can restrict aways EV drivers in using a charging station.

- We advise to apply a time window of 10:00-22:00 to guarantee access for EV drivers.
  - ▶ Data shows that only 3% of charging sessions start beyond this time.



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www.engie.nl/laadpalen/ > Jacco van der Burg | Director of E-mobility & Smart Mobility

What specific things

did you want to find

out? How exactly do

the research projects

How do we see the sensitivity

evolving? How does the failure

of a specific station affect the

impact do variable prices have

rest of the network? What

on network usage?

contribute to your

of the charging network

work?

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#### ► How are you involved in electric driving?

Traffic is one of the main causes of air pollution in the city of Rotterdam. In order to improve air quality, Rotterdam is encouraging the use of electric transport. With the increasing number of electric cars, more than 1,700 public charging points have been installed throughout the city to date to meet growing need for charging points.

The municipality is constructing a charging infrastructure network that will cover the entire area. It is also working on various innovative projects and experiments for electric driving and charging. At the municipality of Rotterdam, I am responsible for the application and implementation process for charging facilities in public spaces. What specific things did you want to find out? How exactly do the research projects contribute to your work?

The dashboard developed by IDO-laad has become essential for me. I work with it on a daily basis, and it is particularly useful for responding to questions relating to charging data. As a municipality, we asked for a tool in the dashboard that shows how many unique users in a neighbourhood use the charging stations that have been installed there, rather than simply the number of unique users at one charging station. We also wanted an overview of the occupancy rate of a charging station in a 24-hour period to see when it is most frequently used. In this way, we can quickly decide whether we need to expand the charging network.

#### ▶ What will the future of charging look like?

In the future, I expect that it will become the norm to see electric charging in our streets and that the charging infrastructure will be increasingly integrated into the street furniture, for example.

People will travel from A to B in cleaner and different ways. This will mean less need for people to have their own car and increased demand for shared electric cars.

In line with the government agreement, in the current coalition agreement Rotterdam has committed itself to reducing CO2 emissions by 49% by 2030.

#### How are you involved in electric driving?

ENGIE aims to be the leader of the energy transition. To achieve this, we want to exploit the energy potential of electric transport through providing energy infrastructure for the electrification of mobility. This means that we supply, install, manage and operate charging stations for cars, lorries, buses and ships. For passenger vehicles, ENGIE provides charging infrastructure in various markets. For example, as a charge point operator (CPO), we install and operate charging stations in more than 70 municipalities. We also install charging stations at large companies and employees' homes.



#### What will the future of charging look like?

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The future of charging will primarily focus on integrating the large number of stations that will soon be needed in our public space. This will require smart new solutions to facilitate the growth of EV. It is vital that the current infrastructure is intelligently optimised and that there is a good balance between AC and DC charging as well as between public and semipublic charging facilities. Important developments include single-phase-charging vehicles for which charging behaviour is completely different from the new Teslas and new German cars with large batteries. In turn, this will give renewed impetus and momentum to the rollout of appropriate charging infrastructure. Finally, the development of smart charging will be essential to ensure that we can charge as much as possible within the current grid connections.

Charging hubs can function as a way to cluster the EV charging infrastructure. This enables a single grid connection to facilitate multiple charging points and might be a solution to reduce impact on the public space, parking supply in the city and the electricity grid. How should such a charging hub be designed? How many parking spots should be reserved and what are the effects on neighbouring charging stations?

## Performance of a charging hub, and the effect on its surroundings

n order to experiment and find answers to these questions, the city of Rotterdam started a pilot project. In November 2018, the public EV charging hub named Veerkracht was opened. Veerkracht has five charging poles with two sockets each, connected to the grid at a single central point. Each socket has its own parking spot, with four of them initially being labelled as exclusively for

EV, while the other six spots can be used for parking by both electric and non-electric vehicles.

With the charging data from the first four months, the usage of the charging hub and the effect on the other charging stations in the neighbourhood has been investigated.



Initially four parking spots were exclusively reserved for EVs. The sockets at these spots are used much more often compared with the sockets at the parking spots not reserved exclusively for EV parking.

Interestingly, the socket next to the reserved parking spots is used the least. It is uncertain whether non-EV cars obstruct utilisation of the sockets at the parking spots not labelled as exclusively for EV, or if the demand for charging is simply lower than the available number of charging points at the hub. Parking sensors will be installed in the near future for further research.







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Location: Charging hub Both Surrounding

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unique RFID's

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Figure 3. Number of unique RFIDs or charging cards used at the charging hub and stations  $\leq$  50m from the charging hub

#### Charging at Veerkracht and stations >50mand $\leq 150m$ away



Figure 4. Number of unique RFIDs or charging cards used at the charging hub and stations > 50m and  $\leq$  150m from the charging hub.

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## Effect on the surrounding charging stations

## Veerkracht and its surrounding charging stations



*Figure 2. Veerkracht's surrounding EV charging stations. Colours indicating the walking distance from Veerkracht to the charging station.* 

A charging hub creates new clustered charging opportunities in a neighbourhood. This could serve as a back-up for EV drivers who usually charge at single charging stations in the neighbourhood. Data analysists found that the charging hub is a serious alternative for users of the closest single charging station (within 50 metres from the hub). Most users of this close station moved to the hub for charging. For the charging stations at a distance between 50 and 150 metres, the hub mainly functioned as a backup. The number of users remained similar at these stations compared with before the charging hub was installed, but 15% to 20% of the EV users also visited the hub as a back-up in case the single charging stations were not available. For single charging stations beyond a distance of 150 metres from the hub, the hub barely serves as a back-up. Figures 3-5 illustrate this backup function by showing the number of unique charging cards or RFIDs using the hub and surrounding stations. INFRA

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Location: Charging hub Both Surrounding

Figure 5. Number of unique RFIDs or charging cards used at the charging hub and stations > 150m and  $\leq$  250m from the charging hub.

The provisional results show that charging hubs can be a way to offer clustered charging infrastructure and serve as a back-up for its surroundings. It is important to monitor the utilisation in terms of kWh charged, the number of unique users, how parking spots are being used and how the utilisation relates to surrounding single charging stations. This can help to find out how many parking spots at the hub need to be exclusively reserved for EVs and how this should develop over time as the number of EVs on the road increases. Parking sensors can play an important role to monitor this in more detail.

## Take-aways

► Charging hubs can provide an effective way to serve as a back-up for surrounding charging stations, while reducing grid connection costs and the impact on public space.

► For users of charging stations that are closer than 50 metres to a new charging hub, the charging hub seems to become the favourable location for these users. This is possibly due to higher probability of finding a free charging point.

 Results indicate that a charging hub provides an alternative for users of single charging stations up to 150 metres from the hub in case these single stations are occupied or malfunctioning.
 Further research is required to better understand dynamics of charging hubs and surrounding chargers, and clarify motivations and preferences of users.

## SIMULATION STUDIES

Simulation models can support policy-makers to simulate different future scenarios and assess their impact on the charging infrastructure. This section describes the SEVA simulation model developed to simulate charging infrastructure utilisation. It describes important metrics such as 'failed sessions' and vulnerability, as well as how the model is simulated using available datasets. The results of two simulation studies are presented, namely the transition from plugins to full-electric vehicles, and the growth of electric car-sharing schemes.

· Vulnerability of charging infrastructure	85-88
Simulating Electric Vehicle Activity: why? and how?	90-92
Simulating the transition from PHEV to large battery BEV	93-96
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Introducing a free-floating car sharing scheme: simulated	101-103

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#### ► How are you involved in electric driving?

In my role as project leader for electric transport, I'm responsible for the rollout policy for the charging network in the Hague. This covers tasks like deciding what type of charging points are required in which locations, as well as how many are needed. In this way, we are trying to both facilitate and stimulate the transition to zero-emission vehicles. A potential future EV driver should never have to worry about finding the right charging point.

What specific things did you want to find out? How exactly do the research projects contribute to your work?

We mainly had questions related to policy: What impact do parking windows have on usage? What kind of complaints are made about



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the charging network? What is<br/>the optimal ratio between fast<br/>and regular charging? How do<br/>park thei<br/>charging hubs compare with<br/>regular charging stations?where may<br/>park thei<br/>mistake r<br/>Lease-flex<br/>stop using<br/>that can be<br/>anywhere<br/>charging station do EV drivers<br/>experience problems caused<br/>at a different station?where may<br/>park thei<br/>mistake r<br/>tease-flex<br/>stop using<br/>that can be<br/>anywhere<br/>a charging<br/>that can be<br/>anywhere<br/>that can be<br/>anywhere<

#### What will the future of charging look like?

Charging in private spaces – namely outside the public domain – will become more predominant, with "P&R areas" becoming "the budget charging stations of the future". Since there are so many advantages to offering charging facilities in areas where many people already park their cars, it would be a mistake not to invest in that. Lease-fleet owners will also stop using the fuel card that can be used to refuel anywhere at anytime. However, will they provide a charging pass that allows unlimited charging at work? There will only be a limited number of kWhs available in public spaces and from fast chargers.

As a result, there will be a less pressing need to develop the public charging network. However, given that the public charging network will continue to be very important for some EV drivers, its development will also remain hugely important.

For the municipality of the Hague, little will change over the next 2 to 5 years. We will continue with our developments and we are committed to crafting a roll-out strategy that best meets current charging requirements.

## Vulnerability of charging infrastructure

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Typical performance metrics for charging infrastructure include the utilisation rate, kWhs charged or the number of weekly users. However, metrics focused more on the EV user are lacking, such as the availability of alternative charging stations if a preferred station is occupied or not functioning. In this project, we looked at the vulnerability of a charging network, in particular the question: To what extent can the rest of the charging network act as a buffer if a particular charging station is out of order or occupied by a new user?

Regular users of public charging infrastructure tend to have one preferred charging station. However, if one or more new EV driver start to use the same charging station or if this station is out of order, EV drivers who are dependent on charging will have to look for an alternative charging station in the area. This relocation can then lead to "competition" at the alternative charging location, which in turn can similarly prompt competition at other surrounding stations. This effect is referred to as "cascading failure" and was studied to better understand the interconnected nature of the charging system. An algorithm was developed to evaluate the number of cascading failures in case a particular charging station is no longer available. For this purpose, two performance indicators were defined to indicate the vulnerability of the system:

► Service failure vulnerability concerns the fraction of charging sessions that cannot be accommodated by the network in the case of "competition". This could lead to disappointed EV drivers.

► Inconvenience vulnerability counts the number of charging sessions that must be moved to an alternative location due to "competition" at a single initial loading location.

The higher the inconvenience vulnerability, the more drivers who need to charge at an alternative

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Is there an

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loading location due to a new driver joining the network. Vulnerability was simulated by removing a particular charging station and establishing for each charging session at that station (i) whether there are accessible stations within 500 metres, and – if so – (ii) to what extent these new charging sessions would obstruct other EV drivers who were planning to charge there (see figure 1).

### Service failure vulnerability

Simulation results show that service failure vulnerability is high in places with a low network density, i.e. with few or no alternative charging locations within 500 metres. Figure B shows the service failure vulnerability for the city of Amsterdam. Each of the dots represents one of the 764 charging locations. The yellow and red dots in figure B indicate charging

No cascade but a

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locations with a high service failure vulnerability. These 'vulnerable' charging stations mainly lie in the outskirts of the network. By contrast, vulnerability is much lower in the city centre, with a high density of chargers (shown in green).

