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Car2Flex

PROVISION OF SYSTEM FLEXIBILITIES FROM E-VEHICLES FOR VARIOUS END USER APPLICATIONS

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Car2Flex

PROVISION OF SYSTEM FLEXIBILITIES FROM E-VEHICLES FOR VARIOUS END USER APPLICATIONS

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Table of content

ABBREVIATIONS

Abbreviation	Meaning
aFRR	Automated frequency restoration reserve
AC	Alternating current
AI	Artificial intelligence
API	Application Programming Interface
BEV	Battery electric vehicle
BEÖ	Bundesverband Elektromobilität Österreich
BMS	battery management system
BS	Battery Storage
CAM	Control area manager
CAN	Controller area network
CCS	Combined Charging System
CP-line	Control pilot line
CPO	Charing point operator
CS	Charging Station
DA market	Day-ahead market
DC	Direct current
DER	Distributed energy resources
DSO	Distribution system operator
eCar	Electric car
ElWOG	Electricity Act (*Ger. Elektrizitätswirtschafts- und -organisationsgesetz*)
EMC	Electromagnetic compatibility
eMSP	e-mobility service provider
ESC	Energy supply company
EV	Electric vehicle
EVCS	Electric Vehicle Charging Station
EVPP	Electric Vehicle Car Park Power Simulation
EVSE	Electric vehicle supply equipment
FCR	Frequency containment reserve
G2V	grid to vehicle
GCP	Grid Connection Point
GDPR	General Data Protection Regulation
GO	Guarantee of origin
GVW	Gross vehicle weight
HEM	home energy management system
HP	Heat Pump
ID market	Intraday market
KEM	Climate and energy model regions (*Ger. Klima- und Energie-Modellregionen)*

IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCOS	Levelized Cost of Storage
LIS	Local infrastructure system
LV	Low-voltage
M1	Passenger car (*Ger. Personenkraftwagen (PKW)*)
MCP	Market clearing price
mFRR	Manual frequency restoration reserve
MID	Measuring Instruments Directive
MSP	mobility service provider
MV	Medium Voltage
N1	Vehicles for the carriage of goods (*Ger. Fahrzeuge zur Güterbeförderung*)
NE / NL	Network level (*Ger. Netzebene*)
OCPP	Open charge point protocol
OCHP	Open Clearing House Protocol
OICP	Open Interface Charge Protocol
OEM	original equipment manufacturer
OSCP	Open Smart Charging Protocol
OTC	Over the counter
PEF	Product environmental footprint
PHEV	Plug-in hybrid electric vehicle
PPA	power purchase agreement
PV	Solar Photovoltaic Panel
RAM	Balancing energy market (*Ger. Regelarbeitsmarkt*)
RCD	Residual current device
RE, REN	Renewable electricity
REC	Renewable Energy Community
REEV	Range extended electric vehicles
RES-E	Renewable energy-sourced electricity
REX	Range extender vehicle
RfG	Network Code on Requirements for Generators
RL	Residential Load
ROI	Return on investment
SDAC	Single day-ahead coupling
SDG	Sustainable development goal
SIDC	Single intraday coupling
SIM	Subscriber identity module
SME	Small- and medium-sized enterprises
SOC	State of charge
SOH	State of health

TOR	Technical and organizational rules for network operators and users (*Ger. Technische und Organisatorische Regeln für Betreiber und Benutzer von Netzen*)
TSO	Transmission system operator
UC	use case
UCC	Unidirectional controlled charging
V2G	Vehicle to grid
V2H	Vehicle to home
V2L	Vehicle-to-load
V2X	Vehicle to X
VPP	Virtual power plant
YEC	Yearly Energy Consumption

1 Introduction

The transformation of Europe’s energy and mobility systems requires innovative solutions that enable deeper integration of renewable energy while ensuring grid stability, affordability, and user acceptance. Vehicle-to-Grid (V2G) technologies and smart charging concepts are increasingly recognized as key elements of this transition. By leveraging the flexibility of electric vehicles (EVs), these technologies can provide storage capacity, reduce the curtailment of renewable generation, and create new opportunities for sustainable business models. At the same time, they raise questions regarding user acceptance, economic viability, regulatory barriers, and their overall contribution to sustainable development.

Electric vehicles (EVs), through bidirectional charging technology (V2G/V2X), have the ability to act as mobile energy storage units. They can both draw power from and feed power into the grid, thereby contributing to grid stability and enabling prosumers or end users to participate in energy markets.

The Car2Flex project examined the technological and economic potential of bidirectional charging under current framework conditions. An important aspect of this research was also the acceptance of bidirectional charging among different user groups, in order to better understand their attitudes toward this technology.

In particular, given the growing number of energy communities in Austria and the market potential of bidirectional charging within such communities, a detailed assessment was conducted to evaluate the motivations and capabilities of households that both own an electric vehicle and participate in an energy community.

The introduction and wider roll-out of bidirectional charging technologies (e.g., EV wall boxes and other technical components) lead primarily to three key questions:

1. Integration of renewable energy (especially solar power via photovoltaics) to reduce energy costs and promote more climate-friendly behavior.
2. Monetary incentives through charging at low electricity prices and discharging or selling electricity at high prices, depending on grid price fluctuations.
3. In the long term, bidirectional charging aims to help reduce grid volatility and enhance energy and supply security in Austria.

At present, no bidirectional charging facilities for V2G/V2X applications exist in Austria.

At the European level, the European Union aims for a comprehensive deployment of V2X technologies by 2030. In addition to their positive ecological and sustainability impacts in terms of climate change mitigation, V2G technologies make a significant contribution to the stability of Europe’s energy grids by balancing supply and demand.

The European Commission projects that the energy system's daily flexibility must increase by 133% by 2030 and by 250% between 2030 and 2050. While China currently leads globally in the implementation of V2X/V2G technologies, the success of V2G in Europe depends critically on two factors:

- User acceptance, and
- The implementation of supportive policy measures.

Through real-life demonstrators, the Car2Flex project has shown which technological and regulatory challenges have already been solved and which still need to be addressed. User groups were actively involved to identify design features and incentive structures that could promote the adoption of bidirectional electric vehicle charging.

2 General framework conditions and definitions

2.1 Use Cases

2.1.1 Use Case 1: Sharing

A good transport connection is one of the essential basic needs. In order to be flexible and independent of public transport timetables, car sharing concepts can be used.

Therefore, use case „Sharing" deals with the collaborative and digitally organized usage of electric passenger vehicles (EVs) by several users. The concept of sharing vehicles with other participants allows the occasional rent of passenger vehicles without possessing one. The EVs as well as the charging infrastructure are in possession of the respective housing association or the carsharing provider (Table 1). This combines the advantages of owning an own car to meet individual mobility needs. Consequently, fixed costs of cars are shared over a larger number of users. For the user, on the other hand, fixed costs of car ownership are replaced by variable maintenance and insurance costs of the vehicle[1]. Costs of car usage are included in the user fees. With eCar sharing, vehicles are shared by some or all residents of a building, thus requiring fewer vehicles and fewer parking spaces (Table 1). As a result, the car usage becomes much more economically attractive and cost-effective for each individual user. From an economic perspective, this is particularly interesting, as the reduced need for parking spaces has a significant impact on the construction costs of residential projects, especially if garage spaces have to be used due to structural conditions. Since a large part of the costs, especially for second cars, is caused by investment and maintenance costs, it makes sense to divide these vehicle-specific costs among several parties. By participating in the energy, - grid service, - and flexibility market, additional profits can be made for the car sharing company on the one hand, and on the other hand, the costs for the customers can be reduced, which creates an additional incentive. Additionally, the PV self-consumption of a shared PV device can be increased which leads to further costs savings for the residents. Within the Car2Flex project the car sharing company is the owner of the used cars.

The carsharing concept often supplements other interlinked mobility concepts (walking, bicycle, public transport, etc.), to fulfil all mobility needs[2]. In accordance with Brendel (2016)[3], commercial carsharing systems are classified based on their operation form: Station-based carsharing requires the return of vehicles to defined locations. Free-floating systems allow the return of vehicles anywhere in the supplied area of the carsharing provider. In this project, we exclusively analyze station-based carsharing concepts.

Besides commercial providers, the sharing of (electric) vehicles could also be enabled by housing communities, e.g., in multi-apartment buildings (Figure 1). For providing EVs' flexibility, vehicles are coordinated either by the housing association or the carsharing provider.

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[1] Shaheen, S.A.; Mallery, M.A.; Kingsley, K.J. Personal vehicle sharing services in North America. Research in Transportation Business & Management 2012, 3, 71–81, doi:10.1016/j.rtbm.2012.04.005.

