Monitoring and demonstration activities

Project deliverable D4.2

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1.1 Legal Disclaimer

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2 Project Executive Summary

SCALE (Smart Charging Alignment for Europe) is a three-year Horizon Europe project that aims at preparing EU cities for mass deployment of electric vehicles and the accompanying smart charging infrastructure.

3 SCALE partners

List of participating cities:

- Oslo (NO)
- Rotterdam & Utrecht (NL)
- Eindhoven (NL)
- Toulouse (FR)
- Greater Munich Area (GER)
- Budapest & Debrecen (HU)
- Gothenburg (SE)

List of partners:

- (Coordinator) STICHTING ELAAD NL
- POLIS - PROMOTION OF OPERATIONAL LINKS WITH INTEGRATED SERVICES, ASSOCIATION INTERNATIONALE POLIS BE
- GoodMoovs NL
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- FIER Automotive FIER NL
- Emobility Solutions Kft. HU

- Serviced Office Belbuda Kft HU
- Enedis FR
- L'ASSOCIATION EUROPEENNE DE LA MOBILITE ELECTRIQUE (AVERE) BE
- Norsk elbilforening NO
- VDL ENABLING TRANSPORT SOLUTIONS BV NL
- Urban Electric Mobility Initiative UEMI DE
- Renault FR
- Chalmers University SE
- Polestar SE
- Hyundai NL NL

Social Links:

twitter.com/scaleproject_

www.linkedin.com/company/ scale-project-smart-charging-alignment-for-europe

www.youtube.com/channel/UC1HVFu5uJPCNSV96b3l_rcg

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4 Introduction

SCALE (Smart Charging Alignment for Europe) brings together cities, industry partners, and research institutions across Europe to accelerate large-scale electric vehicle (EV) adoption and the deployment of smart charging solutions. This deliverable, developed under Task 4.2 in Work Package 4 (WP4), is crucial to understanding how the project's innovations perform in real-world environments. It builds on the KPI definitions and data requirements initially introduced in Deliverable 4.1 and aligns with WP4's broader goals: to validate and demonstrate novel charging concepts, test them under diverse conditions, and measure their real-world impact.

The monitoring framework presented here provides an in-depth overview of how performance metrics are collected, tracked, and analyzed for the SCALE project's different use-cases—covering vehicle-to-home, vehicle-to-business, and public charging scenarios. By harmonizing data collection and focusing on shared data points, the deliverable enables direct comparisons across demonstration sites and pilot activities. This consistency further supports related tasks in WP4—such as T4.3, where aggregator and market approaches are explored, and T4.4, which examines how well these solutions scale. Beyond WP4, the insights generated will inform activities in WP2 (use-case and requirements definition), WP3 (data architecture and interoperability), and WP5 (policy recommendations, replication, and exploitation).

Early results indicate measurable benefits from smart and bidirectional charging, including peak-load reduction, energy cost savings, the integration of local renewable energy sources, and reduced CO_2 emissions. By analyzing these KPIs, the consortium can refine technical requirements, enhance operational strategies, and provide fact-based guidance for policymakers and stakeholders. Ultimately, the findings in this deliverable serve as a foundation for ongoing and future SCALE research, driving progress toward a sustainable, large-scale EV charging ecosystem in Europe.

5 Concept

The aim of the monitoring is to deliver consistent and use case specific KPIs, these KPI are always related to a specific use case and innovation cluster. The calculation of KPI can be done automatically. If the use case adheres to the SCALE specifications concerning monitoring data exchange. In case use cases are running over a longer period, the automated way of calculating the KPI can be executed and implemented in Work Package 4. The advantage of collecting centrally the monitoring data is that afterwards additional KPI can be calculated on the same data and have a calculation of KPI over all the use cases. These specifications are described in the later chapters.

The exception to the automated process can be valid for use cases where a limited number of tests over a time period of the project will be carried out or the KPIs are already part of the use-case platform. As a result, the use case may decide to calculate itself the KPI's and make the raw data not available.

As all the use cases are working in one way or another with EV's, the EV session data and running parameters are the most essential parameters that will be collected in the SCALE project. The type of data is divided into 4 parts:

- EV session data (start, stop, …)
- EV periodic data (actual, base line, optimal, …)
- Periodic site data if available (solar production, …)
- Semi static data (configuration information, optimization, or delivered service cases)

The periodic data has a resolution that is as fine as possible but for the resolution of 15 minutes data is considered optimal. When the use case delivers grid services, detailed measured data are required but are not needed as monitoring requirements. The basic assumption here is that the resources need to go through a pre-qualification and validation step. This pre-qualification report contains all the required KPI data as a result the monitoring resolution timesteps do not need to be lowered. The prequalification needs detailed measured data, the granularity of the data needs to be on second level. Based on the consumed/delivered power different parameters for the qualifications are measured like the ramp-up rate, sable situation, ... Basically a pre-qualification report or the fact that a pool of assets is qualified to deliver a service gives a DSO stamp to the pool and the service provided by the pool.

6 KPI

The maximum KPI as defined in Deliverable 4.1 are listed below with some additional remarks connected, depending on the use-case the number of KPI's are restricted. In the next chapters the specific KPI list per use-case will be enumerated. The formula can also be found in the same deliverable, the description of the needed data is based on the KPI's and the formula.

KPI name	Remarks
Utilization rate of EV chargers	
Self-sufficiency	Can only be calculated with local production
Self-consumption	Can only be calculated with local production
Energy curtailment	Can only be calculated with local production
V2G efficiency (accounting for roundtrip V2G losses)	Can only be measured/calculated in lab environments
Energy exchange with the grid (bi-directional)	
Peak load reduction	Is calculated on a day basis between base scenario and actual scenario.
Amount of time providing flexibility services (locally or to the grid)	
Energy system flexibility	This could also be calculated as what amount of loading is shifted off peak. As the DSO peak is not necessarily known to the use case.
Reaction time to increase/decrease power delivery	Can be taken from the pre-qualification report
Time-of-Use Load shifting	
Congestion management Income (Short term)	
Power quality control	Can only be calculated/measured in lab environment option 2
Back-up power in islanding mode	Not applicable in any use case
Saving from charging	

Reserves adequacy	
Operational Congestion Management (non-contracted bids)	

A lot of the KPIs are calculated in comparison to the base scenario. The base scenario is that the EV charges at maximum speed from the moment the car is connected (session starts) and defined by the car/charging station combination. Depending on the information provided about the EV session, the optimization is based upon data provided by the driver or generated by AI to define the energy to be charged and the departure times of the car.

7 Data content

The specific data is divided per type of information and the frequency of the data requirements. Depending on the protocol version some of the information will not be filled in or calculated by the flexibility service provider. An example with OCPP 1.6 protocol no departure times are delivered, depending on platform some of the information are calculated with forecasting algorithm.

7.1 EV Session data

The session data contains all EV session related data. The first time the session data is written into this file some basic data is filled in. If the session ends, the end time and global parameters for the session are added. The session related data contains all the open sessions and recently closed sessions. The field charged energy forecast can be filled in via a generated algorithm or via the driver, depending on the protocols that are used the car/driver delivers the needed energy and what time the car will leave. In the actual situation some systems forecast the values, these values come out of a forecast algorithm. These covers part of the OCPP 2.0.1 specifications appendix 2 data 3.2.12 from the connected EV data.

Content:

- time of departure in epoch format
- transformer Id (Identification of EV subgroups)
- controlled session (true) means that this session is used for smart charging
- Add a site EAN or to the basic data of the charge point id
- additional information about the State of Charge actual, maximal and required can be added in this session data (only available in OCPP version 2.0.1 or higher)

session id	transformer id	charge point id	controlled session	time of arrival (epoch)	time of departure (epoch)	time of departure forecast (epoch)	maximum power (W)	charged energy (kWh)	charged energy forecast (kWh)
NL_LMS#NLLMS53480935	72014862	NL_LMS#1800499*2	TRUE	1648989805	1649058879	1649003844	5524	26.54	24.61

7.2 EV Periodic data

The time period is set on a 15-minute base if possible. An example of the information is given, if all the values are zero then no consumption is measured over the 15 minutes period. This is a connected car but a charged one.

time (epoch)	EVSessionID	realized (W)	baseline (W)	optimisation(W)
1649023200	NL_LMS#NLLMS53480935	0	0	0
1649024100	NL_LMS#NLLMS53480935	0	0	0
1649025000	NL_LMS#NLLMS53480935	0	0	0

7.3 Site Periodic data

The site periodic data contains additional site data with the same time update frequency as the EV periodic data.

This file contains the additional data points and the type of optimization in action unless the complete use-case site has always the same optimization.

- Time (epoch)
- Transformer id (identification of group)
- Produced Energy
- Consumed Energy outside the EV scope
- Eventually price information if applicable

Example the optimization of a complete office building is executed then the EV data, Production Energy and consumed energy are input parameters to execute the KPI calculations.

7.4 Site basic data

The site-specific data contains the site parameter this information can be provided as static data and configured once in the central business system. The needed parameters are the short description of the optimization algorithm, maximum grid connection, name and number of connection points. Electricity contract information or reference to the variable prices that are used day-ahead market Epex price, …

7.5 Transfer of data

The data can be received centrally based upon file transfer or can be made available via rest API, the rest API needs to be defined by the use case itself.

7.6 File transfer

Each of the use cases will have a separate directory (To be defined where), in this directory the files are uploaded on a frequency defined by the use case. The structure of the filename says something about what type of content can be found in the file but all the data for the specific type of file is always fully defined in the file itself.

Structure file:

Session file format: timeseries_xxxxx.csv
EV periodic data format name: sessions_xxxxxx.csv
Periodic site data: site_timeseries_xxxx.csv
Site config data: site_config_xxxxx.csv

The file is a csv file containing the required fields and the xxxxx is a variable part of the filename to make the file unique.

The files once processed will be removed from the upload directory.

7.7 Data processing

The central system will be collecting the data regularly and extract the needed KPI. Some of the sites had the API implemented, the other use-cases did calculate the data with the local data.

7.8 Methodology and usage of open data

The KPI definitions and their calculation can be found in the deliverable D4.1 this specification together with the following list of KPI and the specific usage in the use-cases will be used in this document to show the relevant KPI per use case.

