SEEV4-city Flexpower 1

analysis report of the first phase of the flexpower pilot

SEEV4-city
Flexpower 1

Subtitle: Analysis report of the first phase of the flexpower pilot

Author: Amsterdam University of Applied Sciences/Urban Technology

Date: 11th of November 2019

Participants:
Aymeric Buatois
Pieter Bons
Robert van den Hoed
Nanda Piersma
Ramesh Prateek

Executive summary

The city of Amsterdam set the ambitious target of having local zero emission transport in 2025. To achieve this challenging goal, the network of public charging stations needs to be developed. This expansion will increase the load on the local electrical network. To avoid overload and instability in the electrical distribution network, smart charging needs to be implemented.
During a period of 8 months, from January to Augustus 2018, the Flexpower 1 pilot is one of the 6 pilots of the SEEV4-City project, supported by the North Sea Region Interreg programme.

From the 2100 public charging stations present at this time across the city of Amsterdam, 102 were selected for a split-run testing. 50 of the charging stations were used as reference with a constant available charging current of 25 A. The other 52 were deployed with a time dependent current limitation. During the peak hours, in the morning, from 7:00 to 8:00 and in the evening from 17:00 to 20:00, the current available for the charging stations is limited to prevent overload. Outside these hours, the current is set to 35 A, a higher value than the reference stations.

During this pilot, data was collected for 8208 users involved in 43904 unique charging sessions. The analysis of this data shows a globally positive impact on the users and the expected result on the power grid.

Indeed, outside the limitation hours, the vehicle charged faster and more vehicles reached a full battery using the Flexpower 1 profile than using the reference profile. Even if the electric battery didn't reach a full charge, more energy could be transferred to it.

Finally, most of the charging volume associated with the battery electric vehicles could be postponed until after the household energy consumption peak without negatively affecting users

Consequently, the Amsterdam city SEEV4-city pilot was a successful experiment with a positive outcome. It proved possible to shift the electrical vehicle charging peak to later in the evening, occurring daily after the peak in household demand, improving the utilisation ratio of the low voltage electrical network and avoiding grid reinforcement investments. At the same time, most of the BEV users showed a reported improvement in the charging comfort of their vehicles.

Table of Contents

Terms and abbreviations

Split-run testing	Also known as A/B testing. This is a way to compare a test group with a reference group to evaluate the effectiveness of a system.
Charging Station	Electric vehicle supply equipment with one or multiple charge points (connectors)
Capacity profile	A capacity profile is sent from the DSO to the CPO and consists of a certain current per phase in intervals of 15 min.
Charge point (connector)	The connection point on the charging station to which the EV is connected.
Charging capacity	The maximum energy a charging point can transfer to a vehicle.
Charging power	The maximum power available at a connector.
Charging profile	Th profile followed by a charging station to vary the charging power during a certain period.
Charging time	The total amount of time an EV is actually charging.
Connection time	The time between the moment de plug is connected until the moment it is removed.
Full charge	A vehicle reaches full charge when the power transferred to the battery is lower than 100W for at least 15 minutes.

EV	Electric vehicle
BEV	Battery Electric Vehicle
PHEV	Plug-In Hybrid Electric Vehicle
DSO	Distribution System Operator
A	Ampere
V	Voltage
W	Watt
CTR	Charge Time Ratio
CPO	Charge Point Operator
RFID	Radio-frequency identification
SOC	State of charge (in %)

1. Flexpower 1 pilot

1.1. Background

In 2012, 2100 battery electric vehicles (BEV) were present in The Netherlands. The following year saw the introduction of the plug-in hybrid electric vehicles (PHEV). Since then, the number of electric vehicles is growing, reaching a total of more than 142000 on the Dutch roads (Figure 1).

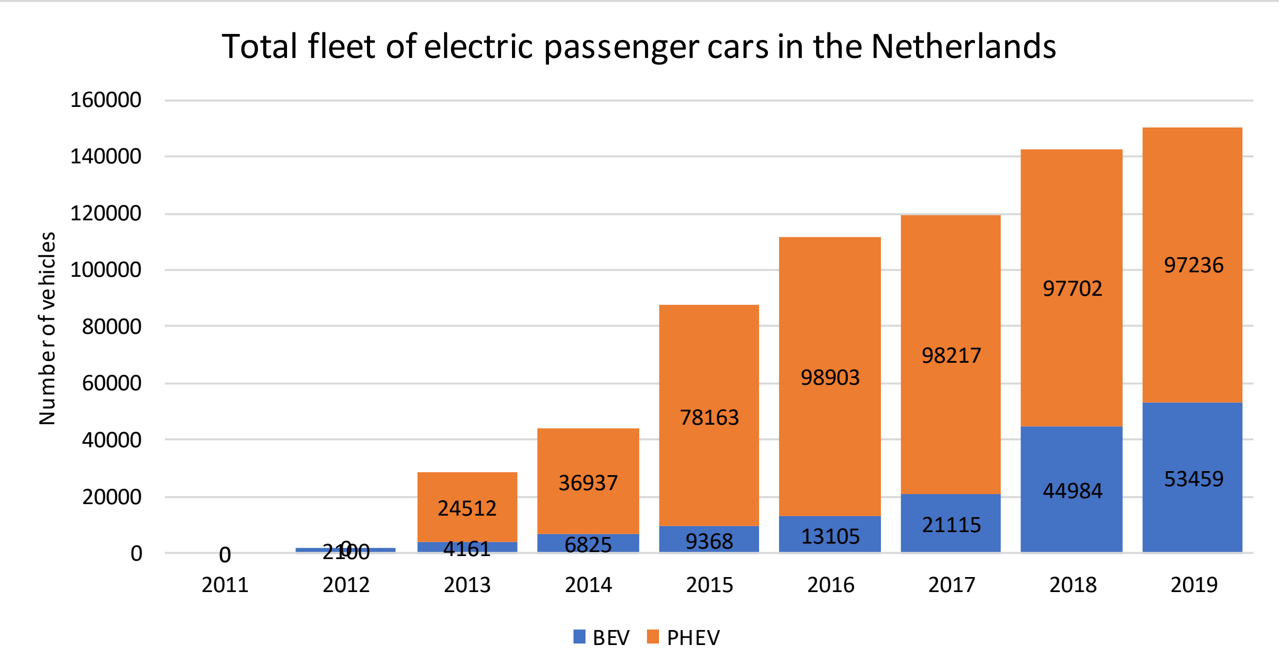

Figure 1: Number of passenger electric vehicles in The Netherlands. 2019 is based on extrapolated data [1].

In line with this growth, the city of Amsterdam set up the ambition in 2015 to have as much zero-emission traffic as possible by 2025 [2]. Consequently, in 2019, 2600 public charge points are now available for electric vehicles.

The Flexpower 1 pilot was deployed in Amsterdam from the beginning of January 2018 up to the end of August of the same year. During these 8 months, data from 102 charging stations across Amsterdam was collected involving 8208 unique users and 43904 charging sessions.
To allow for a comparison, the charging stations were separated into two groups for a split-run testing. 50 of the charging stations were configured with a constant current profile. The current is limited to 25 A per phase on the grid connection during the entire day. These stations are the reference stations and are identical to a standard charging station in Amsterdam.
The other 52 charging stations are configured with a flexible current profile. Outside the peak hours, from 7:00 to 8:00 and 17:00 to 20:00, the current from the grid in limited to 35 A per phase, a value higher than the reference stations. During the morning and evening peak hours, the current is limited to between 20 and 6 A per phase (see section 2.3 for the full details).
Amsterdam provides a perfect environment for large-scale innovative pilots like this one, given that:

- The Flexpower 1 pilot focuses on the next generation battery EVs (BEVs) which have a larger battery with higher charging speed. Amsterdam is a place where relatively many of these cars are present, for instance: Tesla taxis from Schiphol.
- Very few households in Amsterdam have a private parking lot. Users therefore depend on public charging points.

1.2. Project partners

The Flexpower 1 pilot is supported by six partners:

- City of Amsterdam
- Nuon-Vattenfall, energy provider and Charge Point Operator (CPO) in Amsterdam.
- Liander, local grid operator.
- Amsterdam University of Applied Sciences
- Elaad NL, knowledge and innovation centre in the field of smart charging infrastructure in The Netherlands.
- Interreg North Sea Region though the SEEV4City project.

1.3. Energy consumption profile.

The energy consumption profiles of electricity customers follow a daily pattern. It is composed of base consumption, generally to be found between 2:00hrs and 6:00hrs, with two increases. One at the beginning of the morning (from 6:00 to 8:00, when people wake up) and another at the beginning of the evening (from 17:00 to 22:00, when people come back home). Between 8:00 and 17:00, the household's consumption decreases when people leave home.

In The Netherlands, Alliander has made an hourly aggregated profile available [3] of the energy consumption profile for the year 2009, shown Figure 2. It is based on the aggregation of 10000 customers with a connection lower or equal to 80 A per phase. These customers can be households or small companies. They can also be part of a group having a constant energy price or a reduced price during the night. The share of the customers between the two groups is unknown.

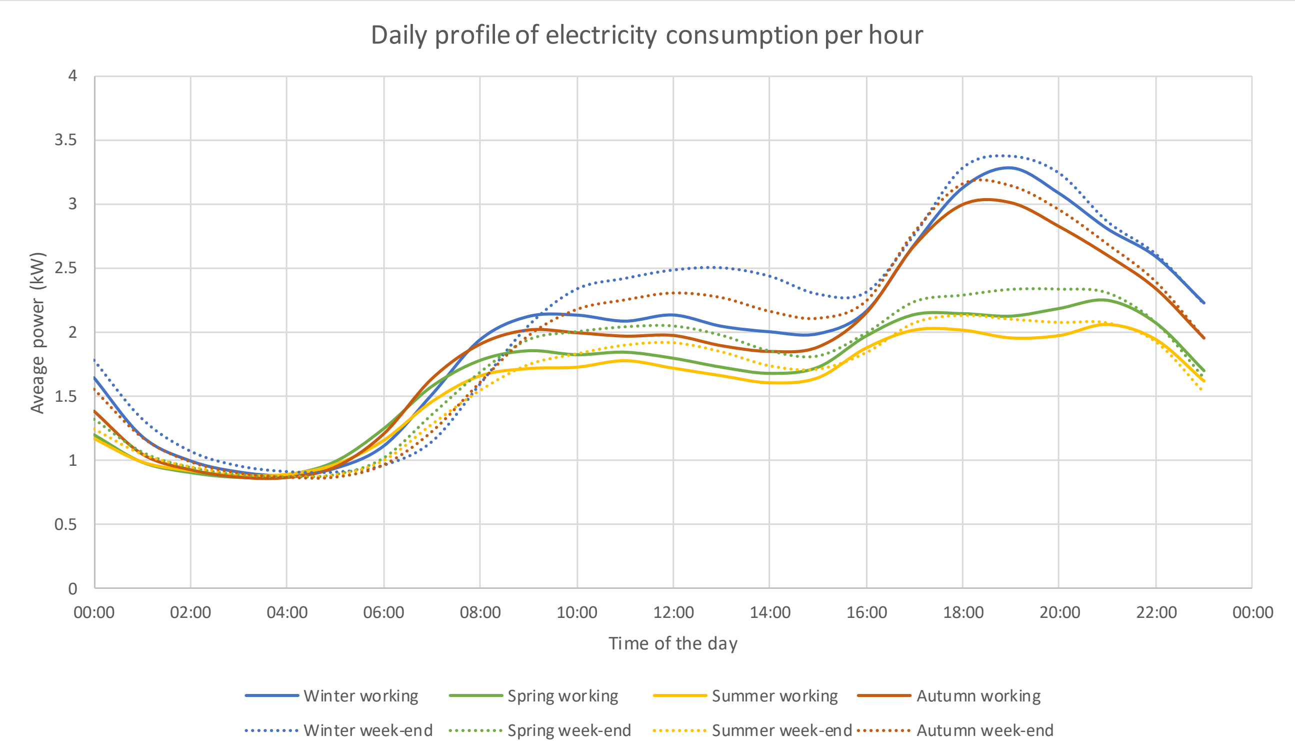

Figure 2: Daily consumption energy profile in The Netherlands based on the aggregated data of 10000 customers [3]

The morning and evening peaks are visible in Figure 2. During the night, the energy consumption drops to 1 kW. At 6:00 the electricity consumption rises to approximately 2 kW. Because the consumption profiles include all electrical connections below 3x80A, it also includes companies. It explains the stabilised level of consumption during the day. Indeed, the consumption of the households is compensated by one of the companies. After 16:00, the evening peak starts, reaching a level of 3.2 kW around 19:00. Finally, the consumption drops from 22:00 to reach the night level.

It can be noticed that energy consumption during the night (from 2:00 to 6:00) is independent of the season.

During the day (from 6:00 to 16:00), the profiles are also similar, even though the winter and autumn profiles show higher values than the spring and summer ones.

The most significant differences can be found during the evening peak. The autumn and winter peaks are clearly visible, increasing the energy consumption with a factor 1.5 compared to the warmer and lighter seasons.

1.4. Pilot objectives

Improving the utilisation rate of the electrical network is one of the goals of this project. Indeed, the electric network was designed several decades ago, obviously without taking in consideration electric vehicles. The increasing number of EVs creates an extra load (Figure 3, top) on top of the household evening peak. It can potentially create an overload and even instability in the grid. To prevent this instability and increase the utilisation rate of the grid, the charging of electrical vehicles can be shifted in time to another moment when the network demand is lower (Figure 3, bottom). Looking forward, the energy contained in the electric vehicle batteries could be used to support the local network during the high demand periods using vehicle to grid technology.

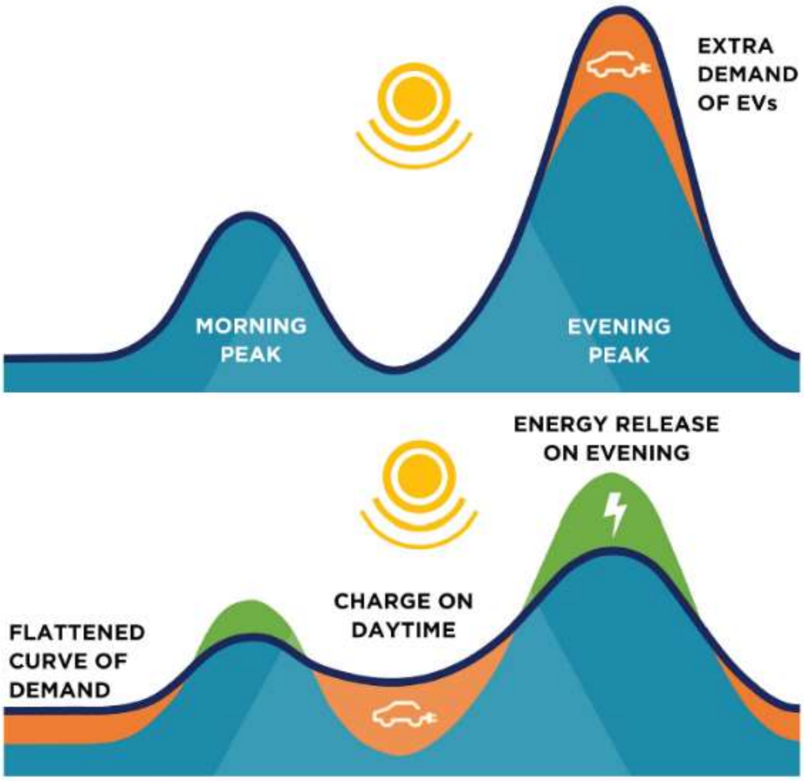

Figure 3: Energy peak during the day and demand shifting

2. Data collection, charging stations and profiles

2.1. Data collection, selection and processing

2.1.1. Data collection

There are two datasets which were used for the Flexpower 1 analyses: the transaction data and the meter values.

The transaction dataset contains the Charging Data Record (CDRs). For each charging session, it comprises the start time, end time, duration and total energy of the transaction, as well as the RFID of the user. This data is automatically sent to the CHIEF database each month, which is managed by the AUAS / HvA. More information on this dataset can be found in [4].

The meter values are the actual meter readings which are stored in 15 minutes intervals relative to the start of a transaction. The measures are made by the charging station independently for each connector.

The transaction data does not have enough resolution for the Flexpower 1 analysis. For example, a transaction with a duration of 4 hours and total energy of 44 kWh could have been achieved by non-stop charging at 11kW, or by charging at 22kW for 2 hours and waiting for 2 more hours because the battery was already full.
To address this issue, we also use the meter value data, which contains the value of the meter in the connector (in units of kWh) for every 15 minutes during charging, and for every 2 hours during connection without charging. This allows us to monitor the charging behaviour during the connection and the two scenarios as described before would be easily distinguishable.
The meter value data was delivered in csv format by Nuon/Vattenfall. The meter values alone are not sufficient to do the analysis for two reasons. First, the dataset does not contain RFID information, which allows us to connect different transactions by the same user. Second, the meter values don't cover the full charging session. The first meter value is sent 15 minutes after the start of the transaction and the last meter value is sent some time before the end. This means the start and end times cannot be matched between the two datasets. Moreover, the difference between the last and the first meter value is often slightly smaller than the total energy found in the transaction data (since some energy is loaded in the first 15min and in the last couple of minutes).