[2] Hildebrandt, Björn; Hanelt, Andre; Piccinini, Everlin; Kolbe, Lutz; and Nierobisch, Tim, "The Value of IS in Business Model Innovation for Sustainable Mobility Services - The Case of Carsharing" (2015). Wirtschaftsinformatik Proceedings 2015. 68. https://aisel.aisnet.org/wi2015/68

[3] Brendel, A.B., Brauer, B., Hildebrandt, B., 2016. Toward user - based relocation information systems in station-based one-way car sharing. In: AMCIS. pp. 1–10.

The usage of carsharing services often requires a digital end user interface (e.g. a web application), to query available vehicles and to book vehicles in advance. However, the digital booking platform enables detailed knowledge about available vehicles at any time, which is crucial, for providing grid ancillary services (Table 1)[4].
Potential stakeholders that take part in the electric car (eCar) sharing concept are the property developer, property management, eCar sharing provider, the energy supplier and the residents (see Figure 1).

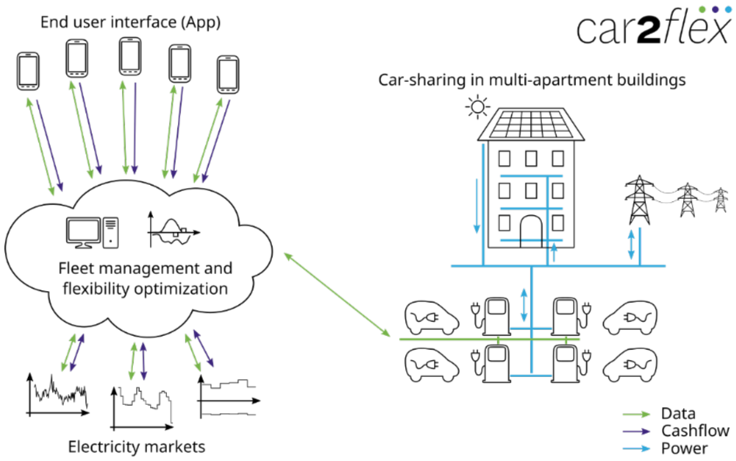

Figure 1 Stakeholders within the sharing concept considering use case "Sharing"

2.1.2 Use Case 2: Fleet

Numerous commercial fleets have been electrified in the past years due to favorable economic conditions, e.g., lower costs of ownership (Table 1). This trend is further increased by improved charging network density and government incentives. Use case "Fleet" takes the commercial operation of numerous EVs by small- and medium-sized enterprises (SME) into account. On the one hand, the company fleet includes the transport of material goods, e.g. last-mile delivery vehicles, postal courier services, etc. On the other hand, this use case also considers passenger transportation by company cars of e.g. energy supply companies or mobile service companies. Despite an increasing number of available medium- and heavy-duty vehicles (e.g. e-vans or e-trucks), at this moment about 99 % of electric fleet vehicles are light-duty vehicles. Hence, this use case focusses on light-duty vehicles exclusively[5]. All vehicles and charging infrastructure are in possession of the respective enterprise; thus, their access is restricted to certain users (Table 1). Based on numerous vehicles, commercially operated EV fleets show significant potential for providing flexibility. Therefore, all EVs are coordinated by the SME to provide the required flexibility. On the one hand, the electrification of commercial fleets enables the increase of PV self-consumption, which decreases costs of operation. On the other hand, the flexibility of large-scale EV fleets can be used for providing grid ancillary services (Table 1).
Similar to use case "Sharing", the fleet operator of this use case requires real-time information of all operated vehicles. This information includes, e.g., the location of vehicles, their batteries'

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[4] Handke, V.; Jonuschat, H.; Wölk, M. Untersuchung zur Akzeptanz von Elektromobilität als Stellglied im Stromnetz, 2017.
[5] EY: How commercial fleet electrification is driving opportunities - Understanding emerging opportunities and challenges as commercial fleet operators rapidly adopt electric vehicles

state of charge, or the remaining distance on their route. The required information is provided by various end-user interfaces, e.g. tracking, electronic schedules, booking platforms, etc., demonstrated in Figure 2[6]. Hence, the charging behaviour of large-scale EV fleets can be planned and organized in advance, which allows optimal application for providing grid ancillary services (Table 1)[7].

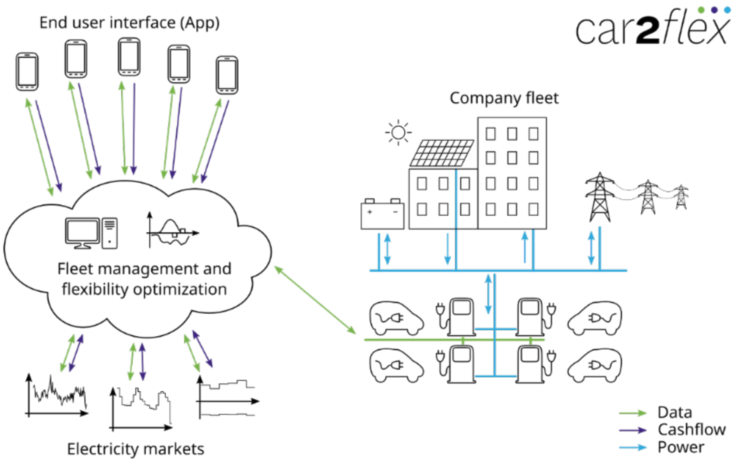

Figure 2 Stakeholders within the sharing concept considering use case "Fleet"

2.1.3 Use Case 3: Private/Individual

About 95 % of charging processes take place at home or work at private charging points[8]. The European Directive 2014/94/EU of the European Parliament and of the Council of October 22nd, 2014, on the deployment of alternative fuels infrastructure (Alternative Fuels Infrastructure Directive, hereafter AFID) and its implementation by the federal law BGBl. I Nr. 38/2018[9], define public charging infrastructure for electric vehicles by a non-discriminatory access for all users within the European Union. Due to a missing definition of private charging, all charging possibilities, which violate a non-discriminatory access e.g. by several kinds of authorization, usage or payment, are consequently defined within this project as private or individual charging. Based on this definition, use case "Private/Individual" deals with private charging of passenger vehicles at home or at work (at enterprise charging points). Private EVs charged at home or at work are owned by private individuals (Table 1). The charging infrastructure, on the other hand, is either in possession of the vehicle's owner (charging at home) or the employer (charging at work). As a result, energy costs due to EV charging are either billed by the conventional electricity bill or the vehicle user's payroll.

Similar to use case "Sharing", EVs (either charged at home or work) allow users to reduce maintenance and operation costs of transportation. Private EVs enable the increase of PV self-consumption, either for a private individual (charging at home) or the employer (charging at home). In addition, the vehicles' battery can be used during parking periods, to provide flexibility to the power system. Thereby, private EVs charged at home are aggregated to one

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[6] Fraunhofer-Institut für Arbeitswirtschaft und Organisation - IAO, Wirtschaftsministerium Baden-Württemberg, e-mobil BW GmbH - Landesagentur für Elektromobilität und Brennstoffzellentechnologie Systemanalyse (2010): BWe mobil, IKT- und Energieinfrastruktur für innovative Mobilitätslösungen in Baden-Württemberg, Stuttgart

[7] Peters, A., Dütschke, E.(2010): Zur Nutzerakzeptanz von Elektromobilität Analyse aus Expertensicht. Fraunhofer ISI.

[8] Transport & Environment: Roll-out of public EV charging infrastructure in the EU - Is the chicken and egg dilemma resolved?, 2018

[9] Federal Law establishing uniform standards for infrastructure development for alternative fuels (German: *Bundesgesetz zur Festlegung einheitlicher Standards beim Infrastrukturaufbau für alternative Kraftstoffe*).

virtual power plant and controlled by one central control unit, e.g. the distribution system operator. Considering EV parked at work, this task is done by the employer, though, assuring the fulfilment of her vehicle user's mobility needs. For both charging at home and charging at work, an interface between vehicle user and central control unit must be established (Figure 3).

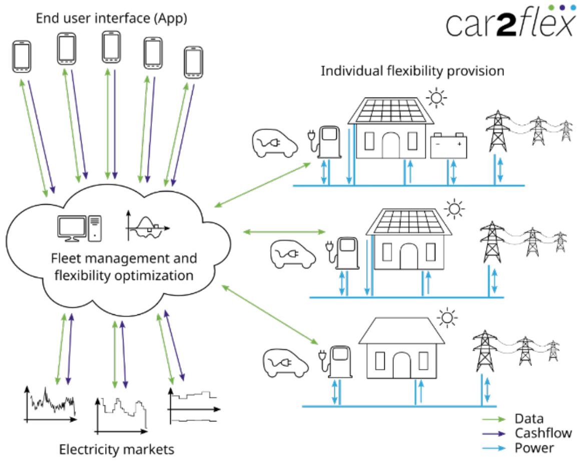

Figure 3 Stakeholders within the sharing concept considering use case "Private/Individual"

Table 1 General framework conditions of the analyzed use cases

	Sharing		**Fleet**	**Privat/Individual**	
	Multi-apartment buildings	Commercial carsharing	SME	At home	At work
Objectives of user	Cost reduction, increase of PV self-consumption		Increase of PV self-consumption, Mitigation of peak loads	Cost reduction, increase of PV self-consumption	Cost reduction
Objectives of provider	Reduction of parking lots, increase of PV self-consumption, profitable use of EVs' flexibility	Profitable use of EVs' flexibility	Increase of PV self-consumption, Profitable use of EVs' flexibility		Increase of PV self-consumption, profitable use of EVs' flexibility
Owner of the EV	Housing association	Carsharing provider	SME	Private individual	
Owner of charging infrastructure				Private individual	Employer
Billing of energy demand	Carsharing fees		-	Electricity bill	Electricity bill / payroll
Information exchange already established?	Yes, via booking platform			No.	Yes, via booking platform
Vehicle class	Passenger vehicles		Light-duty vehicles	Passenger vehicles	
Coordination of flexibility	Housing association	Carsharing provider	SME	e.g. DSO	Employer

2.2 Use case-specific user behavior

Mobility patterns of future EV fleets are estimated based on the following indicators: time of arrival, time of departure, covered distances and the number of trips per day. Statistical data of these indicators are described for each use case in the following sections.