Partner lead	We Drive Solar	E-Mobility Solutions	Emobility, Solutions	Enedis	Chalmers	Current	VDL	VDL	ElaadNL	Current	EMS
Pilots KPIs	Utrecht, NL	Debrecen / Budapest, HU	Budapest, HU Cardealer	Toulouse, FR	Gothenburg, SE	Oslo, NO	Eindhoven, NL	Eindhoven, NL	Rotterdam / Utrecht, NL	Oslo, NO	Hungary
Use Case	00	B1	B2	B3	B4	C1	C2	C3	C4	D1	**D2**
General											
Utilization rate of EV chargers	O	O	O	No calculation	O	O	Test facility	Test facility/ Simulation	Public chargers no data	O	O
Self-sufficiency	No solar/ renewables	No solar	O	Not	O	O	O	O	No solar	No solar	No solar
Self-consumption	No solar	No solar	O	O (simulated)	O	O	O	O	No solar	No solar	No solar
Energy curtailment	No solar	No solar	Not executed but optimal charing based on solar	Not possible	Not possible	No Solar	Not executed , not enough solar to curtail	Not executed , not enough solar to curtail	No solar	No solar	No solar
V2G efficiency (accounting for roundtrip V2G losses) *	V2G efficiency can only be analysed at Elaad. See D4.5	No V2G	V2G efficiency can only be analysed at Elaad. See D4.5	V2G efficiency can only be analysed at Elaad. See D4.5	O	O	No V2G	No V2G	V2G efficiency can only be analysed at Elaad. See D4.5	V2G efficiency can only be analysed at Elaad. See D4.5	V2G efficiency can only be analysed at Elaad. See D4.5
Energy exchange with the grid (bi-directional)	O	No V2G	No V2G	0	O	O	No V2G	No V2G	0	No V2G	No V2G
Peak load reduction	O	O	O	O (locally)	O	O	O	O	Optimisation on costs	O	O
Amount of time providing flexibility services (locally or to the grid)	O	Only smart charging	Local optimisation	Optimisation on peak-load	O	O	O	O	Costoptimisation	0	0
Energy system flexibility	0	O	O	Optimisation on peak-load		O	maybe	maybe		O	O
Reaction time to increase/decrease power delivery	O	O	O	Only simulation	With OEM	O	maybe	maybe		O	O
Use Case Specific											

Time-of-Use Load shifting				O	If TOU tariff used. Currently it is spot price tariff.	O				O	
Congestion management Income (Short term)						O				O	
Power quality control						maybe				maybe	
Back-up power in islanding mode						maybe				maybe	
Saving from charging	0				O	O				O	
Reserves adequacy						O				O	
Operational Congestion Management (non-contracted bids)						O				O	

The emissions of the electricity production per country can be found on the following site and is used for a calculation of the CO2 emissions on average per period. (ref: https://www.nowtricity.com/)

7.9 Marginal emissions

Smart charging or shifting of the electric an EV when done at times when the electricity prices are high is beneficial for the CO2 emissions. This is called **Marginal Emission Factor (MEF)** represents the additional greenhouse gas (GHG) emissions (typically in CO_2 equivalents) that occur as a result of producing one additional unit of energy, typically measured in kilograms of CO_2 per megawatt-hour (kg CO_2/MWh). This factor is used to understand the environmental impact of increasing electricity consumption, especially in contexts like energy policy, carbon pricing, or grid management. In the Utrecht use case this factor is calculated for each time slot, together with the shifting of the energy the additional reduction of CHG is calculated.

8 Use-cases

Most of the use cases have been using the monitored data based from standard charging session and extended with tests on small samples of monitored data with V2G sessions. In some cases the captured session data with or without smart-charging have been used to simulate the V2G uses cases and the expected result of these use cases. The only use-case where no real monitoring or simulation data were available comes from the Hungarian use cases. As the installation and first set-up is at the time of writing being finalized. The Hungarian use case have some aspects of the Utrecht Use case but with a smaller number of charging stations and lower utilisation of the charging stations. The other use case is similar to an office building with a small amount of flexibility.

8.1 Vehicle to Business (V2B)

8.1.1 Goteborg

The demonstrations in Göteborg was divided into two parts, AC smart charging demonstration and DC bidirectional charging demonstrations. This section will present the evaluation of the demonstration results.

8.1.1.1 AC smart charging real life demonstration

Due to the lack of available AC bidirectional EVs, the AC demonstration focused on unidirectional smart charging. For the evaluation, data from November to December was utilized for a charge station located at Chalmers. During the period 49 charging sessions were recorded with a total duration of 221 hours. To start a charging session the user logged in to the user interface where they enter information on planned parking duration, requested energy and maximum fuse level. This information was then stored in a database and used to calculate the possible cost and CO2 savings. Figure 1 presents the user-interface used for the demonstrations.

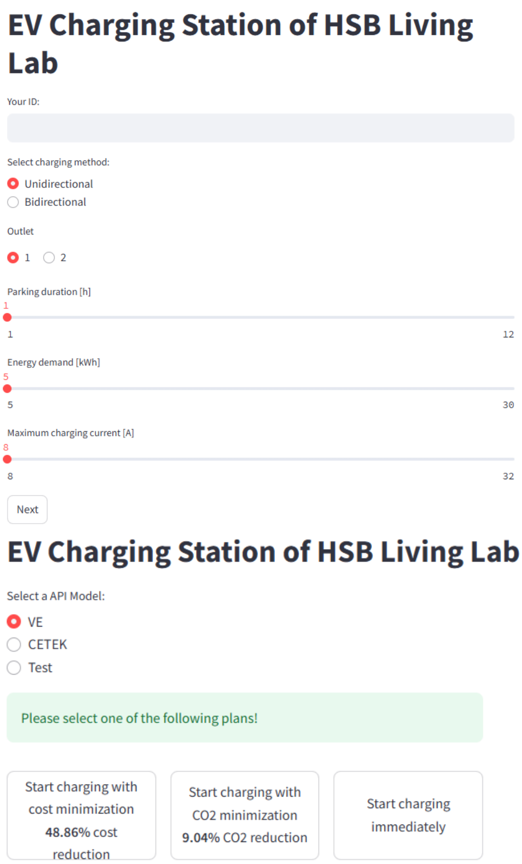


Figure 1: user interface for smart charging

8.1.1.2 KPI evaluation

8.1.1.2.1 Utilization rate of EV chargers

Based on the average charge duration the charge utilization was calculated to 15% during the period.

8.1.1.2.2 Self-sufficiency

The demand and production in HSB LL are presented in Figure 10.2.2. During the demonstration period the building demand was substantially higher than the local production from PVs due to the winter period. The total production during November and December reached 320 kWh while the consumption during the same period was found to be 20,5 MWh resulting in a self-sufficiency rate of 1,5%.

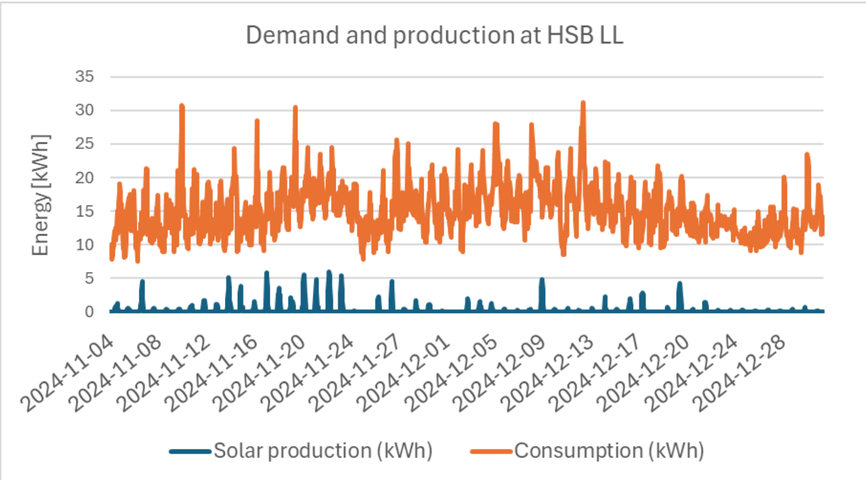


Figure 10.2.2: Production and consumption in HSB Living Lab

8.1.1.2.3 Self-consumption

During the evaluated period, all locally produced energy were consumed within the building, mainly due to the low amount of solar production, as can be seen in Figure 10.2.2

8.1.1.2.4 Energy curtailment

During the evaluated period no energy was curtailed either in the baseline or in reality.

8.1.1.2.5 V2G efficiency (accounting for roundtrip V2G losses) *

Not applicable for the smart charging case

8.1.1.2.6 Energy exchange with the grid (bi-directional)

Not applicable for the smart charging case.

8.1.1.2.7 Peak load reduction

To calculate the peak load reduction the electricity import was compared with a base line electricity import based on the charging profile calculated from the direct charge profile. Figure 2 presents the electricity imported for the smart charging scenario and the direct charging scenario. As can be seen, during one of the peak time period an EV was connected and would have charged with 22 kW. While with the smart charging strategy, the charge session was moved to off-peak hours with a lower charge power resulting in a lower peak demand.

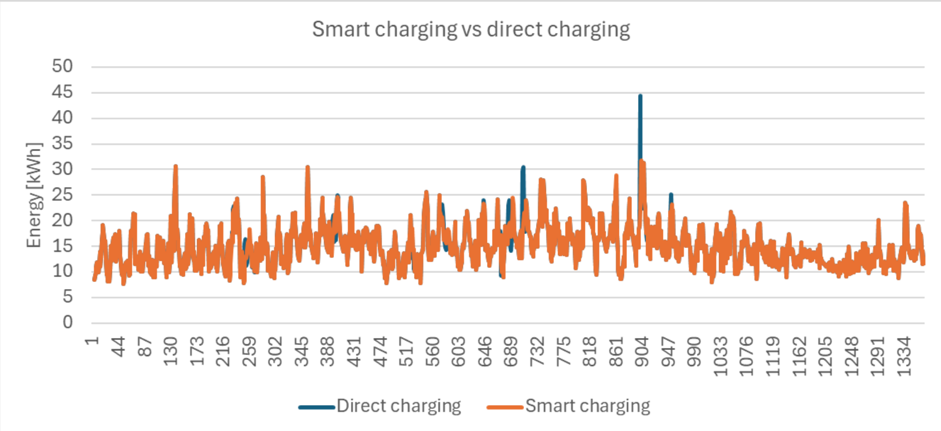


Figure 2: Electricity import for HSB LL for the smart charging vs. direct charging case

Figure 3 presents the daily peak demand reduction per day, as can be seen for most days there is no or limited impact on the peak demand while for certain days the peak demand reduction could reach approximately 30%.

