SMAC
Smart Charging Study
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Exploring the Potential of Smart Charging for Electric Vehicles in Germany

Insights from USER-CHI project

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1. Introduction

The main objective of the SMAC service in USER CHI is to provide CPOs the ability to implement smart charging strategies over the Charging Points under their control giving them the possibility to outsource the calculation of those optimum profiles to a third-party service provider (the Smart Charging Service Provider actor - SCSP). This approach will help them to optimize their energy-related costs, enable a better utilization of renewable energy sources and allow their participation as active actors in the smart grid management, both as participants of implicit demand-side management strategies (i.e. by the exposure to dynamic energy tariffs) and explicit demand-side management campaigns (i.e. by being required to temporary reduce their load to support the grid management). The SMAC deliverable has been implemented by ETRA and was supposed to be tested at USER CHI demo sites. The demo sites in Berlin are built up at 2 semi-public sites on GEWOBAG premises, operated by Qwello. Since the sites are accessible to the public and legally defined as publicly accessible charging infrastructure, the German calibration law applies according to PTB-A regulation 50.7.

The law does currently not allow variable tariffs as drafted in the SMAC proposal. Therefore, in alignment with the USER CHI project lead it was decided not to showcase SMAC as real-life demo at Berlin demo sites but rather evaluate the SMAC solution based on German market specifications and user behaviors and use cases.

The on-hand study is the result of this research.

2. Methods

The study comprises all charging sessions at Qwello charging infrastructure in Germany in public space in 2023.

In detail:

- 80,117 charging sessions
- 283 charge points (CPs)
- 118 locations
- >20 cities and municipalities

With the spread of the charging infrastructure in larger and smaller municipalities all over Germany, the study gives a statistic relevant mix of use cases like overnight charging in residential areas as well as very short charging sessions during shopping in mixed areas with numerous Points of Interest (POIs).

The data is extracted from Qwello backend with all common Charging Data Records (CDRs) and Qwello specific ones like Power Curves (PCs). Insights into PCs take the EV fleet structure in Germany into consideration and its ability to maximize charging power.

To calculate potential savings in energy sourcing the intraday spot prices are taken from EPEX Spot (https://energy-charts.info/charts/price_spot_market/chart.htm?l=de&c=DE) as traded at the Energy Exchange in Paris and Leipzig. The prices vary on a 15min basis. The prices are assigned to the charging sessions and according 15min periods in 2023.

With the given data different SMAC scenarios are simulated.

3. Energy price development Germany

a) Energy production Germany, energy mix and cost structure

With the decision of the German government to shut down nuclear plants and fully shift to renewable energy, the energy mix has changed and offers less stable energy production. Target is to have 80% renewable energy production in 2030.

The following diagram shows the energy mix in Germany in 2023 in TWh:

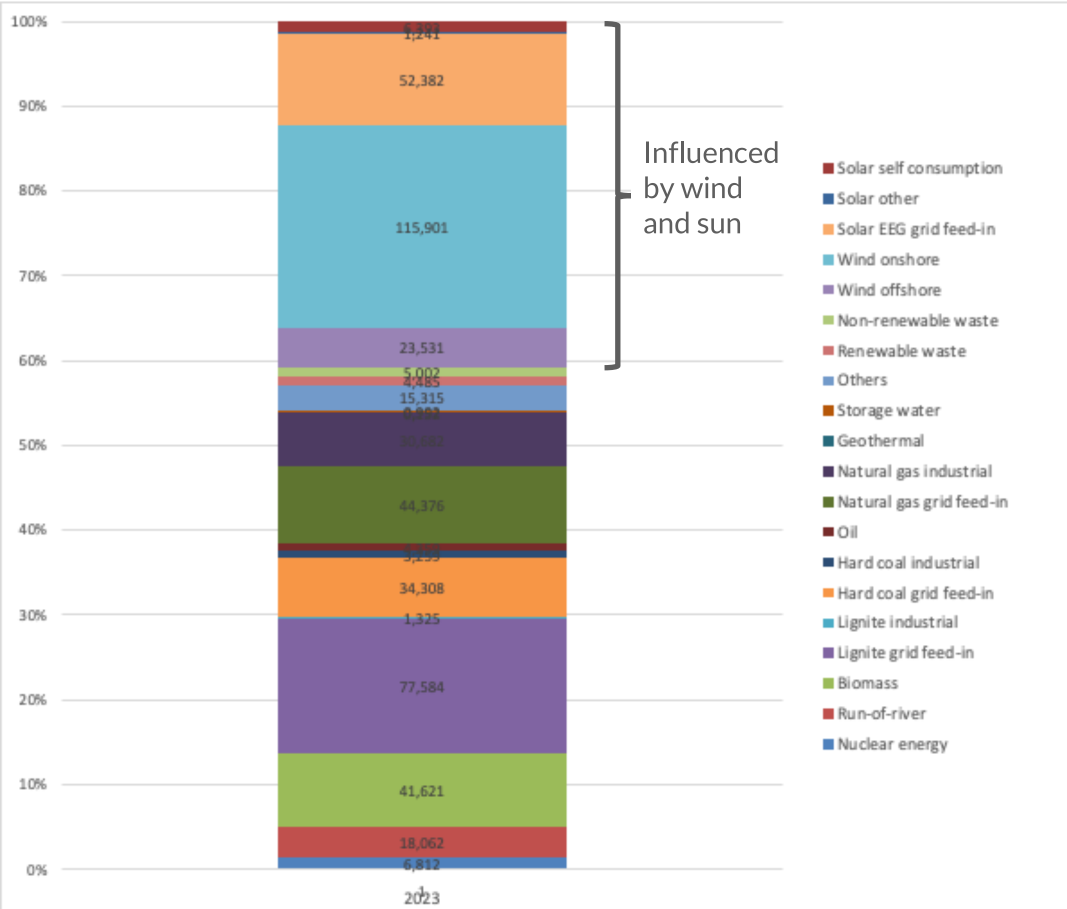

Figure 1: Energy mix in Germany 2023, https://www.energy-charts.info/charts/energy/chart.htm?interval=year&year=2023&source=total&stacking=stacked_percent

The high portion of power generation influenced by wind and sun (>40%) leads to a volatile energy stock price. For load peaks expensive power plants like gas need to be booted. The pricing mechanism in the electricity market is based on the principle of marginal cost pricing or merit order. Marginal cost pricing means that the price for the most expensive kWh determines the price for the entire available quantity of electricity. The generation costs of the last needed power plant set the market price, which is usually gas power plants.

Next to the power generation price, which is defined by marginal cost pricing, the German energy price to end consumers is also majorly defined by other cost elements:

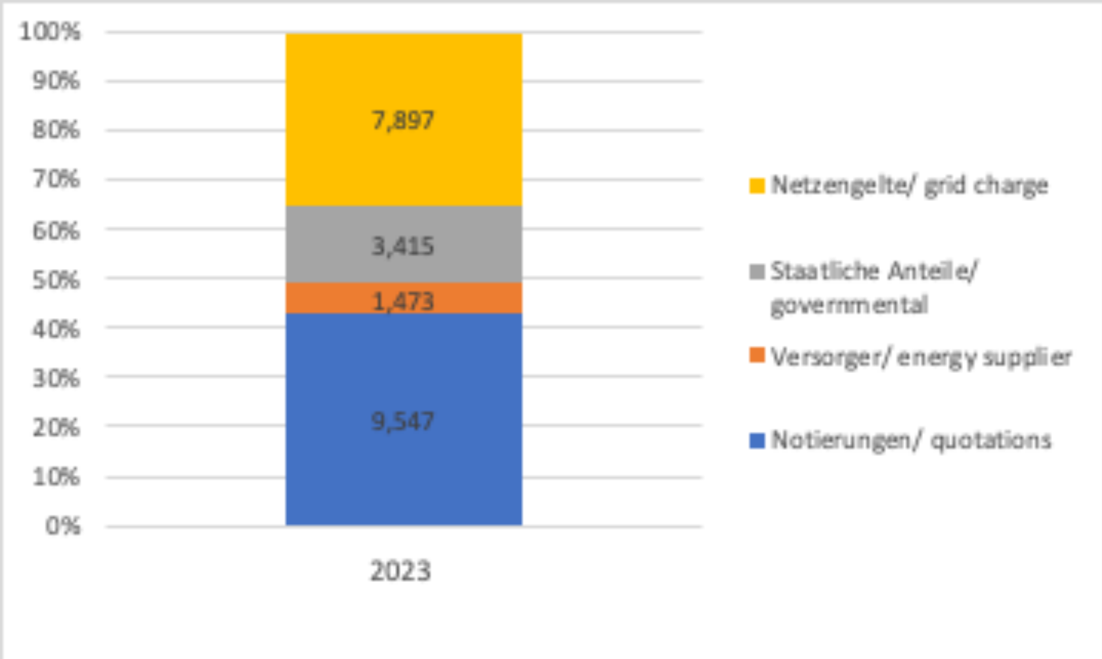

Figure 2: Avg energy cost structure in Germany in 2023 for end consumers in EUR ct, example Munich, Qwello sourcing Munich

The power generation cost (stock quotations) only account for 43% of the total cost. The other cost elements like governmental or grid charge from the Distribution System Operator (DSO) are not influenced by the volatile stock energy price and are defined each December for the next year. DSO charges vary from city to city. In Germany approximately 800 DSOs are active with different costs applying. Governmental charges are the same for all of Germany.
This implies that the majority (57%) of the energy cost to the CPO cannot be influenced by smart charging approaches.

b) Power and price fluctuation, external factors

Main external factors like Ukraine war, cold winter, extremely warm summer with low water levels in the rivers, low gas storage level influence energy prices over a longer period. Factors influencing the energy market on a daily and intraday basis are:

- Marginal cost pricing or merit order, costs of the last needed power plant
- Amount of sun = solar energy
- Amount of wind = wind energy

Largest factor is the mechanism with marginal cost pricing.
In 2023 energy prices in Germany have majorly decreased after the extraordinary year 2022. On average the energy stock price stabilized at 10 ct in 2023.