2.2.1 Use Case 1: Sharing

To evaluate the flexibility potential of the car usage within the use-case “Sharing” already existing data from the project partner fahrvergnügen is used. This dataset contains 11338 car bookings of 20 different cars within the whole year 2019.

Figure 4 shows the prevalence of departures and arrivals of the cars. It is evident that the drives take place almost exclusively between 8 a.m. and 8 p.m., although these are relatively evenly distributed over this period.

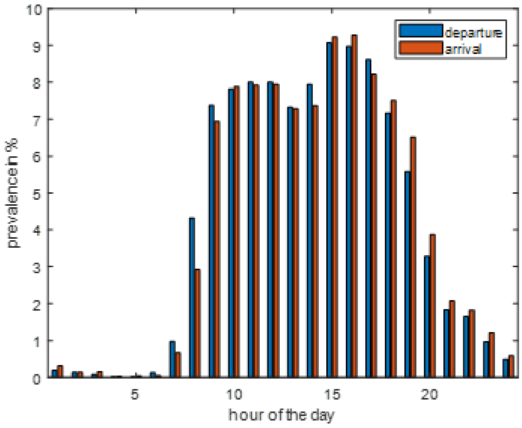

Figure 4: Prevalence of departure and arrival of the cars considering use case “Sharing”

The distribution of the trip range (Figure 5 and Figure 6) shows that most drives only cover up to 10 kilometres. Moreover, 35% of the drives are between 0 and 5 kilometres. Hence it arises a huge potential for the energy and flexibility market since the demand of energy per charging process is relatively low and be compensated within a short time.

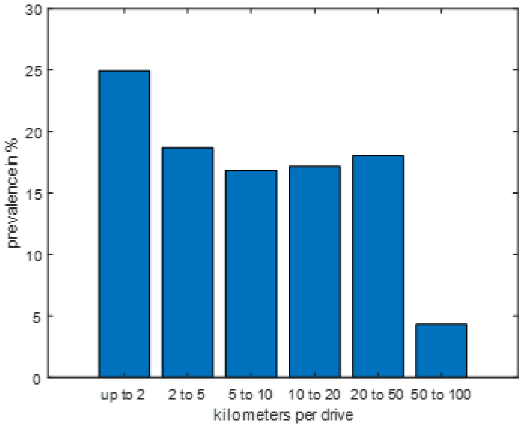

Figure 5: Distribution of kilometres per journey

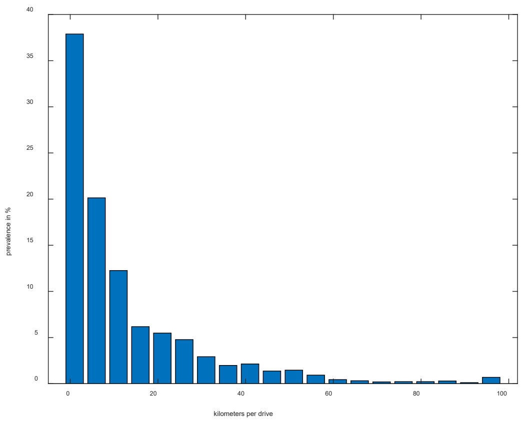

Figure 6: Detailed distribution of kilometres per journey

The number of car usages per car is shown in Figure 7, whereby 37.5% of the cars were used only once or twice a day. The combination of the number of journeys per day and the generally rather short journey distance shows that there is huge flexibility potential within this use case.

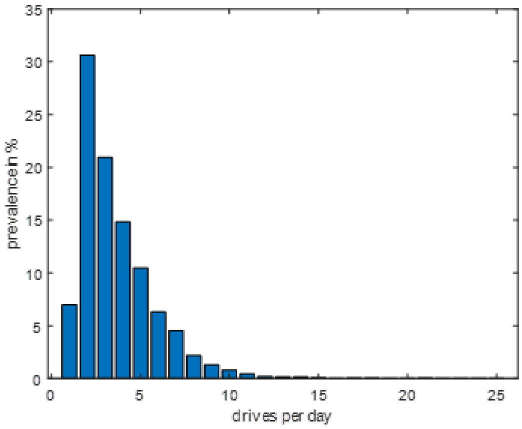

Figure 7: Drives per day and car

2.2.2 Use Case 2: Fleet

According to recent studies[10], fleet vehicles are mainly used for field service, service trips and transport trips. (Figure 8). About 16 – 20 % of fleet vehicles are provided to employees, either as incentives or billed by the employer's salary. The enterprise's number of employees has only little impact on this distribution. While fleet vehicles are, to a great extent of 80%, parked in company-owned parking lots, they are also parked at employees' homes 29% (the values do not sum up to 100% due to mixed parking at company parking lots and homes).

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[10] CVO – Corporate Vehicle Observatory von Arval (2011): CVO Barometer 2011, Kirchheim.

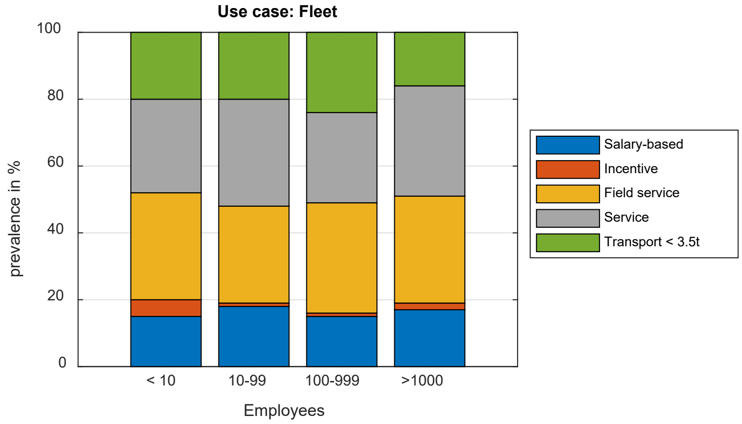

Figure 8 Purpose of fleet vehicles[10] *(own illustration)*

Mobility patterns of use case "Fleet" are derived by journey logs[11], including the time or arrival, the time of departure as well as the covered distance for each trip. Exemplary for this use case, we select fleets of energy supply companies (ESC) and postal services. Figure 9, for example, demonstrates the prevalence of the time of arrival and the time of departure of vehicles operated by an ESC. As illustrated, the majority of the ESC's vehicles of starts (81 %) and ends (79 %) their trips between 8:00 – 16:00 (Figure 9).

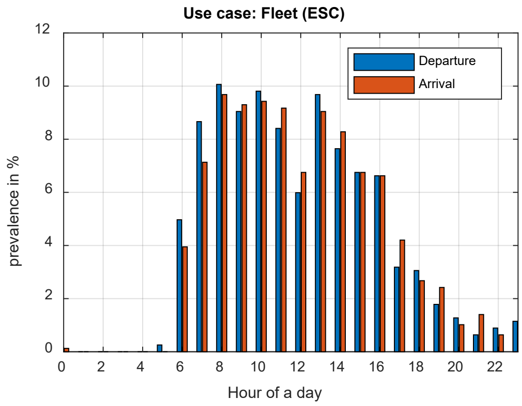

Figure 9: Prevalence of departure and arrival of the cars considering use case "Fleet" (ESC)[11]

The prevalence of arrival and departure of vehicles operated for postal services show a similar characteristic (Figure 10). Tough, in contrast to ESCs, some postal vehicles even start (3 %) and end (3 %) their trips between 00:00 and 05:00.