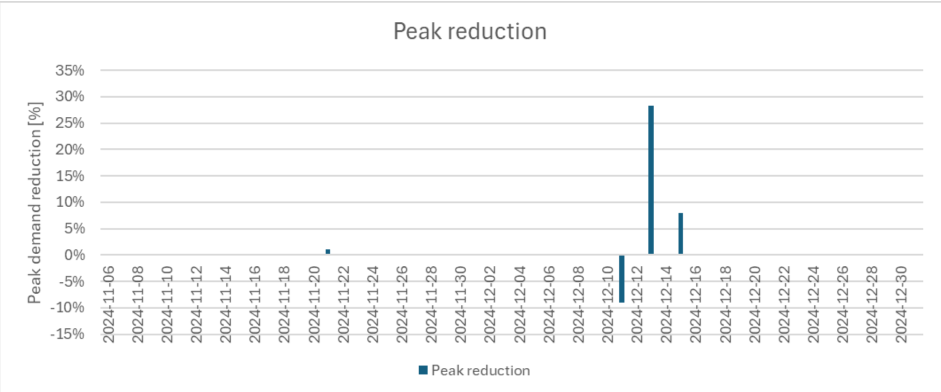


Figure 3: Peak reduction smart charging vs direct charging case

8.1.1.2.8 Amount of time providing flexibility services (locally or to the grid)

Since the SOC was not available through the OCPP 1.6 the flexibility time was estimated based on the user preferences in the user interface, e.g. the parked duration, the maximum charge current and the requested energy. Figure 4 presents the duration the charge session that could be flexible for all charging sessions initiated through the user interface. It should be noted that all charge sessions entered in the user interface did not result in a physical charge session.

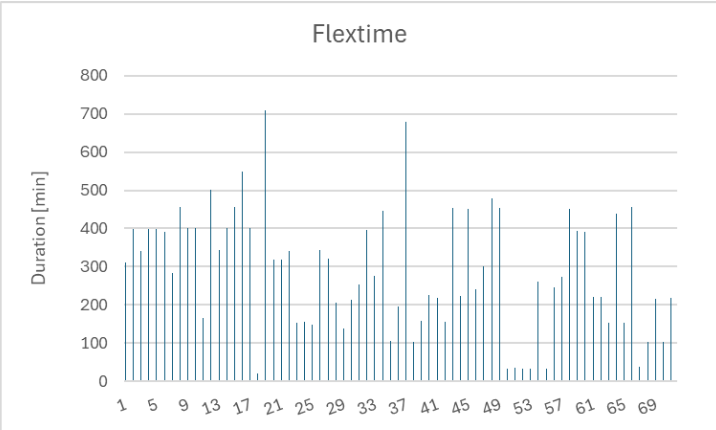


Figure 4: Flexibility time during each charging session, based on user input

8.1.1.2.9 Saving from charging

The demonstrations showed that from the smart charging sessions a possible cost reduction by 19,8% could be achieved while reducing the CO2 emission by 1,3% (based on electricity maps energy mix for Sweden (area3)). The main part of the savings was achieved by reducing the peak demand but also due to reduced charging during hours with high electricity prices.

8.1.1.2.10 DC bidirectional charging

A bidirectional DC charging station has been installed and demonstrated within Chalmers campus. During the evaluation period between November and December tests were conducted utilizing different EVs to assess if they were capable of conducting bidirectional power transfer. It was found that many manufacturers were limiting the possibility to discharge the EVs and stopped the discharging session shortly after that the session started. Due to the limited number of EVs capable of bidirectional charging the demonstrations have mainly been conducted with a special company EV (Volvo C30) and a polestar 2.

8.1.1.2.11 Utilization rate of EV chargers

Not applicable since the charger mainly been used for demonstration purposes.

8.1.1.2.12 Self-sufficiency

Due to the winter period the self-sufficiency was low and not directly affected by the bidirectional charger this was found irrelevant for the use case.

8.1.1.2.13 Self-consumption

During the evaluated period, all locally produced energy was consumed within the building, mainly due to the low amount of solar production during the winter period.

8.1.1.2.14 Energy curtailment

During the evaluated period no energy was curtailed either in the baseline or in reality.

8.1.1.2.15 V2G efficiency (accounting for roundtrip V2G losses) *

To estimate the charging/discharging losses a step test was conducted when the charging power decreased from 10 kW down to –10 kW with 2 kW step size. The efficiency for the DC inverter is presented in Figure 5. As can be seen the efficiency is around 90-95% for most of the operating points although it reduces drastically for low power outputs, e.g. 65% when the charge power is 300W.The discharge efficiency was also found to be lower compared to the charge efficiency.

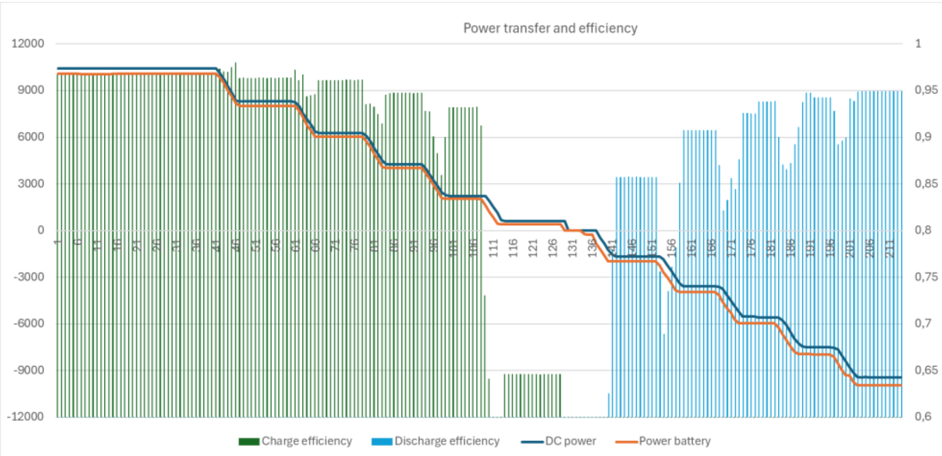


Figure 5: Power transfer and efficiency for one of the bidirectional charging/discharging demonstrations

8.1.1.2.16 Energy exchange with the grid (bi-directional)

Due to the high building demand the charger was never able to provide power back to the grid from the charger. With more EVs and bidirectional chargers the charger would be able to supply power back to the grid.

8.1.1.2.17 Peak load reduction

During the demonstrations the charger was able to reduce the peak demand by 10 kW, which was limited by the fuse of the connection. By replacing the fuse, the charge station could potentially reduce the peak demand by 20 kW if properly controlled.

8.1.1.2.18 Amount of time providing flexibility services (locally or to the grid)

Since the bidirectional charge sessions were mainly conducted to demonstrate the V2G functionality the flexibility time was not calculated for the use case.

8.1.1.2.19 Reaction time to increase/decrease power delivery

From the step test conducted it was found that it took approximately 7 seconds to reduce the power by 2 kW (285W/second). To increase the power from +/-10 kW to 0 kW took 24 seconds (416 W/second).

8.1.2 Toulouse

This use case aims at optimizing charging strategies within logistician depots to facilitate electric vehicle (EV) grid integration in case of massive future uptake of EVs

Scenarios ranging from 100 to 500 EVs to be daily charged are simulated with and without smart charging.

As a Distribution System Operator, Enedis is looking at optimizing charging strategies within logistician depots to facilitate electric vehicle (EV) grid integration in case of massive future uptake of EVs.

This study focuses on two main objectives:

- Preventing the need for further grid reinforcements by optimizing the required power capacity.
- Identifying the optimal charging strategy through simulation.

The year 2023 has been tracked for a full site consumption analysis. It provides the minimum, the maximum and averages for the whole year. The idea is to use this reference to make comparison with future simulated scenarios.

8.1.2.1 Local solar Data Analysis

As the site is covered by 12MW PV rooftop, managed by an independent company in a feed in tariff scheme. As both point of connection are connected to the same substation, we could assume and simulate self-consumption impacts, thanks to EU public generation data (Figure 6).

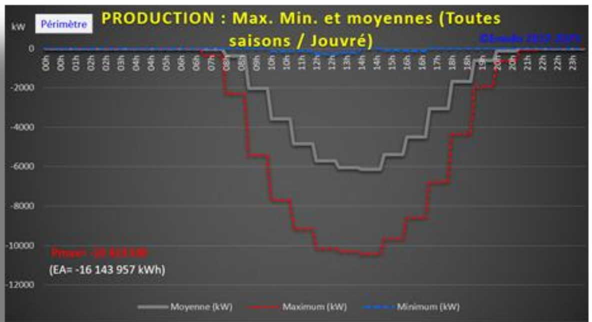


Figure 6: Solar data analysis

8.1.2.2 Simulation results for future scenarios

Here, we forecast future demand by simulating three scenarios for daily electric vehicle (EV) charging fleets. Due to lack of space only 1 scenario is displayed (full paper will include the 3 major scenarios: 2023+ 100 EVs; 2023 + 250 EVs; 2023+500 EVs). For every scenario, illustration are displayed: in yellow dumb charging, in green with smart charging. Simulation results indicate that utilizing off-peak charging periods (both day and night) **reduces the required power capacity by 50%** (Figure 7), compared to maintaining charging exclusively during daytime hours.