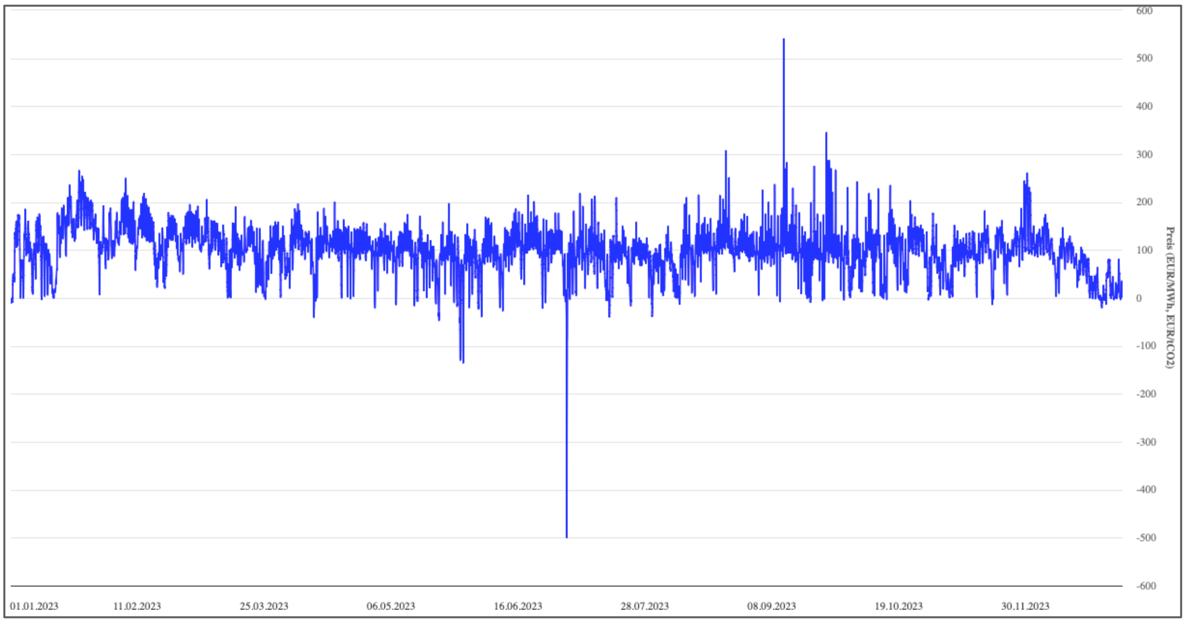

Figure 3: Energy price development 2023, EPEX intraday, https://energy-charts.info/charts/price_spot_market/chart.htm?l=de&c=DE&year=2023&legendItems=000000001000000&interval=year

c) Intraday 15min pricing

The following figures shows the volatility of the intraday trading energy prices at the EPEX in 2023 based on all 15min data points. While the mean (blue line) varies around 10ct, maximum or minimum (red lines) peaks exceeds a range of 300ct. Those extraordinary events e.g. with negative prices due to excess supply of wind or solar only occur very seldom.

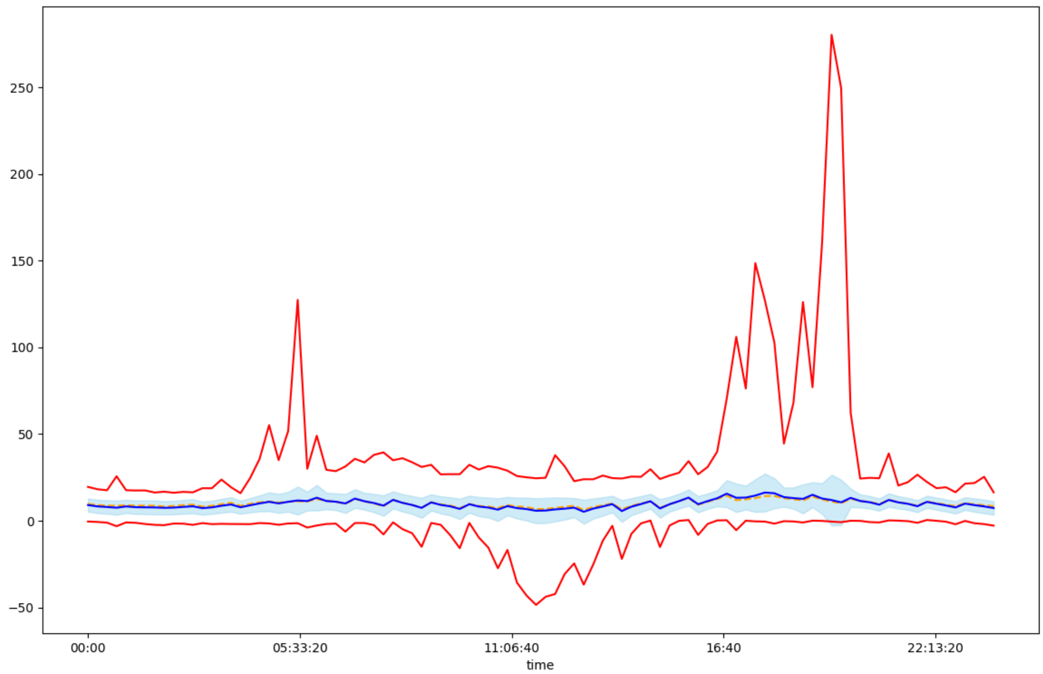

Figure 4: 15min intraday EPEX energy prices 2023 in ct, mean, max, min

Leaving the extraordinary events out of the evaluation, the mean and 1 deviation plus and minus are shown in the following figure:

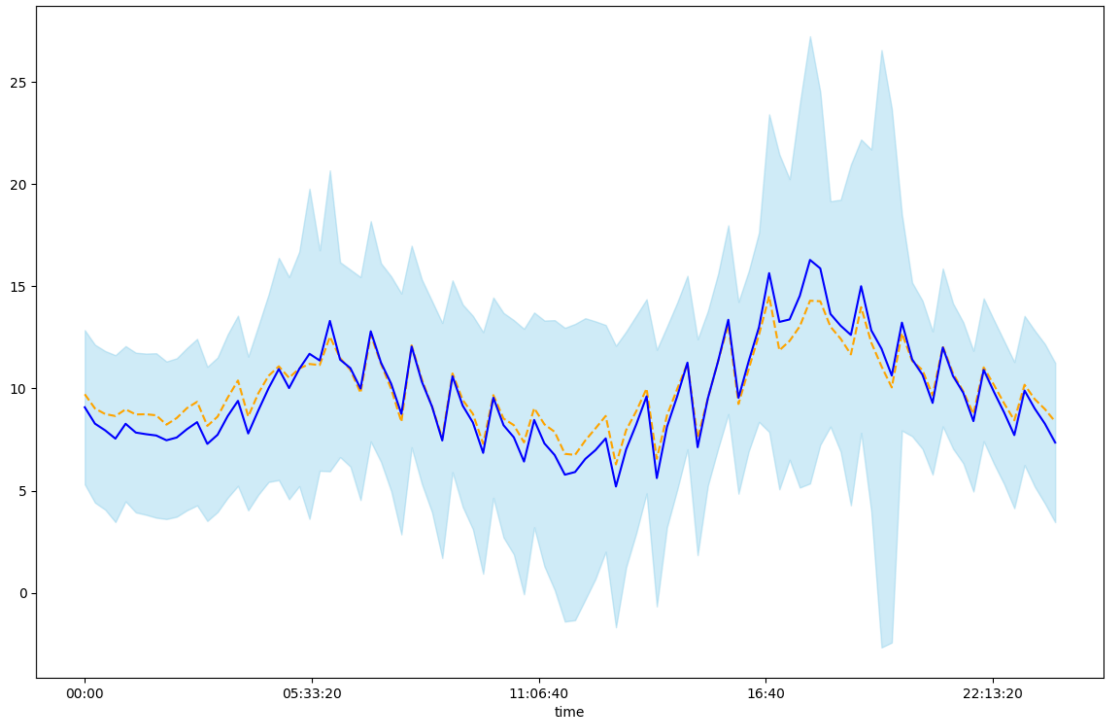

Figure 5: 15min intraday EPEX energy prices 2023 in ct, mean, standard deviation+/-