[11] REM 2030 Driving Profiles zur Verfügung gestellt von Frauenhofer Institut

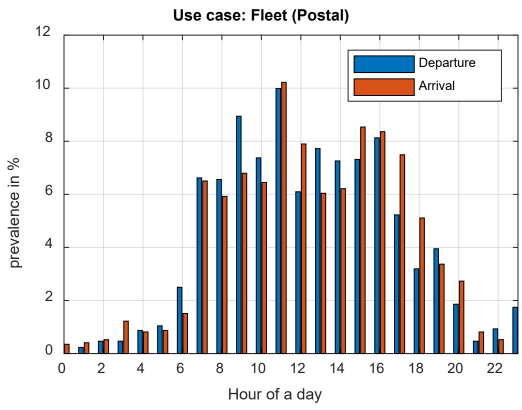

Figure 10: Prevalence of departure and arrival of the cars considering use case "Fleet" (Postal service)[11]

In addition to temporal mobility patterns, we derived the prevalence of the number of trips per day considering vehicles of ESCs and postal services (Figure 11). 93 % (ESC) and 84 % (postal) of vehicles undertake less than ten trips per day.

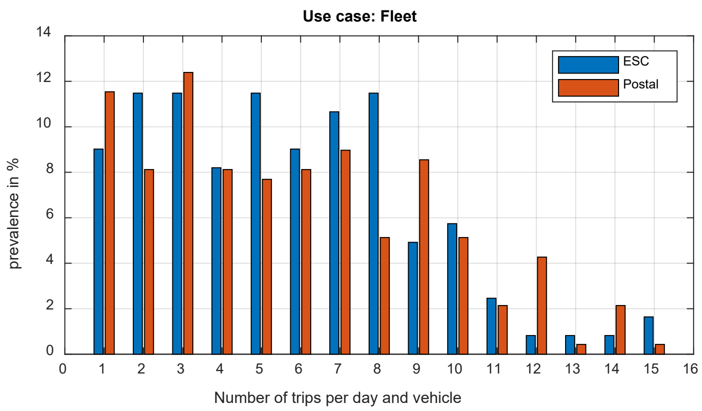

Figure 11: Prevalence of the number of trips per day considering energy supply companies (ESC) and postal services[11]

Furthermore, we determined the vehicles' covered distance per trip (Figure 12). Vehicles operated by ESCs are characterized by short distances (96 % of trips cover a distance lower than 20 km). The prevalence of postal vehicles' trips indicates their use also for larger distance: 28 % of trips have a distance higher than 20 km (Figure 12).

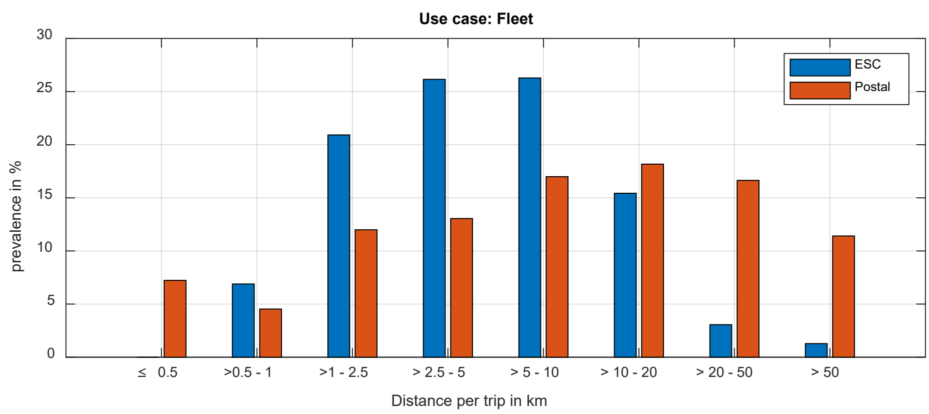

Figure 12: Prevalence of the covered distance per trip considering energy supply companies (ESC) and postal services[11]

2.2.3 Use Case 3: Private/Individual

Considering vehicles parking at home (Figure 13) or at work, their prevalence of departure and arrival are derived by destination matrices according to Bosserhoff[12i]. On workdays, the majority of trips (99%) starts between 05:00 and 13:00. Most vehicles (69 %) return at home between 15:00 and 19:00.

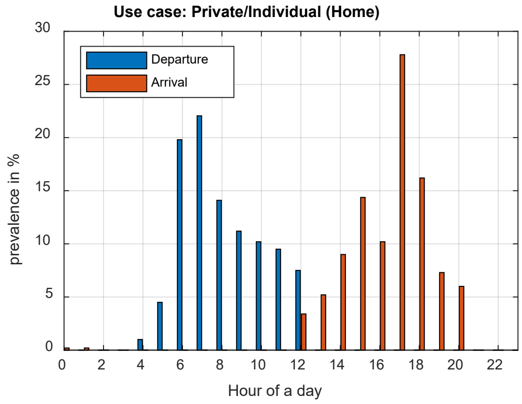

Figure 13: Prevalence of departure and arrival of the cars considering use case “Private/Individual” (Home) on workdays[12]

In contrast to vehicles parking at home, most vehicles arrive at the work place either between 06:00 and 08:00 (50 %) or between 12:00 and 15:00 (23 %), illustrated in Figure 14. Vehicles departure from their parking lots at work primarily between 12:00 and 18:00 (62 %).

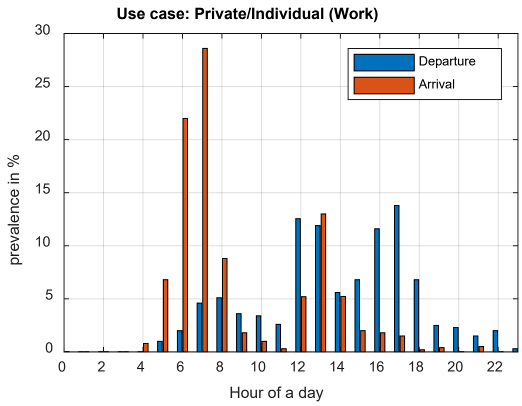

Figure 14: Prevalence of departure and arrival of the cars considering use case “Private/Individual” (Work) on workdays[12]

Aside from the prevalence of arrival and departure, destination matrices according to Bosserhoff[12] also provide information regarding the prevalence of parking vehicles (Figure 15). Between 18:00 and 06:00 the next day, at least 75 % of vehicles park at home. On the contrary, between 12:00 and 12:00 only 3 % of vehicles are parked at home.

[12] Bosserhoff, D. Integration von Verkehrsplanung und Räumlicher Planung. Teil2: Abschätzung der Verkehrserzeugung durch Vorhaben der Bauleitungplanung; Hessisches Landesamt für Straßen- und Verkehrswesen: Wiesbaden, Germany, 2000.

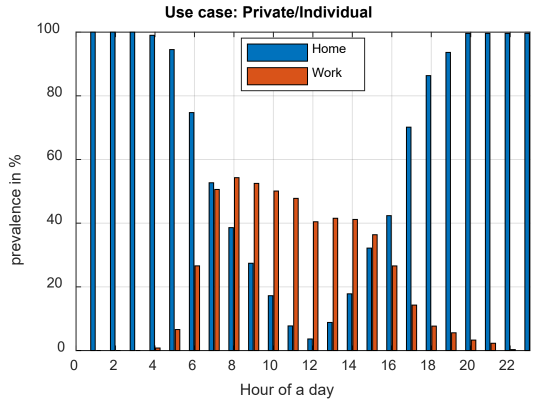

Figure 15: Prevalence of parking vehicles considering use case "Private/Individual" on workdays[12]

Based on the characteristic of the time of arrival and departure, vehicle park at work during 05:00 and 22:00. Between 10:00 and 17:00 the share of parking is rather constant between 40% and 50 % (Figure 15). Similar to use cases "Sharing" and "Fleet", we estimated the prevalence of the covered distance per trip homeward or to work (Figure 16) based on traffic surveys[13].

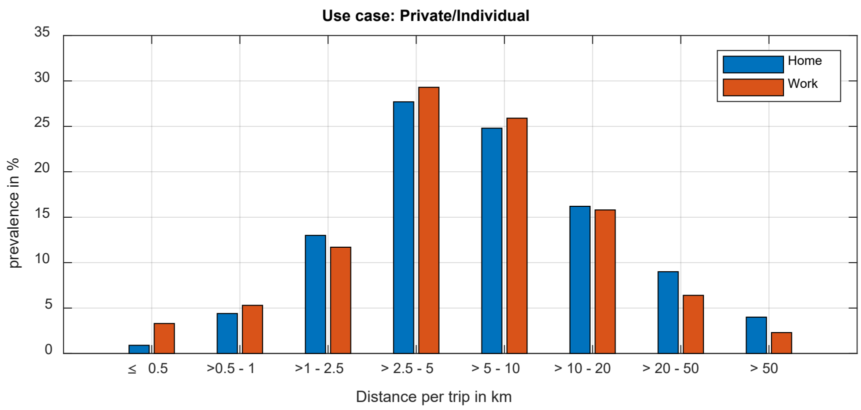

Figure 16: Prevalence of the covered distance per trip considering use case "Private/Individual"[13]

On workdays, most private trips homeward (29 %) are characterized by a distance between 2.5 and 5 km. However, about 96 % of trips are shorter than 50 km. Trips to work show a rather similar trend: While the majority of trips (27 %) are between 2.5 and 5km long, only 2 % of all trips are longer than 50 km (Figure 16).