8.1.2.2.1 Scenario 1 – 2023 + 100 additional EVs per day

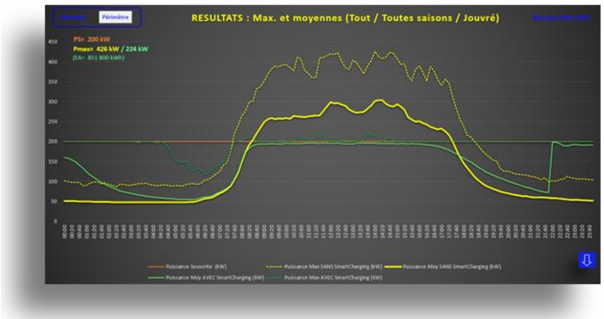


Figure 7: yearly maximum power (dots) and average (plain)

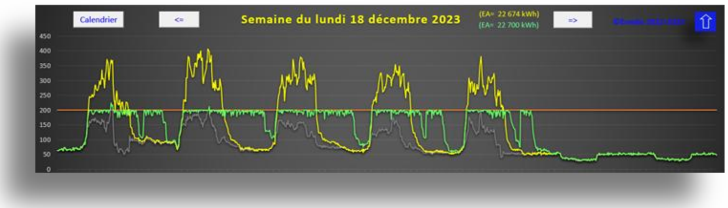


Figure 8: Weekly Load curve

Several KPI's are evaluated for a better understanding on the impact of the proposed solutions to the results. The following KPI's are computed for this specific use case:

- Peak load reduction (50%)
- Self-consumption (70% self-consumed if site owner was the PV manager, which is not the current case)

8.2 Vehicle to Depot (V2D)

8.2.1 VDL (2 cases)

We as VDL suggest renaming chapters 11.3 and 11.4 with a prefix of “VDL” and remove this chapter.

8.2.1.1 Highway charging

Reaching carbon neutrality in road freight- and passenger transport zero emission vehicles are the backbone to meet these goals. Next to Electric public transport buses these kind of EV vehicles starting to hit the market. Today the charging infrastructure that is indispensable to operate heavy duty EV's on the European highways is almost complete missing and not adapted to the specific needs, power demands and sizes of parking spaces of these types of sustainable transport. Executing simulations is a convenient way to investigate improvements for the charging infrastructure. Simulating the optimal set up for highway DC High Power charging for long haul e-coaches is base of this use case.

8.2.1.1.1 Input data used and modelling approach

This use case focuses on highway charging of e-coaches along the highway. E-coaches are a new segment and there is not much real data about charging e-coaches along the highway. Therefore, assumptions and a hypothetical charging time scheduling are needed to create a realistic use case and to verify the model. This use case is based on driver rest times and typical bus stops used during long-haul trips involving coach buses. Below the assumptions that have been made and applied for the simulations can be found.

- Solar data used of 8 months (limitations of recorded data Valkenswaard site. Period from 01-02-2024 to 30-09-2024).
- Reference bus with a capacity of 676 kWh ([VDL Van Hool CX45E].)
- 3 chargers (1 charger 450 kW with priority, 2 chargers 225 kW only during the night).
- Varying energy prices for a period from 01-02-2024 to 30-09-2024 ([EMBER])
- Grid peak price obtained from Enexis and are fixed for the simulation period [Enexis]

The coach is starting the journey with a fully charged battery (100%). The coach operates at an ambient temperature of 15°C. The HVAC consumption influences the distance, and therefore, an assumption of 15°C ambient temperature has been made. During the trip, the battery is charged up to 80% and discharged to 20% of its capacity. The maximum power output of the highway charger site (Maximum charging power of the that specific location is 450kW, or 2 times 225 kW) is 450 kW. It is assumed that the coach can consistently charge at 450 kW, as this rate does not exceed the typical 1C charging rate.

This use case primarily focuses on charging touring coaches. According to EU regulations, drivers are permitted to drive for a maximum of 4.5 hours before taking a mandatory 45-minute rest. [Rijksoverheid drive and rest hours].

Given that this use case involves a highway charger, it is assumed that the coach predominantly travels on highways at speeds of 80, 90, or 100 km/h.

Based on the mentioned assumptions, some simulations have been performed to foresee the maximum distance that a coach can achieve driving on the highway before the battery is fully discharged. The results can be seen in the picture below.

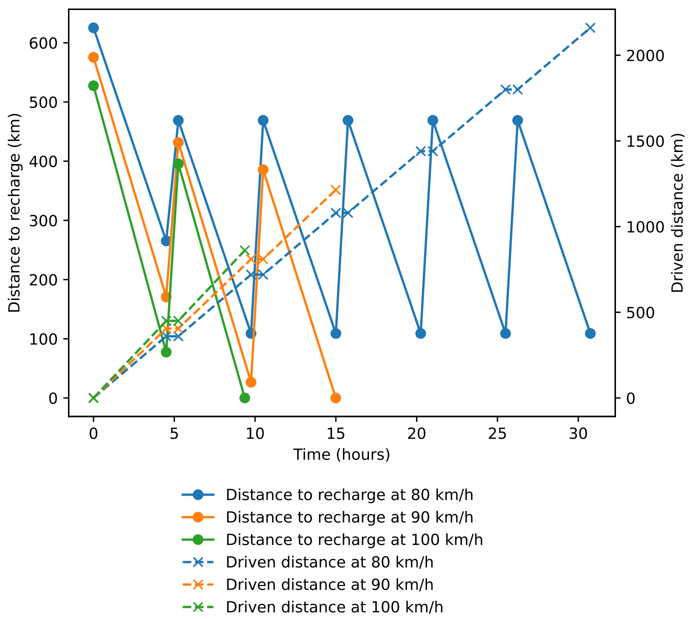


Figure 9: Simulated kilometers driven and kilometers to charger over time

Figure 9 shows that 450 kW is sufficient charging power to drive the coach more than 1000 km at speeds of 90 km/h or lower, while adhering to EU regulations on rest and driving hours.

The optimal driving speed depends on the distance to the destination. For shorter distances, the coach can travel at 100 km/h. For international trips, the coach can travel at 80 km/h, allowing for an unlimited distance according to this schedule. At 90 km/h, the coach can travel alongside trucks without overtaking them.

This use case does not aim to optimize the coach's time schedule but rather to make realistic assumptions for highway chargers within the limits of current charger installations. More charging power would make the system more robust. However, chargers of 450 kW are feasible with today's technology and are already installed across Europe ([ChargeFinder]). Therefore, it is assumed that the coach will charge for 45 minutes at a power of 450 kW. During the night, the coach can charge at a lower power for a longer duration.

A network is created using the PyPSA toolbox [PyPSA], based on the specified assumptions and input data. Initially, a blank system is used, and the model searches for an optimal configuration by adding components to achieve a cost-efficient solution. This simulation is conducted with various grid connection sizes. The network's solar energy capacity is fixed to match the size of the solar installation in Valkenswaard. The model optimizes the battery size and the energy flow to ensure minimal investment and operational costs.

8.2.1.1.2 KPI evaluation

Several KPI's are evaluated for a better understanding on the impact of the proposed solutions to the results. The following KPI's are computed for this specific use case:

- Energy curtailment
- Peak load reduction
- Self-sufficiency
- Self-consumption

8.2.1.1.3 Energy curtailment

Energy curtailment refers to the intentional reduction of energy output from renewable sources to balance supply and demand or to prevent overloading the grid. Since the energy consumed by the load is orders of magnitude greater than the generated energy and the BESS is used to store the energy that cannot be used by the load at the specific moment of energy generation, the KPI is zero in this use case.

8.2.1.1.4 Peak load reduction

The reference case is a network with only a grid connection, without battery and solar panels installed. This network introduces a peak on the grid that is equal to the peak load, taking into account the efficiency of the inverter. The grid peak power obtained from the reference case is 0.474 MW.

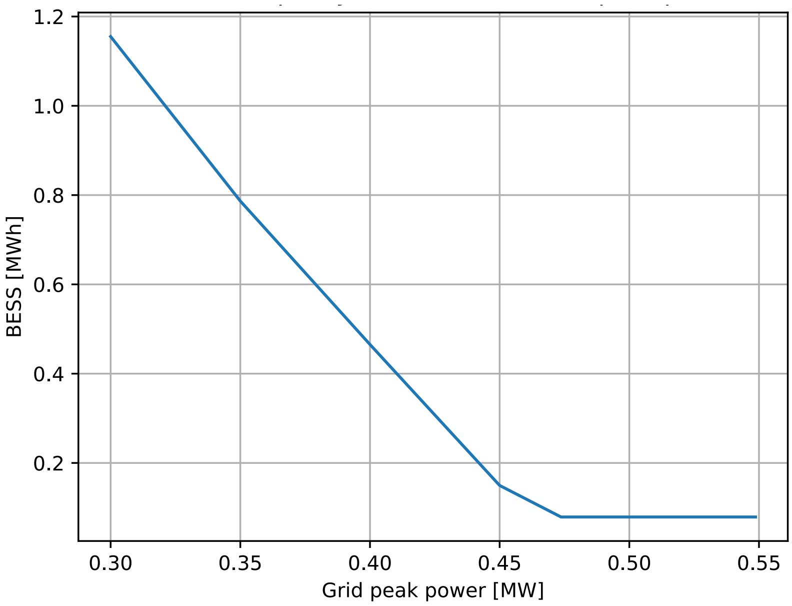


Figure 10: The BESS capacity in function of the max peak power

In Figure 10 above the BESS capacity in function of the grid peak power can be seen. The solar installation is always the same size as mentioned in the assumptions and therefore the influence of the solar is the same for all simulations. When the energy model is allowed to add solar and battery to the network then the minimum grid peak power connection that is needed is 0.3 MW. The plot shows that a smaller peak power connection is achieved by increasing the BESS capacity.

The max peak load reduction possible is around 36.7%. This value has a BESS capacity of 1.15 MWh. The gain of the last percentages for a better peak reduction comes with a higher cost - advantage ratio. The plot above shows a steeper line at lower peak power which represents a less optimal cost – peak reduction ratio.

8.2.1.1.5 Self-sufficiency

The self-sufficiency of the network is 3.14%. The model has a fixed size for the solar installation (Valkenswaard) thereby the local production of energy is always the same. In the model the energy is not given back to the grid and does not allow curtailment. All the solar energy produced by the solar panels is consumed and the load is the same in each simulation case.

8.2.1.1.6 Self-consumption

The self-consumption KPI is not relevant for this case. The load that needs to be met is considerably higher than the locally generated energy that is consumed, giving not much room to deliver energy back to the grid. Therefore, this feature is not implemented into the model and thus the self-consumption will be equal to 1.