Unfortunately, the two datasets do not have a shared transaction ID column which can be used for merging. And because the datasets do not have an overlapping start time, end time or total energy there is no single unique property to use as a match between the two datasets. The merge was performed by finding the transaction that has a start time *before* the first meter value of the session and an end time *after* the last meter value on the corresponding connector and charging station. This gave a 97% match. The difference can be explained by the removal of several records in the data cleaning stages (section 2.1.2).

2.1.2. Data selection

Unfortunately, not all the data collected during the period were identified as valid or useful. Consequently, before doing any analyses, some filtering was required.

The filtering is made by using the following steps:
- If only one meter value is recorded for the transaction, it is not possible to compute the power, since this is done by taking the difference of multiple measured energy values.
- No vehicle can be charged with a power higher than 50 kW or the energy can't be recovered from the vehicle (negative power). Transactions which contain these properties cannot be real events.
- Some transactions have zero energy transferred.
- The largest size available for a battery is 90 kWh [5]. Any transaction showing more than 120 kWh has been removed as it is not realistic (sometimes this is the sum of small amounts of charging over a period of weeks)
- For some transactions, it wasn't possible to find a matching RFID. These transactions are also discarded.

The count of the filtered transactions is shown in the Table 1.

Table 1: Filtering of transactions from raw data

Numbers of Transactions	Removed transactions	Explanation
48152	-	Raw number of transactions
45657	2495	Transactions with only one record (or multiple transactions but very close together so effectively only one)
45620	37	Transactions with charging > 50 kW or negative charging
44326	1294	Transaction that do not charge at all (TotalEnergy = 0)
44324	2	Transactions charging > 120 kWh
43904	420	No RFID match from CDR table

About 8.8% of the transactions recorded were not usable and thus removed from the analyse.
This filtered data is used for the data analyse.

2.1.3. Relation between power and current in low voltage three phases system

The project involves vehicle charging on the low voltage distribution grid. The normalised voltage is 230 V between neutral and phase or 400 V between two phases. The Table 2 shows the relations between the current and the power for single and three phase grid connections.

Table 2: Relation between current and power in low voltage distribution network.

Current	Single-phase	**Three phases**
16 A	3.7 kW	11 kW
32 A	7.4 kW	22 kW

Power computation is made using the formulas:

For 1 phase: $P_{1P} = U \cdot I = 230V \cdot I$

For 3 phases: $P_{3P} = 230 \cdot I_p \cdot 3 = 400 \cdot \frac{I_p}{\sqrt{3}} \cdot 3$

2.1.4. Preliminary data analysis

The vehicles are categorised according to the power measured during the charging process. These categories correspond to the different technical implementations (number of phases and current limitation) available on the market. The number of vehicles identified, transactions and total energy loaded for each types of vehicle are summarised in Table 3 and presented in Figure 4 to Figure 6.

Table 3: Transactions and number of vehicles involves in the Flexpower 1 pilot.

Power (kW)	**Criterion**	**Number of vehicles**	**Number of transactions**	**Total energy loaded (MWh)**
3.7	P_{Charge} < 4 kW	6055 (74 %)	28550 (65 %)	171.5 (34%)
7.4	4 kW < P_{Charge} < 8.14 kW on Flexpower 1 and P_{Charge} < 4 kW on reference	126 (1 %)	559 (1 %)	6.9 (1%)
11	8.14 kW < P_{Charge} < 12.1 kW on Flexpower 1 and 4 kW < P_{Charge} < 12.1 kW on reference	1812 (22 %)	10140 (23 %)	170.7 (34%)
22	12.1 kW < P_{Charge}	215 (3 %)	4655 (11 %)	149.6 (30%)
Total		8208 (100 %)	43904 (100 %)	498 (100%)

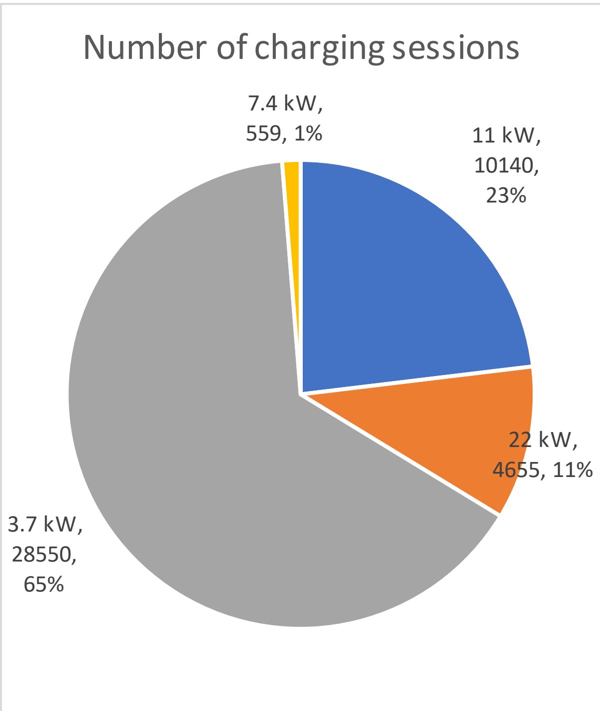

Figure 4: Market share of the type of vehicles involved in the Flexpower 1 pilot.

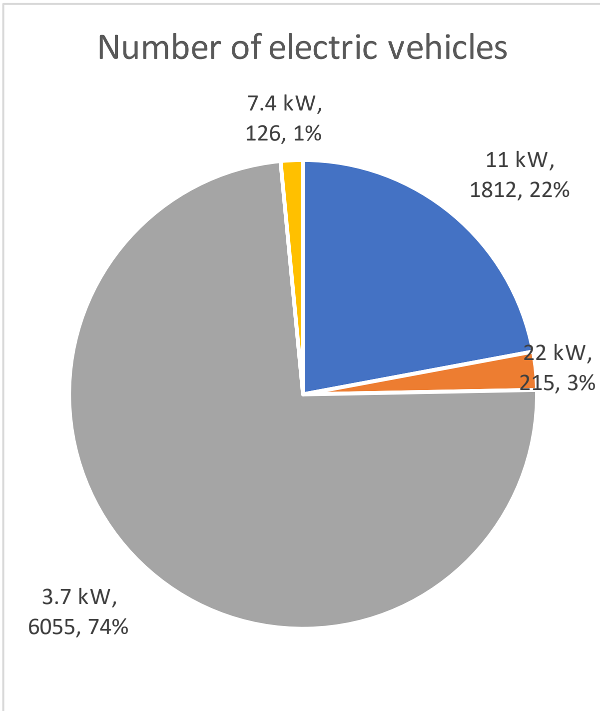

Figure 5: Number of charging sessions recorded by types of vehicles involved in the Flexpower 1 pilot.

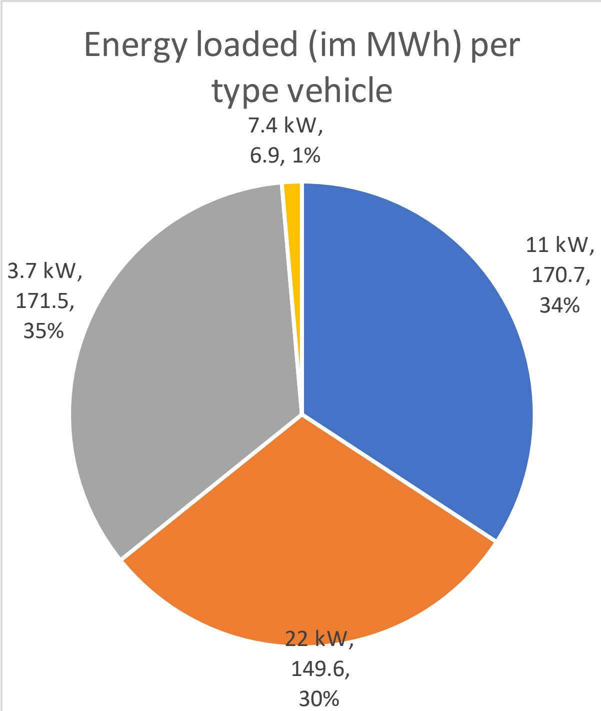

Figure 6: Volume loaded (in MWh) per type of vehicles involved in the Flexpower 1 pilot.

The proportions between the four categories of vehicles are relatively equal in Figure 4 and Figure 5.
On Figure 6, apart from the 7.4kW which only represents 1% of the charged energy, the share of energy is equally distributed between the 3.7, 11 and 22 kW vehicles. This means that the 3.7 kW charge less energy per session on average, and the 22 kW charge more energy per session. This could be explained by the fact that 3.7 kW vehicles are often PHEVs that do not only rely on their battery and 22 kW vehicles are commonly used as taxi's.

2.2. Charging stations

The pilot runs on 102 out of the 2100 charging stations publicly available in Amsterdam in January 2018.
These charging stations are managed by Nuon-Vattenfall and are equipped with two connectors provided by EVBox and installed by Heijmans.
Of the charging stations in the pilot, 50 have the same constant charging profile configuration as any non-flexpower charging station in Amsterdam. The 52 others are configured with the Flexpower 1 profiles. The Table 4 and Figure 7 give explanations about the types and location of the charging stations in the city.
The Flexpower 1 stations are separated in two groups, high and low load, separated as follows:

The low load group is defined with the criteria:
- Low voltage cables loaded less than 50% of their capacity during measured peak.
- Medium to low voltage transformers loaded less than 75% of their capacity during measured peak.
- Less than 30 connections points on the low voltage network.

The three criteria need to be valid to be in the low load group.

The high load group is defined with the criteria:
- Low voltage cables loaded more than 50% of their capacity during measured peak.
- Medium to low voltage transformers loaded more than 75% of their capacity during measured peak.
- More than 30 connections points on the low voltage network.

At least one of the criteria needs to be valid to part of the high load group.

The peak was measured in February, when the energy demand is at its highest.

Table 4: Number of stations per types

Type charging stations	Label	Number	Observations
Reference		50	Mainly located in the city centre.
Flexpower 1 high load		40	Limited spatial overlap with the reference stations.
Flexpower 1 low load		12	Mainly located in Nieuw-West.

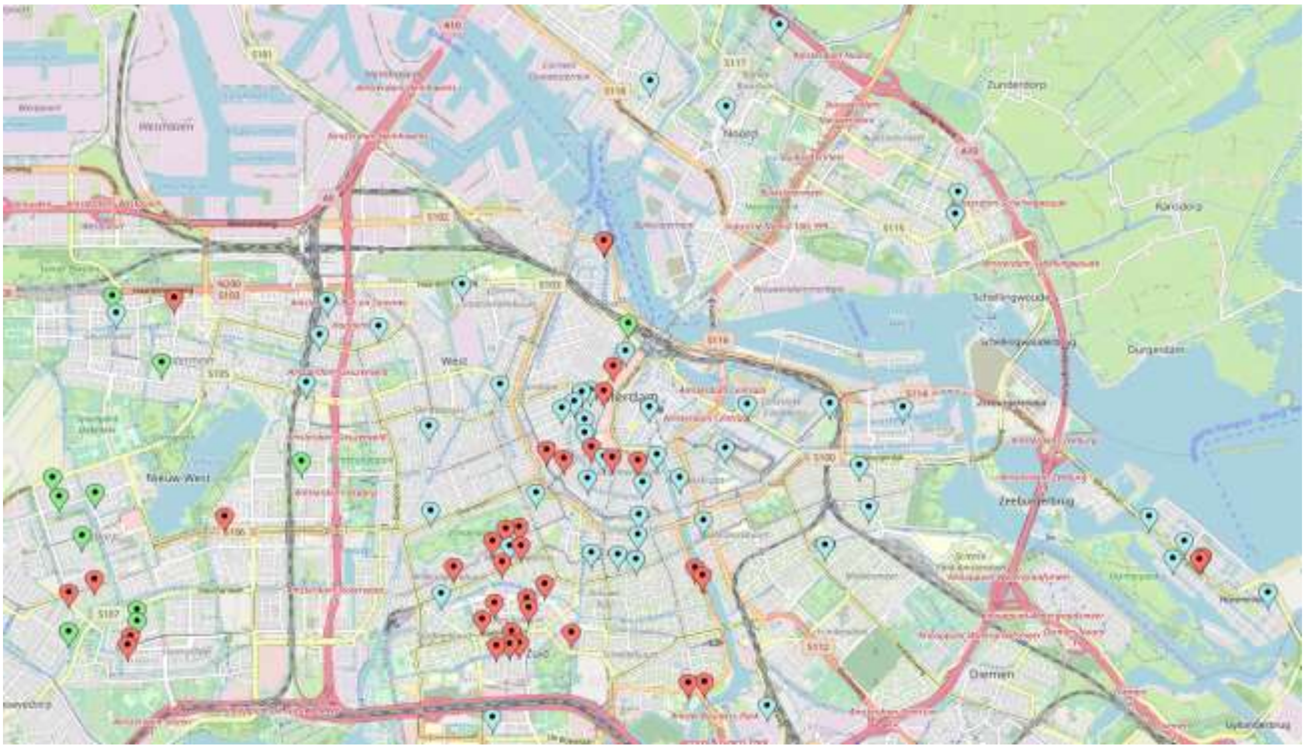

Figure 7: Locations of the 52 Flexpower 1 charging stations in Amsterdam. Green represents low load, red represents high load and blue is the reference profile [6].

On the map Figure 7, it is visible that the reference charging stations are mainly concentrated in the city centre of Amsterdam, with a few of them in the suburbs. A few of the high load stations are located in the city centre and most of them are located in the south-west part of Amsterdam. The spatial overlap between the reference and the Flexpower 1 high load is thus limited.
The low-load stations are mainly located in the western suburbs of Amsterdam, where only one reference station is present.

A deeper analysis of the collected data also shows a difference in the behaviour of the three profiles (Reference, Flexpower 1 high and low load).
By looking at the distribution of the amount of charged energy, plotted in Figure 8, a strong similarity between the reference and the high load profile is visible. However, the reference and the low load profiles are showing a very different pattern. Indeed, the probability to load a little amount of energy (less than 10 kWh) is lower in the low load group than the two other profiles, whereas the probability is higher for the large amount of energy.

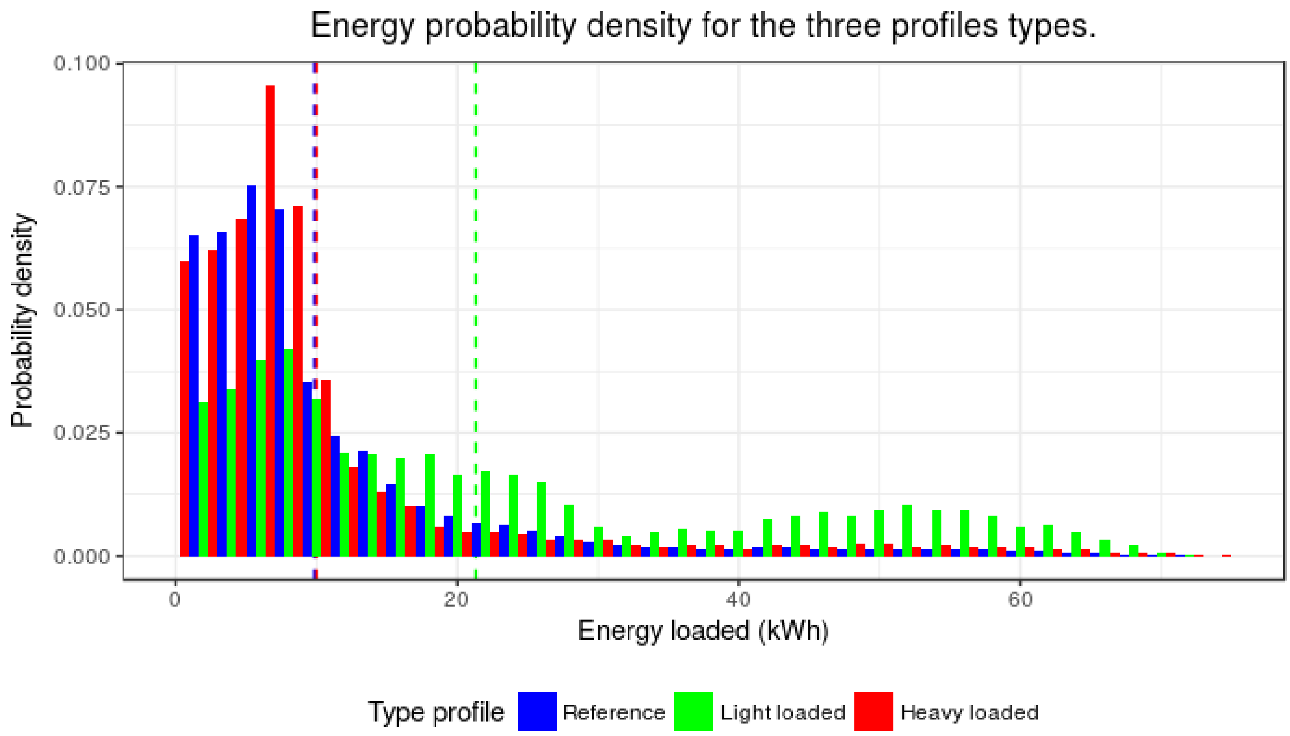

Figure 8: Probability density of the energy loaded per session for the three charging stations profiles.