Based on traffic surveys[13], we also derived the number of trips per day and vehicle (Table 2), which depend on the considered region. An average of 1.25 trips are undertaken on workdays in summer in urban areas. In suburban or rural areas 1.89 or 1.92 trips are undertaken in average.

[13] Bundesministerium für Verkehr, Innovation und Technologie: Ergebnisbericht zur österreichweiten Mobilitätserhebung „Österreich unterwegs 2013/2014"

Table 2: Expected values of the number of trips per day and vehicle (workdays in summer)[13]

	Charging at home	Charging at work
Urban	1.25	1 or 2 (depending on additional charging at home)
Suburban	1.89	
Rural	1.92	

Considering charging at work, each vehicle covers either one or two trips per day, depending on the possibility of additional charging at home.

2.3 Technical requirements and framework conditions

This section describes the protocols and standards that have been clearly defined for many years. The regulatory topics (e.g., regarding grid connection) and those that still have gaps in standards are described in Sections 2.5.4 and 2.5.5.

EV charging is defined by several standards and regulations involving mechanical, electrical, safety- and IT-relevant specifications.

IEC 62196 standardizes plugs, socket-outlets, vehicle connectors and vehicle inlets for conductive charging of electric vehicles. It includes the widely common Type 2 plug, the Combined Charging System (CCS) plug as well as other charging systems such as the Japanese CHAdeMO. Figure 17 shows all relevant grid-sockets and plug types in use in Europe.

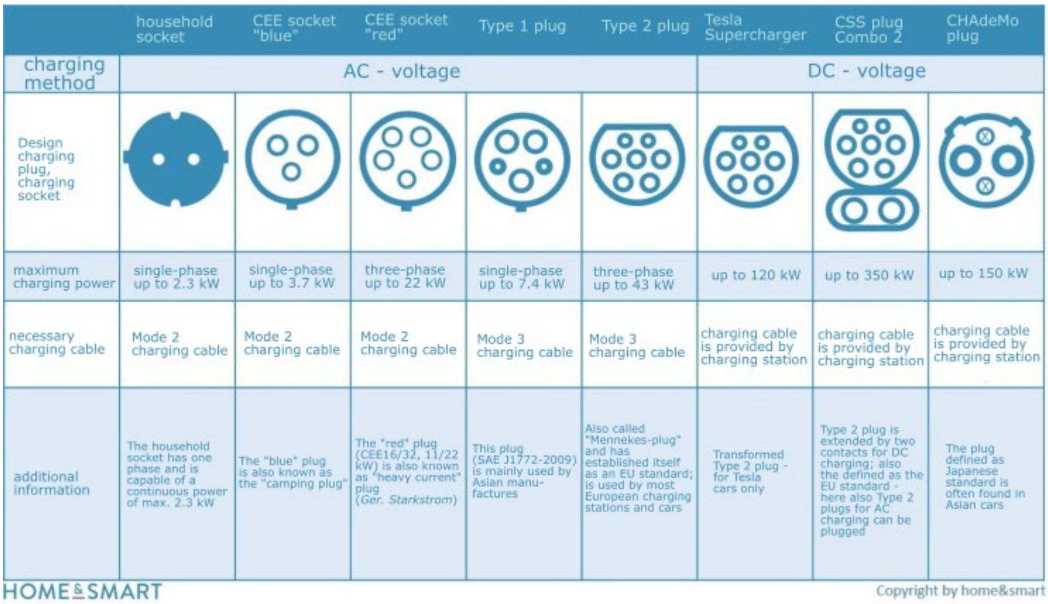

Figure 17: Plug types for EV charging (translated into English from [14]). The different charging modes are described in Figure 18

The required analogue low-level communication of charging parameters between the EV and the EVSE is defined in IEC 61851-1 Annex A. This communication is responsible for cable proximity checks, simple status messages and a basic possibility for the EVSE to set the target charging current. The system is implemented as an analog circuit between the EV and the

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[14] M. Artmann, Home & Smart: Die wichtigsten Ladestecker- und Kabeltypen für Elektroautos, 2017. https://www.homeandsmart.de/ladestecker-ladekabel-ein-ueberblick

EVSE. The circuit carries a 1 kHz signal sent by the EVSE. The voltage of this signal can be manipulated by the EV, which is measured by the EVSE. Furthermore, the EVSE sets the duty cycle of the signal which the EV can measure. In doing so, both actors can send simple information to their counterpart.
To get an overview of the standardized technical implementations of EV charging, Figure 18 summarizes the 4 different charging modes according to IEC 61851-1.

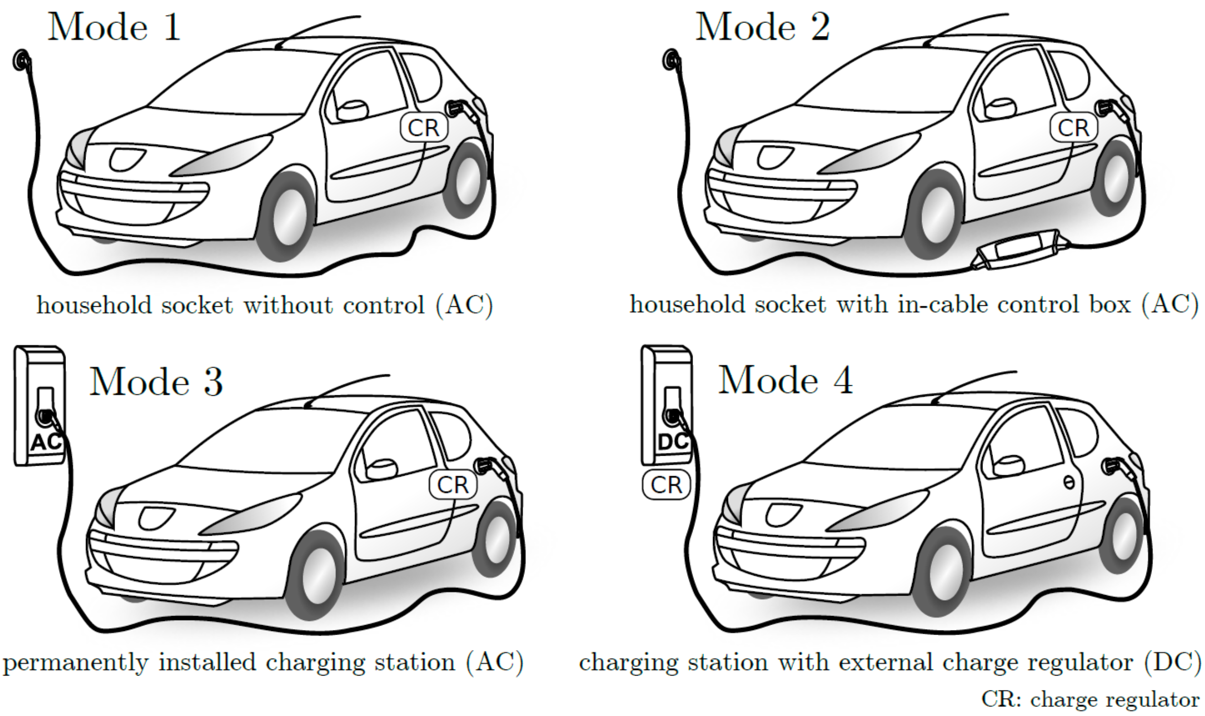

Figure 18: Charging Modes defined in IEC 61851-1 (figure from [15])

1. In mode 1, the EV is charged via conventional household sockets connected to the AC supply network with a maximum charging current of 16 A. In this mode, only the built-in charger of the EV (which rectifies the AC voltage) can control the charging process of the battery.
2. Mode 2 allows a single- or three-phase charging current of up to 32 A per phase (in total 22kW). The charging cable, however, needs an in-cable control box which implements a residual current device (RCD) and extended pilot functions to regulate and secure the charging process in addition to the charger of the EV. Conventional AC single- or three-phase socket-outlets can be used in this mode.
3. Mode 3 requires a dedicated EVSE which is permanently connected to the AC supply network.
4. In mode 4, an off-board charger is used to charge the EV with DC up to 400 A (according to IEC 62196-1). This mode is intended for fast charging and requires the use of a digital high-level communication between the EV and the EVSE (in addition to the basic analogue signals from IEC 61851). IEC 61851-24 and ISO 15118 describe the requirements of the high-level communication which is used for high-power charging in Europe.

Collectively, a list of relevant technical standards for EV charging is given below.

- Communication between EV and EVSE

[15] M. Nöhrer. “Flexible Co-Simulationsumgebung zum Testen von Ladeinfrastrukturen für Elektromobilität”. MA thesis. TU Wien, 2014.