## Inconvenience vulnerability

If an alternative charging station is available, the question emerges concerning the extent to which other drivers are affected by an EV driver who could not use his/her preferred charging location. The results of this "inconvenience" indicator are shown in figure C. Red and yellow dots indicate charging locations with

### Service failure



SERVICE FAILURE VULNERABILITY SCORE 1.00 0.75 0.50 0.25 0.00

Figure 2. Service failure vulnerability scores (radius 500m)

Are there any

relevant

alternatives?

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Figure 1. Simulating EV users' reactions to failure

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#### Inconvenience



Figure 3. Inconvenience vulnerability in Amsterdam, December 2015 (Radius 500m)

## Take-aways

- The vulnerability indicators provide valuable additional performance metrics for policy-makers to optimise roll-out strategies.
- Vulnerability simulations complement the data analysis of successful charging attempts by sheding light on unsuccessful charging attempts by EV drivers.
- Repeating the vulnerability analysis integrating the latest charging data

can helps to assess the effect of newly realised charging infrastructure or growth of number of EV users on inconvenience and service failure.

Implementing the vulnerability simulation algorithm in decision support tools can include generating suggestions for alternative charging locations to minimise cascading effects and thus the inconvenience for EV users.



www.uva.nl 
Michael Lees Assistant Professor

#### How are you involved in electric driving?

We are a research university and impact of new battery sizes. my group has been working in the area of modelling e-mobility for the past ten years. We have had a particular interest in trying to understand behavioural components of EV users and the impact of behaviour on the demand for energy and infrastructure. We have been using computer models and complex systems analysis to explore the problem in a unique way. We have built agent-based models to develop what-if analysis for future scenarios of the EV landscape.

#### What specific things did you want to find out? How exactly do the research projects contribute to your work? future of EV charging. It's clear

I think that the most exciting aspect of this project has been the unique dataset that the project provided. This huge dataset allowed us to look into fundamental questions like never before. These have

included very practical questions such as how the current roll-out strategies have performed or the More importantly, it has also allowed us to ask very fundamental questions,

including whether there is a typology of EV users and if we observe generic behaviours within these different user types. Finally, some of the research has led to highly novel deployment strategies, using complex network analysis to identify fragility in the infrastructure.

#### What will the future of charging look like?

From the analysis conducted, in my opinion the next five years could be crucial for the



that government initiatives (e.g. subsidies) have a major impact on the EV market. If the market grows I think that we will see a very interesting shift in the behavioural aspect of charging. In some cases, we already start to see social charging behaviour, while the important question is how this can be supported (to maximise infrastructure efficiency). There is a danger that once the density of ownership and infrastructure increases, the system may become increasingly competitive. I think that two other important technical innovations could also play a major role within the next 5-10 years. First, regarding vehicle-to-grid and home storage, the energy transition could push the adoption energy micro markets and EVs will most likely play a crucial role here. Second, autonomous vehicles could completely change the mobility landscape, potentially having a huge impact on car ownership and hence the demand for charging

infrastructure.

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## Simulating Electric Vehicle Activity: Why and How?

How can we anticipate a doubling of the number of electric vehicles that want to charge in a city? What will happen if electric vehicles have a much larger battery capacity? How can fast-charging stations relieve the AC charging infrastructure in the city? Alternatively, suppose that the taxi sector will be fully electric by 2025: what kind of public charging infrastructure should a municipality provide? The Simulating Electric Vehicle Activity model: a crystal ball for anticipating the future?

he SEVA model provides insights into the effects of incentives and roll-out strategies before they are implemented in practice. Such predictive simulation models allow scenario testing and enable policy-makers to anticipate based on simulation results. The SEVA model is one of the results of the IDO-laad research project. The SEVA model is able to simulate charging transactions of agents, namely EV drivers. Computational Scientists calibrated and validated the model using a dataset of charging transactions from the public charging infrastructure of the four largest cities in the Netherlands.

The model contains three entities: [i] the environment, [ii] the agents and [iii] the simulation handler. The environment is defined as the collection of all CPs together including their spatial location and placement date, maximum power and number of sockets. Each CP has two or more sockets, which can be either occupied or available. Multiple agents can be connected to a single CP at the same time, based on the number of sockets installed.

Agents are defined as the combination of the EV users and their EVs. Agents are identified in the data by their charging card used. Therefore, if a whole family uses one charging card, this family is regarded as one agent. The behaviour of each agent is generated as distributions in time and space based on the charging transactions executed with one charging card. The agents' behaviour within the model is dynamic. Newly added agents can cause existing agents to choose a different location for charging in the model, compared to their most preferred location based on the existing agent's distributions.

The model assigns preference rules to each EV driver: [i] when and where loading will start (connection), [ii] when and where loading will stop (disconnection), and [iii] which charging point will be chosen (selection). Based on the characteristics of the charging points and EV drivers, it is possible to accurately predict the preferred charging point of each EV driver or agent.

If several agents are connected at a CP and thus all sockets are taken, then no additional agent can connect to this CP. This results in a failed connection attempt if an extra agent tries to connect. This extra agent might be a virtual EV driver added based on the simulated scenario.

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### EV user's charging area



Figure 1. Cluster of most preferred charging stations for one EV user or agent.

Agents are defined as having several areas in which they frequently charge. In these areas, agents regularly display the same type of activity. Each area contains one or more CPs at which the same charging card has been used in the past. The SEVA model calculates a cluster of most preferred charging stations for each agent based on the historical charging data (Figure 1).

The model's strength is based on its data-driven nature. The rules used to simulate future scenarios are based on a large set of real-life charging transactions from the public charging infrastructure in the Dutch cities of Amsterdam, The Hague, Rotterdam and Utrecht. The SEVA model is able to look beyond what can be described based on historical data. For example, it can reveal EV users' failed attempt to connect to fully-occupied charging points. In addition, the model can also reveal the effect of EV user convenience such as preferred walking distance to a CP.

## Simulating Electric Vehicle Activity

The SEVA base model defines behavioural rules on how, where and when EV drivers will charge based on historical charging transactions. The results of the following future scenarios are presented in this publication:

- Expansion of the number of various use types of EV drivers.
- Introduction of a free-floating car-sharing system.
- Increasing battery capacity: shifting from PHEVs to FEVs.

## Simulating the transition from PHEVs to largebattery FEVs

**=** Contents

Charging point operators and policy-makers expect a transition of the Dutch EV fleet from PHEVs to FEVs in the near future. This is supported by EV sales trends in the Netherlands showing that more than 90% of EV sales in 2018 were FEVs. This raises the question whether FEVs charge distinctly differently than PHEVs? What is the effect of battery size on charging behaviour? In this research, we simulated the differences in charging behaviour between PHEVs with both small- and large-battery FEVs, using the SEVA simulation model.

or policy-makers, it is relevant to understand the effects of the changing portfolio of EV types on the market and different charging behaviour. For example, if FEVs charge less frequently than PHEVs, it may make sense to adjust roll-out scenarios accordingly. One way to explore the effects of the transition from PHEVs to FEVs is through simulation. Therefore, the first step is to establish any differences in charging behaviour by looking at historical data. INFRA

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Lees, M., et al. (2018). Simulation of Future Electric Vehicle Charging beha effects of transition from PHEV to FEV.



For policy-makers, it is relevant to understand the effects of the changing portfolio of EV types on the market and different charging behaviour. For example, if FEVs charge less frequently than PHEVs, it may make sense to adjust roll-out scenarios accordingly. One way to explore the effects of the transition from PHEVs to FEVs is through simulation. Therefore, the first step is to establish any differences in charging behaviour by looking at historical data.

### Charging behaviour differences between PHEVs and FEVs

In this study, EV drivers in the dataset were divided into three groups based on their car type and battery size:

- (I) PHEVs (1,727 users)
- (II) FEVs with a battery capacity less than 33kWh ("low-FEVs", 283 users)
- (III) FEVs with a battery capacity more than 33 kWh ("high-FEVs", 162 users).

Differences in charging behaviour between these groups were analysed; for instance, related to location of charging (number of charging stations, distance from each other) and timerelated charging behaviour (e.g. starting time, connection time, time between sessions). These differences form the basis for simulating a transition to FEVs.

Three main differences in charging behaviour were found: [I] high-FEVs tend to use fewer locations, [II] low-FEVs have higher walking preparedness, and [III] the disconnection duration – i.e. the time between two sessions – significantly differs for high-FEVs compared with PHEVs and low-FEVs. Of course, the pattern of kWh charged per session also differs for each of the three groups.

In terms of location, the most notable differences can be seen between low-FEVs and PHEVs/high-FEVs. Low-FEVs tend to use more locations ("centers"), more charging stations per centre and display more 'walking preparedness' than both PHEVs and high-FEVs. The higher urgency to charge for low-FEV drivers is likely to explain these differences. High-FEVs only differ from PHEVs in the number of charging stations used by location.

In terms of time-related factors, high-FEVs show distinct behaviour, with much fewer short sessions (compared with both PHEVs and low-FEVs). Furthermore, the disconnection duration (or time between sessions) is much longer for high-FEVs (see figure 1). 49% of high-FEVs' disconnections are longer than 24 hours, while for both PHEVs and low-FEVs this is only 30%. High-FEV users thus tend to skip transactions and charge less frequently, but with larger transactions (in kWh).



Fig. 1 Distribution of disconnection duration for the different battery groups

#### **Simulation setup**

Based on the different charging profiles of the three groups, we can start to simulate a transition from PHEVs to FEVs with the SEVA simulation model. The model contains agents whose behaviour is derived from historical sessions. A scenario is simulated with a transition from 100% PHEVs to 100% high-FEVs in a five-year period. As such, the simulation contains the 1,727 PHEV agents and is performed in five simulation runs of one year. Every year, 20% of the population is transformed from PHEVs to high-FEVs. Effects were monitored in relation to [1] the average connection duration per charging point per week, [2] the average number of unique users per CP per week, [3] the average number of charging transactions per CP per week, [4] the average kWh charged per CP per week.

## Take-aways

► Overall, the results of this study show that FEVs with a large battery capacity charge less often but higher kWh per session compared with low-battery FEVs and PHEVs. This is likely to have effect on charge point utilisation, as fewer charging points are likely to facilitate more EVs. As more electricity is charged per charging point on a weekly basis, the business case for charging points is also likely to increase.



Fig. 2 Weekly number of transactions per charging point related to EV fleet transformation



Fig. 3 Weekly connection duration per charging point



Fig. 4 Weekly transaction volume (kWh charged) per charging point

## Simulation results

Figures 2, 3 and 4 (on the next page) show the effects of an EV transformation from PHEVs to high-FEVs, showing that:

► The number of charge sessions per week decreases significantly by 17%, whereby a shift to FEVs leads to fewer transactions. The connection duration per week also decreases by 8%. The weekly charged electricity (in kWh) per charging point significantly increases up to 70% (Fig. 4). PHEVs tend to use their full battery each day, while their transactions are limited by their battery size rather than the length of their daily trip. High-FEVs will drive their full daily trip electric and charge less frequently, but with higher quantities.

## Failed connection attempts: Simulating that you are not able to charge

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What do you do if you arrive at a charging station and it is occupied or out of service? Although in reality web applications might inform the EV driver in advance, they will experience the inconvenience of being unable to charge at their most preferred location. The SEVA model simulates these so-called "failed connection attempts", thus optimising rollout strategies.