The explanation for this phenomenon can be found in the share of vehicle characteristics, as plotted in Figure 9. The two reference and high load profiles again show similar distributions between the four categories of vehicles, with a large part for the 3.7 kW charging capacity vehicles. On the other hand, the low load stations have a dominance over the high-power vehicles. Indeed, the 11 and 22 kW categories represents 76% percent of the share. This presents a totally different picture than the two other profiles, where these categories represent only 33% and 36% of the vehicles.

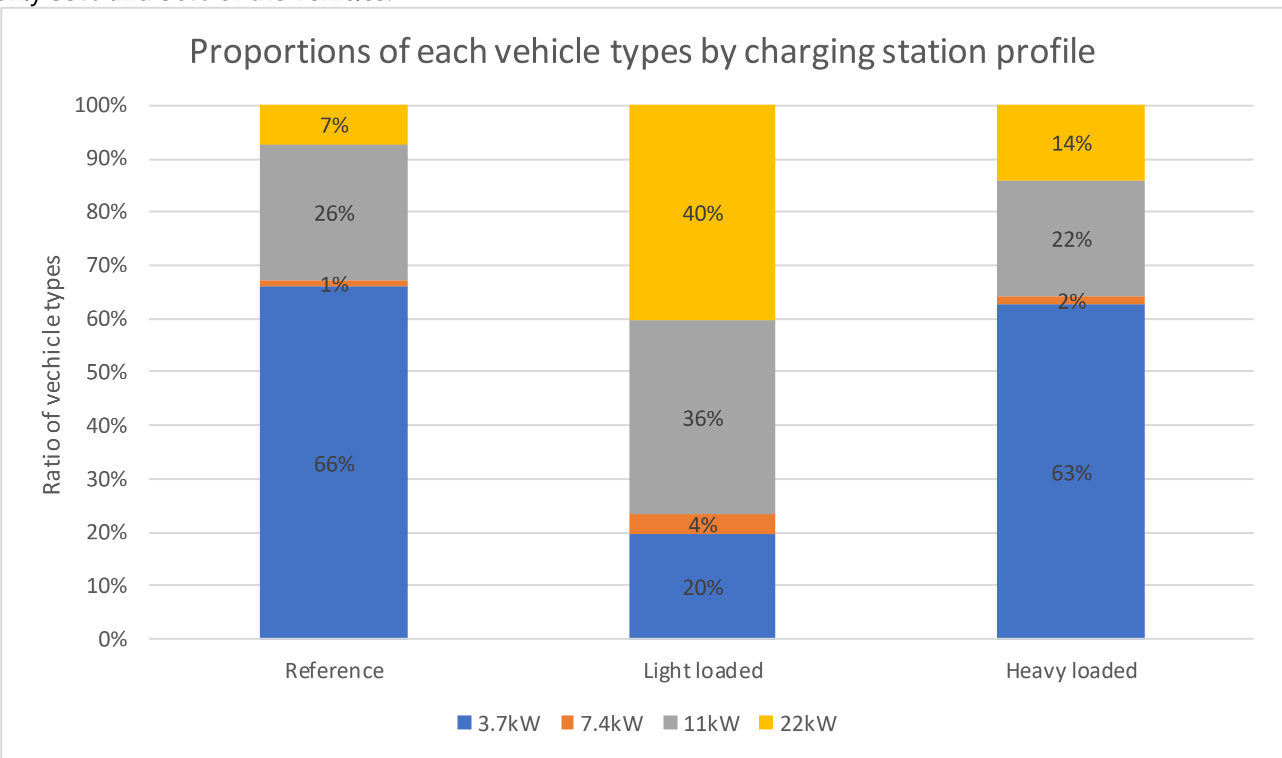

Figure 9: Ratio of vehicle type per charging station profiles

The combinations of a) a mismatch of the low load charging stations compared to the reference stations, b) a different distribution of the energy loaded per session, and c) a predominance of the high-power vehicles, shows that the light load profile has a different behaviour than the reference and high load areas. Consequently, these low load stations will not be discussed during the evaluation of the research questions (chapter 3), as they cannot be properly compared to the reference stations.

2.3. Reference and Flexpower 1 profiles

2.3.1. Overview

The reference power stations have a 3x25 A grid connection. For each connector, the current is limited in the charging station to 16 A per phase. This limit is constant during the whole day.
For the Flexpower 1 stations, the current limitation for charging the electric vehicles is modified depending on the time of the day and the expected energy demand on the local electrical network.

Two area profiles are presented:
- One for the low load areas, where the peak demand is light.
- The second for the high load areas, where the peak demand is the heaviest.

These two area profiles are modified according to the day of the week or period of the year:
- Weekday profile, covering the Monday to Friday.
- Weekend profile (Saturday and Sunday).
- Holiday profile (Taking the North-Holland school holidays into consideration).

During the data analysis, only the data collected during the working days (from Monday to Friday) were used to reduce complexity.
Weekday profiles Table 5 and Figure 10 illustrate the limitation induced by the week-day profiles. The reference 3x25 A profile is plotted to compare with the low and high load profiles.
In these profiles, the current is limited during the morning peak (between 7:00 and 8:00) to respectively 30 A and 20 A. The restriction is more severe during the evening peak. Indeed, the current for the low load profile is limited to 20 A between 17:00 and 20:00. The high load profile has an even stronger limitation during this interval as the current is limited in two steps of 13 and 6 A (see Table 5 for details). Outside these restricted periods, the current limitation is set to 35 A.
The power on three phases is also computed for convenience.

Table 5: Flexpower 1 charging profiles during weekdays. Currents are in amperes and powers in kW for 3 phases.

Time interval	Profiles limitations					
	Reference		Low load		High load	
	Current (A)	Power (kW)	Current (A)	Power (kW)	Current (A)	Power (kW)
00:00 – 07:00	25	17.25	35	24.15	35	24.15
07:00 – 08:00	25	17.25	30	20.7	20	13.8
08:00 – 17:00	25	17.25	35	24.15	35	24.15
17:00 – 17:30	25	17.25	20	13.8	13	8.97
17:30 – 19:30	25	17.25	20	13.8	6	4.14
19:30 – 20:00	25	17.25	20	13.8	13	8.97
20:00 – 00:00	25	17.25	35	24.15	35	24.15

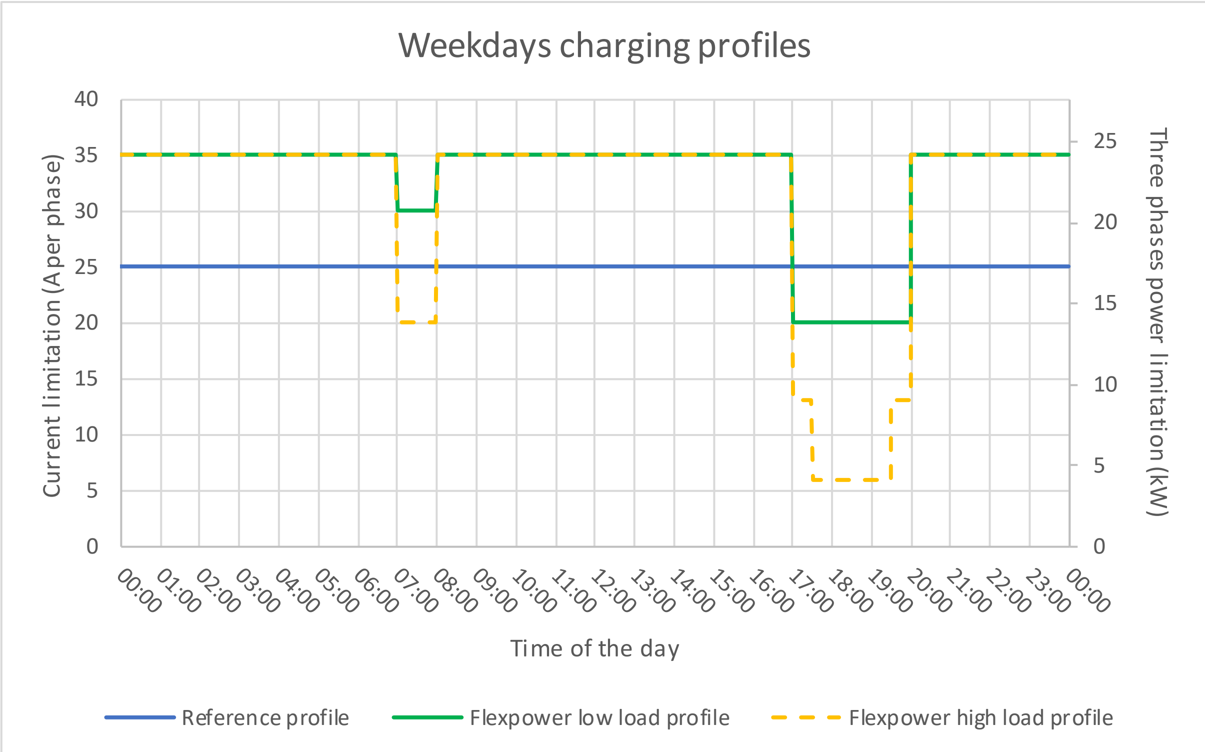

Figure 10: Weekday profiles for residential areas with a high/low load compared to the normal 3x25 A connection profile. The horizontal axis shows time in hours, the vertical axis shows current per phase in Amperes.

2.3.2. Weekend profiles

The weekend profiles are applied on Saturdays and Sundays, but also during the bank holidays. In this configuration, the current for the high load is only limited during the morning peak to 25 A.
During the evening peak, between 17:00 to 20:00, the current on both the low and high profile is limited to 30A and 13A respectively, as shown in Table 6 and illustrated in Figure 11.

Table 6: Flexpower 1 charging profiles during weekends. Currents are in amperes and powers in kW for 3 phases.

Time interval	Profiles limitations					
	Reference		Low load		High load	
	Current (A)	Power (kW)	Current (A)	Power (kW)	Current (A)	Power (kW)
00:00 – 07:00	25	17.25	35	24.15	35	24.15
07:00 – 08:00	25	17.25	35	24.15	25	17.25
08:00 – 17:00	25	17.25	35	24.15	35	24.15
17:00 – 17:30	25	17.25	30	20.7	13	8.97
17:30 – 19:30	25	17.25	30	20.7	13	8.97
19:30 – 20:00	25	17.25	30	20.7	13	8.97
20:00 – 00:00	25	17.25	35	24.15	35	24.15

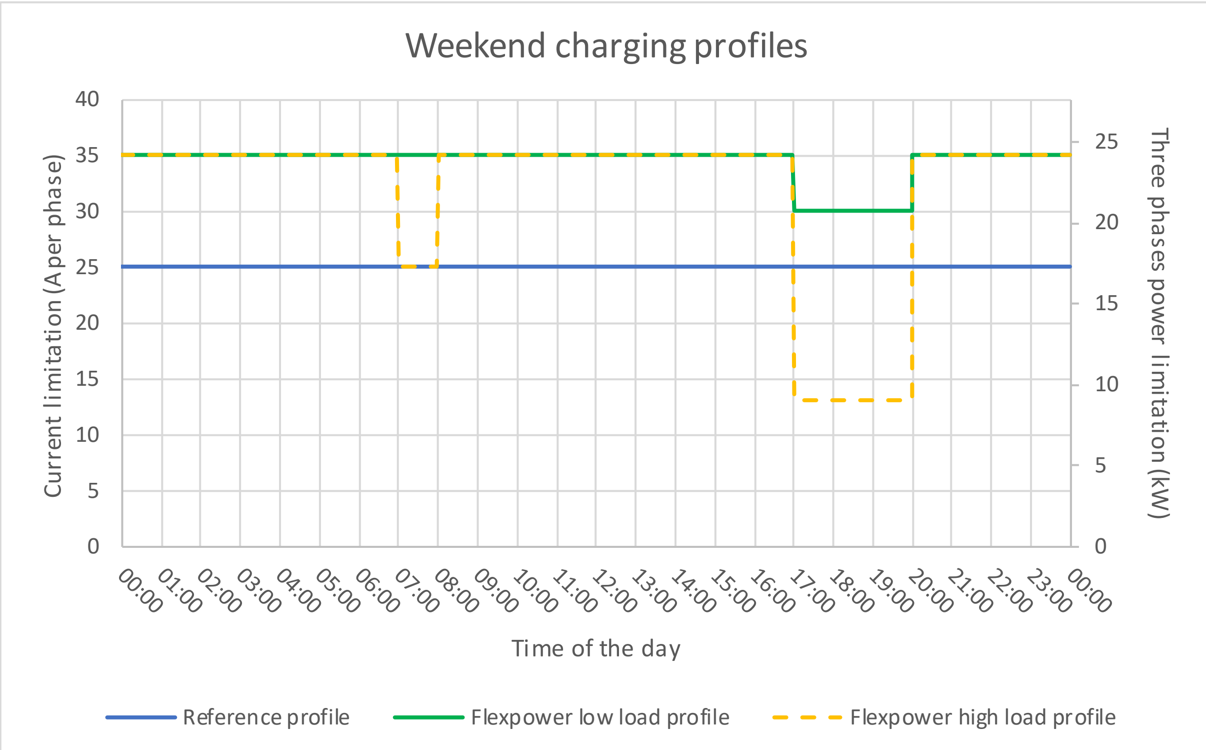

Figure 11: Weekday profiles for residential areas with a high/low load compared to the normal 3x25 A connection profile. The horizontal axis shows time in hours, the vertical axis shows current per phase in amperes.

2.3.3. Holiday profiles

The holiday profile is very similar to the weekend profile (see 2.3.2). The only difference is the start of the evening peak limitation, occurring at 18:00 instead of 17:00 in the other profile. The details are visible in Table 7 and plotted in Figure 12.

Table 7: Flexpower 1 1 charging profiles during holidays. Currents are in amperes and powers in kW for 3 phases

Time interval	Profiles limitations					
	Reference		Low load		High load	
	Current (A)	Power (kW)	Current (A)	Power (kW)	Current (A)	Power (kW)
00:00 – 07:00	25	17.25	35	24.15	35	24.15
07:00 – 08:00	25	17.25	35	24.15	25	17.25
08:00 – 18:00	25	17.25	35	24.15	35	24.15
18:00 – 20:00	25	17.25	25	17.25	13	8.97
20:00 – 00:00	25	17.25	35	24.15	35	24.15

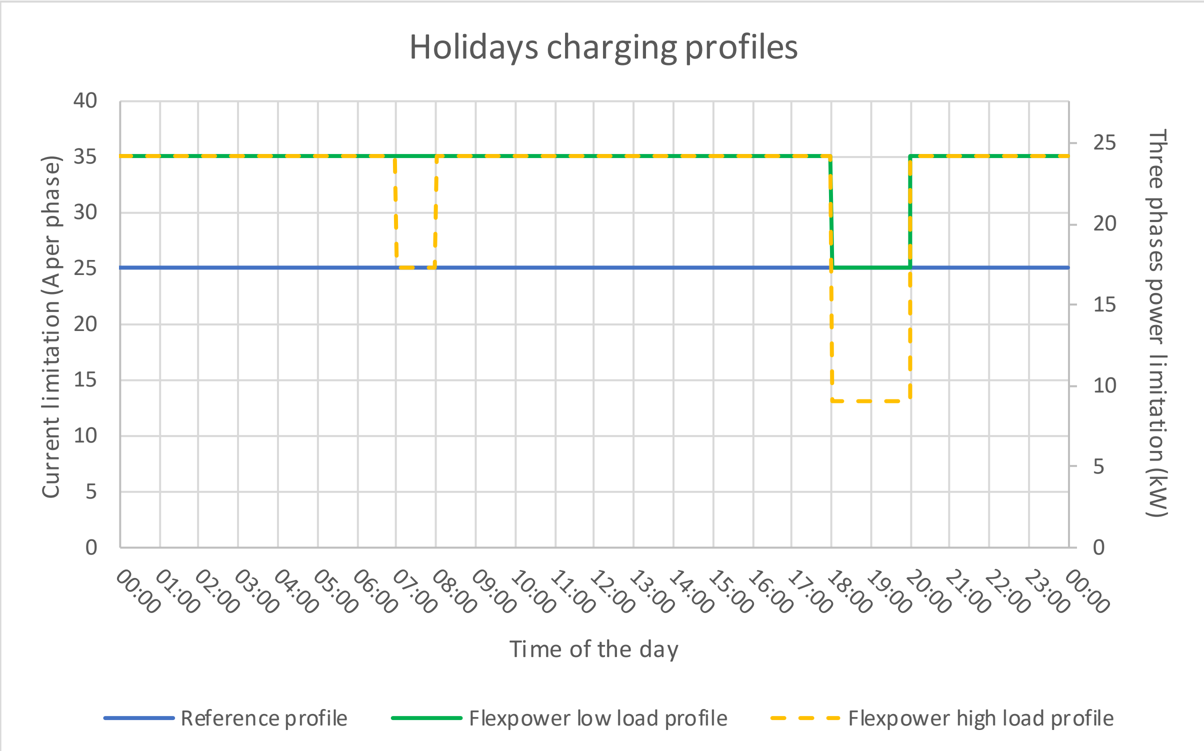

Figure 12: Holiday profiles for residential areas with a high/low load compared to the normal 3x25 A connection profile.