    - IEC 61851-1: Electric vehicle conductive charging system
    - IEC 61851-23: Electric vehicle conductive charging system - Part 23: DC electric vehicle charging station
    - IEC 61851-24: Electric vehicle conductive charging system - Part 24: Digital communication between a d.c. EV charging station and an electric vehicle for control of d.c. charging
    - DIN Spec 70121: Digitale Kommunikation zwischen einer Gleichstrom-Ladestation und einem Elektrofahrzeug zur Regelung der Gleichstromladung im Verbund-Ladesystem
    - ISO 15118-2: Network and application protocol requirements
    - ISO 15118-20: - unpublished - 2nd generation network and application protocol requirements
    - CHAdeMO / GB-T
- IEC 62196: Plugs, socket-outlets, vehicle connectors and vehicle inlets
- IEC 61851-21-1: Electric vehicle on-board charger EMC requirements for conductive connection to an AC/DC supply
- OCPP (no official standard): Open Charge Point Protocol – Communication between EVSE and central management system

2.4 Economic factors and framework conditions

Electrification in the mobility sector is ongoing. The EV stock is increasing worldwide, as can be seen in Figure 19. In 2020, the global EV stock was greater than 10 million which represents about 1% of the total car share. Battery electric vehicles (BEVs), in comparison to plug-in hybrid electric vehicles (PHEVs), constituted two thirds of the fleet in 2020. Although China accounts for the most EVs, Europe had the largest fleet increase up to 3.2 million in 2020. Europe's strong eCar market despite Covid-19 can be traced back to 2020 being the target year for EU CO_2 emission standards for new cars combined with increasing subsidies in European countries[16].

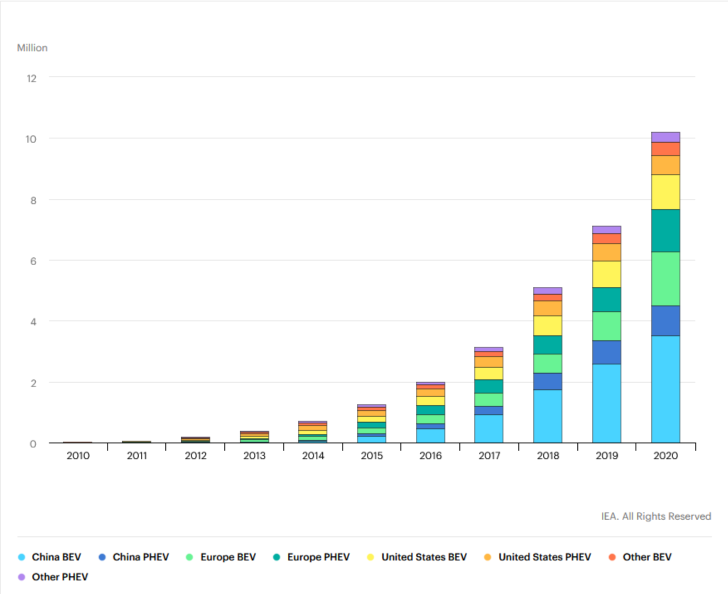

Figure 19: Global eCar stock 2010-2020 [17]

The following sections highlight important economic aspects of EVs, whereas enabling and hindering factors are presented. The analysis focuses on the three Use Cases "Sharing", "Fleet" and "Private/Individual" and investigated the situation in Austria.

2.4.1 eCar prices and storage capacities

In Europe, the battery demand in 2020 (52 GWh) was greater than domestic production. Battery production is dominated by China with a battery cell production of 70% of global demand. The average cost of EV batteries was about 137 USD/kWh (116 €/kWh) in 2020, which corresponds to a decrease of 13% compared to 2019[18]. Battery prices are strongly related to EV sales[19]. Data and forecasts on battery prices for eCars are depicted in Figure 20, where it can be seen that prices are foreseen to decrease mainly through learning effects and

[16] IEA: Trends and developments in electric vehicle markets, 2021. https://www.iea.org/reports/global-ev-outlook-2021/trends-and-developments-in-electric-vehicle-markets

[17] IEA: Trends and developments in electric vehicle markets, 2021. https://www.iea.org/reports/global-ev-outlook-2021/trends-and-developments-in-electric-vehicle-markets

[18] IEA: Trends and developments in electric vehicle markets, 2021. https://www.iea.org/reports/global-ev-outlook-2021/trends-and-developments-in-electric-vehicle-markets

[19] S. Heitel, K. Sedding, J. Gómez Vilchez, P. Jochem: Chapter 15 - Global electric car market deployment considering endogenous battery price development, 2020. https://doi.org/10.1016/B978-0-12-818762-3.00015-7

innovation[20]. The actual breakdown of the cost components of an EV and a trend for the year 2025 and 2030 is shown in Figure 21 (Chinese manufacturing costs), whereas the share of the costs for the battery are foreseen to decline significantly. Concerning the total EV costs for customers, Figure 22 shows trends until 2035 for a mid-size eCar.

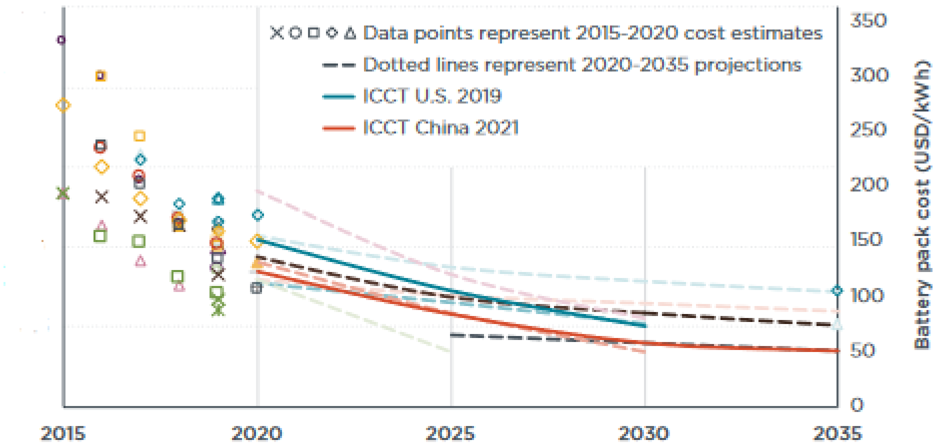

Figure 20: Price development and forecast of eCar batteries [21]

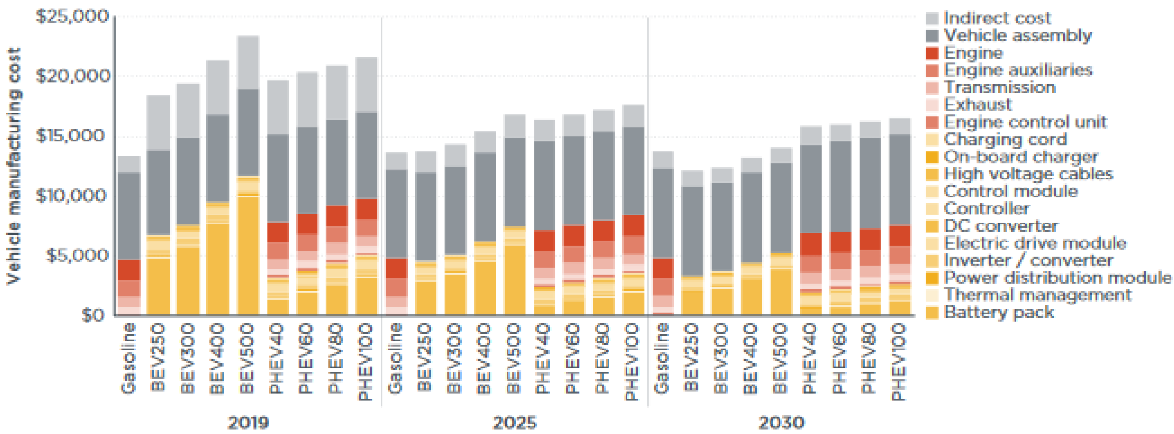

Figure 21: eCar manufacturing costs 2019, 2025 and 2030 (China). (BEV=battery electric vehicle, PHEV=plug-in hybrid electric vehicle. 250, 300, 400 and so forth stands for the electric range in km) [22]

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[20] H. Ritchie: The price of batteries has declined by 97% in the last three decades, June 2021. https://ourworldindata.org/battery-price-decline

[21] N. Lutsey, H. Cui, R. Yu: Evaluating electric vehicle costs and benefits in China in the 2020-2035 time frame, April 2021. http://www.indiaenvironmentportal.org.in/files/file/EV%20costs%20benefits%20china.pdf

[22] N. Lutsey, H. Cui, R. Yu: Evaluating electric vehicle costs and benefits in China in the 2020-2035 time frame, April 2021. http://www.indiaenvironmentportal.org.in/files/file/EV%20costs%20benefits%20china.pdf

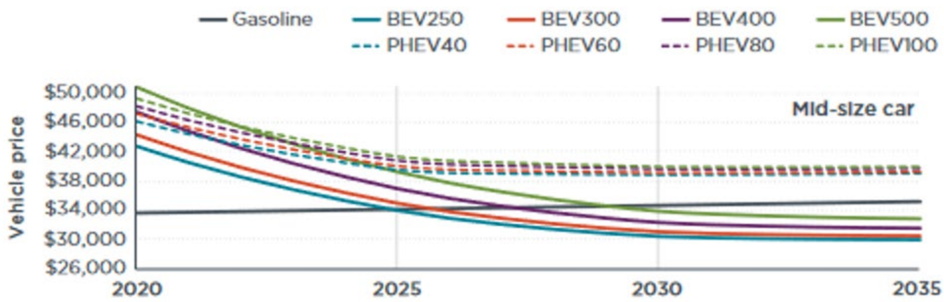

Figure 22: Customer eCar price development until 2035 [23]

Concerning EV prices, to include current investment costs (the costs are displayed, if not stated otherwise, with German VAT of 19% in 2021). The result is depicted in Table 3. The list of EVs can only display a selection of the large number of eCar models available on the market.