Energy price volatility can also be seen in the next figure for an average week in 2023. Visible is the peak in the morning around 06:00 am to 08:00 am and in the evening around 04:00 pm to 07:00 pm which expresses the classical duck curve dilemma:

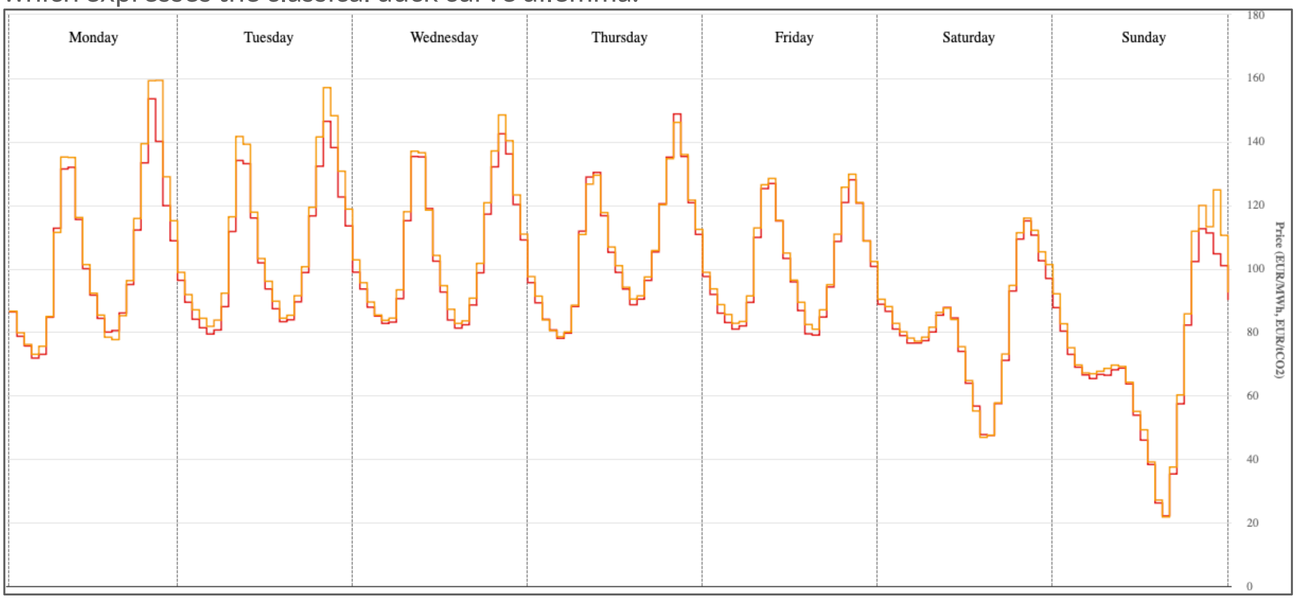

Figure 6: Average weekly day ahead and intraday energy prices 2023, https://energy-charts.info/charts/price_spot_market/chart.htm?l=en&c=DE&year=2023&legendItems=00000011000000&interval=week&week=-2&timeslider=1&enableStepping=1

d) Regular energy contracts

CPOs are legally end consumers in Germany with regards to energy sourcing. For energy sourcing several options are available:

1. Standard contract per site/ grid access with fixed prices. This option is especially convenient for only very few sites. For multiple sites this option is too complex since each site requires a new contract with individual conditions like notice period etc.
2. Frame agreement with energy agents, bundling volumes from various consumers for structured sourcing. This option will provide fixed prices on a monthly basis
3. Frame agreement with dedicated energy suppliers to source energy at stock prices on a monthly basis
4. Frame agreement with dedicated energy suppliers to source energy at stock prices on an intraday basis (every 15min cycle)
5. Power Purchase Agreement (PPA) with a larger energy supplier based on a large sourcing volume. This option is only valid for larger CPOs and will secure fixed sourcing cost over a longer period of time

With regards to the listed options, only the 4. option is a feasible contract to participate in smart charging improvements and may not be achievable for every CPO since a certain size needs to be given. Energy suppliers have additional administrative work in this contract and calculation structure which needs to be justified by higher volumes.

In Germany the local CPO monopolists are the utility companies which mostly have inhouse power generation plants. The type of internal contract is not known. Most other CPOs follow the contract type 3 if possible.

Next to contractual barriers to leverage smart charging options, also technical barriers like intelligent Metering Systems (iMSys) occur.

4. Charging

a) EV fleet structure, avg battery capacity, max charging power

EV ramp up in Germany has seen a steady growth. As of January 2024, in Germany 1,408,681 BEVs and 921,886 PHEVs are registered. An increase of 39% for BEVs and 7% for PHEVs compared to the stock in January 2023.

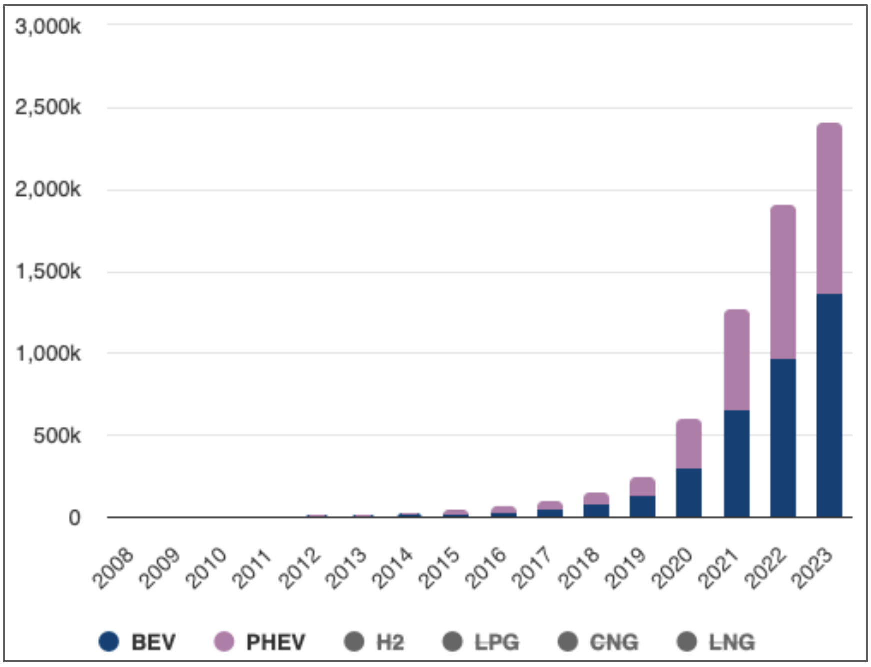

Figure 7: EV growth in Germany in units, https://alternative-fuels-observatory.ec.europa.eu/transport-mode/road/germany/vehicles-and-fleet

Nevertheless in 2023 the share on new registrations of EVs decreased in Germany due to stop of subsidiaries, long lead times and pricely EV portfolio.

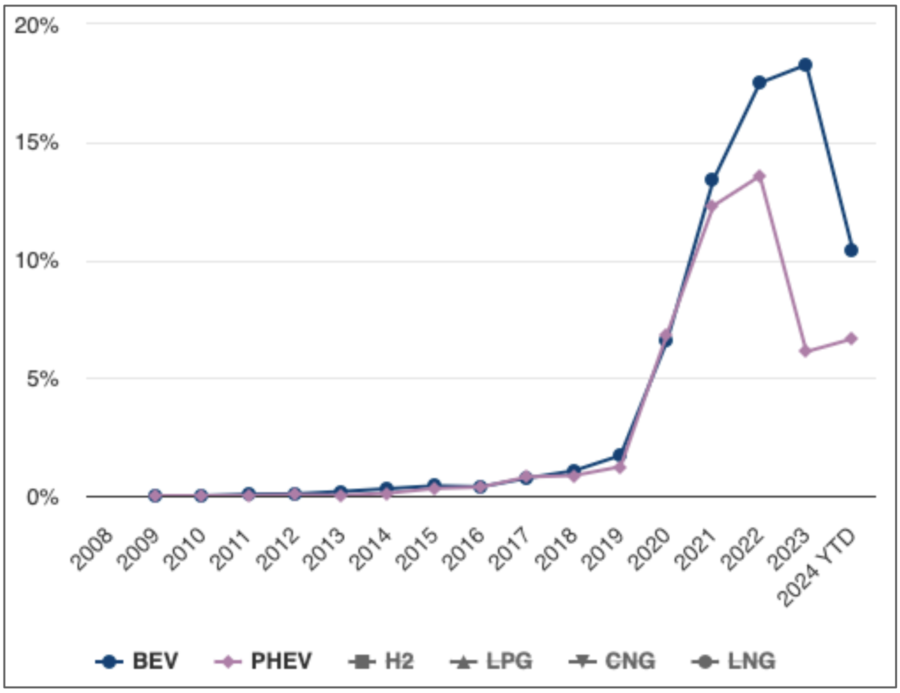

Figure 8: Share of EV new registrations on total PV fleet

PHEVs have a share of 39% on all EVs. Currently there are approximately 47 PHEV models available in Germany (https://www.goingelectric.de/wiki/Plug-in-Hybride-Uebersicht-und-technische-Daten/). Of those 72% can only charge with one phase 3,7 kW AC, 21% with 2 phases up to 7,4 kW AC and only 1 model with 3 phases up to 11 kW AC. This means, that the majority of all PHEVs on German streets cannot utilize a higher power in smart charging algorithm than 3,7 kW. This minimizes options to load at higher speed in times of cheaper energy or to balance the grid.
On BEV side all vehicles can charge with 11 kW AC. Only 7 models have a standard 22 kW AC onboard converter (https://www.praxis-elektroauto.de/e-autos/22-kw-onboard-lader.html). Further 17 models offer an optional 22 kW AC converter. The absolute majority of BEVs is only capable for 11 kW AC charging. In reality the load curves only allow less than the maximum power for the majority of the charging session.
The maximum charging power for PHEVs and BEVs can also be seen in the following figure. The figure shows all charging sessions in Germany in 2023 with maximum charging power, requested from the vehicle. A clear majority is at 3,7 kWh for PHEVs and around 11 kWh for BEVs. 22 kW is used very seldom.