2.3.4. Daily energy available

Even if the Flexpower 1 profiles limit the power at some moments of the day, the total amount of energy available during the complete day is higher than in the Reference case. See the details in Table 8.

Table 8: Daily energy (in kWh) available for the various profiles

Profiles	Reference	Flexpower 1	
		Low load	High load
Weekdays	414 (100%)	545 (132%)	514 (124%)
Weekends	414 (100%)	569 (138%)	527 (127%)
Holidays	414 (100%)	566 (137%)	542 (131%)

2.4. *Software selectivity*

2.4.1. Conventions

The wire colours used in the Figure 13 to Figure 22 are based on the IEC 60446.

Table 9: Colour wiring according to the IEC 60446 and used in this document.

Wire colours	Functions
Brown	L1 phase
Black	L2 phase
Grey	L3 phase
Blue	Neutral

Table 10: Single and three phases vehicles pictograms used in this document.

Single-phase vehicle (3.7 kW or 7.4 kW)

Three phase vehicle (11 kW or 22 kW)

2.4.2. Charging station phases rotation

The charging stations are coupled to the low voltage electrical grid via a three phase connection. In the reference stations configuration, the grid connection is limited to 25 A and each connector of the charging station is limited to 16 A. The control electronic allows the charging of the vehicle by closing the contactor associated to each connector. Between these two connectors, there is a phase rotation, allowing simultaneous charging of two single-phase vehicles with maximum power. This is illustrated in Figure 13.

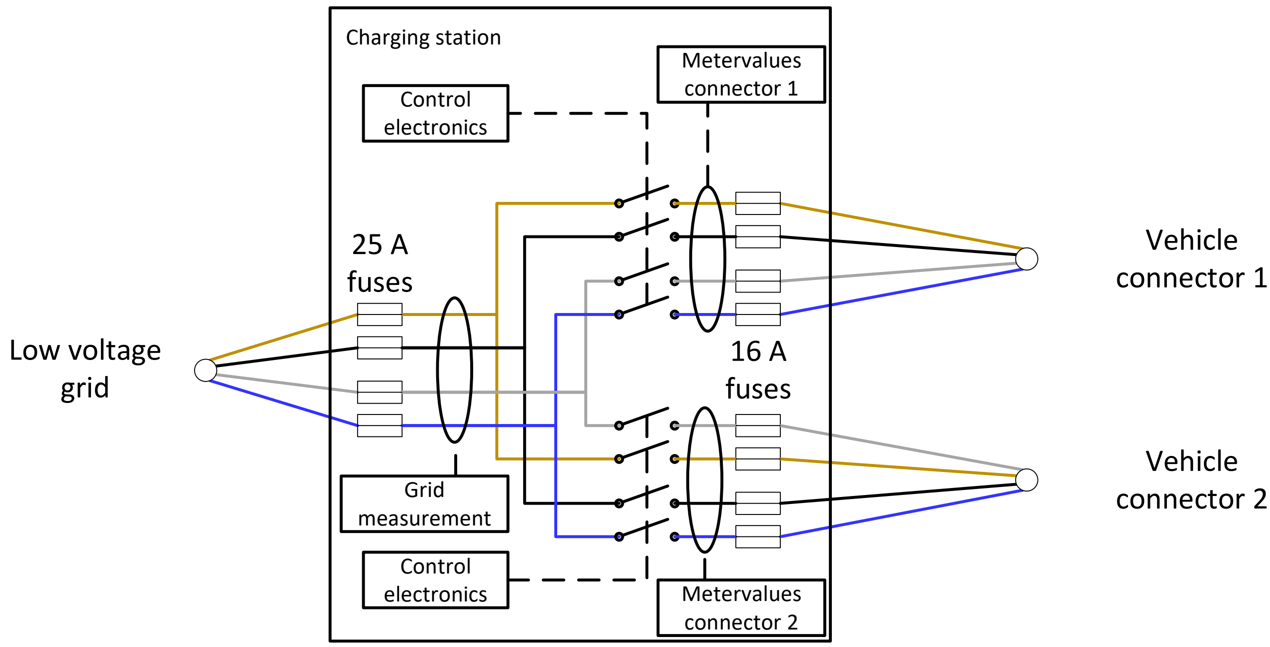

Figure 13: Protections and phases rotation for the reference charging stations. The wire's order is shifted between the connector 1 and 2.

In the Flexpower 1 configuration, the phase rotation is the same, but the maximum protection current on the grid connection is upgraded to 35 A and each connector can deliver up to 32 A. In reality, the fuses are not present, and the current is monitored by the control electronics of the charging station. They are however drawn to illustrate the current limitations in the Figure 14.

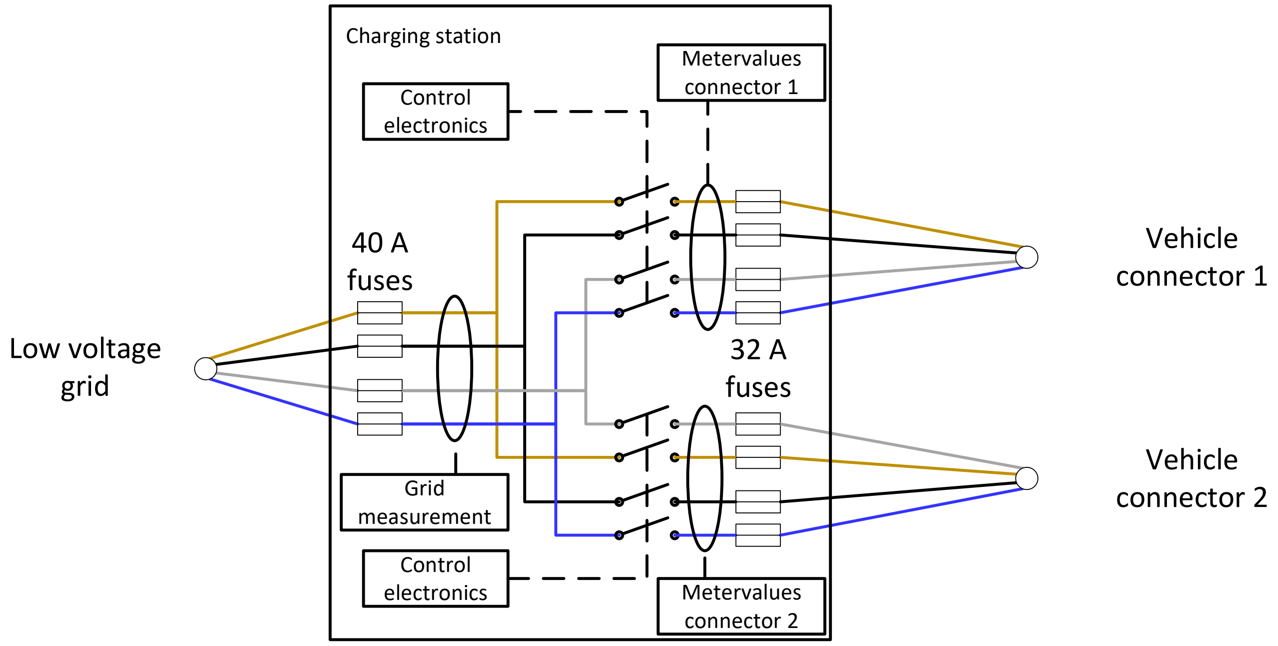

Figure 14: Protections and phases rotation for the Flexpower 1 charging stations

An explanation of the various configurations is detailed in the chapters 2.4.3 to 2.4.6. A summary table is presented in section 2.4.7.

2.4.3. Single vehicle connected

The power available for each of the two individual connectors changes with the number of connectors that is occupied, since the charging station has to distribute its current over both connectors.
The reference profile charging stations are configured to deliver at most 16 A per connector, even if the grid can deliver up to 25 A. When one vehicle is connected, the full power (16 A / 11 kW) is available (see Figure 15).

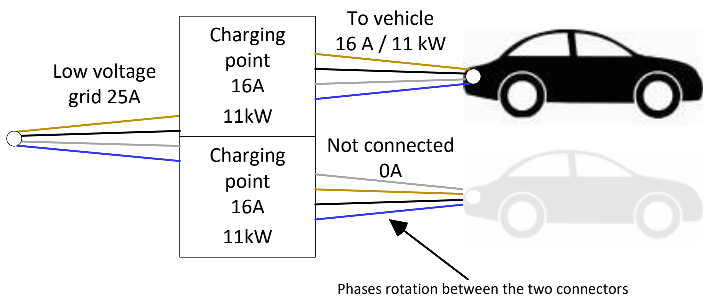

Figure 15: Current limitations for the reference charging stations. In this configuration, only one three phases vehicle is connected, taking full advantage of the power available.

The Flexpower 1 charging stations are connected to a three phases (3ϕ) 35 A grid connection. The maximum current is internally limited by the charging station to 32 A [7] per connector, as illustrated in Figure 16.

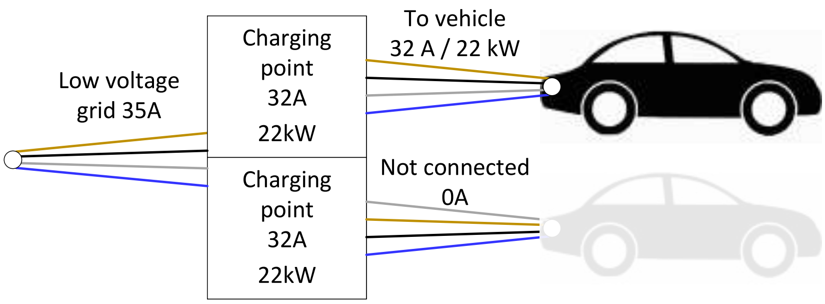

Figure 16: Power limitations in Flexpower 1 station. In this configuration, only one three phases vehicle is connected, taking full advantage of the power available.

2.4.4. Software selectivity with two three phase vehicles connected

If a second three phase vehicle is connected on the other connector of the station, the maximum current that the grid connection can deliver is shared between the two vehicles. Consequently, both vehicles charge with 8.6 kW or 12.5 A per phase (see Figure 17). This software selection is applied even if the second vehicle does not have the capacity to use the power available (PHEV, charging on a single-phase with 3.7 kW for example).

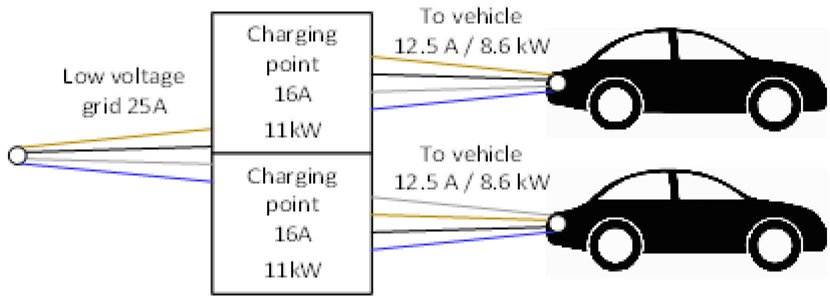

Figure 17: Illustration of the software selectivity principle for reference stations. Two three phases vehicles are connected. The software selectivity equally shares the power available from the grid between the two vehicles.

In the Flexpower 1 configuration, if two vehicles are connected, the current from the grid is equally shared between the two vehicles (17.5A or 12.1 kW), even if one of the two vehicle is unable to take advantage of it (see Figure 18).

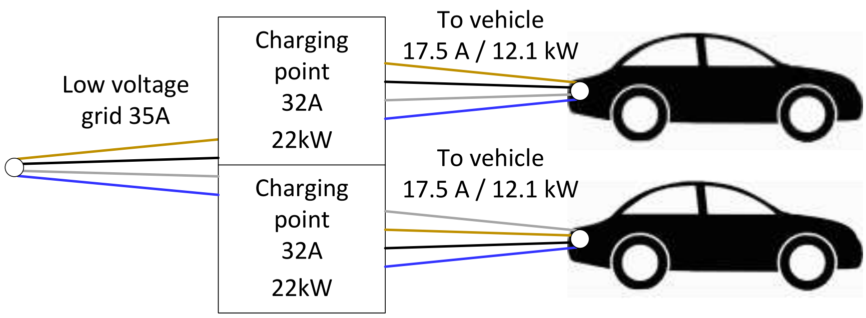

Figure 18: Illustration of the software selectivity principle for Flexpower 1 stations. Two three phases vehicles are connected. The software selectivity equally shares the power available from the grid between the two vehicles.

2.4.5. Software selectivity with one single and one three phases vehicles connected

This case is similar to the previous one. The difference is that, obviously, the single-phase vehicle will use only one phase of the connector. The case is illustrated in Figure 19 for the reference profile and in Figure 20 for the Flexpower 1.

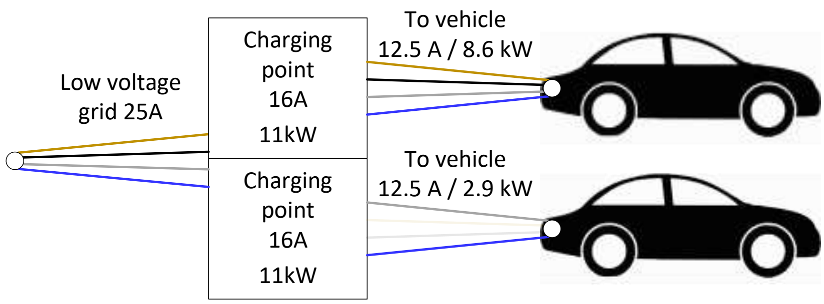

Figure 19: Illustration of the software selectivity principle for reference stations. One three phases vehicle (above) and a single-phase vehicle (bellow) are connected on the same charging station. The current per phase is in the same way limited for both vehicles.

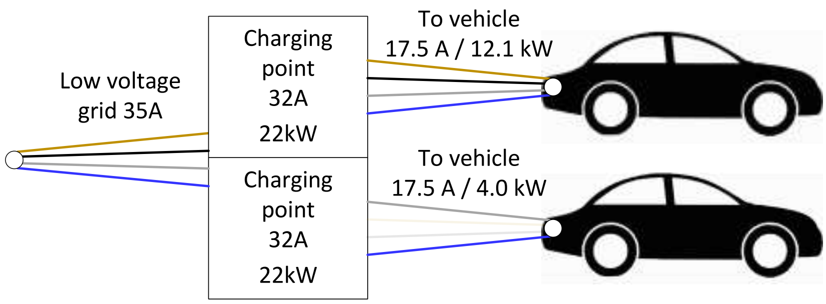

Figure 20: Illustration of the software selectivity principle for Flexpower 1 stations. One three phases vehicle (above) and a single-phase vehicle (bellow) are connected on the same charging station. The current per phase is in the same way limited for both vehicles.

2.4.6. Software selectivity with two one single-phase vehicles connected

This configuration is very advantageous for the single-phase vehicles. Indeed, due to the phase rotation between the two connectors, the two single-phase vehicles are able to charge at the maximum speed allowed by the charging station. Seen from the grid, two phases are used at their maximum capacity whereas the last one is left unused.

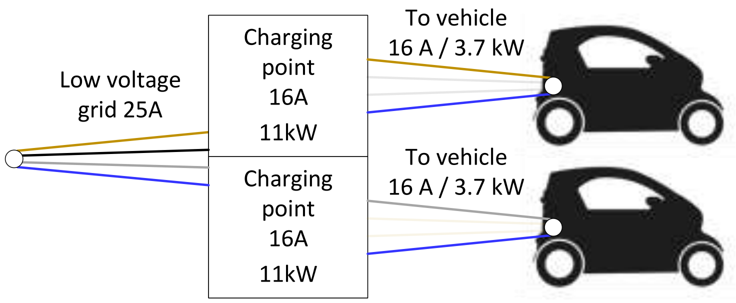

Figure 21: Illustration of the software selectivity principle for Flexpower 1 stations. Two single-phase vehicles are connected. Thanks to the phases rotation, both vehicles are able to charge at the maximum possible power.