Table 3: Costs of a selection of commercial eCars (prices, if not stated otherwise, with German VAT)[24]

Manu-facturer	EV Model	Battery capacity (kWh)	Investment costs (€)
'RENAULT'	'ZOE' (Z.E. 40)	41	29.990
'TESLA'	'MODEL 3' (Performance)	75	58.560
'BMW'	'I3' (120 Ah)	37.9	39.000
'VW'	'ID.3 (Pure Performance)'	45	31.960
'SMART'	'FORTWO'	17.6	18.460
'AUDI'	'E-TRON' (55 quattro)	95	81.500
'HYUNDAI'	'KONA'	64	41.850
'NISSAN'	'LEAF'	40	29.990
'SMART'	'FORFOUR'	17.6	19.120
'HYUNDAI'	'IONIQ'	38	35.350
'KIA'	'SOUL' (39 kWh)	39	33.990
'JAGUAR'	'I-PACE'	90	77.300
'TESLA'	'MODEL S' (Plaid) (from 2022)	90	126.990
'VW'	'UP'	36.8	12.601[25]
'NISSAN'	'NV200'	40	31.000 (net)

2.4.2 Construction of eCar charging points

The use cases “Fleet”, “Sharing” and “Private/Individual” were defined for the project. Since the use cases FLEET and SHARING are very similar with regard to the equipment of the charging infrastructure and thus also the costs incurred, a distinction between these two cases

[23] N. Lutsey, H. Cui, R. Yu: Evaluating electric vehicle costs and benefits in China in the 2020-2035 time frame, April 2021. http://www.indiaenvironmentportal.org.in/files/file/EV%20costs%20benefits%20china.pdf
[24] Electric Vehicle Database, 2021. https://ev-database.de/
[25] M. Diethelm: VW bringt Billig-Stromer zurück, 2021. https://efahrer.chip.de/news/vw-bringt-billig-stromer-zurueck-hier-gibts-den-elektro-up-fuer-12000-euro_104159

is not made here. For the sake of completeness, however, the costs of a public charging bay are also listed (2x50 kW DC and 4x22kW AC).

Use Case 1 and 2: Sharing and Fleet

For this use case, it is assumed that the parking space (parking lot) is owned by the customer and that there are no additional investment costs for construction, etc. that could be allocated to the charging infrastructure. However, the investment costs already include a share of the upstream infrastructure (meter, distributor) per charging point. The costs in Table 4 are depicted per charging point.

Table 4: Costs for eCar charging points (fleet/sharing) per charging point

Semi-public charging points (each 22kW) "Fleet"/"Sharing"

Investment costs	
Hardware	*€ 1 300,00*
E-installation material (incl. share of upstream infrastructure)	*€ 300,00*
Installation and commissioning	*€ 400,00*
Documentation (certificate, test report, data sheets)	*€ 35,00*
Total	**€ 2 035,00**
Operating costs internal (monthly)	
Backend (incl. SIM cards)	€ 3,50
Maintenance and inspection	€ 5,00
Fault clearance	€ 1,50
Total	**€ 10,00**

Use Case 3: Private/Individual

For the use case "Private/Individual", an 11kW AC charging infrastructure is assumed which is installed in the private area (garage, carport) of a user. An increase of the purchased grid power is not considered, but an increase of the pre-meter fuse from 25A (approx. 18kW) to 32A (22kW) is mentioned as an option. Costs for a bidirectional DC wallbox cannot yet be quoted here, as this will only be developed in the course of the project and the economic effects can therefore only be presented at a later date.

For the running costs, an offline wallbox is assumed for the starting point of this use case; optionally, the additional costs for an online-capable wallbox are listed, as this is necessary for controlling the charging process as envisaged in the car2flex project. Likewise, for the "private charging" - use case with offline wallbox no backend costs are assumed, but since this is necessary for the defined functionality of the project, the running costs for this are optionally listed.

Table 5: Costs for eCar charging points (private) per charging point

Home charging (1x11kW)	
Investment costs	
Hardware	*€ 940,00*
Surcharge online (optional)	*€ 400,00*
E-installation material	*€ 200,00*
Installation and commissioning	*€ 550,00*
Digital submeter (optional)	*€ 270,00*
Conversion 32A back-up fuse (optional)	*€ 150,00*
Documentation (certificate, test report, data sheets)	*€ 100,00*
Total	**€ 2 610,00**
Internal operating costs (monthly)	
Backend costs (for online operation, incl. SIM costs)	*€ 2,00*
Total	***€ 2,00***

2.4.3 Current eCar charging tariffs

In Austria, approximately 1.7% of eCar owners use charging points in public places (e.g. public car parks, supermarkets etc.) and 1.5% use charging stations (i.e. on motorways) (Baresch&Moser, 2019)[26]. Energy suppliers provide most charging points in Austria. However, there are also a few private providers establishing a network of charging points throughout Austria and beyond.

Table 6: eCar charging tariffs of energy suppliers[27]:

Provider / **Plug Type**	Energie AG OÖ (4,500 charging points)	Energie Burgenland (-50% for customers)	Energie Graz	EVN	Innsbrucker Kommunal-betriebe (33 charging points)
AC 3.7 kW	€0.015/min €0.24/kWh	€0.022/min €0.36/kWh		€0.020/min €0.32/kWh	€0.014/min €0.22/kWh
AC 11kW	€0.032/min €0.18/kWh	€0.066/min €0.36/kWh	€0.04/min €0.22/kWh	€0.065/min €0.36/kWh	€0.014/min €0.22/kWh
AC 22kW	€0.065/min €0.18/kWh	€0.132min €0.36/kWh	€0.14/min €0.38/kWh	€0.130/min €0.36/kWh	€0.014/min €0.22/kWh
AC43 kW	€0.299/min €0.42/kWh	€0.258/min €0.36/kWh		€0.260/min €0.36/kWh	
DC20		€0.150/min €0.45/kWh			

26 Baresch, M.; Moser, S. (2019). Allocation of e-car charging: Assessing the utilization of charging infrastructures by location. *Transportation Research Part A 124,* 388-395

27 Ladetarife der BEÖ Mitglieder • BEÖ •• Bundesverband Elektromobilität Österreich (beoe.at)

DC 50 kW	€0.332/min €0.40/kWh	€0.300/min €0.36/kWh	€0.44/min €0.53/kWh	€0.300/min €0.36/kWh	
DC bis 75 kW	€0.542/min €0.43/kWh			€0.300/min €0.24/kWh	

Provider / **Plug type**	Kelag (base fee € 5.40 p.m., 250 charging points)	Linz Strom GmbH	Salzburg AG (240 charging points, 30 fast charger)	VKW (600+ charging points)	Wien Energie (1.000 charging points)
AC 3.7 kW	€0.0264/min €0.43/kWh	€0.016/min €0.26/kWh			City €2.90/h €0.78/kWh Parking €1.20/h €0.32/kWh
AC 11kW	€0.0398/min €0.22/kWh	€0.040/min €0.22/kWh			Parking €2.90/h €0.78/kWh
AC 22kW	€0.0665/min €0.18/kWh	€0.079min €0.22/kWh	€4/hour (up to 22 kW) €0.19/kWh	€0.11/min (until 22kW) €0.3/kWh	Parking €4.90/h €0.22/kWh
AC 43 kW	€0.1994/min €0.28/kWh	€0.182/min €0.25/kWh	€11/hour (up to 22kW) €0.26/kWh	€0.30/min (from 43 kW)	€15/h (fast) €0.35/kWh
DC 25 kW	€0.1662/min €0.40/kWh				
DC 50 kW	€0.2659/min €0.32/kWh	€0.225/min €0.32/kWh			€15/h (fast) €0.3/kWh
DC bis 100 kW	€0.5318/min €0.32/kWh	€0.550/min (>50kW) €0.33/kWh			
DC bis 150 kW	€0.7313/min €0.29/kWh				
DC bis 350kW	€1.1966/min €0.21/kWh				