8.2.2 Charging depot

Given the substantial load on the grid in the Netherlands, it is crucial to significantly reduce grid dependency. Especially when considering the high charging powers involved when charging heavy-duty transport vehicles. Hence, an investigation is done for a charging depot using simulations on how to reduce the grid strain. This is mainly achieved by adding a BESS and applying smart charging strategies. The optimization is then done by minimizing the operational costs, in which the costs for the grid peak power are included. As a result, grid dependency is decreased. The simulations for the charging depot are based on real data obtained from an electric city bus fleet operator, from which the charging needs per bus are obtained.

From this data it can be seen what the availability of the bus is for charging, when the charging sessions occur and how much the battery needs to be charged per session. Then, the charging process can be optimized by considering smart charging strategies or through adjustment of the local energy network at the charging depot.

The optimization is done by optimizing the operational grid costs (i.e. the grid peak power spendings and spendings on buying energy) and this is done for different charging strategies and BESS sizes. Since using a higher grid-peak power results in higher operational costs, it will be minimized during the optimization and therefore the grid dependency is aimed to be reduced.

The following assumptions are applied for the simulations of this use case:

- Data used of 8 months (limitations of recorded data Valkenswaard site from 01-02-2024 to 30-09-2024)
- An electric city bus fleet composed of 10 vehicles
- 10 chargers (300 kW charging, 45 kW discharging).
- Grid connection of 1.2 MW.
- Second life BESS and solar panels for energy storage and generation, respectively 0-700 kWh BESS, solar power maximum of 50 kW inverter power.
- Varying energy prices for a period of 01-02-2024 to 30-09-2024 ([EMBER])
- Grid peak price obtained from Enexis and are fixed for the simulation period [Enexis]

8.2.2.1 KPI evaluation

8.2.2.1.1 Energy curtailment

Energy curtailment refers to the intentional reduction of energy output from renewable sources to balance supply and demand or to prevent overloading the grid. Since the energy consumed by the load is orders of magnitude greater than the generated energy and the BESS is used to store the energy that cannot be used by the load at the specific moment of energy generation, the KPI is zero in this use case.

8.2.2.1.2 Self-sufficiency

The simulations are performed for different charging strategies over different BESS capacities. Since these are our differentiators to assess the results, other parts of the network are kept the same for each simulation case. Hence, the local energy generated and the total energy demand from charging the buses are fixed. This implies that self-sufficiency is similar, regardless. Locally, a total of 43.7 MWh of energy is generated by solar panels. The total energy demand is 191.4 MWh and comes from charging the city buses. This results in a self-sufficiency of 22.8% over the simulation time.

8.2.2.1.3 Self-consumption

Similar to the highway charging use case, self-consumption is not relevant for this case. The load that needs to be met is considerably higher than the locally generated energy that is consumed, giving not much room to deliver energy back to the grid. Hence, this feature is not implemented into the model and thus the self-consumption will be equal to 1.

8.2.2.1.4 Peak load reduction

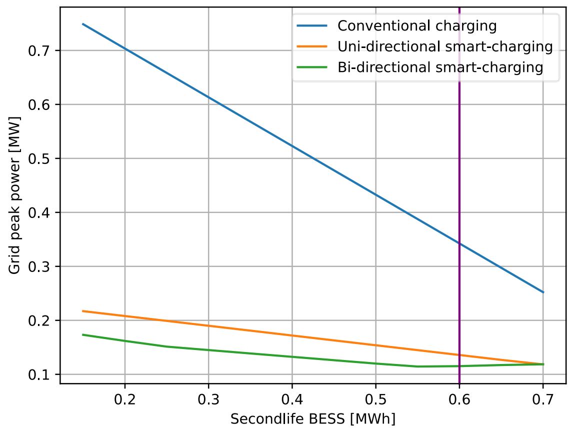


Figure 11: Grid peak power over battery capacity for different charging strategies

In Figure 11 it can be seen that when considering a smaller second life BESS, smart charging shows a positive influence on the grid peak power consumption over conventional charging. By applying smart charging, the charging demand can be spread over a longer period. By increasing the BESS size, peak-shaving can be achieved with conventional charging as well. The grid peak power gap for different charging strategies appears to narrow down when increasing the BESS capacity.

To obtain a grid peak power reduction, a reference is needed. For the reference case, a similar network is simulated without a BESS and solar generation. The grid peak power obtained from this reference case is 0.891 MW.

To do a fair comparison, the grid peak power for the different charging strategies is compared for the same BESS capacities. For a BESS capacity of 0.55 MWh, the optimum is reached considering bi-directional smart charging (purple line, 0.114MW) and the rest of the comparison will be done using this BESS capacity. For this capacity, the grid peak power is 0.342 MW for conventional charging and 0.136 MW for smart charging. A lower grid peak power could be achieved for conventional charging and uni-directional smart charging if the BESS capacity would have been increased more. To make the comparison uniform, this has not been done. Using a second-life BESS system, the investment costs would be minimal so in practice expanding the BESS should not have a huge impact on the total investment. This is assuming that the batteries that are replaced from the city buses can be used for this purpose.

These grid peak powers lead to a reduction of 56.5% for conventional charging, 83.7% for uni-directional smart-charging and 87.2% for bi-directional smart-charging.

8.2.2.1.5 Utilization rate of EV chargers

The utilization rate during the day for the combined set of chargers can be seen in the following figure.

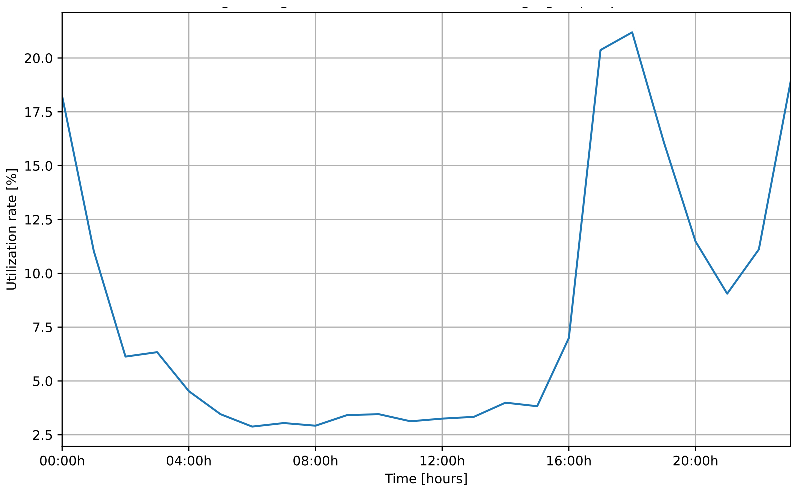


Figure 12: Average charger utilization for the charging depot per hour

The chargers are generally active during the night and in the late afternoon to early evening. During other hours, specifically between 5:00h and 16:00h, the utilization rate is low. These are the typical scheduled hours for the city buses to be operated and hence they are not available for charging. During the evening hours, specifically between 19:00h and 21:00h, a dip in the utilization rate is visible as well. These are the typical evening hours of the busses to be scheduled.

8.2.2.1.6 Amount of time providing flexibility services (locally or to the grid)

Due to time constraints, we have not been able to evaluate the outcome of the model to provide a value for this specific KPI.

8.2.2.1.7 Operational costs

From the perspective of a charging depot owner, it is important to reduce the operational costs as much as possible to create a good business case, which is the reason why the operational costs are evaluated as KPI as well. Operational costs refer to expenses that can be managed by optimizing the energy flow within the network. Costs can mainly be saved by reducing the grid peak power consumption and by spending less money buying electricity by aiming to buy it when prices are lower.

The baseline variable costs are calculated and are equal to 67433 euros. To assess the reduction in variable costs, the optimized costs at a BESS capacity of 0.55 MWh are considered.

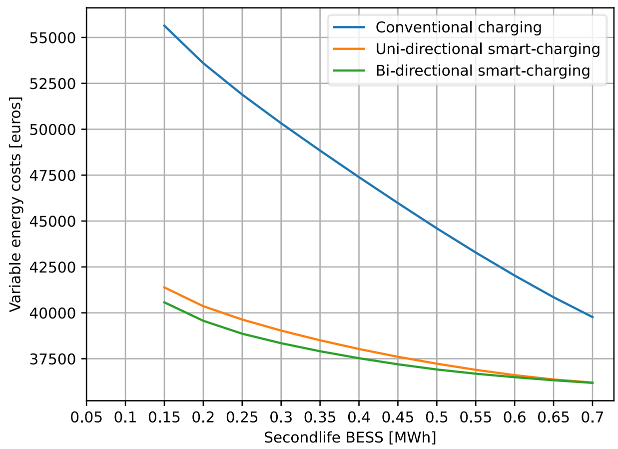


Figure 13: Variable energy costs over battery capacity for different charging strategy

In Figure 13, the overall trend of variable energy reduction can be seen. The figure indicates that implementing more advanced charging strategies positively impacts variable energy costs. The biggest leap is seen when going from conventional charging to uni-directional smart charging (V1G). The reason is that advanced charging strategies and having a higher BESS capacity provide more opportunities to purchase energy at lower prices, allowing for more optimal energy use. Additionally, by distributing charging needs more evenly, peak power consumption from the grid can be reduced, resulting in cost savings through peak-shaving.

The transition from uni-directional to bi-directional smart charging (V2BESS) shows some additional savings on the variable energy costs as well, although minor.

Increasing the second life battery size shows an improvement as well. With such an approach, it is possible to decrease the variable costs, due to the fact of saving up more energy at cheaper prices and distributing it more efficiently over a larger period, reducing the peak power consumption.

Regarding the specific cost reduction at a BESS capacity of 0.55 MWh, values of 43285, 36895 and 36684 euro are obtained for respectively conventional charging, uni-directional smart charging, bi-directional smart charging, leading to a reduction of respectively 35.8%, 45.3% and 45.6% compared to the baseline.

8.2.3 Rotterdam

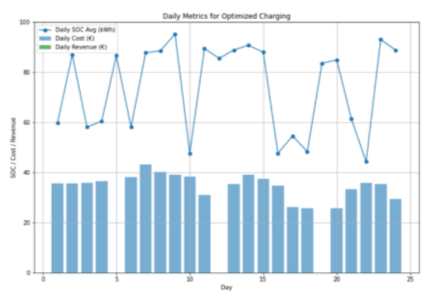
The Rotterdam use case consists of x number of electrical vehicles used by the DSO and are used as working VANS. In the evening the van's are charged on different places in the city via public charging stations. Some of the van's are available on the charging plaza of the DSO.