Policy-makers often focus on expanding charging infrastructure based on performance measurement. Indeed, roll-out decisions are made based on performance indicators such as the kWh charged or the number of unique users at a charging station. By contrast, user convenience or minimising user inconvenience have received little attention. Adding extra charging capacity at locations with a high number of failed connection attempts and thus high inconvenience might be a more optimal roll-out strategy compared with adding extra capacity at locations with high kWh or a high numbers of unique users. INFRA

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### Defining user inconvenience

In this research, we define user convenience as an EV driver being able to charge his/her EV at the most preferred charging station upon arrival. In research terms, the connection attempt is successful. From this, we define two levels of inconvenient EV driver experiences:

#### 1. A failed connection attempt

relates to an unsuccessful attempt to connect to a preferred charging station and it can be caused by an occupied charging station or a malfunctioning charging station. The EV driver might either move to another charging station or decide not to charge at all at that time. If the EV driver is able to charge at another charge station close to the first one, the charge session is successful, although there was one failed connection attempt.

2. We define a **failed charge session** if all attempts are unsuccessful. The EV driver is unable to charge at the preferred location or in the surrounding area at the arrival time.

### Measuring user inconvenience

By definition, failed connection attempts are not seen in the reallife charging data and therefore they are simulated. If an EV driver cannot charge at his/her preferred charging station and moves to another station, another EV driver might not be able to charge at that charging station because the first EV driver is now charging there. Accordingly, this might cause a cascade of failed connection attempts. Many EV drivers can experience inconvenience due to one new EV driver starting to use a charging station. Therefore, a roll-out strategy focused on user convenience improvement may lead to fewer failed connection attempts and fewer cascades caused by EV drivers searching for an available charging station.

Residents, commuters, visitors, taxis and car-sharing users show different charging patterns in terms of where and when they prefer to charge. A typical difference between these user groups is their base strength. While residents use a few charging points close to each other, car-sharing cars use charging points scattered over the whole city. As such, an increased number of users of a specific user group may affect the convenience of other user groups. EVs with unpredictable charging patterns like car-sharing fleets and visitors with semi-random behaviour have a strong influence on the user convenience of users with predictable charging behaviour. Therefore, a roll-out strategy focused on user convenience may lead to additional charging points in specific areas where EV drivers with both predictable and unpredictable charging patterns are present. The question now arises concerning how to expand charging infrastructure with high user convenience rather than based on traditional performance indicators like kWh charged or the number of unique users.

The SEVA model evaluated four rollout strategies: [i] random expansion of charging infrastructure, [ii] expansion of charging infrastructure at locations with a high number of unique users, [iii] expansion of charging infrastructure at locations with high kWh charged, [iv] expansion of charging infrastructure at locations aiming to minimise the number of failed connection attempts.





Figure 1. graphs show the reduction of failed connection attempts by adding charging infrastructure in each of the four cities.



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The SEVA model simulated charging behaviour in the G4 cities for a year for a stable situation with a fixed number of charging points. For each simulation, two typical KPIs (kWh charged per CP, number of unique users per CP) were gathered as output. In six runs of the simulation, for each run 100 charging points were added to the charging infrastructure. In case of roll-out strategies [ii] and [iii], the charging stations with the highest kWh charged or the highest number of unique users were expanded with two extra sockets. Therefore, in each simulation run the 50 best-performing charging stations expanded with two sockets. With the random expansion strategy, two sockets were added to 50 completely randomly-selected charging stations. This strategy was simulated as a benchmark for the other three rollout strategies. With roll-out strategy [iv], in each run of the simulations two sockets were added to the 50 charging stations with the highest number of failed connection attempts.

On the x-axis, the figure shows the number of sockets added to the existing charging infrastructure. For each roll-out strategy, the fraction of failed connection attempts relative to all charging sessions is depicted on the y-axis. The vertical error bars in plot D indicate the standard deviation of the different simulation runs. The plots show that each roll-out strategy improves user convenience. This is logical due to increasing the number of CPs to use for an equal number of EV drivers. Nonetheless, the roll-out strategy aimed at reducing the simulated number of failed connection attempts is most efficient for all cities in terms of increasing user convenience. The curves show a steep decrease with only a limited number of sockets added.

## Take-aways

Simulating failed connection attempts helps to reveal dynamics in the system of charging infrastructure that are not present in real-life charging data.
 Roll-out strategies based on KPIs derived from real-life charging data (like kWh charged and the number of unique users) increase user convenience.
 User convenience increases more rapidly when applying a roll-out strategy aimed at reducing the number of failed connection attempts.

In many cities, policy-makers are questioning [I] whether EV car-sharing is economically and spatially feasible and [II] what the ideal fleet size of a EV car-sharing scheme would be given potential demand, the city size and charging infrastructure presence. We studied the effect of adding free-floating car-sharing vehicles on the availability of charging infrastructure for habitual users such as residents and commuters.

Introducing a free-floating car-sharing scheme: simulated impact on charging convenience.

Arious electric car-sharing programmes have been driving in Amsterdam between 2014 and 2019. Research has shown that these so-called freefloating shared cars drive around in an unpredictable pattern. Indeed, mathematical models can predict neither the time nor the place. Car-sharing cars connect to the charging infrastructure across the whole city, while they partially follow typical traffic patterns, with flows from residential areas to office areas in the morning and vice versa in the evening. INFRA

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Therefore, free-floating car-sharing EVs may occupy charging points of regular commuters and residents. This may have a negative effect in terms of convenience through occupying a preferred CP. Accordingly, adding car-sharing vehicles may lead to an unexpected and counterintuitive performance of charging infrastructure and user convenience. Consequently, it is important to take this impact into account when planning charging infrastructure roll-out.

#### What is a "non-habitual" EV user?

Non-habitual EV users are users of the charging infrastructure without a clear user pattern or "habit", using charging locations all over the city and arriving or leaving at unpredictable times. By contrast, habitual users such as residents or commuters tend to use only a few specific charging locations nearby their home or work location, whereby they arrive and leave at predictable times.

In this research, we investigated the effect of adding non-habitual users on the convenience for habitual users. We added non-habitual users to an existing EV population in the SEVA model and then calculated the effect on user convenience. The SEVA model simulated the charging behaviour of both habitual EV users and non-habitual EV users. Several simulation runs were performed with an increasing number of non-habitual EV users added to the existing population of habitual users. For each run, we added non-habitual users, increasing their ratio to habitual users from 0.0 to 2.0 in steps of 0.25. For instance, if the simulation for a city contained 2,000 habitual EV users, we ran simulations adding 0, 500, 1,000, 1,500, etc., eventually up to 4,000 car-sharing EVs. We modelled the behaviour of non-habitual users using a biased random model. This model selects a charging point location for the non-habitual user based on weights for city district, neighbourhood and finally the CP at a given time. The bias for choosing a city district, neighbourhood and CP location was calculated from historical charging sessions of EV car-sharing vehicles in the city.

Figure 1. shows boxplots of failed connection attempts as the percentage of the total number of transactions of habitual users. This percentage is plotted on the y-axis, while the x-axis shows the ratio of non-habitual to habitual EV users. The boxplots are based on the distribution of percentage of failed connection attempts per CP. The addition of non-habitual EVs increases the values in the

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distribution and lengthens the distribution. The outliers are further away from the mean and at some CPs approaching 100% failed connection attempts. Besides, it can be seen that the effect of the addition differs among the G4 cities: while Utrecht seems less affected, Amsterdam and Rotterdam show high sensitivity towards this addition.

## Adding free floating car sharing agents



Figure 1. Failed connection attempts for habitual EV users as a percentage of successful connection attempts.

## Take-aways

► The SEVA model allows to simulate the effect of the increased number of car sharing vehicles on the performance of the charging infrastructure.

▶ Results show how there are significant differences between cities how introduction of car sharing schemes impacts the charging infrastructure, most notably in terms of failed sessions.

▶ Policy makers can use the model to explore effects of particular growth scenarios and how they should respond in terms of when and where to place new charging stations to reduce the number of failed sessions.

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## SMART CHARGING

Charging electric vehicles in a smart way can prevent negative impacts on the grid. In these chapters, we provide a definition of different smart-charging strategies, present the potential for smart charging on public charging infrastructure, and provide results of actual smart-charging pilots (Flexpower and Arena). Being able to predict connection times and cluster transactions provide crucial expertise for implementing smart charging in practice.

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# Smart Charging Strategies

The charging behaviour of current EV drivers shows that high electricity demand for EV charging is expected to concentrate in the morning and the evening. Household electricity consumption shows exactly the same peaks, especially in the evening between 16.00 and 20.00 when people get home. Smart charging strategies are often mentioned as way to reduce net impact. Here, we define smart charging and provide an overview of smart charging strategies.

### Parameters of charging sessions

A charging session is characterised by three parameters: the connection time, charging time and power. The connection time relates to the start and end time of being connected to a charging station, while the charging time is the time during which an EV is actually charging. In most charging sessions, the connection time is significantly longer than the charging time. Accordingly, a charging session almost always includes idle time. A charging session can be rescheduled in this idle time. The provided power corresponds with the height of the rectangle in the figure defining charge session parameters. The higher the power, the faster that the battery of an EV is fully charged. The area of the grey rectangle (power \* time) is the amount of energy charged to an EV. This representation is used to illustrate smart charging strategies.

Fifteen-minute intervals are visualised because the charging station measures the uptake of energy at this frequency. This corresponds with the interval in which energy is traded (e.g. APX). This provides a useful unit of analysis to optimise and reschedule charging.

## Parameters of a charging session



### Four categories of smart charging strategies

Smart charging is defined as optimising a charging session along three dimensions: [I] the time, [II] speed of charging, and [III] the direction of charging. Four main categories of smart charging strategies are discerned. First, a **postponement** strategy reschedules a charging session to a later point in time. Finding the optimum postponement strategy corresponds with finding the optimal shift of individual sessions.

#### Postponement Strategy

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The **cut-and-divide** strategy splits a charging session into a set of smaller sessions of 15-minute intervals, and distributes these within the available connection time. It can thereby follow a predetermined optimisation objective. Optimising the cut-anddivide strategy aims to find the optimal number of cuts and intervals between each charging interval.



#### The **bidirectional cut-and-divide**

method splits a charging session into a set of charging and discharging intervals while keeping the state of charging as desired by the EV user. This implies that for each discharging interval an added charging interval is required. INFRA

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The slower charging strategy reduces the power and thus the charging speed at which an EV is charged. As a result, it is necessary to increase the charging time to charge an EV to the same level Optimising the charging speed aims to reduce power at peak times, while meeting the demands for charging EVs.





### Combining strategies: the hybrid (smart) charging strategy

Theoretically different strategies can be combined to achieve an optimal charging strategy given a particular optimisation objective, such as reducing grid impact. The figure below depicts what such an optimal charging strategy may look like.

### Smart charging objectives

Smart charging is carried out with a particular objective in mind. In practice, there are three main categories of indicators to optimise. First, smart charging can reduce impact on the grid (net congestion) by charging outside energy consumption peaks. Second, smart charging can facilitate charging to take place during periods of renewable energy (RE) generation (matching EV demand and solar/wind availability). Third, energy prices on (wholesale) energy markets differ across the day, allowing smart charging to benefit from lower prices in the energy market.

Datasets on energy market prices or grid utilisation can be used to identify optimal smart charging strategies. Within the TKI National Data Platform Smart Charging project, the potential for smart charging was first established for a large public dataset. In SIMULAAD, clustering of charging sessions was carried out to establish optimal strategies per type of session.