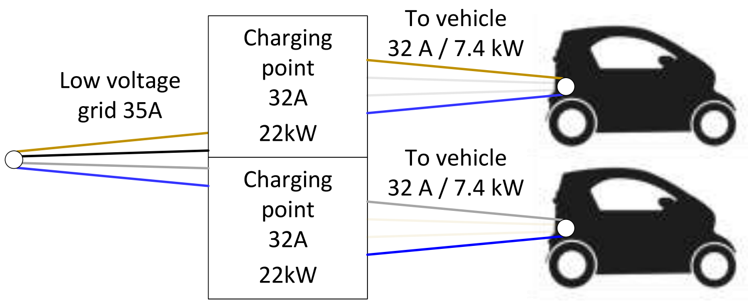

Figure 22: Illustration of the software selectivity principle for Flexpower 1 stations. Two single-phase vehicles are connected. Thanks to the phases rotation, both vehicles are able to charge at the maximum possible power.

2.4.7. Maximum charging powers and configurations

From the previous pieces of information, Table 11 (no restriction) and Table 12 (heaviest profile during peak hours, between 17:30 and 19:30) are built to summarise the various configurations and obtainable powers.
At the top of the occupancy column, the 1 and 2 numbers designate the identifier of the connector. In this column, three values are possible:

- Free: no vehicle is linked to the connector.
- 1ϕ: A one phase charging capacity vehicle is connected.
- 3ϕ: A three phases charging capacity vehicle is connected.
- *: In the case of two 1ϕ vehicles, due to the phase rotation, the two vehicles are still able to charge a maximum power.

The load factor is the ratio between the total power delivered by the connectors and the maximum power the grid connection can deliver (on three phases). Losses in the charging station are neglected.

The Flexpower 1 / Reference ratio is the ratio between the power that could be delivered by the Flexpower 1 profile and the reference profile for the same vehicle configuration. The ratio is not computed when no vehicle is connected.

Table 11: Overview of the different charging configurations and maximum related powers outside the peak hours.

Profiles	Connectors						Grid			Flexpower / Reference ratio
	Occupancy		Current (A)		Power (kW)		Current (A)	Power (kW)	Load factor	
	1	2	1	2	1	2				
Reference	Free	Free	0	0	0	0	0	0	0%	
	1ϕ	Free	16	0	3.7	0	16	3.7	21%	
	1ϕ	1ϕ	16	16	3.7	3.7	16	7.4	43%	
	3ϕ	Free	16	0	11	0	16	11	64%	
	3ϕ	3ϕ	12.5	12.5	8.6	8.6	25	17.2	100%	
	3ϕ	1ϕ	12.5	12.5	8.6	2.9	25	11.5	67%	
Flexpower	Free	Free	0	0	0	0	0	0	0%	-
	1ϕ	Free	32	0	7.4	0	32	7.4	31%	200%
	1ϕ	1ϕ	32	32	7.4	7.4	32	14.8	61%	200%
	3ϕ	Free	32	0	22.1	0	32	22.1	92%	201%
	3ϕ	3ϕ	17.5	17.5	12.1	12.1	35	24.2	100%	141%
	3ϕ	1ϕ	17.5	17.5	12.1	4	35	16.1	67%	140%

From the last column of the Table 11, it is visible that outside the limitation periods, the power available is always higher for the Flexpower 1 profile than for the reference profile. It is interesting to notice that even for vehicles that could only charge with 16 A, the Flexpower 1 is beneficial as it allows two vehicles to charge simultaneously on the same charging station with the maximum power, whereas they would otherwise be limited to 12.5 A.

Table 12: Overview of the different charging configurations and maximum related powers during the most restricted peak hours (weekday, between 17:30 and 19:30).

Profiles	Connectors						Grid			Flexpower / Reference ratio
	Occupancy		Current (A)		Power (kW)		Current (A)	Power (kW)	Load factor	
	1	2	1	2	1	2				
Reference	Free	Free	0	0	0	0	0	0	0%	
	1ϕ	Free	16	0	3.7	0	16	3.7	21%	
	1ϕ	1ϕ	16	16	3.7	3.7	16	7.4	43%	
	3ϕ	Free	16	0	11	0	16	11	64%	
	3ϕ	3ϕ	12.5	12.5	8.6	8.6	25	17.2	100%	
	3ϕ	1ϕ	12.5	12.5	8.6	2.9	25	11.5	67%	
Flexpower	Free	Free	0	0	0	0	0	0	0%	-
	1ϕ	Free	6	0	1.4	0	6	1.4	6%	38%
	1ϕ	1ϕ	6	6	1.4	1.4	6	2.8	12%	38%
	3ϕ	Free	6	0	4.1	0	6	4.1	17%	37%
	3ϕ	3ϕ	3	3	2.1	2.1	6	4.2	17%	24%
	3ϕ	1ϕ	3	3	2.1	0.7	6	2.8	12%	24%

During the most restricted hours (from 17:30 to 19:30), it is clear from Table 12 that vehicles will charge slower during the peak hours. The power available will drop down to 0.7 kW for the single-phase vehicle, 25% of what is available for the reference station. The low voltage electrical network will thus be less loaded, which is the objective of this pilot.

2.5. *Theoretical benefit of Flexpower 1 on reference profile*

2.5.1. Assumptions and method

It is possible to make a more theoretical detailed analysis of the benefit of the Flexpower 1 profile over the reference profile. To do so, we can compute the ratio of energy available at different moments of the day for different connection lengths.

The computation is done twice. The first time for the vehicles with a maximum charging capacity of 16 A (Figure 23) and the second for a maximum of 32 A (Figure 24). In both cases, only the three phases vehicles are considered. For both plots, the horizontal axis shows the starting time of the charging session. The vertical axis shows the duration of the charging session.

The colour of the points shows the total energy ratio between the Flexpower 1 and the reference profile. The colour gradient ranges from red to green via the yellow. The colours indicate:

- Red to yellow: the ratio is below 1 during this session. The Flexpower 1 profile delivers less energy than the reference profile.
- Yellow, the ratio is 1, both profiles deliver the same amount of energy.
- Yellow to green, the ratio is higher than 1 during this session. The Flexpower 1 profile delivers more energy than the reference profile.

In both cases, it is assumed:

- The vehicle can charge on three phases (16 A -> 11 kW, 32 A -> 22 kW).
- The battery capacity is 50 kWh. This is oversized for the 16 A vehicles, but it allows for a comparison.
- The battery is completely depleted (SOC is 0%) at the beginning of the session.
- Charging is done at full power until the battery is completely full (no decay above 80% SOC).

2.5.2. For the 16A vehicles

The 16 A vehicles have a charging capacity of 3.7 kW on 1 phase or 11 kW on three phases. The Table 13 and Figure 23 show the theoretical results for the three phase vehicles with a battery of 50 kWh.

On Figure 23, most of the points are yellow, meaning an energy ratio of 1 between the two profiles. The red area around 18h is due to the severe limitation during the peak hours. This area is the only case where this category of vehicles suffers from restriction. Indeed, during the morning limitation, the power that the Flexpower 1 can deliver is higher than the one the vehicles can accept, so there is no limitation.

If the vehicle is connected long enough, even during the limitation period, the ratio goes to 1 as in both configurations, because the battery of the vehicle reaches full charge.

No point is higher than 1 in this plot. This category of vehicle is thus not able to take advantage of the supplementary power delivered by the Flexpower 1 profile as shown in the Table 13.

Table 13: Comparison of energy availability between the Flexpower 1 and the reference charging stations

Energy available	Percentage of cases
Lower	10%
Higher	0%
Equal	90%

Though the result looks negative, there is one configuration where the Flexpower 1 is beneficial for the 16 A vehicles, namely when both connectors are occupied on the charging station. Indeed, like explained in chapter 2.4.7, if two vehicles are charging simultaneously on a Flexpower 1 station, they will be able to charge, at full capacity outside the peak periods.

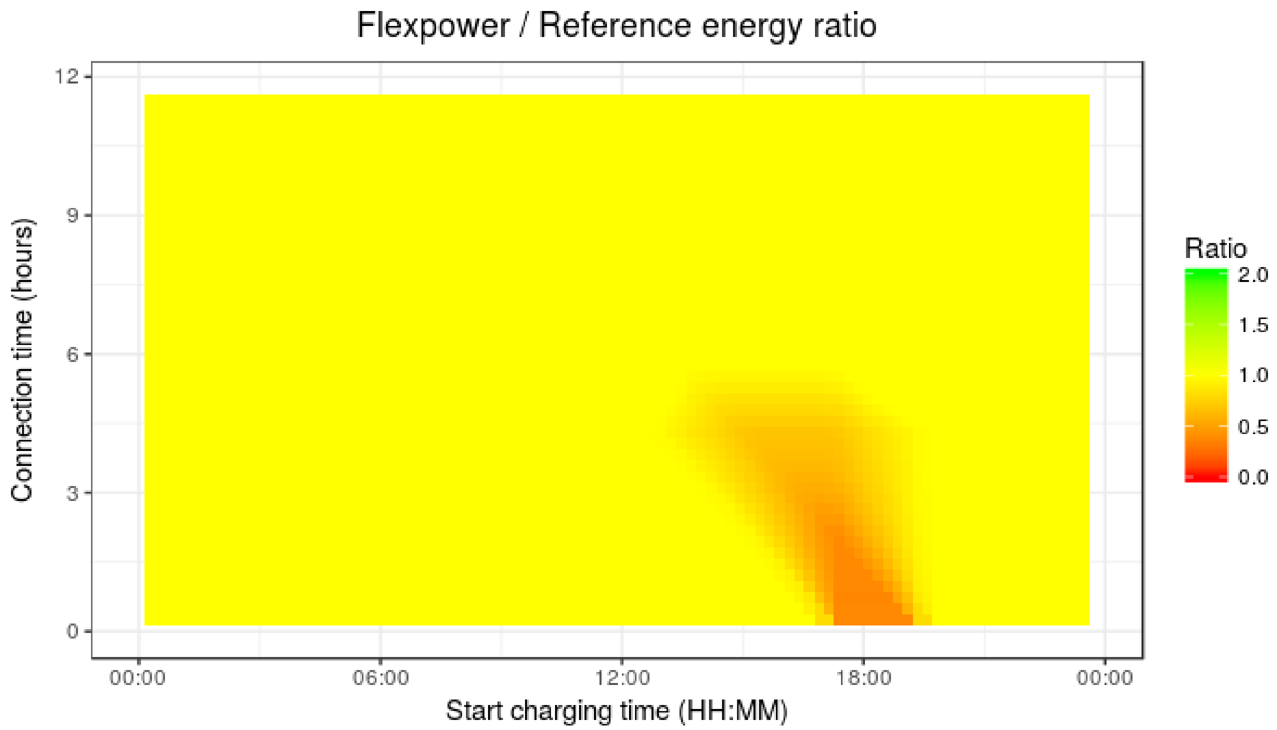

Figure 23: Evaluation of the energy benefit of the Flexpower 1 profile regarding to the reference one for the three phases 16 A vehicles.

2.5.3. For the 32 A vehicles

The 32 A vehicles have a charging capacity of 7.4 kW on one phase or 22 kW on three phases. The computation is made for the 22 kW vehicles.
The result is more positive. Indeed, Table 14 shows that during 34% of the time, the charged energy is higher and it is lower in only 3% of the cases.

Table 14: Comparison of energy availability between the Flexpower 1 and the reference charging stations for the 32 A three phases vehicles.

Energy available	Percentage of cases
Lower	3%
Higher	34%
Equal	63%

This positive result is visible on Figure 24 with the green area close to the horizontal axis. Even if they are penalised during the evening restriction periods, from 17h to 20, when only 38% of the reference energy is available, the higher available power makes the majority of the plot green. This is explained by the fact that the 32 A vehicles can compensate the low power periods when the current restriction is removed.

Obviously, as a vehicle is longer connected, the ratio between the two profiles also reaches 1 as the battery is getting fully charged. The limited and advantageous periods are then no longer relevant.

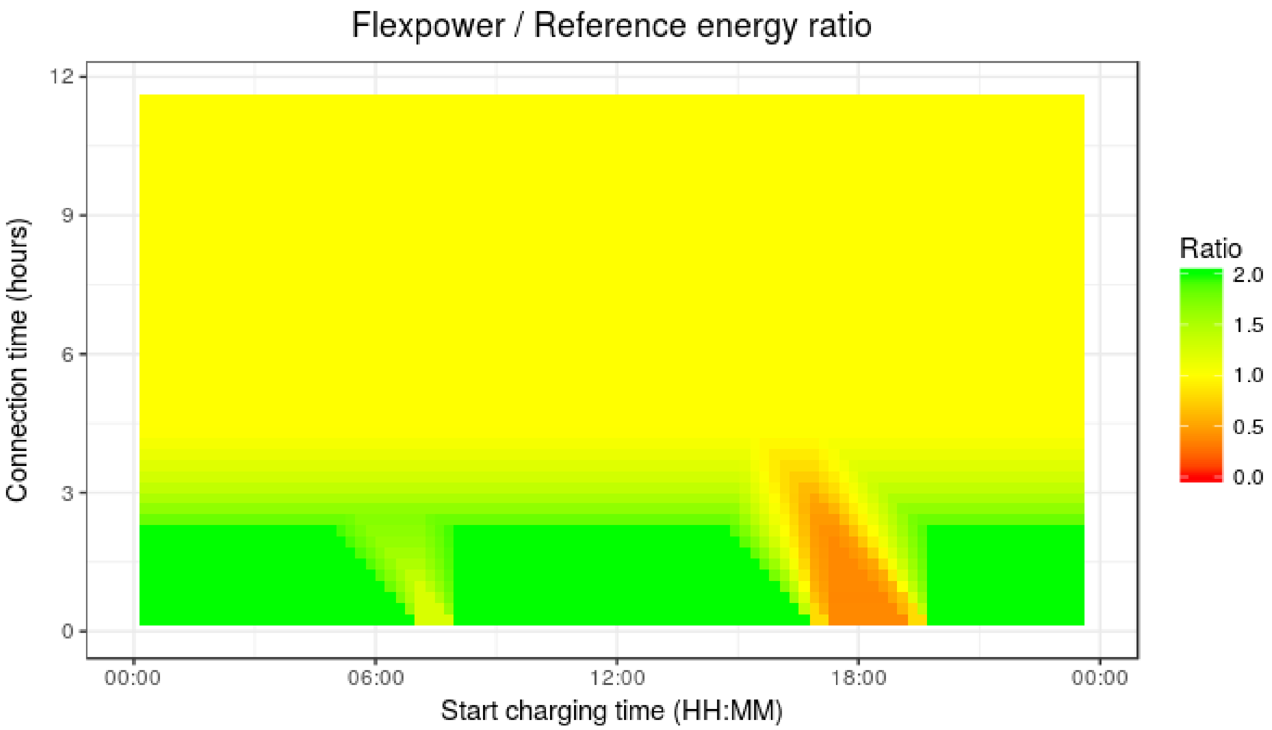

Figure 24: Evaluation of the energy benefit of the Flexpower 1 profile compared to the reference profile for the three phase 32 A vehicles.

The Flexpower 1 profile has a globally positive influence on the amount of energy provided to charge the vehicle's battery.

3. Hypothesis and research questions

3.1. Research questions

To drive this research, several research questions were formulated with the partners:

Table 15: list of research questions.

No	Hypothesis	Description
1	EVs are charged faster	Increased capacity during off-peak hours allows for faster charging, which offsets the reduction in charging speed during peak hours.
2	Users do not experience a reduction in ease of use	Users have sufficient flexibility to cope with the changing charging speeds.
3	Smart charging results in higher charge volumes	Increased capacity during valley hours allows for higher sales volumes on short charging sessions, which offsets the lower sales volumes for short session during peak hours
4	Smart charging results lowers connection costs per charged kWh	Same as H3, with the addition that costs for Flexpower 1 are lower than the costs for a static connection.
5	Smart charging improves the occupancy/efficiency of charging stations	Creates awareness amongst users with regards to their charging time, which causes them to move their EV after they are fully charged.
6	The utilisation rate of the distribution grid can be safely improved without exceeding grid capacity limits	Flexpower 1 allows for more electricity consumption during valley hours, which improves the overall utilisation rate of the grid.

During the investigations, the questions 4 and 6 were not treated because they could not be answered by data analysis.

3.2. Hypothesis 1 – Electrical vehicles are charging faster

The vehicles will charge faster if the average power at Flexpower 1 charging stations is higher than that at the reference stations.

To evaluate this hypothesis, the average power is computed for each quarter hour of the day for the two considered profiles. This is plotted in Figure 25.

Interestingly, even for the constant reference profile, the power variates. This variation is caused by the characteristics of the vehicles (such as battery state of charge) or environmental conditions (temperature) [8].

The Flexpower 1 profile shows a higher power than the reference profile most of the day. Indeed, only when it is heavily restricted during the peak hours, the average power delivered is below the reference profile average. If a user is using a Flexpower 1 charging station during these peak hours, it will charge slower for a short period of time. Otherwise, the Flexpower 1 definitively offers more power and thus faster charging of the vehicle.
N.B. the results are an average of all charging sessions, and therefore a mixture of short sessions, long sessions, PHEVs and BEVs. Only data during active charging are used, not during connection without charging (when the battery is full).