The data and KPI are based upon the charging session of the vans of the last x years. These charging profiles have been used in simulation to see what the benefits of V2G charging can be on the charging costs and on some other KPI's.

All the vehicles are distributed over a larger area in the vicinity of the city of Rotterdam, the VAN are taken home and are charged often overnight on public chargers. Some of them are charged near the office building if the workers and their van’s are not on the road. The calculation for this fleet was carried out based upon the actual charging profiles and the most optimal situation has been calculated when based upon V2G charging with the constraints that the EV was charged on the same level and could be used in the same way as before.

The simulations were executed based on the day-ahead market price and the algorithm made a cost optimization combining V2G and optimal charging to have a the most reduced cost price. The case is similar to the Utrecht case with the exception that the owner of the Fleet is one private company who does not own the public chargers.

Cost optimization when using V2G compared to dumb charging. The price of charging in V2G represented a price of 58% compared to 100 % in the base case scenario. Or a reduction of 42% in electricity costs based on the day-ahead costs.



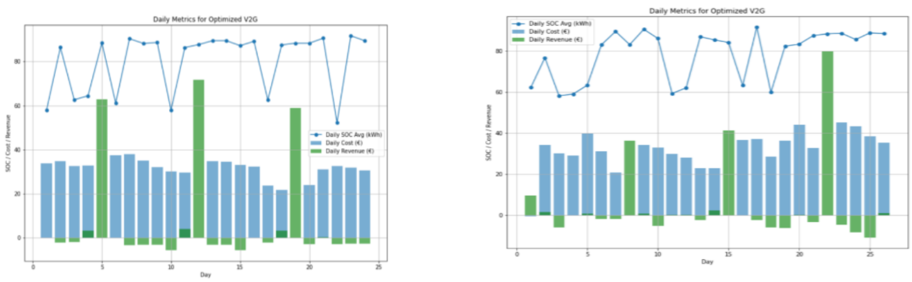


Figure 14: Cost optimization

The calculations have been carried out with the profiles and prices of 2023, no calculation of peak reduction have been carried out as the vans have been distributed over the larger Rotterdam area. The cars and the distribution of the cares cannot contribute to the local congestion markets or other secondary markets.

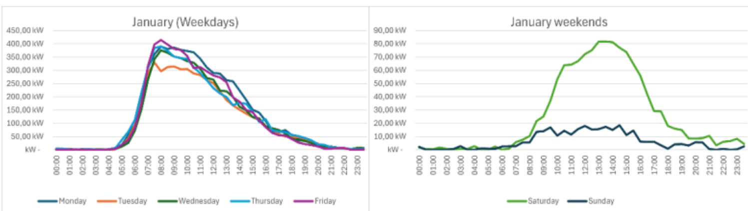
8.3 Vehicle to Public (V2P)

8.3.1 Oslo

The data used for the calculation of the KPI is collected between 1 January 2024 and 23 October 2024, covering 19,016 charging sessions. The data includes activity from 188 charging points.

The chargers are primarily semipublic units with some positioned near a shopping mall. However, these chargers operate independently of building energy systems, meaning optimization and peak reduction cannot be directly linked to office energy use.

During the project period, various developments, tests, and optimizations were implemented on selected chargers. For example, a charging speed reduction algorithm was tested. While some vehicles supported reductions to 0A, others did not. A detection algorithm for identifying vehicles capable of handling this reduction was already implemented before start.



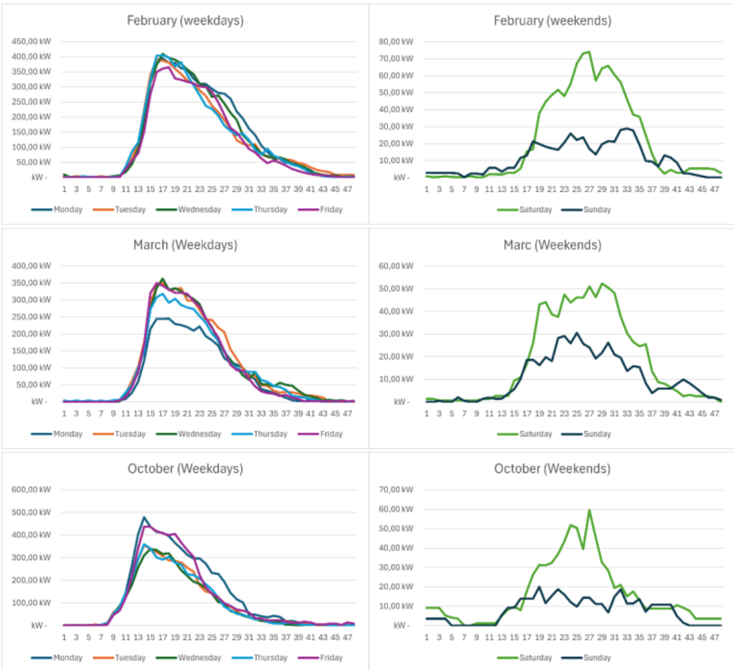


Figure 15: Charging profile

8.3.1.1 Utilization rate of EV chargers

The utilization rate for Pilot C1 reflects total charging time at the charge point over a 24-hour period. The site is primarily active during working hours, with limited activity at other times, except for a few charge points near the shopping mall. Notably, many users park at the chargers without initiating charging, as they may not require it on a particular day. On average, users charge their vehicles 2–2.5 times per week while at the office. Currently, charging is primarily initiated by the company through RFID cards. Starting January 1st, the payment system will change, allowing for more detailed transaction data to provide a clearer picture of user behavior and charging patterns.

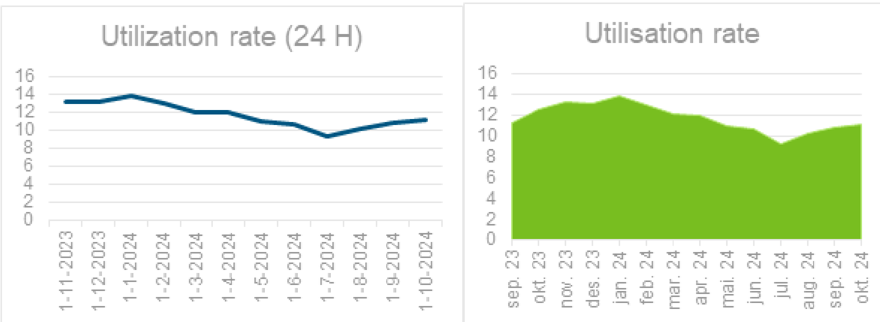


Figure 16: Utilization rate

8.3.1.2 Energy system flexibility (simulation)

Since there is no ISO15118 implemented on existing charge point, energy flexibility is calculated based on historical data and user behavior. With the State of Charge the potential for flexibility would likely increase.

For this simulation this is the parameter that has been used to find the potential revenue and, we have used the data usage data and data from flexibility market to simulate the income.

Assumptions and data

3	activations per month (10 per season/3 months)
26	days per month (mon-sat)
10	hours per day (9-19)
188	points

For the whole year October to March this gave a simulated max value of 708 452 NOK for activating flexibility and 20 261 NOK for reservations over the 6-month period.

Broken down to a acceptable usage for the consumer, can't feel the flexibility, each charge point would produce an extra revenue stream of 46 NOK pr month pr charge point (33 NOK in reservation and 13 in activations)

8.3.1.3 Reaction time to increase/decrease power delivery

System test shows that the response from Charger to Back office to Flexibility market is less than 1 second, thus the site can participate in all market save the FFR market. In the location only FCR-Up is available.

8.3.1.4 Amount of time providing flexibility services (locally or to the grid)

In the simulation we have used the market for 2024 as data and used the actual consummation data at site as the market load.

8.3.2 Time-of-Use Load shifting

Current has introduced a pricing model tied to dynamic energy tariffs based on day-ahead electricity market prices. This model encourages users to charge their vehicles during off-peak hours when energy costs are lower, promoting more efficient energy use and reducing grid strain. By incorporating real-time energy price fluctuations, the pricing structure facilitates load shifting, balancing demand, and supporting cost-effective charging for users. This approach aligns sustainability goals and enhances grid stability by shaping charging behaviors around energy availability and cost trends.

Data comparison with pre-project periods shows a noticeable shift in charging peaks following the implementation of dynamic tariffs. However, there remains significant room for improvement. With the rollout of a new system at the site on January 1st, which provides end-users with real-time energy costs and live site data, we anticipate a further shift in behavior. This added transparency is expected to drive more informed charging decisions, aligning energy demand with lower-cost periods and reducing overall grid impact.

8.3.2.1 Energycost saving

The day-ahead prices of the Norwegian electricity market have been used to calculate cost price for charging, the outbound price for the consumer can be linked to the dynamic spot market price (day-ahead) or a fix rate set by the location owner

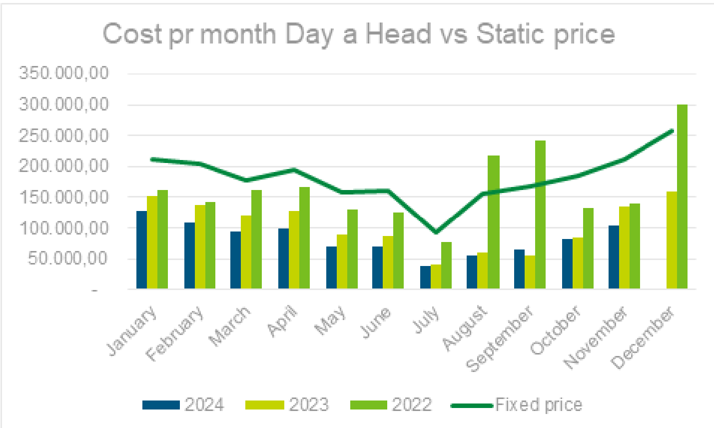


Figure 17: Day a head vs. static price

If the location owner had changed to dynamic pricing the EV driver would have saved:

	January	February	March	April	May	June	Juli	August	September	October	November	December
2024	64,74 %	88,89 %	88,15 %	96,80 %	129,03 %	127,35 %	144,16 %	177,62 %	159,00 %	124,86 %	101,96 %	
2023	39,75 %	47,28 %	48,82 %	50,00 %	76,79 %	82,17 %	129,91 %	161,30 %	209,12 %	119,96 %	54,46 %	63,28 %
2022	31,67 %	43,54 %	10,56 %	15,78 %	19,69 %	26,69 %	18,82 %	-28,36 %	-30,60 %	38,02 %	48,85 %	-13,77 %

Only 3 months in 2022 would have been beneficial for the EV driver. If this is broken down to most optimal hour of the day to charge we would see an even bigger saving potential. But there is a lack of SoC and wanted departure time from vehicles to be able to calculate this potential.