In Flexpower, a practical demonstration of smart charging at 50 public charging points in Amsterdam was evaluated. Finally, in SEEV4City a demonstration with vehicle2grid (bidirectional charging) was initiated at the Amsterdam Arena. The models and demonstrations pave the way for assessing the most likely smart charging strategies and optimisation goals to pursue the coming years. Furthermore, they provide an indication of possible impacts on the grid, cost reductions and matching with RE generation.

## Take-aways

Smart charging has three dimensions: [I] timing , [II] power level and [III] direction of (dis) charging. An ideal smart charging strategies includes all dimensions to optimize the charging process. Three main optimization objectives include to [I] reduce grid impact, [II] to increase the match with renewable energy and [III] to reduce energy costs. Optimizing of charging can

differ from stakeholder to stakeholder, while optimization objectives may differ and lead to conflicting charging patterns.

#### Smart charging strategies and performance indicators







used to optimise for APX prices?

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www.mra-e.nl > Pieter Looijestijn | Charging project manager

## National Dataplatform **Smart** Charging / SIMULAAD

#### **Project duration** From 01-05-2017 till 01-03-2020

Project Objectives The research objective was to calculate the potential for smart charging. The charging data of the four major Dutch cities, the Amsterdam and Rotterdam metropolitan areas and a large part of the public charging infrastructure in the other Dutch provinces was integrated into one database covering 85% of all public charging transactions in the Netherlands. Charging data of the other provinces was provided by EVnetNL.

**Research questions** Many charging sessions starting at the same time causes a large electricity demand and major

impact on the electricity grid, which can be reduced by applying smart charging. The research questions aimed to measure [i] the actual smart charging potential, [ii] the effect of smart charging on grid impact, energy prices and the match with renewable energy, and [iii] the extent to which connection times of charging sessions can be predicted.

**Outcomes** The outcomes of this research include a methodology for assessing the smart charging potential of a network of charging stations based on a portfolio of real-life charging sessions. Furthermore, prediction techniques that enable predicting connection times at the start of a session were evaluated. Together with a clustering approach, this research enables applying smart charging more accurately in practice.

This work was carried out in two sequential projects. In 'National Dataplatform Smart Charging', the methodology for analysing smart charging strategies was set up. In SIMULAAD, more detailed simulations were made to analyse smart charging potential for different optimisation criteria, such as grid impact, renewable energy and energy costs.

How are you involved in electric driving?

I've been working for MRA-Electric since 2012. At that time, the MRA-E project bureau was established by the Amsterdam metropolitan area to promote electric mobility and realise a network of charging points in three provinces with 80 municipalities through a proven pragmatic approach sharing both knowledge and costs. In my position as charging project manager, my main responsibility costs for the municipality (e.g. is to ensure that EV drivers in the region have access to reliable and state-of-the-art charging infrastructure. This requires me to have in-depth knowledge on the performance look like? of the charging infrastructure and the needs of municipalities and EV drivers.

What specific things did you want to find out? How exactly do the research projects contribute to your work?

The research projects give me the opportunity to test our approach and respond

thoughtfully to pressing issues. A useful recent example of this is the smear campaign against people who hog charging stations. After thorough research, it appeared that this was hardly a problem at all, and that spending a long time at the charging station also opens up doors for smart charging. In my research questions, I

always take the electric driver into account. Optimising the use of a charging station (e.g. connection tariffs) or saving a charging hub) can have adverse effects in practice.

### What will the future of charging

Up-scaling and price transparency continue to be key issues. For a healthy and competitive market – and



to make electric vehicles accessible to the masses - a transparent and simple pricing strategy is essential so that people know what to expect before and after charging.

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At present, charging at a destination using a normal charging point will continue to be the main method of charging, whether private or public. Charging at a normal charging point is easy and economical. Smart charging will become increasingly common, with small percentages of power being reserved regionally to respond to fluctuations in the energy market or network load. Price-conscious electric drivers will take out subscriptions, accepting varying charging capacities for a reduced price. We can see from our data that real progress is being made. In order to keep charging the large numbers of electric vehicles and thus meet the climate targets, all stakeholders need to work together, perform at their best and - where possible increase their capacity.



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www.utrecht.nl/wonen-en-leven/duurzame-stad/elektrisch-vervoer/ ► Matthijs Kok | Project manager Electric Mobility

#### ▹ How are you involved in electric driving?

ISince about 2010, I have been involved in electric transport from different sides. I am particularly concerned with charging infrastructure for various vehicles (buses, boats, cars). I am currently working for the municipality of Utrecht, where I am directing the transition of charging infrastructure towards a data-driven approach. For several years, we have been installing charging points for EV drivers upon request. We convert this demand-driven approach into a data-driven one in which we expand the charging network based on the utilisation of the existing charging infrastructure. The Utrecht charging data as managed by AUAS plays a crucial and leading role in managing and expanding the infrastructure, as well as contract management of the public charging infrastructure concession.

What specific things did you want to find out? How exactly do the research projects contribute to your work?

Data-driven roll-out requires good and accurate data management. Our most important question is which performance indicators we can use best to steer datadriven roll-out, i.e. how to end up with a monitoring tool to facilitate this data-driven roll-out.

#### ▶ What will the future of charging look like?

In 2020, we will switch completely to the datadriven placement of charging infrastructure. We will then calculate the performance of our contracted CPO based on the charging data, monitoring KPIs like kWh charged and various occupancy rates. We are convinced that together with our research partners we have developed a valid system through which we can make this data-driven management a success.



# Charging speeds at AC charging stations

**=** Contents

Now that charging infrastructure has reached a more mature stage in Dutch metropolitan areas, questions on actual energy use gain increasing importance. Due to the possibility for demand of peak shaving in the afternoon and the current lack of charging behaviour management, many researchers emphasise the need for smart charging. This can result in many benefits, such as cheaper electricity rates for consumers, peak demand load shaving, and nighttime demand valley filling.



Nonetheless, in order to leverage the full potential of idle times during the connection of EV users at charging points, more insight is needed into the factors influencing the actual charging speed of EVs. In practice many factors may influence actual charging speeds. In addition to this many of these factors are beyond the influence of any type of intervention, such as weather conditions, total surrounding grid capacity and the effect of multiple EVs at the same charging station.

## Factors influencing charging speed



Figure 1. Theoretical model of factors influencing charging speed. I n bold the factors included in this research.

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From the analysis of kWh-metre values, it was found that the shape of the total charging profile appeared more linear than expected. In practice, this means that algorithms predicting charging profiles for smart charging do not need to include a complex S-curve. Next, the effect of reduced charging speed at peak hours (18 to 20hours PM) was not found. The data showed that an increase in temperature of 20 degrees Celsius increases the charging speed by 2.7%.

It was particularly interesting to find that the combination of two EVs at the same charging point could show significant effects on the charging speed of both EVs. A focus was placed on the differences between cars charging at 230V (or single-phase charging) and 400V (three phase charging). 230V cars at a regular

This research focused on the effects of factors on the charging speed by analysing the kWh-metre values. The kWh-metre values of charging points provide insights into the actual energy transmission during each 15-minute period. A standard model assumes that the charging speed is S-curve shaped and dependent on the state of charge (SoC). It comprises two phases: the first phase is the constant current phase with an increasing voltage in the battery, and the second phase is trickle charging current occurring from a high SoC with a constant voltage. The first phase holds particular interest for smart charging. It is known that several factors influence charging speed, such as battery degradation and outside temperature. They can be found in figure 1. The influencing factors in bold were included in this research.

AC charging station can theoretically charge at 3.7kW (and 400V cars at 11kW). Most PHEVs are 230V cars, while certain BEVs (e.g. Tesla model X, Renault Zoe) can charge at 400V.

Figure 2 shows which combinations and effects on the charging speed were found, focusing the analysis on the left car. Interestingly, there is a large contrast between 230V (closed door car) and 400V cars (open door car). In situations I-IV, the results are shown for when a 230V car is charging at the measured socket (socket 1). When another 230V car is connected at the other socket, there is a slightly higher charging speed compared with when a single car is charging (situation I). However, if a 230V car is charging (situation II) at the other socket, the average charging speed decreases by 1.5%. Instead, if the car at the other socket is a 400V car, the charging speed actually increases by around 1.5% when only connected and when charging (situations III and IV). Therefore, it makes a difference for a 230V car if a 400V car is connected and/or charging at the other socket.





Figure 2. Eight charging situations at a charging station with two sockets. The effect on the charging speed is indicated with arrows up, down or insignificant.

Situations V-VIII show the effect on charging speed when a 400V car is connected at socket 1. If a 230V car is charging at the other socket (situation V), this results in a 6% decrease in charging speed, while there is an increase of 3% when the 230V car at the other socket is charging (situation VI). In situation VII, 400V cars are connected at both sockets, which has an insignificant result. However, when both of these 400V cars are charging (situation VIII), the average charging speed declines by 7%.

These results highlight the strong contrast between the charging of 230V cars and 400V cars, as well as the strong effect of the interaction between the cars at the same charging station. The charging speed is dependent on the voltage level of the car at the other socket, as well as whether it is charging or only connected.

### Take-aways

- ► The actual charging speed on public chargers depends on a large number
- of factors, including environmental, charger and vehicle-related factors.
- The most important factor influencing charging speed is double connections at one charging station; which can significantly reduce charging
- speeds particularly with 400V EVs.
  The expected trickle charging behaviour of batteries at high states of charge was found to be a negligible phenomenon.

Smart charging is frequently advocated as a way to reduce impact on the grid and/or increase matching with renewable energy sources. In most cases, the potential of smart charging is hypothesised rather than being backed by data. The combined dataset of the G4/MRA-e and EVnetNL provides a unique opportunity to assess the potential of smart charging on public charging infrastructure in detail. The study confirms that evening sessions have the highest smart charging potential.

Smart charging: potential for rescheduling charging sessions

he adoption of EVs will have a direct impact on the electricity grids via additional demand. For the Netherlands, an instant replacement of the current car fleet (non-EVs) by EVs will lead to an increase in the total annual electricity demand by 23%. Furthermore, the peak load will even rise by up to 43%. However, EVs tend to be connected for much longer than their charging period. On average, EVs only charge for 20% of the total connection time. This suggests high potential for smart charging by optimising a charging session along three dimensions: (I) time, (II) speed of charging, and (III) direction of charging. Four INFRA

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main categories of smart charging strategies are discerned in the "Smart Charging Strategies" chapter. As such, smart charging can reduce peaks in energy demand and the impact of EV charging on the grid. In addition, smart charging can match renewable energy generation profiles with charging sessions.

## Smart charging potential (SCP)

This research aims to develop a methodology to assess the potential for smart charging as a starting point to assess sensible smart charging strategies. It does so by separating sessions based on two criteria: (I) the starting time of the session and (II) the SCP. SCP is defined as the ratio between the connection time minus charging time and the overall connection time during which an EV is connected to a charging point. The charging time is the time during which active energy transfer takes place. As such, SCP is a measure of flexibility to postpone a charging event.

For this study, the 2015 and 2016 datasets of charging transactions at public charging infrastructure in the G4/MRA-e and at EVnetNL charging stations were used. The total set contained over 3 million charging transactions by more than 60,000 RFIDs at approximately 6,000 charging stations. Figure X shows the distribution of charging sessions

#### Smart Charging Potential



EV is connected to a EV is connected and charging station. EV is connected to a EV is connected and charging station but is is actually charging, not charging.