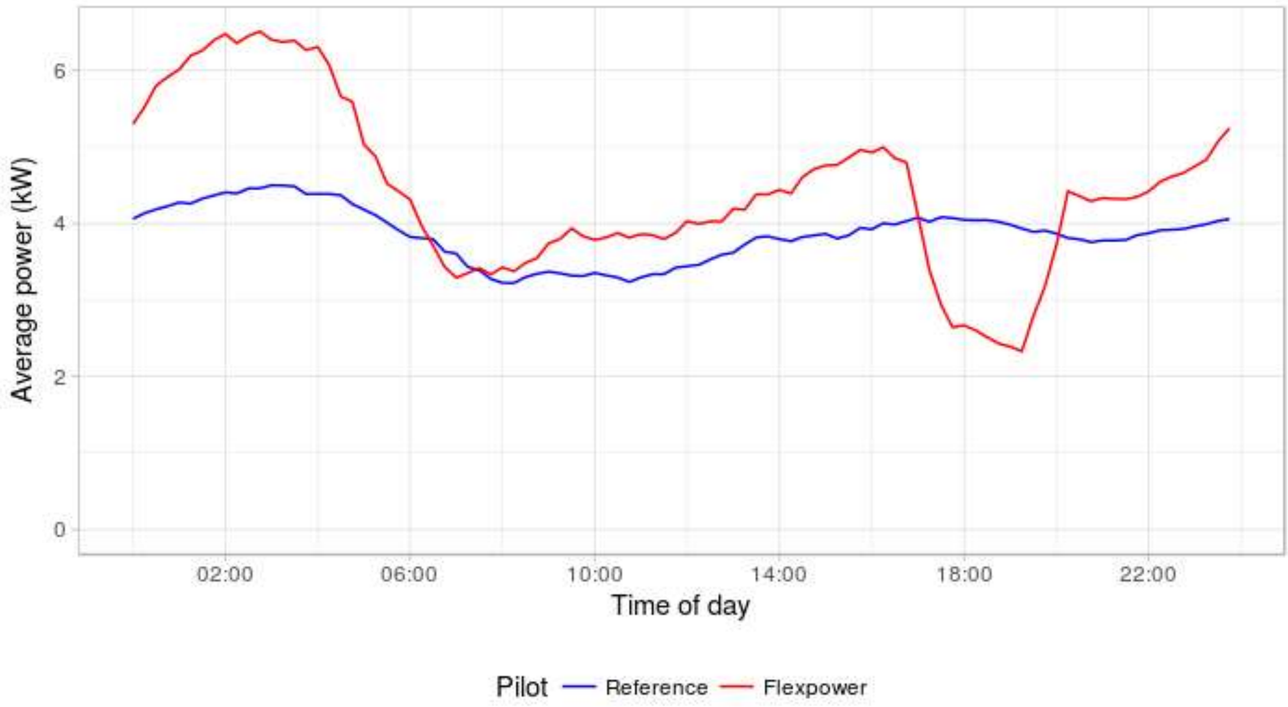

Figure 25: Average charging power (in kW) for the reference stations (blue) and the Flexpower 1 stations (red).

Table 16: Percentages of vehicle reaching full charge.

Charging profile	**Vehicle categories**			
	3, 7 kW	**7, 4 kW**	**11 kW**	**22 kW**
Reference	47%	51%	47%	60%
Flexpower 1	49%	50%	46%	56%

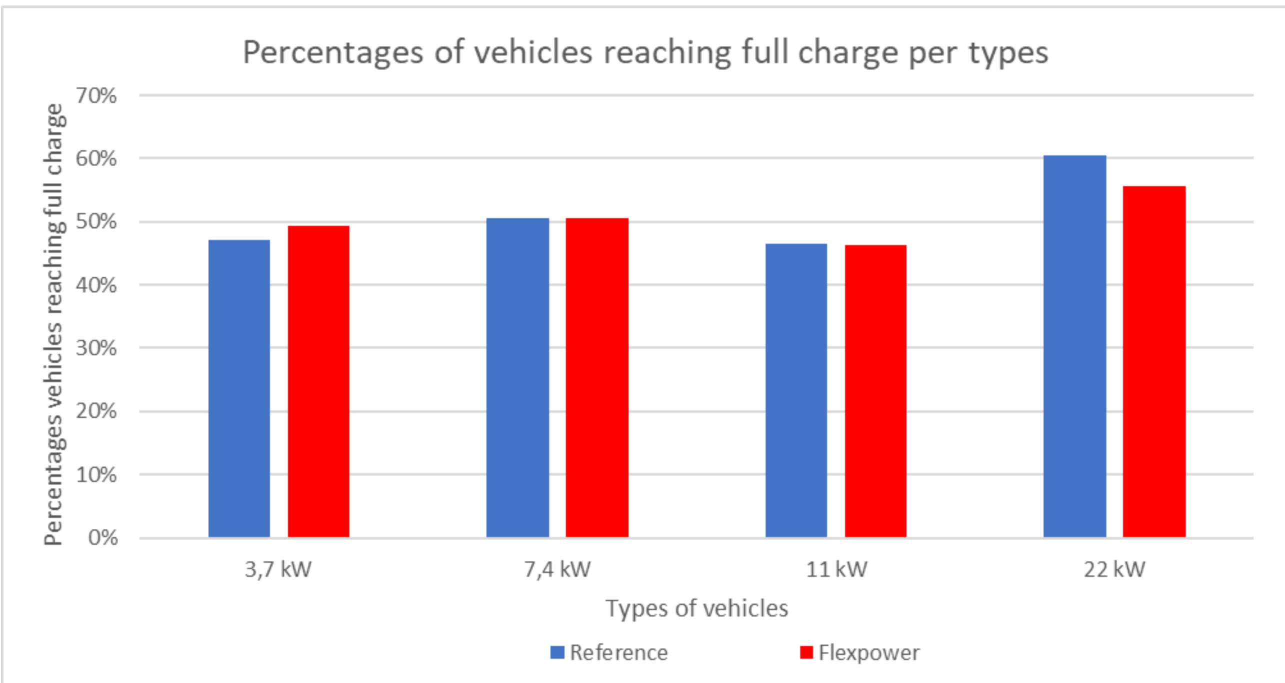

Figure 26: Per type of vehicles and charging station, percentage of vehicles reaching full charge.

Another KPI reflecting the charging speed is the number of battery vehicles reaching full charge during a session. A battery is considered full if at least two intervals of 15 minutes are showing a null (0 kW) power. Table 16 and Figure 26 show a limited improvement for the 3.7kW, an equivalence for the 7.4 and 11 kW and even a decrease

for the 22 kW vehicles between the two type of profiles. This result is counterintuitive and in apparent contradiction with the results previously exposed in Figure 25.
The explanation is to find in the connection times per session, plotted in Figure 27. It shows the aggregated distributions of connection time for the 4 categories of vehicles. A peak is visible around 2 hours connection time for the flexpower station. This predominance of short connection sessions for the Flexpower charging stations remains until 7.5 hours. Above this time, the reference stations are dominant. It suggests that users utilise the faster charging speed to optimise the charging sessions, explaining why there is no improvement in the number of vehicles reaching full charge. With only the charging data available, it is impossible to tell if this is a conscious behaviour of the users or the result of an erroneous selection of the reference and flexpower stations.

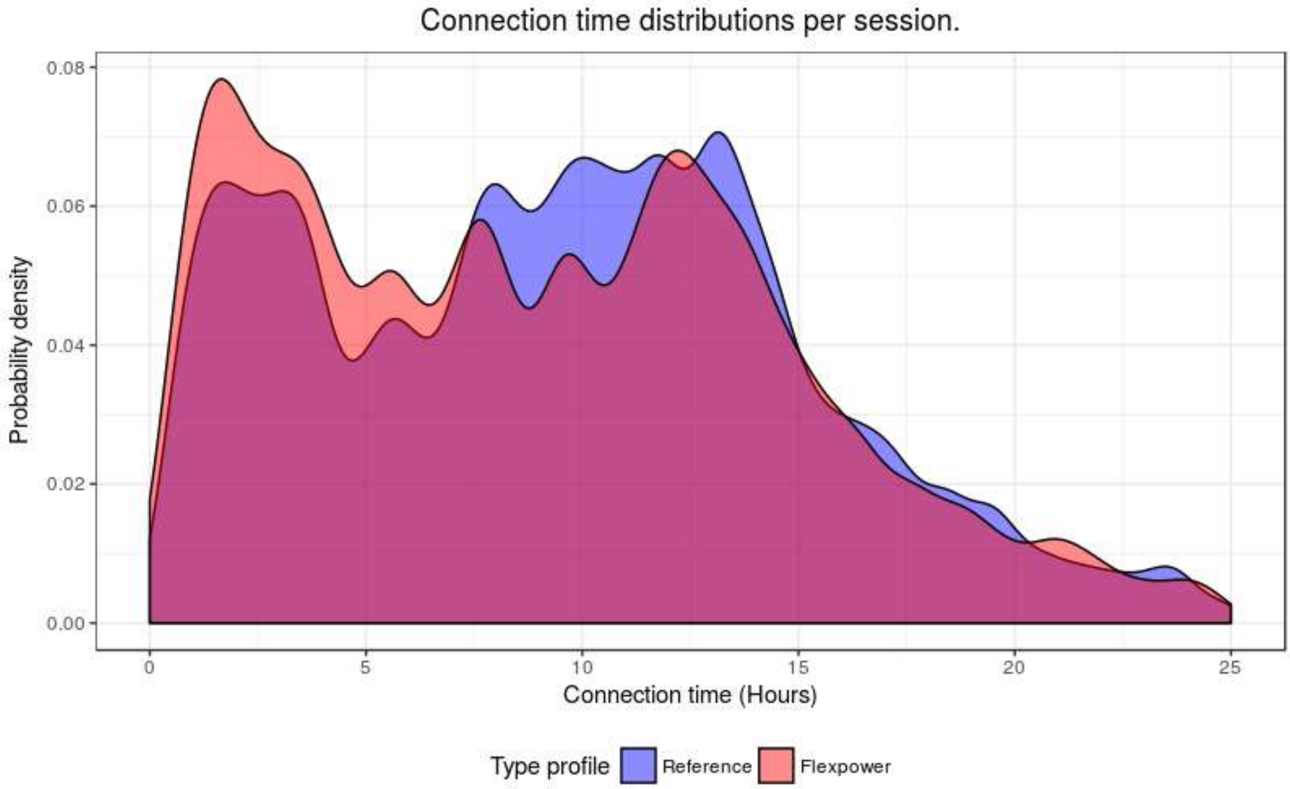

Figure 27: Connection time distributions per session for all types of vehicles.

Hypothesis 1 is confirmed. Except during the restricted period between 17:00hrs and 20:00hrs, the average power delivered by the Flexpower 1 station is higher and thus overall the vehicles are charging faster.

3.3. Hypothesis 2 – Users do not experience a reduction in ease of use

This hypothesis is evaluated by comparing the probability density distribution histogram of the charging powers between the Flexpower 1 and the reference. The values considered the average power for a 15 minutes interval when there is a charging activity, so excluding any idle time at the end of the session. The histogram is computed with bins of 0.1 kW width.

If both distributions are similar in shape, then the user experience will be similar in both cases. If there is a difference, this can signify advantages for the user (shift of the distribution to higher power) or disadvantages (shift to lower power). These two scenarios are not mutually exclusive – the Flexpower 1 profile can negatively affect a certain percentage of the users (e.g. short sessions in evening), but also be an advantage to another group of users (sessions during the day or late at night).
To keep the powers comparable, the probability densities are computed separately for each of the four vehicles categories.
It is interesting to note that these results cannot be reached by a purely theoretical analysis based on the profile characteristics. The actual impact on the users depends on *how* they interact with the charging stations. For example, if all sessions would last 24 hours, the impact would be totally different than if all users charge their

vehicles exactly between 17:00hrs and 20:00hrs even though the profiles are the same in both cases. This shows the importance of analysing actual data from users and the value of performing this experiment as an operational pilot.

3.3.1. 3.7 kW charging capacity vehicles

Figure 28 shows the probability density distribution for the 3.7 kW vehicles (single-phase, 16 A) for sessions using the reference profile (in blue) and the Flexpower 1 profile (in red).
Several peaks in the probability densities are visible and identified by a circled number. The explanations for these peaks are available in Table 17.

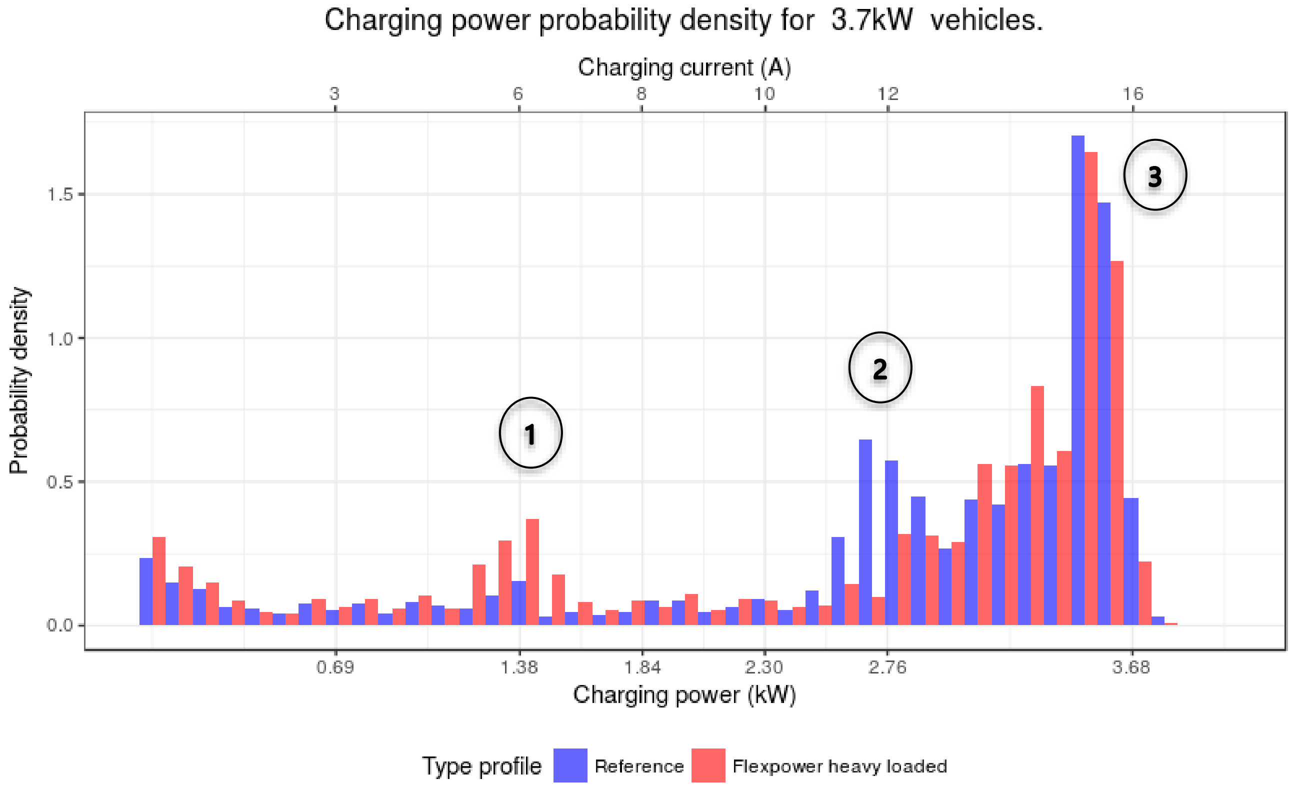

Figure 28: Flexpower 1 impact on 3.7 kW vehicles

Table 17: Charging cases for 3.7 kW vehicles

Marks	Current (A)	Power (kW)	Description
1	6	1.4	Flexpower 1, peak hours, the other connector is not occupied.
2	12	2.8	Reference profile, two vehicles connected to the station. At least one of the two vehicles is a three phase.
3	16	3.7	Reference profile, two single-phase vehicles, allowing each vehicle to charge with 16 A. Flexpower 1 profiles, one or two vehicles connected to the station.

Even if, as on Figure 28, both distributions are quite similar, some differences are visible. The penalty due to the Flexpower 1 current reduction during the peak hours is visible at the mark (1). This is a disadvantage for the Flexpower 1 profile in regard to the Reference one.
However, this penalty might be compensated by the higher power available outside the peak hours, mainly when two vehicles are connected to the station. Indeed, the peak, marked with (2) at 12 A disappeared on the Flexpower 1 station. It means that even with two vehicles connected, the user will take advantage of the highest power available outside the peak hours, even when two vehicles connected. This is an advantage for the Flexpower 1 profile.