8.3.2.2 Reduction of CO2 electrical cars

Charging an electric vehicle (EV) with electricity that results in a CO2 savings of 220 grams per kWh compared to an internal combustion engine (ICE) vehicle highlights the significant environmental benefits of electrification. For an average EV with an efficiency of 15 kWh per 100 kilometers, this translates to a reduction of 3.3 kilograms of CO2 emissions per 100 kilometers driven. Over a typical driving range of 15,000 kilometers annually, the total CO2 savings amount to 495 kilograms per year per vehicle. Scaling this impact across a fleet of EVs or widespread adoption further emphasizes the role of clean energy and EVs in combating climate change and reducing greenhouse gas emissions.

The location charged **418,677 kWh** during the period of the data set and achieved a CO2 saving of **220 grams per kWh**, the total CO2 savings can be calculated as follows:

Total CO2 Savings=418,677 kWh×220 gCO2/kWh

Total CO2 Savings=92,109,940 grams of CO2

Converting grams to metric tons:

92,109,940 grams÷1,000,000 = 92.11metric tons of CO2
During the project period, the location charged approximately **418,677 kWh**, resulting in a total CO2 savings of **92.11 metric tons**.

8.3.3 Utrecht

The data used for the calculation of the KPI is collected between 1 July 2023 and 1 July 2024 over all the chargers of Utrecht. The chargers consist of a mix of public chargers and chargers used for shared vehicles. Some of the chargers are public chargers but close to office buildings but there is no interaction to the energy system of the building so that the optimalisation and peak reduction cannot be related to the office building.

During the SCALE project different developments, optimizations and tests have been carried out on part of the chargers. Such an example is the reduction of the charging speed to 0A, some of the cars were not able to support the reduction to 0A others did support the reduction. The introduction of an algorithm for detecting the cars which are capable of this was introduced during the measurement period. More information about the different developments, tests, optimization are found in the documents of D4.

The data was calculated over 136k load sessions over 794 charging sockets and 397 charging stations.

An uncontrolled session is a session which is charged with full capacity or also known as dumb charging, which is the base-line scenario for the comparisons. When the optimizer has enough information the session will be controlled and lower charging, delayed charging or even discharging can take place.

8.3.3.1 Utilization rate of EV chargers

The coverage of the occupation of the chargers differentiation between weekdays and weekends, the average occupation is between 20 and 30% of the time.

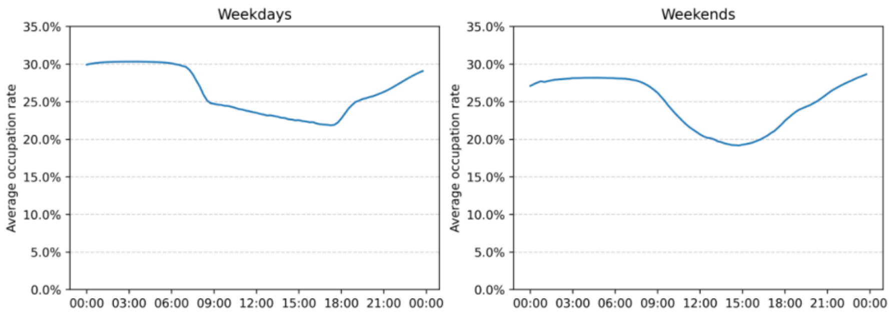


Figure 18: Charger occupation rate weekdays vs weekends

8.3.3.2 Energy exchanged with the GRID

As only within some test cases on power was injection, this is not considered. The V2X technology was not available early enough to be deployed in a complete production environment. The first vehicles and chargers will be used in Utrecht in Q4 2024. The total amount of energy consumed was 5437 MWh over the monitored time (one year).

Commented [KH1]: Describe the test a bit more in detail?

Commented [KH2]: On which timeframe?

8.3.3.3 Flexibility

The system flexibility has been calculated with the following method. The cars need to be charged at the end of the charging session. Depending on the car type a more precise method is used. The shared cars have additional information about the SOC (State of charge) and the amount of kilometers needed for the next trip, the energy available at the end of the charging session. The cars on a public charging station have based upon historical data a knowledge of what energy is needed and what the connection time of the car is. When not enough accurate data is available then the car is charged as fast as possible. The following graphic displays the flexibility in hours of the cars on a specific timeslot. The distinction has been made between office buildings and non-office buildings in the following chart.

Figure 19 displays the charging power that can be shifted and how long. As is seen in this chart on an office location almost no power can be shifted.

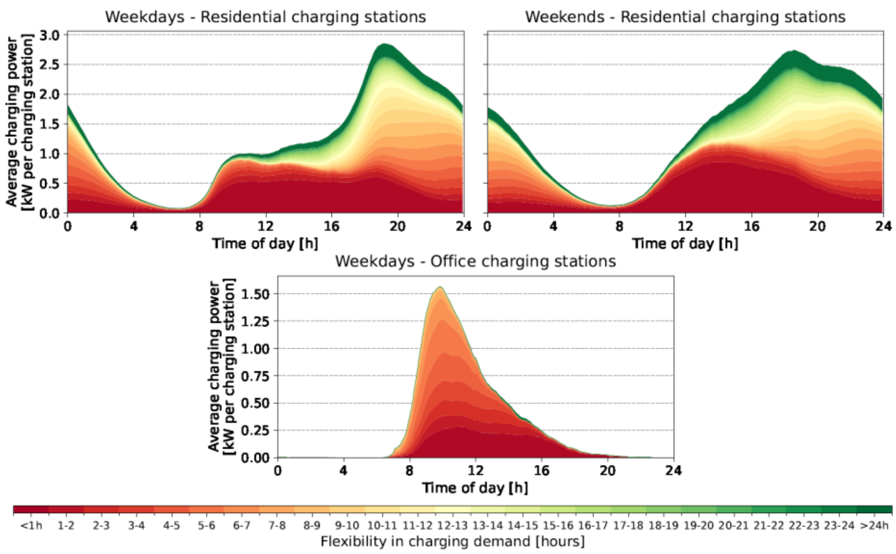


Figure 19: Shifting of charging power

8.3.3.4 Peak load reduction

The Peak load reduction between the uncontrolled charging and controlled charging on average per charging station can be found in the following charts. This peak is reduced based upon the algorithm, this algorithm considers the electricity prices (Day-a-head) an additional price on transformer price, this price is higher when the transformer is under heavy load. The average peak reduction is around 15%.

Commented [KH3]: How is this tested and how is the peak reduced?

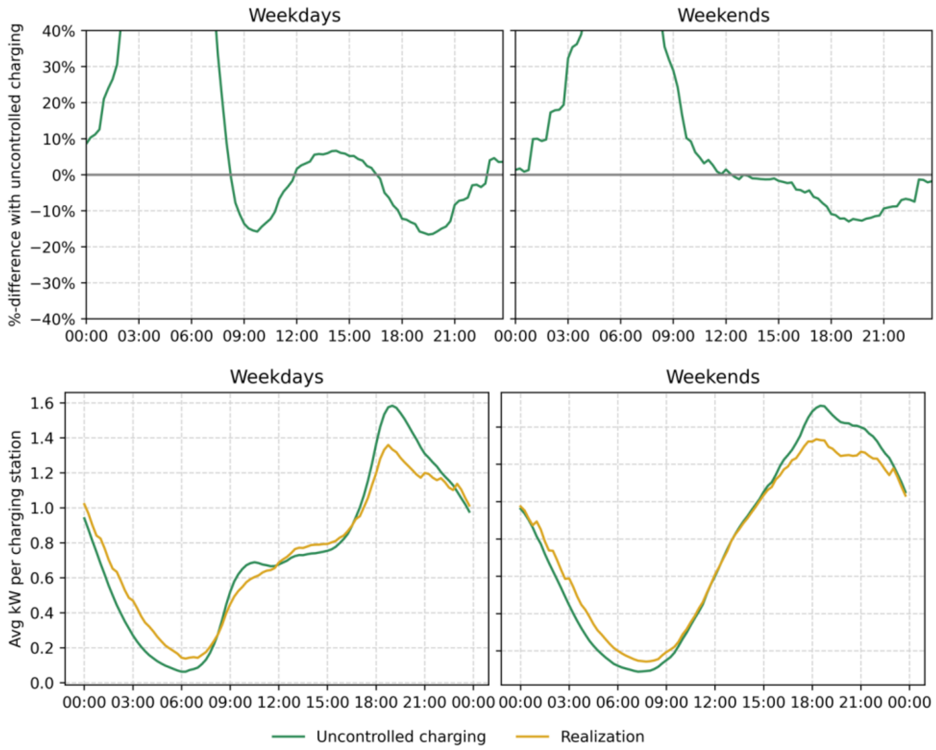


Figure 20: Reduction of charging profiles

Figure 20 comes from the reduction of the charging profiles by optimizing on costs and with the additional cost of overcharging transformers in the different districts of the city of Utrecht. An AFRR experiment have also been carried out on the chargers in Utrecht. There a AFRR signal was given, and the actual fleet was asked to reduce as much as possible the charging current. The experiments allowed only to reduce the charging to be dropped to 6 A, the cleverer algorithm of reducing to 0 or 3 A was not active at that moment.

8.3.3.5 aFRR proof of concept

A proof-of-concept test in Utrecht demonstrated that an aggregated pool of around 100 to 130 electric vehicles can swiftly and reliably reduce charging loads in response to aFRR signals. Although the 1 MW downwards requirement was not fully met, the key limiting factor was the algorithmic restriction that prevented any car from charging below 6 A. Loosening this threshold to 3 A or even 0 A could enable deeper load curtailment, thereby meeting or surpassing the 1 MW setpoint. Another limiting factor was the 15-minute measurement interval, which introduced substantial uncertainty and produced spurious fluctuations not reflective of actual charging behavior. Despite these limitations, the rapid and sustained load reductions observed confirm the strong potential of EV flexibility for providing grid balancing services, particularly if future tests adopt finer-grained data collection and revised charging constraints.