 $P = \frac{Connection time-Charging time}{100} \cdot 100$ 

Figure 1. Schematic definition of Smart Charging Potential.

plotted on the two dimensions of starting time and SCP. The red colour in the heatmap indicates that many charging sessions start at that time of the day. By contrast, blue indicates a low intensity of charging session starting at that time of the day. The heatmaps show how the start of charging sessions is distributed during the day. The Y-axis indicates the SCP of the sessions starting at a certain time of the day.

#### Three main clusters

Figure 2 shows how charging sessions on public chargers in the G4/MRA-E chargers are distributed, showing three main clusters of charging sessions. First, office chargers start in the morning with relatively long connection times, resulting in high SCP. Second, home chargers start in the late-afternoon/ early-evening, with long connection times also resulting in high SCP. Finally, a third cluster is labelled as visitors with relatively short sessions throughout the day.

Sessions of home chargers are dominant in the G4/MRA-e region, and most of these sessions have SCP. Combined with the office chargers, around 46% of all sessions have an SCP of 75%, which indicates a connection time four times longer than the actual charging time. These charging sessions have high potential for rescheduling to reduce net impact, match renewable energy generation or match lower wholesale energy prices. Note that home chargers have particular potential in reducing net impact by rescheduling to nighttime charging. Furthermore, office chargers have potential to match renewable energy generation by rescheduling to daytime charging.

The heatmap allows evaluating differences across different cities, levels of urbanisation and vehicle types. Figures 3, 4 show how BEVs and PHEVs have distinct different distributions. Home chargers (sessions starting between 16:00-20:00) tend to dominate the PHEV-related sessions, with only a small portion of office chargers and limited visitors. On the other hand, BEVs have a much broader variation in session starting times. Apart from a large set of home

#### Distribution of charging sessions and their SCP



Figure 2. Showing three main clusters of charging sessions throughout the day.

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#### Smart Charging Potential of BEV and PHEV

Figure 3 | 4. The distribution of the SCP for BEVs and PHEVs in Amsterdam in the G4/MRA-E dataset.

chargers, office chargers are also included, as well as sessions that start during the day with relatively high SCP. This can be partly explained by BEVs' typically higher charging speed. Therefore, BEVs tend to be charged faster and - with connection times being the same – have higher SCP than slower-charging PHEVs. Another possible factor is that BEVs are more reliant on charging than PHEVs. As a result, PHEVs may choose not to charge on every occasion, while BEVs are more likely to do so. This may explain the larger variance of sessions over the day for BEVs.

#### Take-aways

► More than 40% of all charging sessions on public charging stations have a potential for smart charging of 75% or higher.

Particularly sessions by home chargers can be rescheduled to off-peak hours in the night. Similarly office chargers have high potential to postpone their sessions to match renewable energy generation.

► The methodology and heatmap developed in this project can be applied to evaluate and monitor smart charging potential for different charging infrastructures.

## Predicting and Clustering: Developing Optimal Charging Profiles

Earlier research shows that more than 40% of all charging sessions have major potential for smartcharging, as described in the chapter "Smart Charging: Potential for rescheduling charging sessions". However, when a new charging session starts, we do not know how long the connection time or charging time will be. Thus, this makes it difficult to establish upfront the optimal charging strategy. In this research, together with research partner ElaadNL, we used prediction and clustering techniques to better predict connection times and develop optimal smart-charging solutions. INFRA

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1. A **prediction module** to predict the connection and charging duration of a session.

For this purpose, we developed an "optimal charging" model, comprising three

- 2. A **clustering module** to cluster charging sessions based on connection times and duration.
- 3. An **optimisation module** to reschedule charging sessions based on different optimisation criteria.

Figure 1 shows the model, comprising two parts. First, an offline model is trained in batch, using historical data. It comprises prediction connection and charging durations, clustering of charging sessions and optimisation of charging times. Second, the online model is a refined version of the offline model based on realtime charging data. The offline model is currently being developed.

## Optimal Charging Model

elements:



Figure 1. Model for optimising smart charging solutions.

#### Step 1 Predicting connection duration

A number of mathematical prediction methods were used to predict the connection and charging durations of a charging session (among others, weighted averages, generalised linear models and classification techniques; for details, read the report by scanning the QR code. With non-linear classification techniques, an average accuracy of 80% was reached. The research has shown how charging sessions have a high diversity and are difficult to predict. Even though the results are promising, further work will be carried out to increase prediction accuracy.

#### Step 2 Clustering charging sessions

Charging sessions can be clustered based on two variables used to establish smart-charging potential: [I] start connection time and [II] connection duration. In this study, two different clustering methods were used, namely DBSCAN and Gaussian mixture models. Gaussian mixture models use multiple so-called Gaussian probability density functions to fit the data, modelling the subtle differences in the density of charging sessions. Overall, nine clusters were identified, as shown in figure W.

Each cluster represents a set of charging sessions that show relatively high similarity. To illustrate this, in figure W the sessions in blue are those that can be labelled as evening sessions. This group mainly relates to EV drivers who come home approximately between 16:00h-20:00h, and have a connection time of 12-16 hours. Similarly, in light green a cluster of sessions was found starting in the morning (7:00-10:00) and lasting 2-5 hours, which could be labelled as "short-stay office chargers".

As such, Gaussian mixture models provide a set of fine-grained clusters modelling the subtle differences. By clustering the charging sessions, it is possible to assign optimisation strategies to individual clusters.

### **Optimising charging sessions**

Charging sessions can be optimised with respect to different objectives. In this study, explored [I] grid load, [II] match with sustainable energy generation, and [III] energy prices.

These three optimisation criteria were translated into a cost function. The cost function is a normalised profile over a 24-hour time scale, Commuter

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depicting the cost for charging at that particular time. For instance, evening peak loads translate into a high cost for charging between 17:00-21:00, while the cost curve is much lower after midnight. Similarly, when optimising for solar charging, the cost curve is lowest during the daytime (with relatively more sun) and highest in the evenings and nighttime. Figures 3, 4, and 5 provide an overview of the cost curves for each optimisation criterion.

The cost curve is an important measure to optimise the start time of charging. In this project, a postponement strategy was used, namely rescheduling the complete session to a later stage.

Figure 3 shows how starting times of different clusters of charging sessions change when optimising for solar power. Unsurprisingly, the morning sessions are postponed to a later stage to match solar irradiation. When optimising for solar energy generation, morning sessions are thus most affected.

Figures 4 and 5 show similar analysis results when optimising for grid load and energy prices. When optimising for grid load, the evening and night sessions are shifted to the night. Accordingly, charging is reduced during the evening peak in household energy usage. Similarly, when optimising for energy prices (based on APX prices), a combination of morning and evening sessions are shifted given that energy prices tend to be lower at night an d during midday. Titles and captions of figures 2 | 3 | 4 | 5:



Gaussian Mixture Models provide a powerful clustering technique that allows to distinguish nine separate clusters of charging sessions. ► For every optimisation objective (renewable energy, grid load, energy) price) cost functions were developed. These cost functions enable to optimise charging sessions in line with the optimisation objective. ▶ Conflicts arise when simultaneously optimising for grid load, and renewable energy. This illustrates that there is not one single solution to optimise charging sessions against all criteria.

charging sessions No smart charging strategy applied Figure 2. Identifying nine clusters of charging sessions by using Gaussian Mixture Models. Optimising for grid load Evening sessions postponed Figure 4. Effect of grid load postpone strategy on charging sessions

Clustering



Liander

heymans



www.elaad.nl > Nazir Refa | Data Scientist

#### ► How are you involved in electric driving?

At ElaadNL, I have had the privilege of working on various pilots and research projects in the field of electric transport in the Netherlands since 2015. As a centre of knowledge and innovation, ElaadNL – in collaboration with its partners - conducts research into smart charging, namely the smart and sustainable charging of electric cars. ElaadNL sees smart charging as a crucial building block in developing a sustainable energy system with a lot of solar and wind energy and many electric cars. At ElaadNL, we are examining various aspects of smart charging to facilitate the integration of electric vehicles into the existing energy system.



What specific things did you want to find out? How exactly do the research projects contribute to your work?

In recent years, ElaadNL and the AUAS have worked closely together on various research projects concerning charging infrastructure and the smartcharging behaviour of EVs. For example, researchers from the AUAS and ElaadNL have conducted research into the roll-out strategies for public charging stations as part of the IDO-laad project. In this project, researchers identified which roll-out policy appears to be 'more effective', depending on the degree of EV adoption. For example, as part of the FlexPower Amsterdam and NDSL projects, the potential of using smart charging in public spaces was also examined. The results of these types of data-driven studies help to strengthen the position of EVs in the future energy and mobility system in the Netherlands.

#### ► What will the future of charging look like?

Much uncertainty remains about the future of charging. However, we are reasonably certain that the supply and variability of EV models will rapidly increase. In addition, in the foreseeable future, increasingly more people with a different mobility pattern than today's innovators and lease-car drivers will also be driving electric vehicles. Both developments will have a decisive impact on charging behaviour and the required charging infrastructure. Of course, we will also have smart charging: that will be the norm!

## Flexpower

#### **Project duration**

X City of X Amsterdam

from 01-03-2017 till 01-03-2020

**Project Objectives** The Flexpower project aimed to develop practical knowledge about the technical and contractual possibilities to implement smart or flexible charging profiles at charging stations. From March 2017 until March 2018, 100 charging points were equipped with Flexpower profiles. In phase 2, spanning from March 2019 until March 2020, another 300 charging points have been added and equipped with a more dynamic charging profile.

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**Research questions** One of the research questions was "What is the effect of Flexpower charging profiles on the EV driver?". In detail, the extent to which the Flexpower charging profile leads to a higher or lower amount of kWh charged per session, and thus a higher or lower range facilitated is explored.

**Outcomes** The outcomes show a positive effect of the Flexpower profile for the majority of EV drivers using such charging infrastructure. In general, the project shows that smart charging provides the opportunity to both reduce net impact and improve consumer experience.

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## Flexpower: **Applying Smart Charging in real** life

Electric vehicles can be charged flexibly, storing energy in their batteries when (renewable) energy supply is at a maximum. On the other hand, available charging power might be reduced when energy demand is high. Both scenarios support optimal use of the electricity grid. Accordingly, EV drivers, grid operators and charging stations require flexibility. The Amsterdam Flexpower project has piloted flexible charging, with partners Elaad, Liander, Vattenfall and the municipality of Amsterdam.

was initiated to investigate whether it is possible to adjust charging speeds for EVs to better match the energy availability on the electricity grid. The project partners

he Amsterdam Flexpower project set up a selection of charging stations with special software, through which the charging speeds could be varied at different periods throughout the day. The idea was to facilitate faster charging outside the peaks in energy

consumption, and slower charging during peak hours. This would increase the grid utilisation as well as benefitting most EV drivers.

This flexible electric car charging project started in Amsterdam on 1st March 2017. For the trial, both the hardware and software of 52 charging stations with two connectors each in Amsterdam were adapted. Most charging stations have a standard 3x25A connection to the electricity grid, with a 16A fuse on each connector. For the test, a 3x35A

connection was needed to enable charging at higher power (22 kW). These were equipped with an OCPP 1.6 protocol, making it possible to apply a predetermined capacity profile. The capacity profile was set up to reduce the charging speed between 7:00 -9:00, and 17:00 - 20:00. During the evening peak, charging station capacity was reduced down to 4.1kW (3x6A). Outside peak hours, the capacity was increased up to 24kW. Overall, we analysed over 45,000 transactions of more than 7,000 unique users during a six-month period.