3.3.2. 7.4 kW charging capacity vehicles

The 7.4 kW vehicles are able to charge on a single-phase circuit with 32 A. Thus, with the 16 A limitation of the reference stations, their maximum power is 3.7 kW.
This limitation is also clear in Figure 29, on the blue plot. The probability density distribution is below 4 kW, mark (4) of charging power, just like in Figure 28. The 12 A during the dual charging is also visible, reducing the charging capacities of the vehicle even more.
On the other hand, the Flexpower 1 stations show a wider plot, ranging up to 32 A / 7.4 kW. The higher density at high power shows that the 7.4 kW vehicles can take advantage of the higher power made available by the Flexpower 1 stations (see mark (6)).
Another visible point is during dual charging, which is done with a higher current (17 A/ 3.9 kW) than with the Reference profile (16 A / 3.7 kW) , as seen at mark (5).

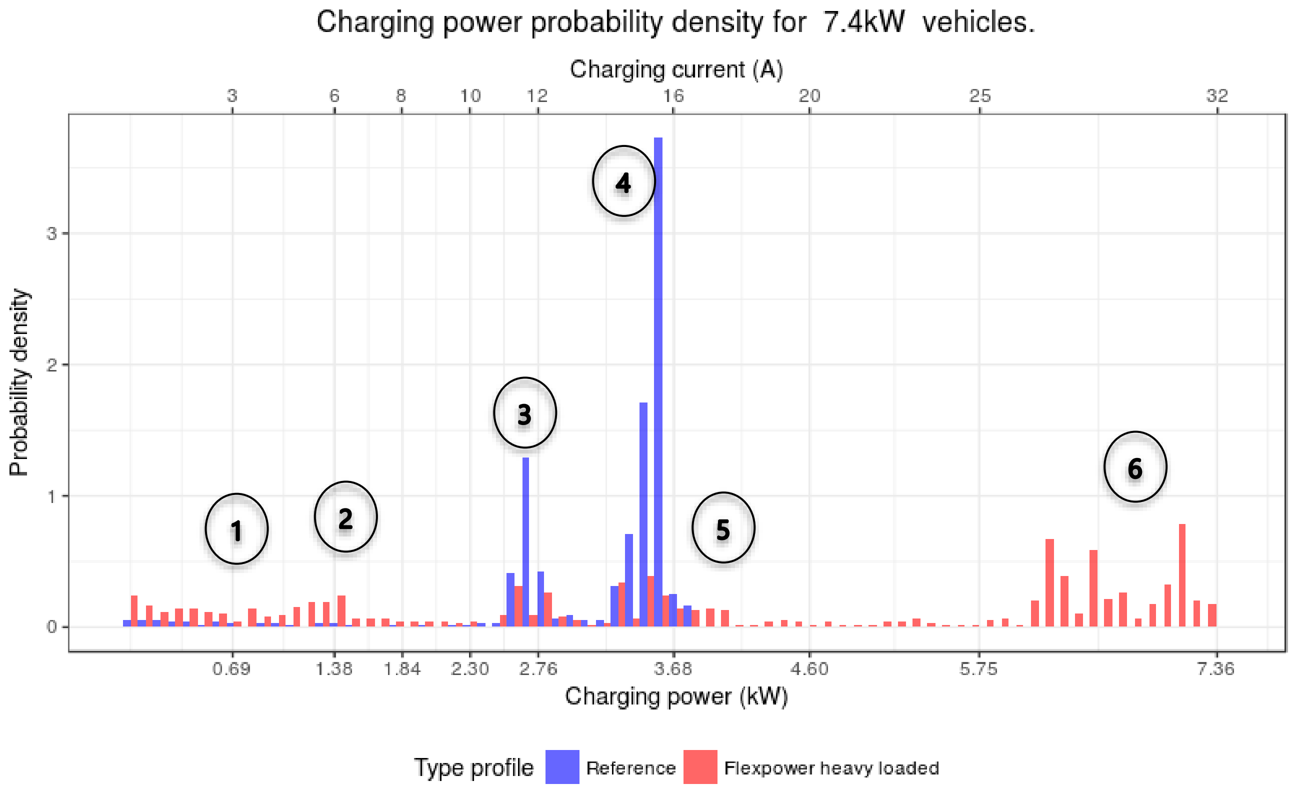

Figure 29: Flexpower 1 impact on 7.4 kW vehicles

Table 18: Charging cases for 7.4 kW vehicles

Marks	Current (A)	Power (kW)	Description
1	3	0.7	Flexpower 1, peak hours, both connectors are occupied.
2	6	1.4	Flexpower 1, peak hours, the other connector is not occupied.
3	12	2.8	Reference profile, two vehicles connected to the station. One is a single-phase (the 7.4 kW) and the second three phases.
4	16	3.7	Reference profile, one or two single-phases vehicles connected.
5	17	3.9	Flexpower 1 profiles, two vehicles connected to the station. One is a single-phase (the 7.4 kW) and the second three phases.
6	32	7.4	Flexpower 1 profiles, two vehicles connected to the station. Both are single phase. The spread in the peak is probably linked with the fact that some vehicles aren't really able to reach the full 32 A charging current.

Figure 29 illustrates the advantage of the Flexpower 1 profile in regard to the reference one. With the reference profile, the 7.4 kW vehicles are restricted to charge at half of their capacities. With the Flexpower 1 profile, this category of vehicles is able to reach their full potential. Even with two vehicles connected to the station, they are still able to charge with full power, thanks to the phase rotation.

Even when cohabitating with a three phases vehicle, the charge is still faster than the reference profile, allowing to charge with 17.5 A instead of 12.5 A.

3.3.3. 11 kW charging capacity vehicles

Like the 3.7 kW vehicles, the 11 kW plot (Figure 30) shows comparable probability density distributions for the reference and Flexpower 1 charging stations. This is due to the maximum charging current of 16 A.
The result in this plot is in line with the conclusion of Figure 26, where the Flexpower 1 station offered similar ease of use as the reference charging stations.

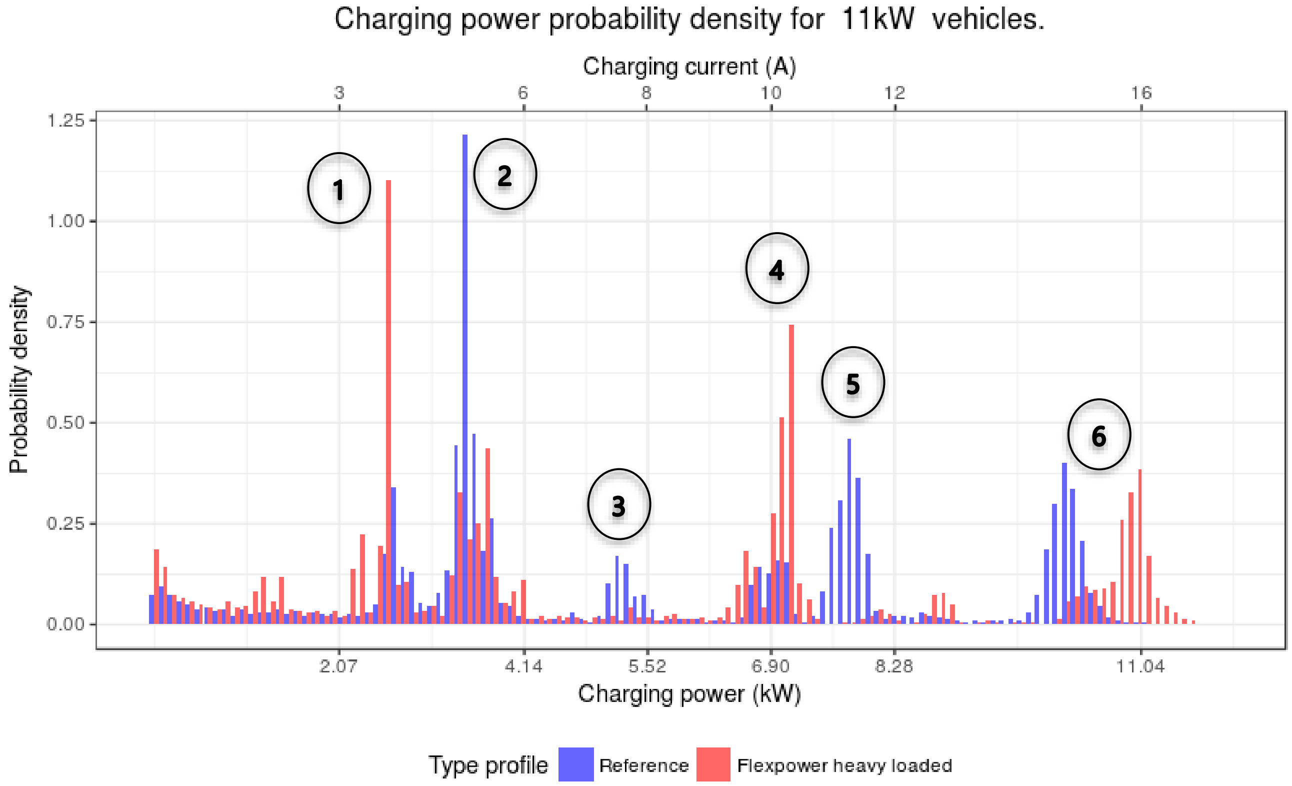

Figure 30: Flexpower 1 impact on 11 kW vehicles

Table 19: Charging cases for 11 kW vehicles

Cases	Current (A)	Power (kW)	Description
1	3.75	2.6	This peak doesn't match with any three phases profile configuration. The most plausible is a wrong detection of a single-phase vehicles (4 A on three phases is equivalent to 12.5 A on one phase).
2	6	4.1	Flexpower 1 during peak hours, the current is limited to 6 A. Reference profile, this power isn't part of this profile. It is however equivalent to a single-phase vehicle charging at 16 A. The identification of the vehicle might be faulty.
3	8	5.5	Reference profile. There no such configuration in the reference profile. This is however equivalent to a single-phase vehicle charging with 24 A. It is most likely linked with a wrong configuration of the reference station and a wrong identification of the vehicle.
4	10	6.9	Flexpower 1 profile. Two vehicles connected during the morning peak (current limited to 20 A). At least one of the two has three phase capacities. 10 A available on each connector.
5	12	8.28	Reference profile. Two vehicles connected to the stations. At least one of the two has three phase capacities.
6	16	11	Reference and Flexpower 1 profiles, one single-phase vehicle connected to the charging station.

The 11 kW category shows a more mitigated advantage for the Flexpower 1. The Figure 30 and its interpretation in the Table 19 is complicated by the presence of configurations not to find in the standard profiles.
However, even if the penalty due to the power limitation of the Flexpower 1 station is visible, the advantage is also highlighted. For the Flexpower 1 station, it doesn't make any difference if one or two connectors are occupied, the vehicles will be able to charge at full power outside the peak hours.

3.3.4. 22 kW charging capacity vehicles

The 22 kW category vehicles show an advantage for the Flexpower 1 charging station (Figure 31). Indeed, the red probability density distribution is clearly wider and centred on a higher power. The Flexpower 1 users of the 22 kW vehicles category experience a higher average power than those at the reference stations.
This result is also in line with the conclusion drawn from Figure 26.

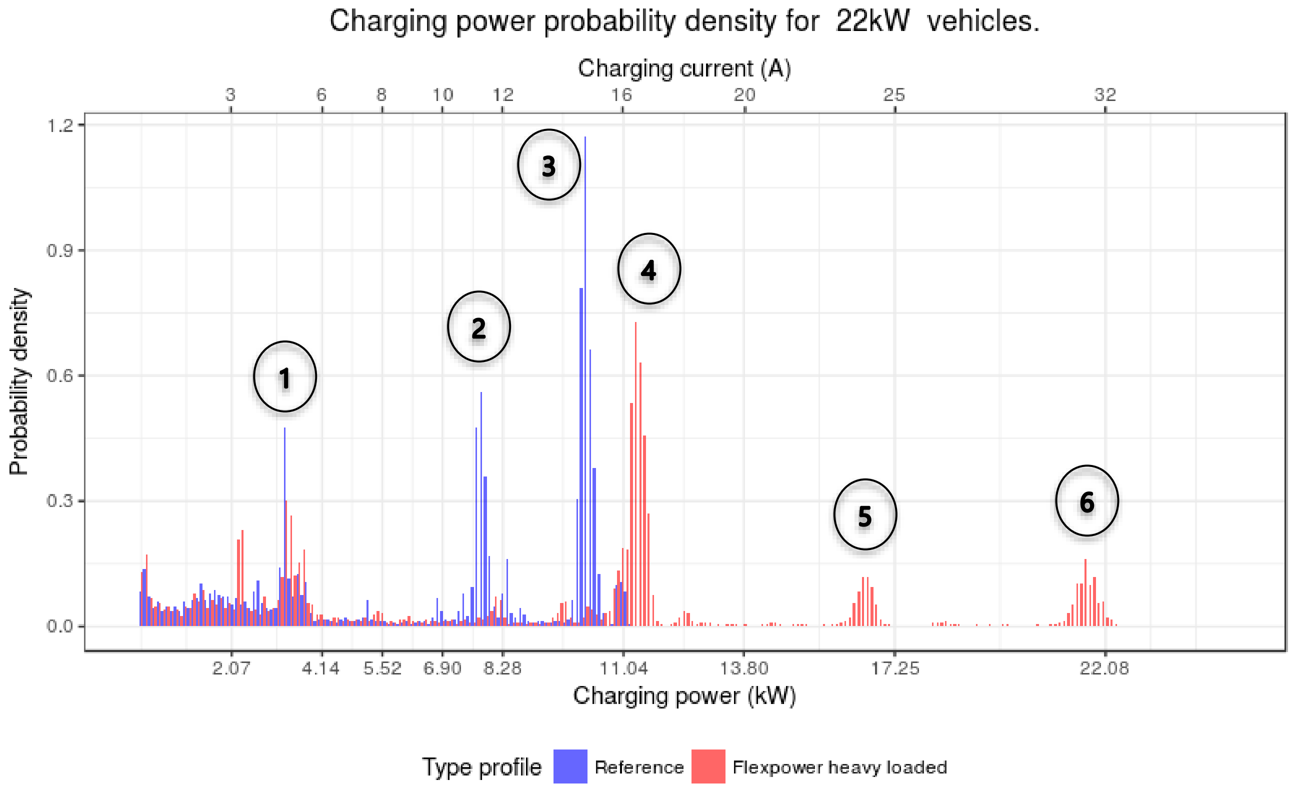

Figure 31: Flexpower 1 impact on 22 kW vehicles

Table 20: Charging cases for 22 kW vehicles

Cases	Current (A)	Power (kW)	Description
1	4.5	3.1	This doesn't match with any three phases configuration. The most plausible is a wrong recognition of a single-phase vehicle, as it is equivalent to a single-phase vehicle charging with 12 A (Reference profile with 2 vehicles connected).
2	12	8.28	Reference profile, two vehicles connected to the station. The second vehicle can be single or three phases.
3	16	11	Reference profile, one three phases vehicles connected.
4	17	11.7	Flexpower 1 profiles, two vehicles connected to the station. The second vehicle can be single or three phases.
5	25	17.2	Flexpower 1 profiles. Some vehicles categorized in the 22kW category are only able to charge with 25 A or 17.25 kW.
6	32	22	Flexpower 1, one three phase vehicle connected.

The Figure 31 and its interpretation on Table 20 concerns the 22 kW category vehicle. The advantage of the Flexpower 1 is here also clear. The power available outside the peak hours is higher, even with two vehicles connected (17 A/11.7 kW available instead of 12.5 A/8.6 kW).

3.3.5. Results

From the investigation presented in this section, we can conclude that hypothesis 2 is also confirmed. Indeed, the four cases investigated before show that the power available, which is directly linked to the ease of use, is equal or higher for Flexpower 1 than for the reference stations.
Indeed, the categories 7.4 kW and 22 kW are clearly taking advantage of the Flexpower 1 profile, as they can charge with a current up to 32 A. The current limitations during the peak hours are largely compensated by the higher current available during the off-peak hours.
Concerning the 3.7 kW and 11 kW charging vehicles, the shape of both power probability densities is very similar. This indicates that the user experiences are also very similar. It might be even advantageous during dual charging.

3.4. Hypothesis 3 – Smart charging results in higher charge volumes

This hypothesis is verified by looking at the amount of energy loaded for each session. If the hypothesis is verified, the amount of energy charged by a session should show a higher energy loaded for the Flexpower stations compared to the reference stations.
The hypothesis is evaluated globally and for the 4 identified categories of vehicles. The reference stations are plotted in blue and the Flexpower stations in red.
A first estimation shows the global average energy loaded for reference and Flexpower 1 categories are similar, with respectively 16.6 kWh and 16.2 kWh per session. This result and the detail per vehicle category is shown in Table 21 and plotted in Figure 32. This result is not in contradiction with the conclusion of the chapter 3.2 as this average is globally computed per category, whereas in 3.2, it was computed per time slot for all the vehicles categories.

Table 21: Average energy loaded per session and category of vehicle (in kWh).