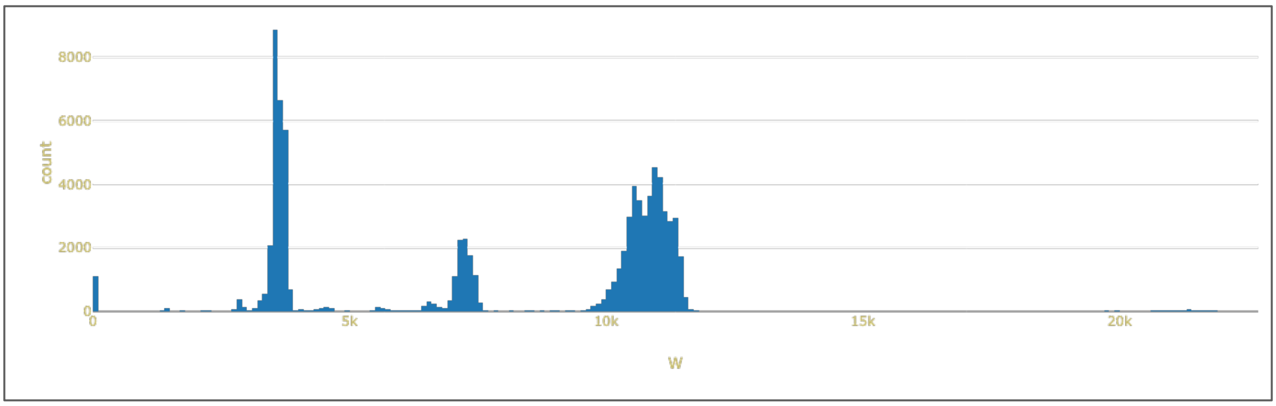

Figure 9: Charging power at Qwello AC infrastructure in 2023 in Germany in W

The average battery capacity of a BEV is 71,7 kWh (https://ev-database.org/de/cheatsheet/useable-battery-capacity-electric-car).

b) Customer charging behavior and preferences

For whole Germany Charging Radar recently published the following data for the usage pattern of the top 10 sites according to power level:

	AC (max 22 kW)	DC (max 50 kW)	HPC (min 150 kW)
Utilization (in %)	64-72	30-40	32-40
Sessions per CP per day	2-4	3-10	3-18
Plug-in duration (in min)	235-360	45-135	29-160

Figure 10: Usage patterns of top 10 locations in Germany in 2023 according to power level, https://www.electrive.net/2024/04/08/laden-in-deutschland-was-sagen-die-zahlen-ludwig-hohenlohe-von-charging-radar/

It needs to be considered, that in Germany different parking regulations for charging infrastructure apply. In most larger cities no time limitation is defined during night hours, usually from 08:00 pm to 08:00 am. During daytime the parking/ charging is limited to 2-4 hours in charging state. Penalties for rule violation have been increased to 55 EUR.

The customer charging behavior is mainly depending on the site localization. Sites in more residential areas have a longer mean charging time per session, while those at POIs show a higher frequency and shorter charging sessions.

c) Session KPIs: Duration, energy charged, parking without charging

The following data are main KPIs from the whole Qwello AC infrastructure in Germany in 2023:

	25 percentile	median	75 percentile
Duration of charging sessions (in min)	80	152	248
Daily started charging session per EVSEid	2,12	2,24	2,39
Energy delivered per Session (in kWh)	6,84	12,1	25,01

Figure 11: KPIs from Qwello charging infrastructure in Germany in 2023

d) Load curves

The load curves of the charging infrastructure in Germany, included in this study, prove the customer behavior to charge most in the morning and evenings, when returning from work.

For a typical week from Monday through Sunday the load curves of provided power are illustrated in the following figure:

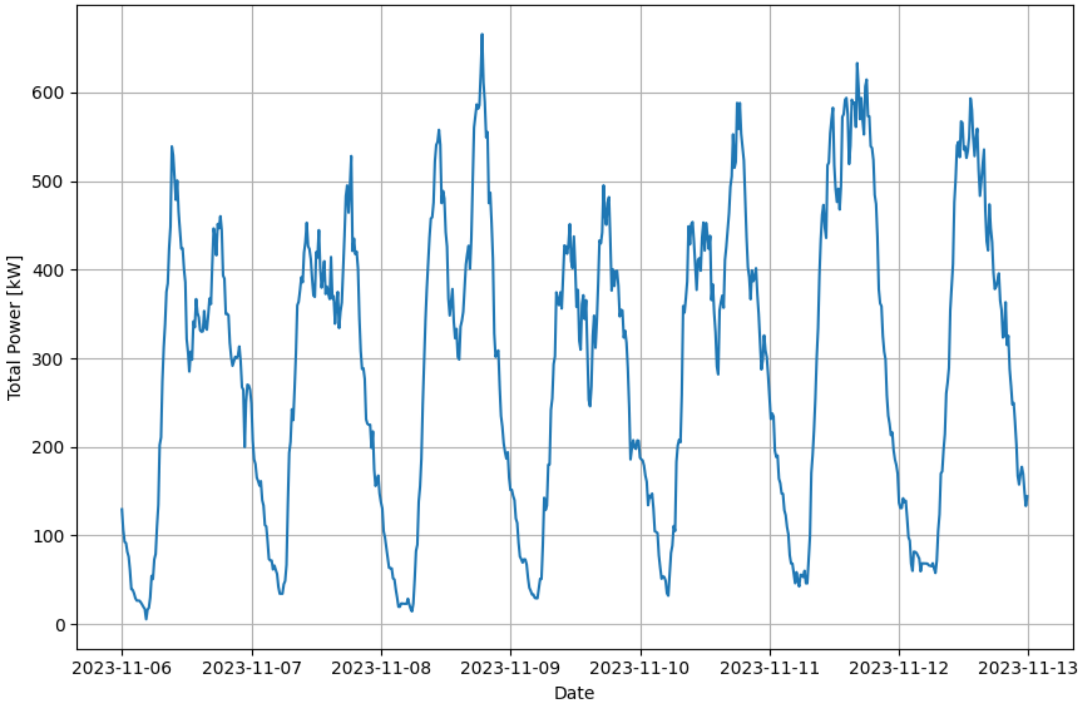

Figure 12: Load curves of provided energy in a typical week, Qwello data

Usually, 2 peaks occur over a day, 1 in the morning around 09:00 am and 1 in the evening around 07:00 pm. The high demand at times of typically low availability of solar and wind energy defines the duck dilemma (see also chapter 3. C).
Only on Saturdays and Sundays the 2 peaks are not visible since mobility patterns change on the weekends and the regular commuting is not taking place.
The curve during Wednesday of the week shown above is detailed below:

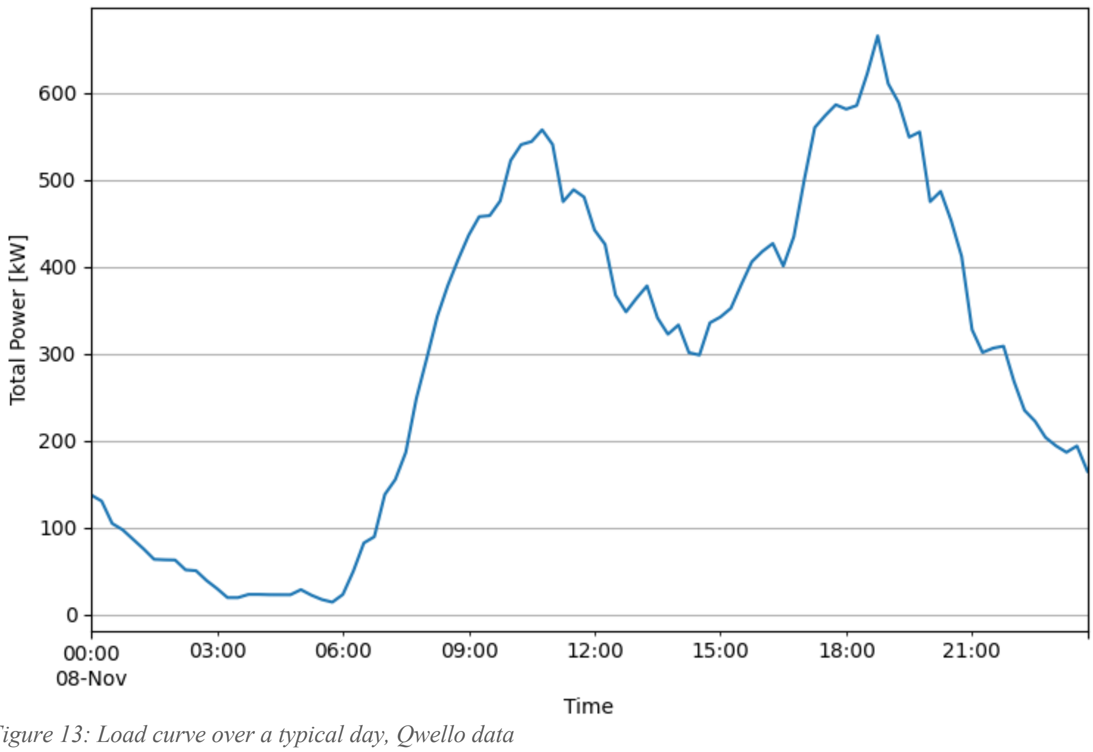

Figure 13: Load curve over a typical day, Qwello data

Main objective of smart charging is to balance the 2 load peaks and incentivize users to charge in time of lower energy prices/ higher energy availability.

e) Market prices kWh

In most German cities the public charging infrastructure is below market demand. Users are therefore less price sensitive with regards to kWh pricing. kWh prices in AC segment range from 0,4 EUR/ kWh to 0,8 EUR/kWh. Also, additional price elements like a penalty after the regular maximum parking period of 2-4 hours, a starting fee or time component apply. Due to the current lack of infrastructure, users do not compare prices and take the risk of driving to another CP if a free one has been found. This also reflects the limited willingness to charge at lower speed or get less energy for a lower price. If more infrastructure has been built up, users might become more comparative and use a variable pricing.

5. Smart Charging

a) Scenarios

Three different scenarios have been evaluated in this study. All are based on the dataset of all real sessions in 2023 and therefore representing real user behavior. The 1st and 2nd simulation will provide the same amount of energy in the same given time of the session. The CPO nevertheless can determine how much energy in which 15min intervals (stock price frequency) is provided at what power level. The 3rd scenario will extent the sessions:

1. Intraday stock price vs monthly average: In this scenario the sessions remain the same. It will be compared, how much a CPO would be saving, if the energy is provided at stock price and not at the most common monthly average stock price, meaning each 15min energy will be priced differently as the stock price intraday
2. Intraday stock price optimized: This scenario optimizes the real sessions. The sessions are divided into x 15min sequences and prioritized starting with the sequency at lowest 15min stock price. The next 15min with the 2nd lowest energy stock price and so on. The total energy provided in the session and the maximum charging speed, defined by the vehicles, is according to the real session, mirroring realistic use cases
3. Intraday plus 1 hour optimized: A 3rd scenario is assuming longer sessions by 1 hour. Every user would have more time and leave the EV for 1 hour longer at the charging station. The CPO has more time to optimize the 15min intervals according to the stock price

While scenario 1 and 2 are corresponding to reality, the 3rd scenario is more theoretical. In real life charging sessions are determined by the use case which are currently maximum load oriented and further by the parking regulations with a daylight maximum of 2-4 hours. It seems not realistic that a user would leave the vehicle 1 hour longer at a e.g. a POI and risk a parking ticket.

b) Scenario 1: Intraday vs. monthly average

The following figures compares the energy cost of all sessions in 2023 on a monthly average price (compare contract type 3) and intraday pricing (compare contract type 4):

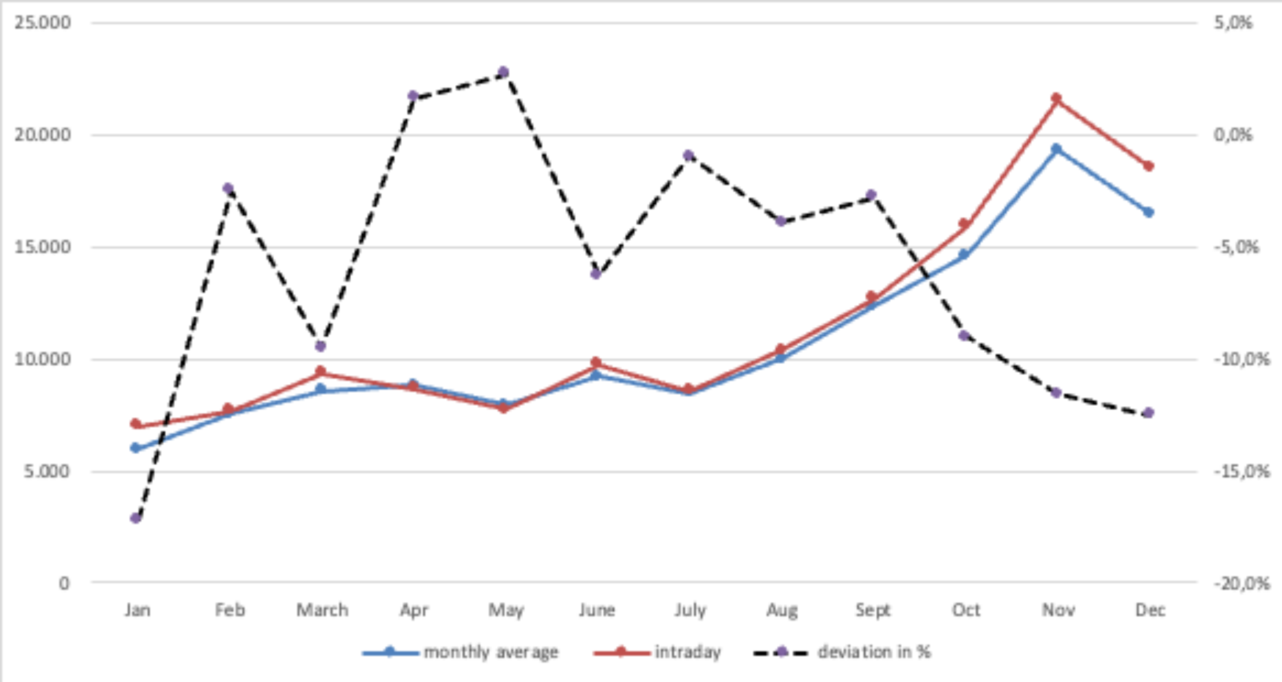

Figure 14: Comparison of monthly energy cost for all sessions on a monthly and intraday basis in EUR and %, Qwello data

The blue line shows the energy cost for the CPO if the sessions are paid based on a monthly average stock price (contract type 3). As alternative it is calculated how the same sessions would be priced if the energy is sourced on a 15min stock price basis. It can be seen, that only in 2 months, April and May, the CPO would have a positive effect in being charged on a stock price basis. In all other months the contract type 3 with an average energy price per month is beneficial.

This scenario does not take smart charging into consideration since the charging speed is not changed over the session period. According to the user behavior, most sessions apparently happen in times with higher 15min price than the monthly average. If most energy would be sourced during nighttime and daylight hours with more solar and wind energy, the result could be reverse.