#### **Background information**

Who can charge quickly? Charging stations are normally equipped with a 16A fuse that limits the current to prevent overloading and/or short circuits. This fuse was temporarily removed from the Flexpower charging stations as the allocation and distribution of power is determined by software. The grid connections were changed from 3x25A to 3x35A which means twice as much power (and thus charging speed) is available in practice outside peak times. Cars used in this study that can charge at higher power optimally benefit from this, and with a 3x35A connection, they can charge 110km per hour (=22kW). Should 2 cars be using the

same charging station at the same time, they can both charge 55 km per hour (= 11kW). All electric cars (both fully electric and hybrid) can use these stations for charging their batteries. Currently, the standard output charging speed for older fully electric and most hybrid cars is only 3.7kW. Unfortunately, these cars cannot benefit from the higher charging speed. The focus of the Flexpower project was mainly on BEVs which will determine the future road-identity; they have relatively large batteries and higher charging speed, for example the Tesla Model S / X / 3, the Hyundai Kona, KIA e-Niro, Nissan Leaf, and the Renault Zoë.

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## *Capacity profile Flexpower*

## Flexpower pilot outcomes



Data analysis shows that 71% of the BEVs (excluding 1x16A BEVs) were actually charged with a higher power. As a result, more batteries were fully charged. In the majority of cases, these vehicles had not been fully charged at departure. As a result, Flexpower helped these vehicles to charge more energy compared with regular charging. Additionally, given that higher charging speeds were available during the daytime, the charging profile better matches profiles of renewable energy generation (solar and wind). As such, Flexpower enables storing renewable energy better than regular charging. Less than 5% of the users were negatively affected due to the lower charging speeds during peak times. For EVs applying threephase charging, the lower charging speeds during peak times are mostly compensated by higher charging speeds in the remaining 19 off-peak hours.



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## Take-aways

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- Smart charging strategies like Flexpower provide opportunities to alleviate the need for a grid reinforcement.
- ► At the same time, smart charging allows a better match between charging demand and the supply of (renewable) energy. For the majority of users, this has a positive effect on charged energy at disconnection. Less than 5% of users had slightly lower charged electricity due to the Flexpower profiles.
- Further work is planned (in Flexpower 2; starting April 2019) to test more dynamic profiles, and better understand the consumer appreciation of flexible power profiles.

### **Future work**

In Flexpower 2, the flexible charging profiles will be optimised to better match the local conditions of each charging station in terms of actual grid load, renewable energy generation and user behaviour. This will allow us to further reduce the negative impact on users and prevent the occurrence of a second delayed load peak on the grid just after the limitations are lifted. The Flexpower 2 experiment will be conducted on 400 charging stations split randomly into two groups to ensure a fair comparison and highly reliable results.

# Image: Second and University of Applied Sciences Image: City of Amsterdam Image: City of Amsterdam

## **SEEV4-City** Smart, clean energy and electric vehicles for the city

#### Project duration from 01-09-2015 till 31-08-2019

**Project Objectives** The SEEV4-City project researches and demonstrates vehicle-to-grid (V2G) and storage solutions to enable the local use of renewable energy generation as well as reducing the grid impacts of largescale electric vehicle implementation. Accordingly, it demonstrates V2G and smart-charging solutions in six operational pilots in five different countries across the North Sea region. **Research questions** Three questions are central in SEEV4-City:

1. What technical and non-technical hurdles exist for demonstrating V2G technology in practice?

2. How can V2G and smart-charging contribute to (i) energy autonomy, (ii) CO2 reduction and (iii) reduced grid impacts?

3. At what aggregation level (house, neighbourhood, city) do V2G and smart-charging solutions make (business) sense?

**Outcomes** Detailed evaluation reports of V2G and smart-charging demonstrations at made at the household, street, neighbourhood, city and stadium level. This provides practical guidance regarding the technical and business potential as well as conditions for success for V2G solutions for different market segments.





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www.johancruijffarena.nl > *Tim Oosterop* | Project Manager Duurzaamheid

#### ▹ How are you involved in electric driving?

The Johan Cruijff ArenA is striving to be the most innovative stadium in the world. Through the Innovation ArenA, many real-world challenges are solved by finding innovative solutions. One such solution is the energy storage system (ESS). This system combines a number of use cases such as peak shaving, grid services, Backup power and V2G by using a 3MW EV battery storage. Not only is the combination of these use cases unique across the world, but also the use of second-life EV batteries. It solves the issue concerning what to do with EV batteries after the economic life of EVs has ended.

What specific things did you want to find out? How exactly do the research projects contribute to your work?

One of the key questions was whether it would be possible to combine multiple use cases and incorporate second-life EV batteries as this has never been done before. We have achieved this over the past year and the next question is how bidirectional charging can be best incorporated in ESS, providing more power for grid services and backup power for the ArenA.  What will the future of charging look like?

#### The immediate future of charging within the ArenA will be a combination of smart charging, bidirectional charging and the ESS. The ESS can provide a lot of power in a very short time for fast charging. Bidirectional charging means that the EV batteries can also be used for grid services and backup power for the ArenA. We will achieve this by starting a pilot with 18 chargers, leading up to 200 chargers in the parking garage below the ArenA.

## Solar Storage: The Case of the Amsterdam Energy ArenA

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The Johan Cruyff ArenA is a multi-functional stadium in Amsterdam, the Netherlands. It has a capacity of 68,000 seats and is ranked as one of the most sustainable stadiums in the world. Within the Interreg-funded SEEV4-City project, the ArenA is one of the six operational pilots demonstrating Vehicle2Grid and smartcharging technology. In this particular pilot, the combination of solar, large-scale battery storage and V2G technology is demonstrated.





he SEEV4City project aims to demonstrate innovative, smart energy pilots that have a major impact on three performance indicators: (I) reduced CO2 emissions, (II) increased energy autonomy and (III) reduced grid investments. ArenA achieves this by demonstrating smart energy solutions on a large-stadium level, with a particular focus on increasing autonomy and reduce grid investments. The so-called Vehicle2Business pilot at the ArenA comprises a large-scale system of photovoltaic modules (PV) and a static battery system. The PV system on the roof of the venue has a maximum output of 1.128 MWp, generating around 12% of the total energy consumption of the stadium. The total

electricity consumption of the Johan Cruyff ArenA stadium is comparable with a district with 2,700 households [1]. The remaining share of electricity is generated through certified regional wind energy.

The static battery is supplied by Nissan, comprising Nissan Leaf battery packs with a capacity of 2.8 MWh (equivalent to 140 battery packs) [2]. The intention to use only second-life batteries from electric vehicles could only be partly (40%) realised due to the lack of used batteries on the market. In the future, the availability of second-hand batteries is expected to increase.

The Johan Cruyff ArenA employs the battery to support the stadium's

energy system during events and as a backup for the Frequency Containment Reserve (FCR) market of TenneT [3]. This unique project is the result of a collaboration between Nissan, Eaton, BAM, the Mobility House and the Johan Cruyff ArenA, supported by the Amsterdam Climate and Energy Fund (AKEF) and Interreg [2] [9].

Although the PV system covers 12% of the consumption, it does not solve the mismatch problem between the generation and consumption of solar electricity. In sunny summer days, when the energy demand of the building is low, the generation of electricity surpasses consumption, which without storage would be provided back to the grid. By contrast, Johan Cruyff ArenA has a very high electricity consumption during sport events as well as concerts in the evening, at moments during which the PV system does not generate electricity. Consequently, Johan Cruyff ArenA is interested in energy storage and V2G applications.

The storage capacity of individual electric vehicles is too small compared with the generation and consumption of energy in the whole stadium. However, the potential is large when a few hundred electric vehicles are in the parking spots. The current ArenA battery has a storage capacity of 2.8 MWh. If 300 electric vehicles are in the parking spots, the storage capacity could increase to 6 MWh or above.

Given that not all solar energy is used locally, there is room to charge EVs with solar (in summer and during daytime). The envisioned enlargement of the PV system would enable charging an even larger share of EVs with sustainable energy.



Technical room with battery packs (Source: B. Jablonska)

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In this operational pilot, it is expected that the charging facilities of the ArenA will provide a significant amount of clean (solar-charged) kilometres for visiting EVs. This can further increase with the eighteen planned new charging poles, three of which are bidirectional. There are plans to reduce the peak consumption of the stadium, which will be translated into economic savings for both the stadium itself as well as the local distribution system operator. The Johan Cruyff ArenA operational pilot will also try to determine the economic savings for the grid, and these results can serve as a development model for other stadiums.

The Mobility House collects all relevant data (building consumption, PV energy generation, PCR market) and manages the energy flow from the energy storage system to/from the grid. Once the V2G units have been installed, the ArenA OP will consider free parking for V2G users during events, so visitors can charge their car at home for about €8 (for a full load) and do not have to be charged €20 for parking.

The Johan Cruyff ArenA has been awarded several prizes, including the Green Apple Award for Environmental Best Practice, the T3 Eco Award and the Accenture Innovation award.

## Take-aways

- ► There are currently limited to no plug-and-play systems available on the market for the combination of solar, battery storage and bidirectional charging, particularly on a larger scale. With pilots like the ArenA project, innovation is likely to be spurred.
- Large-scale battery storage provides opportunities for peak reduction and reduced grid impacts.
- Second-hand automotive batteries provide good second-life opportunities for static storage solutions.

#### References:



Van den Hoed, R. et al. (2019). "Lessons Learnt - A cross-case analysis of six, real-time Smart Charging and V2X Operational Pilots in the North Sea Region.



## ELECTRIC TAXIS

The taxi sector has committed to electrifying more than 4,000 taxis by 2025. In return, the city of Amsterdam has agreed to facilitate this transition by providing (fast-) charging infrastructure, subsidies and implementing innovative measures like clean taxi stands. This chapter provides research results on the effectiveness of these measures, survey results on how taxi drivers evaluate the incentives, and growth requirements for fast-charging infrastructure.

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<ul> <li>Cleaning the Amsterdam Central Station taxi stand</li> </ul>	143-147
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## X City of Amsterdam

Municipality of Amsterdam ► Bertold Plugboer | Project Manager for Emission-Free Taxis and Charging Infrastructure

#### ▹ How are you involved in electric driving?

The municipality of Amsterdam is committed to making the air in the city cleaner and healthier. To achieve this, we're looking at sources of emissions. The municipality has a direct influence on traffic as a source of air pollution. As part of the air quality programme, I am focusing on emission-free taxis and charging infrastructure. In 2016, the municipality of Amsterdam and the approved taxi organisations (Toegelaten Taxi Organisaties, TTOs) reached an agreement – in the form of the Clean Taxis for Amsterdam Covenant – to work together to achieve an emission-free taxi sector by 2025.

What specific things did you want to find out? How exactly do the research projects contribute to your work?

The AUAS's research projects for the municipality of Amsterdam focus on clean taxi ranks and taxi drivers using fast-charging stations. Such research enables the municipality to determine whether there are sufficient clean taxis in the city to meet demand. It also gives us insights into taxi drivers' need for charging stations. Moreover, this AUAS research enables us to see what kind of clean taxis are using the taxi ranks at central station and Leidseplein, as well as when. In other words, we can gain insights into peak times and see - for example - whether those taxis are mostly electric or still run on green gas.