Category	Overall	3.7 kW	7.4 kW	11 kW	22 kW
Reference	16.6	9.49	17	27.6	37.9
Flexpower	16.2	6.99	16	23.7	40.1
Variations	-2%	-26%	-6%	-14%	+6%

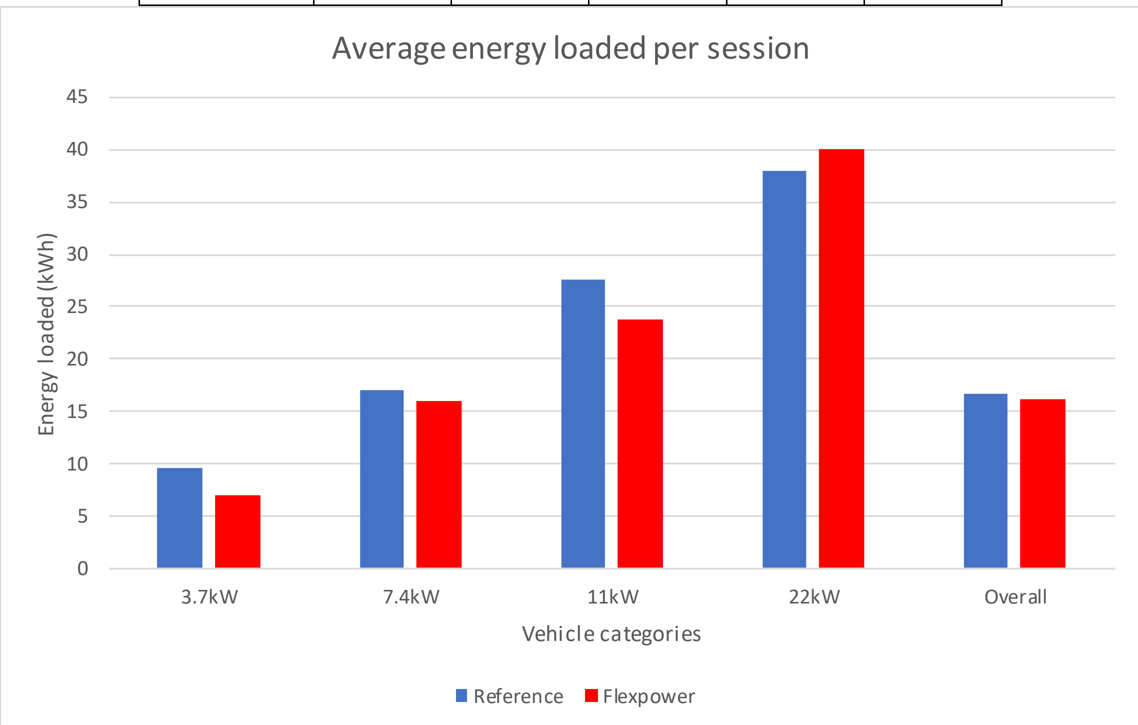

Figure 32:Average energy loaded per session and category of vehicle

In a first approach, the Flexpower station is only beneficial for the 22 kW category, but a more detailed analysis shows a more contrasted picture. Indeed, for the 4 categories of vehicles, Table 22 and Table 23 shows similar information. The average charging power increases but the charging sessions are shorter. The combination of the two parameters explains why the average energy loaded per sessions increases. This result is also in line with the Figure 27.

Table 22: Average charging power per session and category of vehicle (in kWh).

Category	3.7 kW	7.4 kW	11 kW	22 kW
Reference	1.5	1.9	3.37	3.3
Flexpower	1.74	2.78	3.83	7.1
Variations	+16%	+46.3%	+13.6%	+115%

Table 23: Average total charging time per session and category of vehicle (in hours).

Categories	3.7kW	7.4kW	11kW	22kW
Referentie	2.75	5	4.64	4.74
Flexpower	2.49	2.89	3.73	3.93
Variations	-9%	-42%	-20%	-17%

3.4.1. Conclusion

Hypothesis 3, more volume loaded by the vehicle thanks to the Flexpower 1 profile, is here again dependent on the type of vehicle. The 16 A vehicles (3.7 kW and 11 kW) can't compensate the limitation of the peak hours by the surplus of energy outside this restriction hours. It is thus not a surprise that these two categories load on average less energy per session with the Flexpower than with the reference profile.
The picture is different for the 32 A vehicles (7.4 kW and 22 kW). The global average shows similar volume for the 7.4 kW and the 22 kW. The Flexpower profile allows to charge similar of more energy than the reference one.
However, further investigation, impossible with the present dataset, should determine if the shorter sessions shown in Table 23 and influencing the energy loaded per sessions, are due to the awareness of the users or an error in the choice of the charging stations for the attribution of the profiles.
Hypothesis 3 is thus confirmed for the 22 kW vehicles, but not for the other categories. All sessions that result in 100% state of charge will by definition not load a higher volume, since the demand is limited by the size of the battery. Since these are the majority of the sessions, Flexpower has a very limited effect on the total energy sales.

3.5. Hypothesis 5 – Smart charging improves the occupancy/efficiency of charging stations

The occupancy ratio is computed by counting the number of connectors delivering power for each 15 minutes time interval divided by the total number of connectors for each category (reference or Flexpower 1). Figure 33 shows the results.
The computation is made for two subcategories:

- The dashed lines line counts the connector when a vehicle is connected, regardless of whether it is charging or waiting.
- The full line shows only the connectors where a vehicle is connected and actively charging.

Two conclusions can be made from this plot. From the dashed lines, we can see if the users are avoiding the Flexpower 1 stations. If that's the cases, the connection ratio will be lower for the Flexpower 1 than for the reference one.
With the full line, we will see if the Flexpower 1 vehicles are charging faster and therefore shorter.

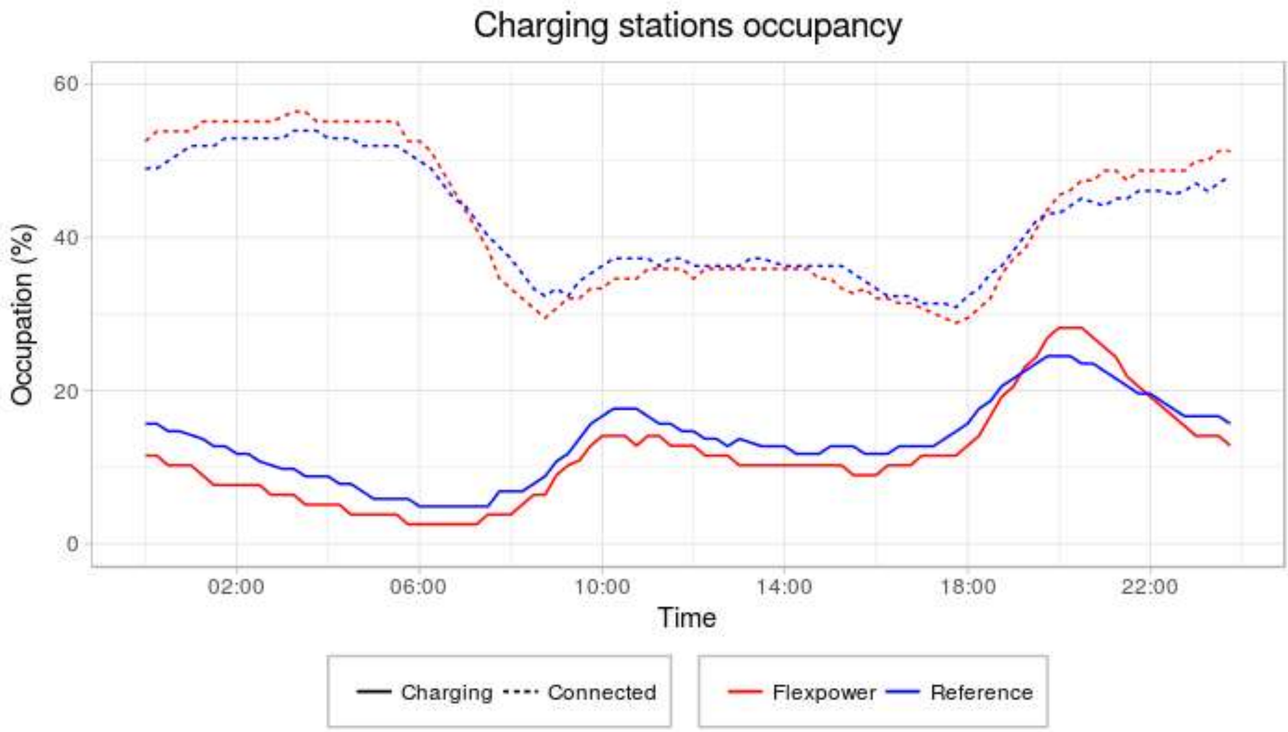

Figure 33: Occupancy of reference and Flexpower 1 stations per time interval of 15 minutes

Concerning the stations charging (full line), the occupancy is lower for the Flexpower 1 station than for the reference station, except during the evening peak hours. This is directly linked with the higher charging capacity of the Flexpower 1. Indeed, as they charge faster, the ratio of charging vehicle is lower (they need less time to charge to full power). This explanation is confirmed during the peak hours. The delivered power is lower, and the ratio of vehicles charging is higher.

The dashed line shows that the Flexpower 1 stations aren't avoided by the users given that the red line is slightly above the blue one and the differences between them are small.

Hypothesis 5 is thus not confirmed. The occupancy is similar for both categories of stations, there is no improvement of the efficiency of a station (serving more vehicles).

3.6. Avoided grid investment

An important indicator of the Flexpower 1 pilot is the impact of the project on the grid. To evaluate this impact, the average energy delivered per time slot of 15 minutes, which represents the load on the electricity grid at that time, is computed for the two populations of charging stations. The result of this computation is shown in Figure 34.

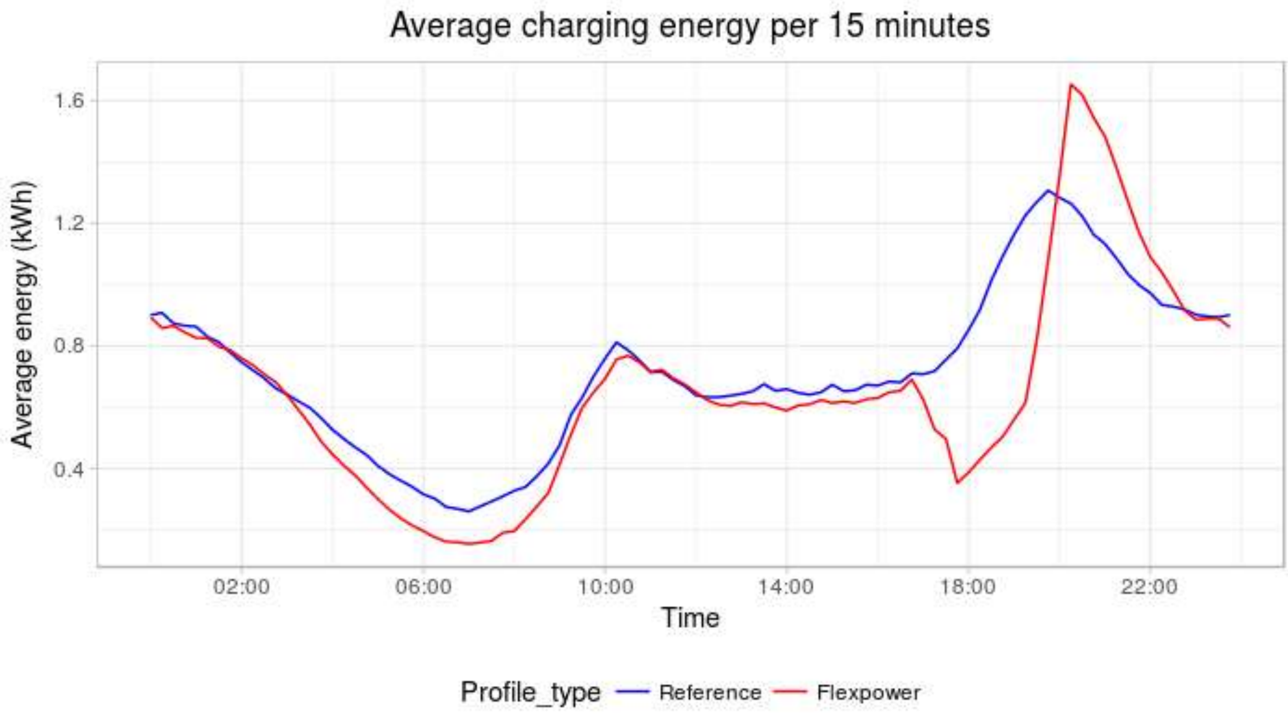

Figure 34: Average power per 15 minutes for each type of charging pole.

The reference and Flexpower 1 charging pole average power curves are similar most of the day. The major divergence occurs when the Flexpower 1 profile is the most limited in the evening, between 17hrs and 20hrs.
During these hours, the Flexpower 1 line clearly shows that less power is available for the charging of the vehicles. The objective to reduce the pressure on the local grid during these hours is thus realised and this avoids the corresponding grid investment.
The drawback of this reduction is that a new high peak of energy consumption appears after 20hrs when all the restricted stations switch to a higher power. This peak is higher than the reference level and occurs when the household peak is not completely over.
This new peak might be an issue for mass deployment of EVs. A smooth transition in time from low to high power is desired to avoid creating a second, even higher, consumption peak.

3.7. Conclusion of the research questions

Four research questions of the six were treated during the investigations. Two out of four questions have been proven to be confirmed. One has been proven wrong. The last one shows a mixed answer.
Indeed, the investigation showed that the vehicles are charging faster (hypothesis 1).
Furthermore, hypothesis 2 demonstrated no reduction of the ease of use (even advantageous effects for a subset of vehicles).
Hypothesis 3 showed a higher charging volume per session in the battery for the 32 A category of vehicle but less for the 16 A. The overview shows a neutral figure for all the vehicles.
Furthermore, during hypothesis 5, the occupancy of the Flexpower 1 stations has been demonstrated similar to the reference stations.
Finally, the Flexpower 1 pilot/station/profile? has shown the possibility to postpone the energy peak generated by the charge of the vehicle during the peak hours and the avoidance of the related grid investments.

4. Summary and conclusion

This first part of the Flexpower pilot focused on the implementation of the variable charging profile, the impact on the users and the benefit for the local power grid.

During the 8 months, from the 1st of January to 31st of Augustus 2018, of the Flexpower 1 pilot in Amsterdam, data was collected of 8208 different vehicles and 43904 charging sessions. The data was collected from 102 charging stations around the city centre of Amsterdam. Of these 102 stations, 50 were configured with a constant charging profile of 25 A. The 52 others were configured with a flexible profile, where the charging current was limited during the morning and evening peak hours but otherwise increased to 35 A.

Due to the lack of comparability between some of the reference and Flexpower 1 stations, only 40 Flexpower stations could be used during the investigation.

A preliminary theoretical investigation showed that the vehicles with a maximum charging current of 16 A, single-phase as well as three phases, would only take advantage of the Flexpower 1 when both connectors of a charging station are in use at the same time.
The 32 A vehicle would be able to compensate the power restriction during the peak hours by the higher power in the off-peak hours.

Six hypotheses were formulated of which four could be answered from the collected data. These four hypotheses are:
- EVs are charged faster (hypothesis 1).
- Users do not experience a reduction in ease of use (hypothesis 2).
- Smart charging results in higher charge volumes (hypothesis 3).
- Smart charging improves the occupancy/efficiency of charging stations (hypothesis 5).

Two out of these four hypotheses were confirmed ((hypotheses 1 and 2). Hypothesis 3 shows a mitigated answer linked with the capabilities of the vehicles. Hypothesis 5 proved to be wrong. This means that the Flexpower 1 pilot brings mainly benefits to the user and is hardly inconvenient.

Finally, it has been shown that it is possible to limit the load created by EV charging during the evening peak by postponing this peak to later in the evening. This leads to a better utilisation ratio of the existing low voltage network and some investment in the electrical network can be avoided.

The Flexpower 1 profile is thus a viable solution, combining a beneficial effect for the users and the avoidance of investments in the low voltage electrical network.

During the second phase of the Flexpower pilot, the focus will be more on the integration of the solar energy to charge the vehicles and more data will be collected from the electrical network to be able to directly measure the impact of the pilot on the electrical network.

5. References

[1] https://www.eafo.eu/countries/netherlands/1746/summary, Consulted the 9th of May 2019
[2] https://www.amsterdam.nl/en/policy/sustainability/clean-air/, consulted the 3rd of April 2019
[3] https://www.liander.nl/partners/datadiensten/open-data/data, Consulted the 2nd of April 2019
[4] University of applied sciences Amsterdam. "IDO-laad". http://www.idolaad.nl/
[5] https://ev-database.nl/, consulted the 10th of April 2019, for vehicle available in 2018.
[6] With help from https://www.mapcustomizer.com/ and the content of the file locaties_verzwaard_ind.xlsx
[7] https://branding.evbox.com/web/4e05cd0712294611/technische-specificaties/?mediaId=3B7A668F-5729-4583-B545F9C6CAE2A031, consulted the 20th of May 2019
[8] Jerome Mies – 2016 - Estimating the charging profile of individual charge sessions of Electric Vehicles in the Netherlands