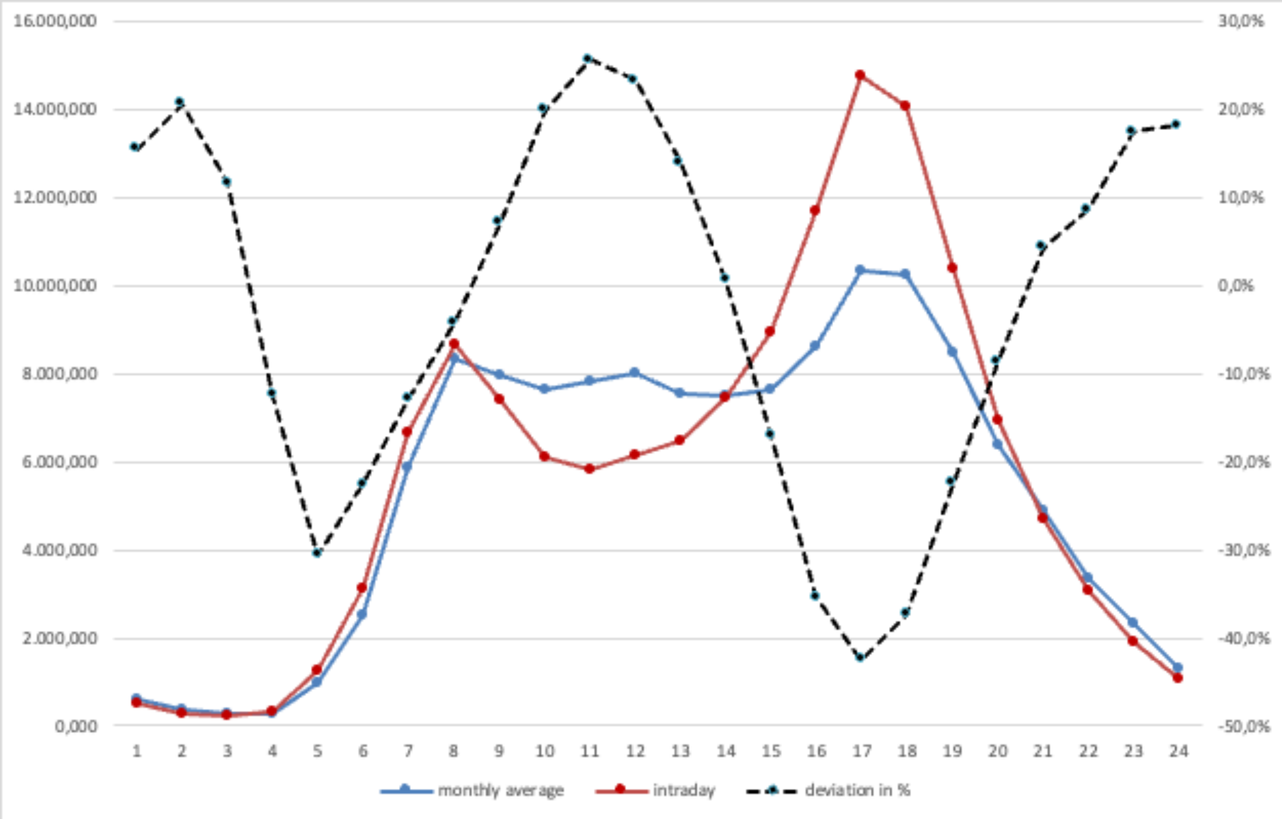

Figure 15: Comparison of hourly energy cost for all sessions on a monthly and intraday basis in EUR and %, Qwello data

The figure above proves that intraday prices are only advantageous during nighttime and daytime between 09:00 am and 02:00 pm. Those times usually offer lower 15min intraday energy costs since sun and wind is available and the energy demand is less.

From CPO perspective this scenario would result in 6.7% higher energy cost for all sessions in 2023, compared to just use a monthly average energy price.

c) Scenario 2: Intraday stock price optimized

As described this scenario prioritizes 15min stock price intervals with lower prices for charging, while intervals with higher prices will be left out. Overall, the user gets the same amount of energy in the same time of parking/ charging at the same point in time (start/ stop date during the day). Conceptually this is a smart charging scenario since the user gives the information of the required energy volume and the time of parking/ charging to the CPO and the COP cost optimizes the energy provision.

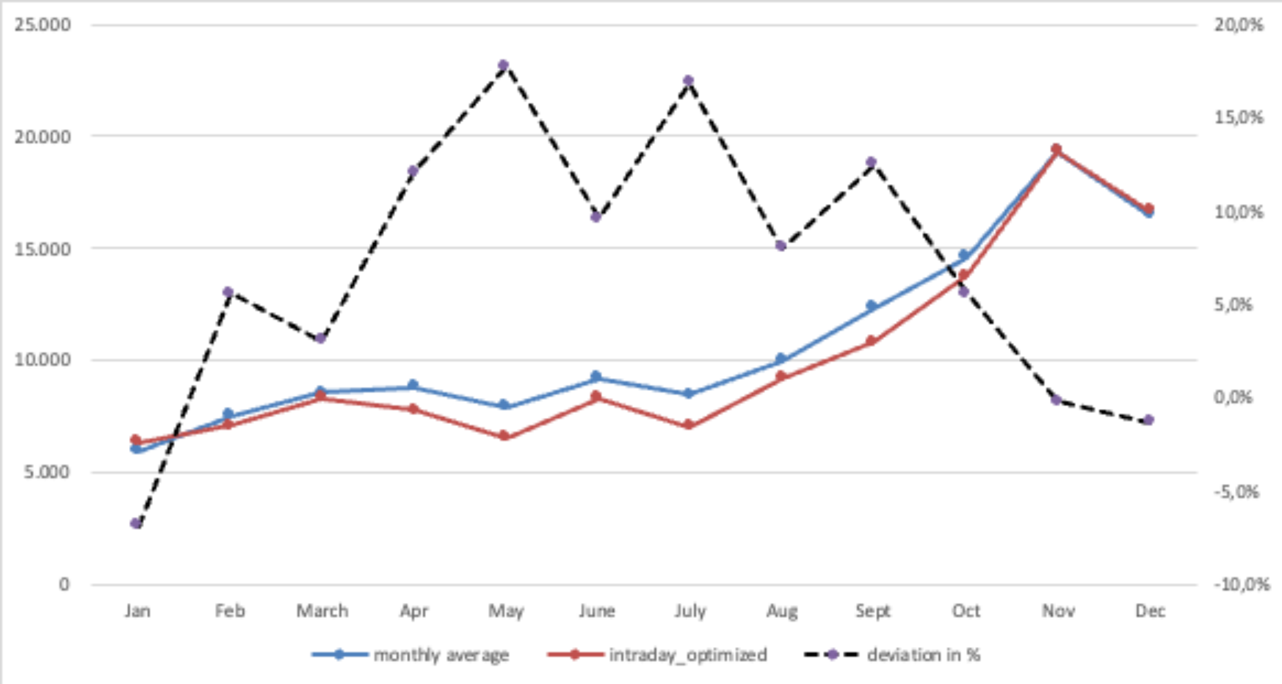

Figure 16: Comparison of monthly energy cost for all sessions on a monthly and intraday optimized basis in EUR and %, Qwello data

Figure 17 shows the deviation over the year 2023. Only during winter time in the months Nov-Jan a monthly average energy price would be advantageous for the CPO. In those months solar and wind energy contribute less to the overall energy mix with subsequently less energy volatility over the day.

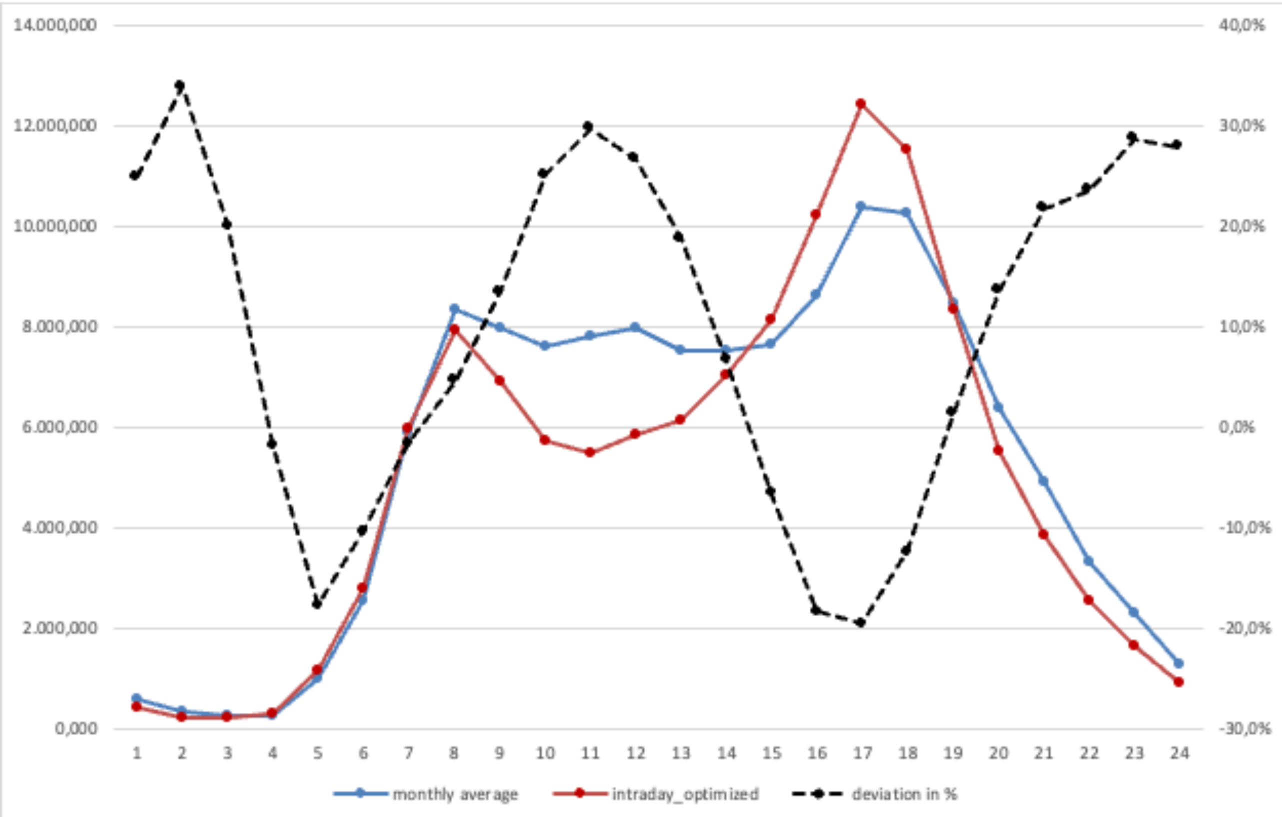

Figure 17: Comparison of hourly energy cost for all sessions on a monthly and optimized intraday basis in EUR and %, Qwello data

In this scenario intervals with especially high energy costs are de-prioritized and intervals with lower prices are prioritized. The overall negative deviation to the monthly average stock price is being reduced and the positive increased. This can be seen in by comparing Figure 13 and Figure 16, a less negative deviation is shown, the positive deviation is higher.