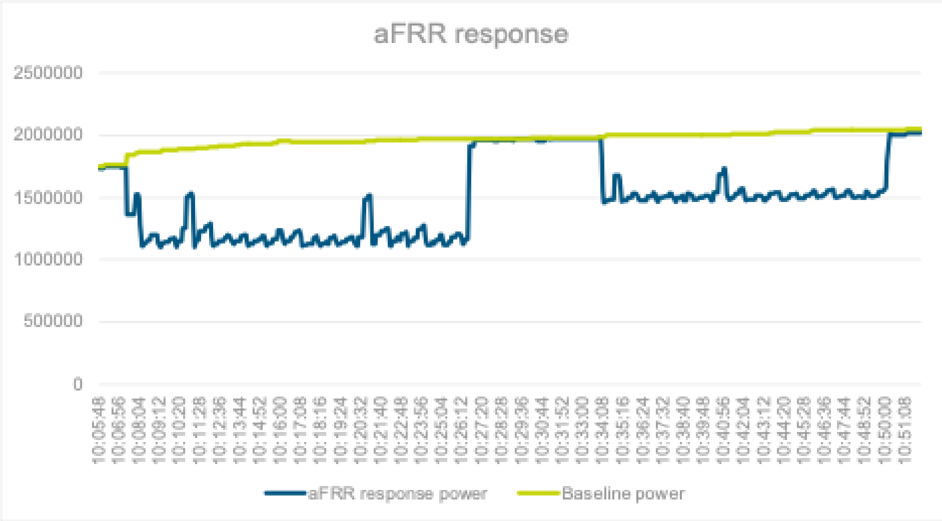


Figure 21: aFRR response

Figure 21 shows that the system could reduce the power from average 1,9 MW to 1,05 MW which is a reduction of 45% taken into account that the cars did receive 6 A but this could be reduced to even more when V2G is in place and the model algorithm of reducing the “known” cars capable of handling less than 6 A and resuming charging.

8.3.3.6 Reaction time increase/decrease

Some tests have been carried out about the reaction time of an EV charger on the decrease of the energy. This is the total reaction time between the sending of the commands from the management systems to the EV charger. The average reaction time is around 10 seconds but with a large variation. This meets the requirements for aFRR and congestion management product and can be supported by a pool of EV cars. The calculation is done based upon the energy usage of the pool/single charging session, the difference in slope of the energy consumption can be seen as the reaction time of the system on a request to reduce the energy consumption. On the right-hand side on sees the response time to the number of chargers responded within the specified times.

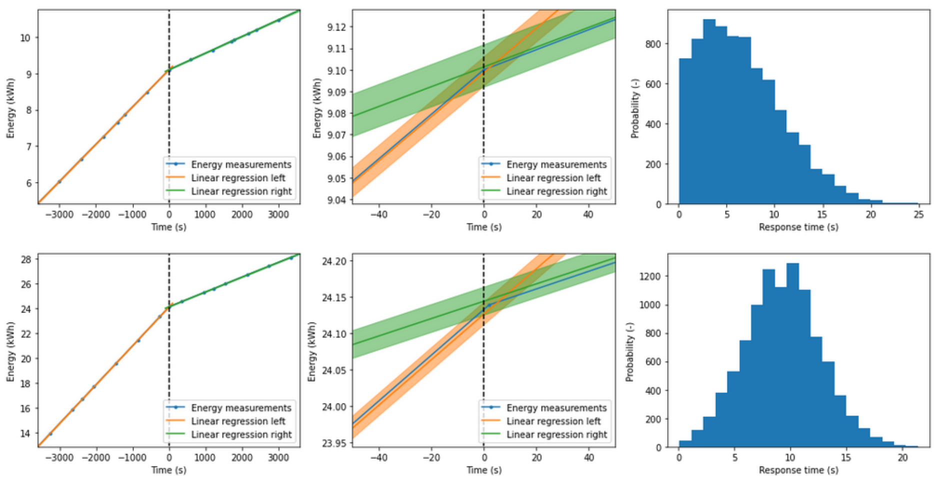


Figure 22: Charger reaction time

An AFRR experiment was carried out and the 1MW was not reached but could be implemented when using now a more sophisticated algorithm but the 500 KW was reached and sustained during the AFRR delivery.

8.3.3.7 Energy cost saving

The day-ahead prices of the Dutch electricity market have been used to calculate different energy cost price between uncontrolled charging and controlled charging.

Uncontrolled average price is 0.0798 euro/kWh.

The controlled average price is 0.0775 euro/kWh.

The saving is 2,89 %.

8.3.3.8 Reduction of CO2 electrical cars

The reduction in CO2 emissions from all kilometers driven during the 137k session is calculated as follows:

The average emission factor in the Netherlands is 0.328 kg CO2/kWh (Source). The total emissions from all EVs between 2023 and 2024 is estimated at 1.784 million tons (Mton) of CO2.

With an average charging efficiency of 93% (source), and an average energy consumption of 0.191 kWh/km (Source). 5437 MWh transforms to Ev km with the following formula: 5437*0.93/(0.191/1000)= 26.47 million EV km.

For conventional cars, the average fuel consumption is 6.5 L/100 km for gasoline vehicles and 5.57 L/100 km for diesel vehicles (source). The ratio between gasoline and diesel cars is 76%/24% (source).

The emission factor for gasoline is 2.821 kg CO2/liter, and for diesel, it is 3.256 kg CO2/liter (Source). The total emissions for the same 26.47 million kilometers, if driven by gasoline and diesel cars, would be calculated as: 26.47 million km*0.76*0.065*2.821+26.47 million km*0.24*0.0557*3.256 = 4.842 Mton CO2

The total CO2 reduction is therefore: 4.842 Mton CO2-1.784 Mton CO2=3.1 Mton CO2. Or a reduction of about 63,16% in emissions is achieved.

One of the major influences in this reduction is the energy mix with which the electricity is produced, the Netherlands has an 0,328 kg CO2/kWh compared to Norway with 0,018 kg CO2/kWh with which the reduction will be even higher.

8.3.3.9 Reduction of CO2 due to load shifting

Shifting electric vehicle (EV) charging to times when grid electricity is cleaner (i.e., when the marginal emission factor is lower) can significantly reduce the environmental impact of EVs. The **marginal emission factor (MEF)** refers to the additional CO_2 emissions produced by the last unit of electricity generated to meet demand. The MEF varies throughout the day based on grid conditions and the mix of energy sources supplying power.

How it works:

1. **Electricity Supply Mix**: Power grids draw from a combination of energy sources (e.g., coal, natural gas, wind, solar). The MEF is lowest when renewable energy sources like wind or solar are dominant and highest when fossil fuel plants are running.
2. **Time-of-Day Variability**: During off-peak hours (e.g., night), grids may rely more on renewable sources if they are available, while peak demand hours might see more fossil fuel use. This creates variability in the carbon intensity of electricity throughout the day.
3. **Shifting EV Charging**: By aligning EV charging with periods of lower MEF, such as during times when the grid is primarily supplied by renewables, you can reduce the carbon emissions associated with charging.

The average of the MEF for the uncontrolled charging (base scenario) over the session was:

481.4 g CO2eq/kWh

For the controlled session the average was:

473.7 g CO2eq/kWh

This results in a 1.7 % better MEF, and this results in a slightly better CO2 reduction of 63,75 compared to the uncontrolled sessions. A more detailed calculation can be found in the deliverable D4.3.

8.3.3.10 What are the effects of V2G

The standard charging profiles of the city of Utrecht have been introduced in simulation runs and an optimisation algoritme was executed to calculate what the benefits of V2G could be for the grid and more specially of the local congestion that the city faces in the future if all the cars would be dumb charging. These results have been published in different papers and presented on internation EV congresses.

A research paper about V2G stated that the introduction and the support of these cars could be more beneficial for the peak hours and could even support the grid. As no V2G cars were ready in sufficient amount the only possibility for SCALE has been simulation data.

9 Conclusions

SCALE's monitoring framework and demonstration activities have confirmed the viability and impact of smart charging and V2X concepts across diverse European pilot sites, directly fulfilling objectives laid out in the project's Grant Agreement. By collecting, analyzing, and comparing key performance indicators—from peak-load reductions of up to 45% in certain demonstrations, to nearly 20% savings on electricity costs, and over 60% reductions in CO_2 emissions compared to conventional vehicles—the project has provided strong, data-driven evidence of how intelligently managed EV fleets can support grid stability and deliver tangible benefits for end-users.

These conclusions not only validate the KPI definitions and methodologies set out in Deliverable 4.1, but also lay the groundwork for designing robust, scalable solutions that can be adapted for wide-scale deployment. Upcoming work in WP5 and WP6 will build on these findings to shape mass-rollout strategies, ensuring that technical solutions, operational guidelines, and policy recommendations align with a future-proof deployment model. By integrating the lessons learned here into broader scaling efforts, SCALE will help Europe maintain grid stability, offer cost-effective services, and accommodate a rapidly increasing number of electric vehicles—reinforcing the continent's position as a leader in green mobility innovation.

10 References

Nowtricity available at: https://www.nowtricity.com/

VDL Van Hool CX45E. Available at: https://abc-companies.com/van-hool-cx45e/

EMBER (2024). European Wholesale Electricity Price Data | Ember Available at: https://ember-energy.org/data/european-wholesale-electricity-price-data/

ENEXIS (2024) Jaarlijkse netwerkkosten | Enexis Netbeheer Available at: https://www.enexis.nl/zakelijk/aansluitingen/tarieven/jaarlijkse-netwerkkosten

Rijksoverheid drive and rest hours Available at: https://www.rijksoverheid.nl/onderwerpen/werktijden/vraag-en-antwoord/rijtijden-en-rusttijden-wegvervoer#:~:text=De%20maximale%20ononderbroken%20rijtijd%20mag,duurt%20dan%20minimaal%2015%20minuten

ChargeFinder Available at: https://chargefinder.com/

PyPSA Available at : https://pypsa.org/ (Accessed: 1 June 2024).