#### What will the future of charging look like?

In addition to the increasing number of electric taxis in Amsterdam, other companies and citizens will also increasingly make the switch to electric transport in the coming years. As such, it is essential to have an adequate fast-charging network in place. The municipality of Amsterdam is aiming to increase the public fastcharging network from 13 to at least 25 fast chargers by 2019. Under the current tendering procedure, this number may be increased to a total of 62. The speed of growth depends on usage. A key issue here is to ensure that the various target groups make optimum use of the available public fast-charging stations. In addition, the municipality also wants to expand the public charging network from approximately 2,800 charging stations to 16,000 by 2025.

## **U-SMILE:** Urban Smart Measures and Incentives for quality of Life Enhancement

Amsterdam VU Materia 🎆 / university of groningen

Monitoring the cleaning of the taxi sector in Amsterdam

#### **Project duration**

from 01-04-2016 till 01-09-2019

#### Projectpartners

AUAS participates in the research project "Urban Smart Measures and Incentives for the Enhancement of the quality of Life" (U-SMILE). Research partners are the principal investigator VU (Faculty of Economics and Business Administration, Department of Spatial Economics), the University of Groningen (Faculty of Behavioral and Social Sciences, Department of Social Psychology), Technical University Delft (Faculty of Civil Engineering, Department of Transport and Planning), Technical University Delft (Faculty of Technology, Policy and Management, Department of Transport and Logistics). The city of Amsterdam and Amsterdam ArenA are the non-academic partners

of AUAS in the U-SMILE project. The city of Amsterdam provided recorded data of the taxi stands within the framework of the U-SMILE research project and data concerning fast chargers within the framework of the IDO-laad project.

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**Project Objectives** Approximately 4,000 registered taxis operate in the city of Amsterdam, as well as several thousand non-registered taxis. Most of them are ICE vehicles emitting a disproportionally large amount of hazardous emissions in many short journeys in the city centre. Therefore, the use of clean taxis is highly desirable to improve air quality in the city.

**Research questions** The city of Amsterdam has given priority to clean taxis at the taxi stands at two important and busy taxi stands in the city centre: Amsterdam central station and Leidseplein. The research question at Amsterdam central station was how effective the priority measure was in attracting clean taxis. At Leidseplein, the main question was whether a sufficient number of clean taxis would be available to service the huge numbers of passengers at peak hours. A third research question was whether a sufficient number of fast chargers are available in the city to facilitate a quick recharge of electric taxis. In addition, AUAS interviewed taxi drivers and sent out surveys to determine their attitudes and behaviours.
## **Voluntary agreement** "Clean taxis for Amsterdam"

In February 2016, the city of Amsterdam and the officially-approved taxi organisations agreed that all taxis should be fully emission free by 2025. This agreement embodies the following measures:

### Clean taxis are given priority

From the opening of the new Amsterdam central station taxi stand, priority was given to clean taxis. At a later stage, the Leidseplein taxi stand was made accessible only to clean taxis. These two taxi stands belong among the busiest taxi stands in the city. More taxi stands will be made accessible for clean taxis only in the near future.

- Sufficient number of fast-charging points Taxis can charge quickly between journeys.
- Free parking at every charging point For electric taxis with a parking permit.
- Environmental zone for ICE taxis ICE taxis from 2008 or older are not allowed in the city from January 2018.
- Subsidy for a clean taxi

Registered taxi drivers can apply for a subsidy of €5,000 when purchasing a clean taxi.

## **Cleaning the** Amsterdam **Central Station** taxi stand

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After the city of Amsterdam gave priority to clean taxis at the Amsterdam central station taxi stand, the number of registered clean taxis in Amsterdam steadily increased in the first year. A steep rise occurred just before the city of Amsterdam allowed only clean taxis at the Amsterdam central station and the Leidseplein taxi stand, the two busiest taxi stands in Amsterdam.

t the entrance of the Amsterdam central station taxi stand (Figure 1), both the driver's taxi permit and the taxi's licence plate are scanned. The taxi is only allowed to enter the taxi stand if the driver and vehicle are both registered as belonging to an official Amsterdam taxi organisation. The software tags the taxi as clean if the vehicle is registered in the clean taxi list kept by the city of Amsterdam. The taxi then parks and waits until being called by the calling board to pick up passengers from the taxi pickup point.

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## Amsterdam CS taxi stand



The privilege measure giving priority to clean taxis at the Amsterdam CS taxi stand started in October 2015. This measure entailed that every fourth taxi called to pick up passengers was a clean taxi, if available at the taxi stand. If no clean taxi was available, then an ICE would be called instead to pick up passengers. This measure gives priority to a clean taxi if more than three ICEs are already waiting for passengers because clean taxis then have shorter waiting times than ICEs.

AUAS analysed the anonymised licence plate data. KPIs offered insights into the number of clean and ICE taxis entering the taxi stand.

At the start of the privilege measure, about 100 clean taxis entered the taxi stand per day. One year later, at the end of the observation period, this number had increased to about 150 (Figure 2). This figure shows the significant growth in the absolute number of electric taxis entering the taxi stand after the privilege measure became effective.

## Clean taxis at Amsterdam CS



Figure 2. Average number of clean taxis entering the Amsterdam CS taxi stand per day. Calculated average based on weektotals between October 2015 and September 2016. In November and December 2015, right after the start of the privilege measure, about one in every seven arriving taxis was clean. Subsequently, gradually more clean taxis came to the taxi stand. In March 2016, one in every five arriving taxis was a clean taxi, and one in four by September 2016. At this point in time clean taxis were no longer privileged compared with ICEVs. The municipality therefore decided to reduce the preference ratio to one clean taxi in three taxis entering the taxi stand. By January 2018, only clean taxis were allowed to enter the taxi stand.

The number of registered clean taxis in Amsterdam shows a steady rise in the first year after introducing the privilege measure and a steep rise by the end of 2017 (Figure 3). The sharp increase occurred just before the city of Amsterdam allowed only clean taxis at the Amsterdam central station and the Leidseplein taxi stands, the two busiest taxi stands in Amsterdam.

### Registered clean taxis in Amsterdam



Figure 3. Arrows and dates indicate the privilege measures taken by the city of Amsterdam e.g. 1:4 means one electric taxi for every fourth taxi is allowed to pick up passengers.

## Take-aways

Giving priority to clean taxis at the Amsterdam central station taxi stand has been an effective measure in promoting the switch from ICE to clean taxis.

► The design of the priority measure allowed for a gradual transition to clean taxis by progressively increasing the required share of clean taxis over a two year period.

Monitoring the incoming share of clean taxis was an important condition for establishing whether the measure was still preferential for clean taxis.

## Taxi drivers' perspective

Interviews with taxi drivers back in November 2016 show that the taxi stand at central station is preferred to other Amsterdam taxi stands due to getting more customers at this location. All interviewees were aware of the measures and policy objectives that the municipality had set for the taxi sector.

The interview results show that the priority arrangement at the central station has achieved the desired effect: all drivers who visit the location are aware of the increased number of clean taxis picking up people at central station. Most of the taxi drivers owning a clean taxi argue that they mainly purchased such a vehicle to use the priority arrangement.

Back in November 2016, clean taxi drivers welcomed an increase in the current priority ration. They previously experienced insufficient benefit from the scheme because the number of clean taxis had increased to such a point that the priority scale did not provide sufficient priority. Taxi drivers who were not allowed to make use of the priority arrangement experienced the measure as unfair, although they indicated that they would continue to visit the taxi rank even if the priority ratio increased to one clean taxi in three taxis. The main reason for this is the large number of customers that the drivers get at this location.

In spring 2018, taxi drivers were interviewed again. The results showed that the priority measure is only advantageous for BEV taxi drivers, who experience the incentive as stimulating. By contrast, green gas drivers feel disadvantaged: they have switched to clean driving but are no longer allowed to pick up customers at the central station. Priority is now only given to drivers with a BEV. For green gas taxi drivers, the benefit of the measure has disappeared for them, causing disappointment and frustration. INFRA

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# Cleaning the Leidseplein taxi stand

At Leidseplein, the city of Amsterdam was uncertain whether a sufficient number of clean taxis would be available to service the huge numbers of passengers at peak hours. A dashboard showing the number of clean and ICE taxis per hour helped the city of Amsterdam to judge when a sufficient number clean taxis were available to service the Leidseplein taxi stand at peak hours and thus not to admit any more ICEs.

E-mobility | getting smart with data

t the Leidseplein taxi stand, huge numbers of visitors seek taxi transportation during the evening and night on Thursdays, Fridays and Saturdays. At peak moments, between 150 and 200 taxis per hour are required to serve all passengers. In mid-2017, there were around 440 registered clean taxis in Amsterdam. The question was whether this number could provide sufficient transportation capacity at peak times.

At the entrance of the Leidseplein taxi stand, the driver pass number and licence plate are scanned. Access to the taxi stand is allowed if the driver and taxi both belong to an official Amsterdam taxi organisation. At the Leidseplein, no calling board is available: taxis have to wait until they are first in the waiting queue to pick up passengers. From 8th January 2018, only clean taxis have been allowed to visit the Leidseplein taxi stand. The city allowed ICEV taxis during an exception period at Saturday and Sunday night from 00:00 to 05:30. The duration of this exception period was reduced in three steps during the year.

Analysis of the scanned data shows that on average more than 100 taxis per hour are required at the peak hours from approximately 00:00 until 04:00.

Figures 1 to 4 show the number of taxis per hour during social nights at Leidseplein. Figure 1 shows the numbers in 2018, week 1, when no restriction of taxi type (clean or ICEV) was active yet. The number of ICEV taxis (in orange) outnumbers the clean taxis (in blue).

Figure 2 shows week 2, when the measure to allow only clean taxis became active, with an exception for the period from 00:00 to 05:30 hours on Saturday night and Sunday night. In this exception period, the amount of ICEV taxis still outnumbered the clean taxis. The figure shows that some ICEV taxis still present themselves before the gate outside of the exception period.

Figure 3 shows week 15, when only clean taxis were allowed, with a shortened exception period from 03:00 to 05:00 on Saturday and Sunday night. In this exception period, the number of clean taxis is larger than the number of ICEV taxis. Some ICEV taxis still present themselves before the gate outside of the exception period.

Figure 4 shows week 30, when only clean taxis were allowed, with no exception period anymore. No ICEV taxis present themselves before the gate anymore.

From week to week, these dashboard graphs helped the city of Amsterdam to judge whether a sufficient number of clean taxis were replacing ICEVs at peak hours. Evaluating the trend in the share of clean taxis helped to decide when to reduce the duration of the exception period and finally to only allow clean taxis at the Leidseplein taxi stand.

## Take-aways

► The Leidseplein case shows how policy makers can transform taxi stands to attracting only clean and electric taxis.

 The gradual scheme that was introduced, allowing non-clean taxis to serve clients during peak times, was successful to overcome the limited amount of clean taxis in the first months of the transition.
Providing a dashboard supported policy makers to make informed

policy makers to make informed decisions about further limiting access to ICE cars at the taxi stand during the transition. 149

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## Clean and ICEV taxis in week 2018-01



*Figure 1. The number of clean taxis (blue) and ICEV taxis (orange) per hour presenting before the gate on Friday, Saturday and Sunday between 18:00 and 06:00 hrs. Policy week 2018-01: clean and ICEV taxis both allowed at the taxi stand.* 

## Clean and ICEV taxis in week 2018-02



Figure 2. The number of clean taxis (blue) and ICEV taxis (orange) per hour presenting before the gate on Friday, Saturday and Sunday between 18:00 and 06:00 hrs. Access policy in week 2018-02: ICEV taxis only allowed access on Saturday and Sunday from 00:00 to 05:30 hours am.