This scenario, illustrating a real smart charging scenario based on maintained user behavior, an energy cost saving for the CPO is possible. Based on the 2023 sessions, an overall saving of 6,1% compared to the regular monthly average energy stock price would have been achieved in 2023.

d) Scenario 3: Intraday plus 1 hour optimized

If the user would be overall willing to park/ charge for 1 hour longer than the current user pattern shows, the CPO would be able to optimize the energy cost intervals over a longer period of time and hence could utilize more intervals with lower energy cost and leave out those with high cost.
The 3rd scenario is assuming overall 60min longer dwell time at the charging point.
The other assumptions remain the same, the user will get the same amount of energy into the vehicle at the maximum charging speed of the vehicle.
Compared to scenario 2, only in January the monthly average pricing would be slightly advantageous for the CPO while in all other months the intraday plus 1 hour optimized scheme would be more attractive. The gap between the both price curves is increasing since as described more intervals with lower prices can be used over the charging session.

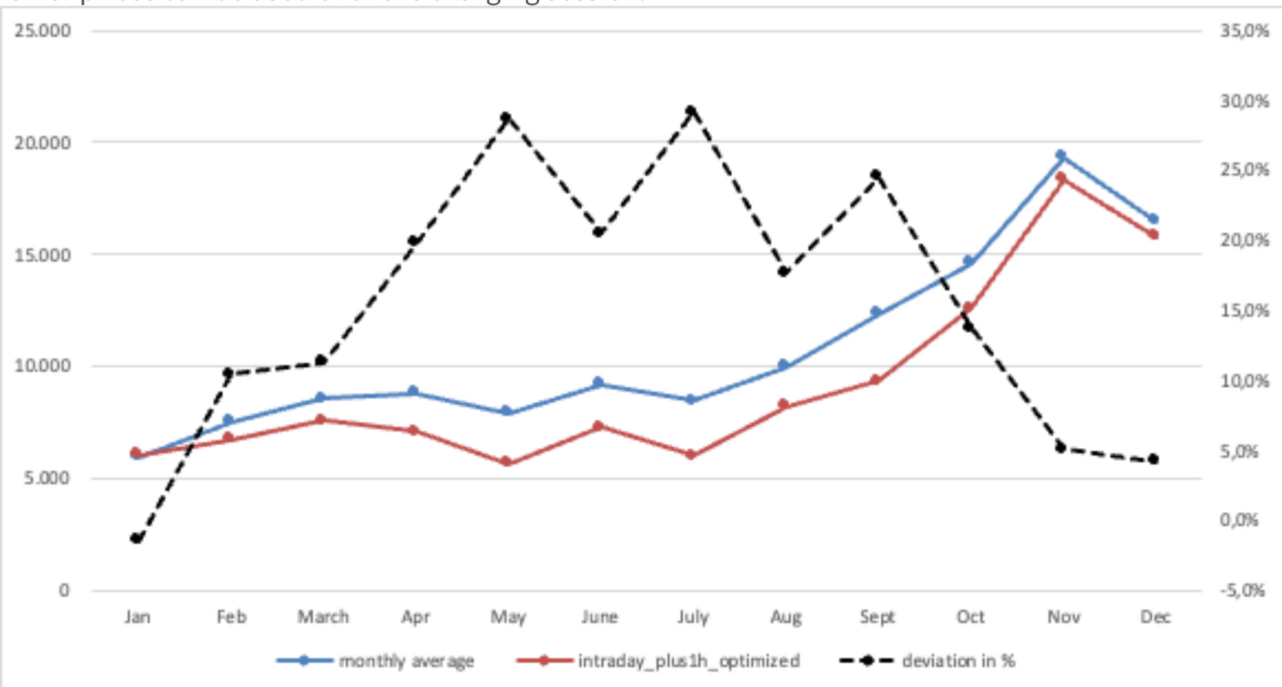

Figure 18:Comparison of monthly energy cost for all sessions on a monthly and intraday plus 1 hour optimized basis in EUR and %, Qwello data

Same finding can be seen in the hourly comparison: Only at 05:00 am in the morning and between 03:00 pm and 05:00 pm would a monthly average pricing be more attractive for the CPO.

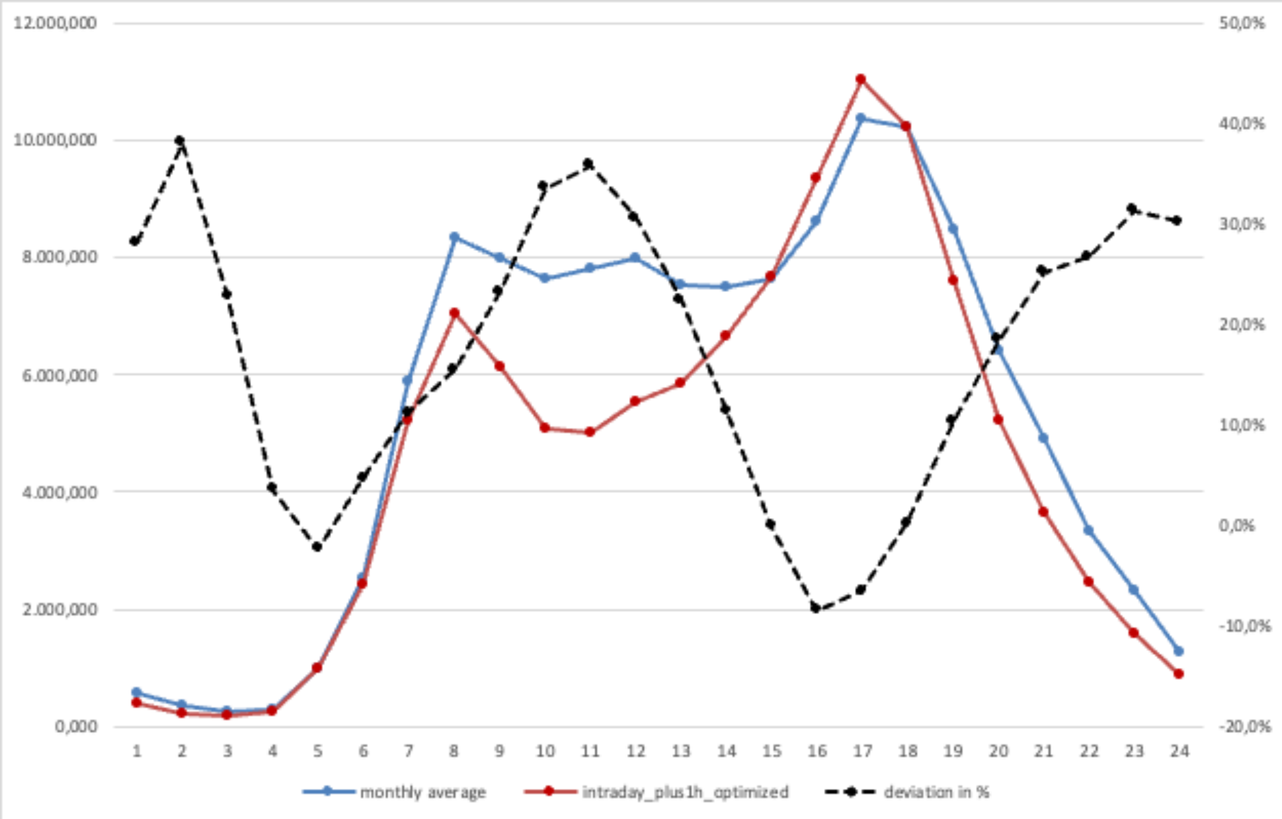

Figure 19: Comparison of hourly energy cost for all sessions on a monthly and optimized intraday plus 1 hour basis in EUR and %, Qwello data

With the potential change of the user behavior in this scenario, a CPO would be able to save up to 14,3% energy cost over the year, based on the real sessions and 2023 intraday energy stock prices.

Nevertheless, not only the user behavior would need to change, also the parking regulations in the majority of German cities would need to be adapted. The median of all Qwello charging sessions in 2023 is 152min. 60min longer charging/ parking would indicate that in cities with 2 or 3 hours charging maximum a parking ticket would be risked.

e) Scenario comparison – benefit for CPO and user

If we compare the 3 described scenarios with the currently most common energy contracts for non-integrated CPOs (not being part of group with own energy production), the 3rd scenario is the most attractive one from CPO perspective:

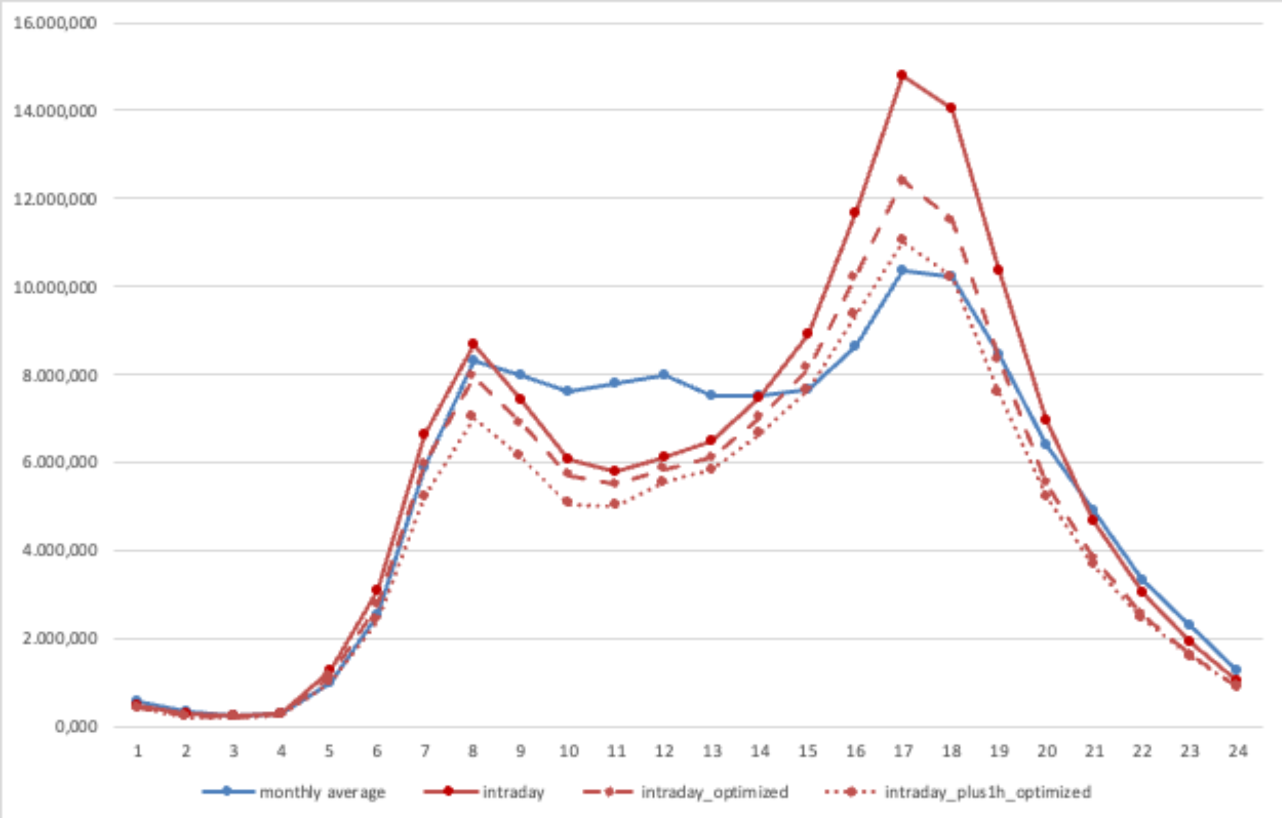

Figure 20: Scenario comparison on average hourly basis in EUR, Qwello data

Savings for the CPO compared to the monthly average are:

- Scenario 1, intraday: -6,7%
- Scenario 2, intraday optimized: +6,2%
- Scenario 3; intraday plus 1 hour optimized: +14,3%

This saving only refers to the power generation price, respectively energy stock price.
As described earlier, this price component only makes approximately 43% of the total energy cost to CPO. Related to the total energy cost at the charging point, the saving would be around 2-3% in the most realistic scenario 2.
If the CPO is willing to share the potential savings, the user could benefit of 1-2% lower energy cost. This is only referring to the energy cost component of the regular charging cost, not taking starting fee, blocking fee and any time component into consideration.

6. Technical barriers and requirements

Main requirements for the interaction between user, intermediate service and CPO are described in deliverable D4.2.
Further technical requirements occur for the interaction between CPO, energy supplier, metering company and DSO, following the Harmonized Electricity Market Role Model (HEMRM) from the European Union Agency for the Cooperation of Energy Regulators (ACER).
To be able to source energy based on intraday stock prices, the charging infrastructure needs to be equipped with a smart meter gateway and smart meter, so called intelligent Smart Meter Systems (iMSys). In Germany those smart meters are still in early roll-out phase and are only common for DC charging infrastructure with energy volumes exceeding 100.000 kWh/ year per grid connection (see also https://www.bundesnetzagentur.de/DE/Vportal/Energie/Metering/start.html). This is not given for regular AC sites with e.g. 4 CPs. Without those iMSys devices the energy supplier does not get

15min energy consumption data and cannot invoice on a 15min interval, thus smart charging with variable sourcing cost is not possible for the CPO.
A widespread implementation of iMSys meters in AC charging infrastructure is foreseen not before the end of 2025.
Next to the hardware implementation, the data from the meter company needs to be shared with the DSO, the CPO and the energy supplier via backend interfaces. Since the roll-out is in early stages, the overall timely data flow to enable 15min energy sourcing cannot be proved currently.
It has to be remembered that not the grid is limiting the maximum power to the vehicle but rather the vehicle, which is in most cases only able to take 11kW AC as maximum. This limits the balancing option for the CPO. If the vehicles would be equipped with more 22kW onboard converters, the options for optimization will increase.

7. Legal barriers and requirements

a) Current calibration law constraints

Public charging infrastructure in Germany must comply with the German Calibration Law (Eichrecht), which is defined in the PTB-A regulation 50.7. Every pole and also the production of the poles must be certified according to the Eichrecht, which is a long, complex and costly process. Any breach of the certified process or change to the product is a legal violation and might lead to the loss of the CPO license.
Germany's Eichrecht is founded on the principle of consumer protection, predicated on the assumption that sellers, without checks and balances, might not always act in the consumer's best interest. This law serves as the trusted third party, a regulatory handshake ensuring that a transaction's integrity is upheld for the consumer.
For EV charging, the temper proof, trusted third party is the electric meter. There are a few ways how this is implemented in practice, a very common one and the one that Qwello is using is that the meter contains a cryptographic chip with well-known public key - the key is encoded in a QR code on the outside of the meter and is scannable by end users on site. After a session ends, the end user receives the start and end measurements of the session from the meter, signed by its key in their invoice. This proves that the data from the meter was passed through as-is without modification or tampering (which would make the signature invalid), guaranteeing that the user indeed got exactly what Qwello was billing.
However, part of the agreement to the end user is of course the cost per kWh - which must be clear to the user <u>before</u> the session starts and is appearing in the signed meter values, making the final price understandable and reproducible. For a fixed tariff, this is technically feasible and in fact how it is done today.
By defining the price before the session starts, puts the risk of the session 15min interval stock price on the CPO. Variable pricing between the user and CPO is therefore currently not possible as indicated by smart charging.

b) Recent discussions

From 2025 on, energy suppliers in Germany must also offer dynamic tariffs for end consumer for the home energy. The idea of also using dynamic prices to balance the grid is becoming more popular and might find its way to public charging. Nevertheless, there is no necessary change to the German Eichrecht with regards to public charging infrastructure defined yet.

8. Critical review

This study is based on real user behavior in Germany with given legal and technical constraints for public charging. The sessions give a good average picture in larger and smaller municipalities for AC

public charging. 2023 was a year, in which the energy prices dropped from 12,8 ct/kWh to 6,8 ct/kWh, a continuation of the decrease after the exceptional increase due to the Ukraine war.
The study shows a potential cost reduction for the CPO in the most realistic scenario 2 with optimized intraday cost of 6,2%. With one hour extra parking/ charging 14,3% cost reduction would be possible (scenario 3). If the sessions would be extended successively, the savings could be in between both values.
Since the energy stock price is only a minor part of the whole kWh price, the overall saving on the kWh price at the point of charging would be less than half of it, if the energy generation price remains on the current low level.
Sharing the savings between user and CPO brings 1-4% savings to the user. For this the user would need to forward necessary SMAC information to the CPO prior to starting the session as an extra effort. With the current lack of charging infrastructure in Germany and less price sensitive user behavior, this extra effort might not be taken from the end user. Furthermore, a great majority of the current EV fleet in Germany are company cars with a corporate roaming card, which further limits the willingness to participate at lower tariffs.
With a change in the legislative and regulatory environment, more charging infrastructure and more price sensitive users, higher grid stress and subsequently potentially incentives to balance the grid, SMAC will become a more important solution to overcome especially the grid balance issue.