Figure 3. The number of clean taxis (blue) and ICEV taxis (ICEV) per hour presenting before the gate on Friday, Saturday and Sunday between 18:00 and 06:00 hrs. Access policy in week 2018-15: ICEV taxis only allowed on Saturday and Sunday night at the taxi stand from 03:00 to 05:00 hours.

## Clean and ICEV taxis in week 2018-30



Figure 4. The number of clean taxis (blue) and ICEV taxis (orange) per hour presenting before the gate on Friday, Saturday and Sunday between 18:00 and 06:00 hrs. Access policy week 2018-30: only clean taxis allowed.



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# Fast charger utilisation in Amsterdam

The number of electric taxis in Amsterdam has been strongly growing since the end of 2017. The municipality has received signals from the taxi sector that it was often very crowded at the fast-charger stations. Data-analysis by AUAS as part of the U-SMILE project confirmed that more fast chargers are needed to facilitate the electric taxis.

## Fast-chargers in Amsterdam



Figure 1. Locations of the public fast chargers.

The total number of fast-charging sessions has sharply increased since the end of 2017 (Figure 2), with taxis as the main cause of this growth. From October 2017 to October 2018, the number of fast-charging sessions in Amsterdam tripled. This confirms the signal of the taxi sector that fast charger stations have high occupation.



Figure 2. The number of fastcharging sessions of taxis and other users per day in Amsterdam in the period from January 2015 until September 2018.



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The number of fast-charging sessions per day strongly varies among locations (Figure 3). For example, in September 2018 there were an average of 35 charging sessions per day at central station (charging station "Stationsplein"), while we see 15 charging sessions per day on Europaboulevard in the same month.



Figure 3. Average number of fast-charging sessions per day per fast charger in the period from January 2016 until September 2018.

The busiest moment of the day at fast-chargers is usually around noon (Figure 4). At this time, there were 1.7 times more fast-charging sessions at central station than the average per day.



Figure 4. Average daily pattern in Q3-2018 of the number of charging sessions per hour per fast charging socket.

The analysis confirms the signals of the taxi sector that the fast-chargers in Amsterdam are heavily used, especially around noon. In the year prior to October 2018, the number of fast-charging sessions in Amsterdam tripled to around 300 per day. It emerges that at least two out of three charging sessions involve taxis. This study supports the city of Amsterdam in its policy to facilitate the electrical taxis by placing more fast chargers in the city.

## Taxi driver survey on fast charging

Taxi driver respons

Threehundred taxi drivers completed a survey in October 2017. 80% of ICEV drivers reported that there were insufficient fast chargers, with 41.6% of all ICEV drivers indicating that the placement of more fast chargers would make it more attractive to adopt a FEV taxi. 89% of the FEV taxi drivers indicated that more fast chargers were needed (Figure 5).



### Yes No

Figure 5. Survey question: "Would you purchase an electric taxi faster if there were more fast-chargers?"



## Survey results - Evaluation of the parking licence incentive and purchase subsidy

### Parking licence incentive

The parking licence incentive in which taxi drivers are exempted from paying parking costs when charging for 30 minutes at a regular charging point in the inner city was considered only mildly attractive by BEV drivers (4.7 on a seven-point scale) and not very attractive by ICEV drivers (2.8 on a seven-point scale).

### Purchase subsidy

The municipality provided a 5,000 Euro subsidy for taxi drivers purchasing an electric taxi. In a 2018 survey among taxi drivers, BEV drivers were asked whether they used the purchase subsidy to finance their current BEV. Out of the 34 respondents who drove a full electric vehicle, 17 used the purchase subsidy. Among these 17 taxi drivers, 11 reported that they would have also purchased the FEV taxi if the subsidy was not made available. The reasons for purchasing the FEV without the subsidy vary, although comments show that some drivers did so due to the voluntary agreement or the mandatory use of electric vehicles in the future. By contrast, others highlighted that driving a FEV was financially feasible or that they purchased a FEV for environmental reasons.

## Take aways

The taxi sector is much more dependent on fast charging infrastructure than regular EV drivers. Taxis are responsible for more than 60% of all fast charging sessions in Amsterdam.
Fast chargers in Amsterdam are heavily used, on average facilitating more than twenty sessions a day. Most sessions start around noon.
Growth in the number of electric taxis will most likely lead to a shortage of fast charging facilities in the region.

## Taxi drivers' attitudes and behaviour in Amsterdam

**=** Contents

Research on taxi drivers' attitudes towards electric taxis, the voluntary agreement and the corresponding measures and incentives tell us more about the transition to a full electric taxi fleet from the perspective and experience of the taxi driver, which could help explain why some incentives are more effective than others.

uantitative data about taxi drivers' attitudes towards the covenant and interest in FEVs was gathered through a survey in October 2017. 307 responses were gathered in total (77.1% ICEV (236), 11.8% FEV (36), PHEV 3.9% (12) and NGV 3.9%(12)). We measured the self-reported degree of interest in purchasing a FEV in the future and the self-reported degree of likelihood of purchasing a FEV in the future.

Out of the 236 ICEV drivers, 139 (58.9%) reported a moderate to strong disinterest in purchasing a FEV, 33 (14%) remained neutral in their interest and 64 (27.1%) showed a moderate to strong interest (Figure 1). In terms of likelihood, 124 (52.5%) ICEV drivers considered it somewhat to very unlikely that they would purchase a FEV in the future, with 45 (19.1%) neutral and 66 (28%) considering it somewhat to very likely. INFRA

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## ICEV drivers' interest in FEV taxi



Figure 1. ICEV drivers' interest in FEV taxi.

### Regarding the attitude towards the voluntary agreement, both FEV drivers and ICEV drivers with an interest in purchasing a FEV acknowledged the importance of the voluntary agreement signed between the municipality and the taxi drivers (5.1 and 5.9 on a seven-point scale, respectively). Acceptability of the voluntary agreement is low among the total group of ICEV drivers (2.6 on a seven-point scale) yet high among the current FEV drivers (5.8 on a seven-point scale). Information can be found in Figure 2.

### Voluntary agreement: acceptability and importance



Figure 2. Rated acceptability and importance of the voluntary agreement.

Results on the attitude towards the instrumental and financial attributes of the vehicle show no considerable distinction between ICEV and FEV drivers concerning purchase price and range (Figure 3). Interestingly, FEV drivers do not have a considerably different perception from ICEV drivers regarding purchase price and range, although ICEV drivers with an interest in purchasing a FEV evaluate the purchase slightly better than current FEV drivers.

## Attitude towards FEV purchase price and range



## Take-aways

► A large share of taxi drivers is still skeptical about electric vehicles. Acceptance of the voluntary agreement by taxi drivers differ strongly, but on average is fairly high.

 Policy makers can increase commitment by informing taxi drivers in a timely manner via multiple information channels about the planned measures and changes to these measures.
 Information meetings about electric driving and provision of objective information can support taxi drivers to start considering electric taxis as a serious alternative. INFRA

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Abbreviation	Meaning	Explanation
API	Application Programming Interface	a set of routines, protocols, and tools for building software applications
AUAS	Amsterdam University of	
	Applied Science	
BEV	Battery Electric Vehicle	type of electric vehicle (EV) that uses chemical
		energy stored in rechargeable battery packs
CDR	Chargepoint Detail Record	Data table; each row representing one charging
		session by minimally a session identification number,
		start time, end time, kWh charged, and charging
		card identification number
CI	Charging Infrastructure	A network of charging points for EV drivers, be it
		level 1, 2 or 3 charging equipment, public, semi-
		public or private and/or charging hubs
СРО	Charge Point Operator	A company operating a pool of charging points
DIM	Dimension	A data set composed of individual, non-overlapping
		data elements. Dimensions provide the opportunity
		to filter, group and label in data analysis
DWH	Data Warehouse	Central repository of integrated data from one or
		more disparate sources used for reporting and data
		analysis
eMSP	Electric Mobility Service	A company offering services to EV owners
	Provider	
ETL	Extract-Transform-Load	Refers to the process of extracting data from data
		sources, transforming the data for storage in the
		proper structure for querying and analysis and
		loading the data into the final data warehouse
EV	Electric Vehicle	
EVS	Electric Vehicle Symposium	Annual Symposium
FEV	Full Electric Vehicle	Equal to BEV: Battery Electric Vehicle
G4	Amsterdam, Rotterdam, the	The four largest cities in the Netherlands
	Hague, and Utrecht	
GDPR	General Data Protection	
	Regulation	
ICEV	Internal Combustion Engine	
	Vehicle	
MRA-E	Metropolitan Region	Project office aimed at stimulating electric mobility
	Amsterdam Electric	and installing public charging points in the
		provinces Noord Holland, Flevoland, and Utrecht

Abbreviation	Meaning	Explanation
MS SQL	Microsoft SQL	Relational database software
MV	Meter Value	Value generated at certain time intervals counting
		kWh uptake of a charging point
KPI	Key Performance Indicator	Metric indicating charging infrastructure
		performance
OCPI	Open Charge Point Interface	Data exchange protocol which standardises file
		formats and API calls. The protocol supports data
		exchange between E-Mobility Service Providers, and
		Charge Point Operators
PHEV	Plug-in Hybrid Electric Vehicles	Hybrid vehicle equipped with a plug-in
		rechargeable battery pack and an internal
		combustion engine
SCP	Smart Charging Potential	Percentage of the time a vehicle is connected to
		a charging station but doesn't charge. Formula:
		SCP=100* (connection time – charging time)/
		connection time
SGZH	Samenwerkende Gemeenten	Collaboration between municipalities in the
	Zuid-Holland	province of Zuid-Holland for centralised charging
		infrastructure roll-out
SoC	State of Charge	the equivalent of a fuel gauge for the battery pack
		in a battery electric vehicle (BEV), hybrid vehicle
		(HV), or plug-in hybrid electric vehicle (PHEV). The
		units of SoC are percentage points (0% = empty;
		100% = full)
SQL	Structured Query Language	Standard language for storing, manipulating and
		retrieving data in databases
SSIS	SQL Server Integration	Platform for building data integration and
	Services	transformation solutions (see also ETL).
V2G	Vehicle to Grid	a system in which plug-in electric vehicles, such
		as battery electric vehicles (BEV), plug-in hybrids
		(PHEV) or hydrogen fuel cell electric vehicles (FCEV)
		communicate with the power grid to sell demand
		response services by either returning electricity to

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NWO Nederlandse Organisatie voor Weterschappelijk Onderzoel





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## Colophon

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#### Disclaimer

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You are about to enter the world of electric mobility, more specifically the world of public-charging infrastructure for electric mobility. Over the past five years, we – researchers, teachers and students, together with municipalities, research institutes and companies – have gathered and analysed the charging data of public-charging infrastructure in the Netherlands. Together, we wanted to get smart, based on data, facts and figures. We have achieved this through experiments, evaluations of roll-out policies, and by developing computational models to simulate the future.

We hope that this book will inspire, make you a little smarter and well equipped to take the right decision regarding charging infrastructure roll-out, e-mobility or the renewable energy transition.

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