Table 7: eCar charging tariffs of private providers[28]:

Provider / Plug type	Smatrics (450 charging points)	da-emobil (120 charging points)	Ionity (16 charging points)	ÖAMTC ePower (3,000 charging points)
AC 3.7 kW				
AC 11kW	€0.06/min €0.33/kWh	€0.05/min €0.29/kWh		
AC 22kW	€0.15/min €0.41/kWh			€0.05/min €0.29/kWh
AC43 kW				
DC20				
DC 50 kW	€0.45/min €0.54/kWh	€0.07/min €0.39/kWh	€0.09/min €0.49/kWh	
DC bis 75kW				€0.07/min €0.39/kWh
DC bis 350 kW	€0.95/min €0.16/kWh		€0.15/min €0.79/kWh	

Most of the energy suppliers bill the charging process per time tariff, more precisely per started minute. The exceptions are Innsbrucker Kommunalbetriebe on part of the energy suppliers and the private providers da-emobil, Ionity and ÖAMTC ePower, which bill the actual charged energy (kW) per hour. As the billing does not end, when the eCar is fully charged, but when the plug is disconnected, and due to the fact that different eCar models need a different amount of time for charging, the time tariff does not seem to be equitable. According to a German Study conducted by Capgemini and HYVE (Capgemini, 2019)[29] eCar users prefer to be charged after loaded energy. In second place a fix tariff is preferred, followed by charging after supply-dependent tariffs (e.g., cheaper during sun hours) and only then comes the time tariff model. Nevertheless, the time tariff is more common because, on the one hand there exists no official ordinance for charging points in Austrian's calibration and measurement law ("Eich- und Messrecht"), which could improve consumers' situation regarding comparison of tariffs. On the other hand, providers use time tariffs to avoid permanent parkers on public charging points (Soder, 2020)[30]. The following table summarizes the advantages and disadvantages of each model.

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[28] Ladetarife der BEÖ Mitglieder • BEÖ •• Bundesverband Elektromobilität Österreich (beoe.at)

[29] Capgemini; Hyve (2019). Wachstumsmarkt Ladeinfrastruktur in Deutschland. Kundenerwartungen und Chancen für die Energiewirtschaft

[30] Soder, M. (2020). E-Mobilität 2020. Ein Update zur Markt- und Preisanalyse für das Laden an öffentlichen Ladestationen. Arbeiterkammer Wien.

Table 8: Pros and Cons of performance based and time tariffs[31]:

	Performance based tariff (kWh)	Time-tariff
Pro	• Fair billing, regardless of the charging performance of the eCar	• Advantage for eCars with higher charging performance • Avoidance of permanent parkers
Contra	• Permanent parking	• Disadvantage for eCars with lower charging performance • Inefficient loading during cold weather

Both, time tariff and performance tariff, belong to the contract tariffs and may be accompanied by a basic fee. Another charging model is the flat-rate, where customers pay a regular fee (e.g., monthly) and therefore do not have to pay for the charging process itself. This is often combined with a "Fair-Use Policy" to avoid consumption exploitation (Soder, 2020). Besides there is also the possibility of "Direct-Payment", which ensures non-discriminatory loading. The study of Capgemini and HYVE (2019) examined that 54% of (potential) eCar users favor a contract tariff, while 44% prefer to be independent. However, for individual customers it is difficult to consider which of these three models is the most economic as the calculation and the comparison are very complex and not transparent at all (Soder, 2020).
When it comes to payment, there also exist different options that vary from provider to provider. Direct payments e.g., via credit card, bank card or PayPal, must be possible on every charging point according to EU regulation. Besides, eCar users can pay via App (e.g., Ionity) or RFID-card (e.g., ÖAMTC ePower, da-emobil, members of BEÖ). According to the study results of Capgemini and HYVE (2019) German eCar users prefer to pay with credit card or bank card directly at public charging points in first place, followed by paying via smartphone or App. Other desired payment methods were ranked by preference as follows: via NFC on the smartphone, cash payment, via RFID-card, on account of invoices sent home and others.

2.4.4 Flexibility in relation to charging tariffs

In order to be able to evaluate the monetary use that arises from the flexibility of electric vehicles, the first step is to collect the revenue mechanisms that flexibilities in the electricity sector can bring. The factsheet "Vehicle to Grid - Customer Benefits and Grid Integration" of the National Platform for the Future of Mobility lists four categories of economic use cases.[32]

- **Optimization of local consumption/own consumption optimization**

This means the provision of electricity from the vehicle battery for direct consumption on site behind the grid connection point in the respective property as part of an overall in-house optimisation by means of a (local) energy management system.

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[31] da-emobil, EMC-Livestream 19.01.2021 ((1) EMC Livestream 19.01.2021 - Abrechnungssysteme für Ladestationen - YouTube)
[32] Nationale Plattform Zukunft Mobilität (2020): Factsheet „Vehicle to Grid" – Kundennutzen und Netzintegration; Zwischenbericht 10/2020; https://www.plattform-zukunft-mobilitaet.de/2download/factsheet-vehicle-to-grid-kundennutzen-und-netzintegration/ abgerufen am 09.06.2021

- **Grid-serving charging/grid services (distribution grid)**

This means that the grid operator influences the charging/discharging behaviour of the vehicle battery against the overall consumer site unit in order to reduce/avoid the grid consumption of the consumption devices present there for a limited period of time. This is done e.g. through time/load windows, ad-hoc control signals and financial incentives.

- **Electricity marketing**

This means the provision and feeding of electricity into the distribution grid on the basis of a contract with a supplier/trader. The provision/feeding takes place according to the specifications/control signal of the supplier/trader and in coordination with the local grid operator.

- **System services**

This means the provision and feeding of electricity into the grid on the basis of a contract with the transmission system operator (TSO). The provision/feeding takes place according to the specifications/control signal of the TSO and in coordination with the local grid operator.

The vehicle battery can generate value contributions at **local** (behind the electricity meter, in the house installation), **regional** (before the electricity meter in the distribution grid) and **supraregional** (before the electricity meter in the transmission grid) level. Depending on the use case, the value drivers for this vary and depend on the design/change of the market model (for example, with regard to grid charges, levies, taxes, etc.). Currently these are:

1. local - volatile energy prices, grid usage charges, levies.

Customers can optimize their interaction with the energy supplier in monetary terms by optimising their supply. Additional options arise from the combination with self-generation (e.g. PV system) or a stationary storage system.

2. Regional - avoidance of grid expansion

Through a secured, plannable controllability of the charging power and the clear local location or aggregation of several charging points, the grid expansion in the distribution grid can be optimized, among other things, through a lower peak load. This would enable grid operators to reduce the need for grid expansion in the low-voltage grid compared to the expansion of uncontrolled charging infrastructure. In addition, customers can benefit from corresponding incentives through the possibility or use of charging control.

3. Supraregional - grid system services, electricity trading

Flexibilities in the electricity grid are becoming increasingly important against the background of the expansion of renewable energies. Above all, vehicle batteries can provide balancing power. Through aggregators, transmission system operators have access to a large supply of energy storage facilities, which provide a secondary benefit. In this way, the costs for system services for TSOs can be reduced and thus also the grid fees for customers. The vehicle battery is also remunerated by the TSO for offering balancing power. Through aggregators, trading electricity from or for the vehicle battery also becomes economically interesting. The targeted feed-out in times of high electricity prices and the charging process in times of low - and increasingly negative - electricity prices create a virtual, centrally controlled "swarm storage" for electricity.

In this context, the following *Table 9* describes the specific revenue mechanisms that can be offered by flexibilities:

Table 9: Revenue mechanisms of flexibilities:

Name	Quantification of economic benefit	Corresponding control strategy according to KPIs	Key-Stakeholders	Example / Data
Self-consumption optimization of end user	- Difference of purchase price (including taxes and grid fees) and feed in prices of electricity	Increased REN share in local installation NE6/NE7 (PV self-consumption opt.)	End user (private or commercial)	Consumption base electricity price including taxes and grid fees (e.g. 17 ct/kWh) -Feed in price for electricity (e.g. 5 ct/kWh) =Revenue: 12 ct/kWh Data: e-control Tariff calculator[33]
Self-consumption optimization of local energy market	- Difference of local and overall grid tariff - Difference of local energy price and energy price from the public grid	Increased REN share in local installation NE6/NE7 (PV self-consumption opt.)	Buyers and sellers within the local energy market	Buyer: Consumption base electricity price including taxes and grid fees from public grid (e.g. 17 ct/kWh) -Electricity price from local energy market including grid fees only for NE6/7 (e.g. 12 ct/kWh) =Revenue: 5 ct/kWh Seller: Selling price on local energy market (e.g. 7 ct/kWh) -Feed in price in public grid (e.g. 5 ct/kWh)

[33] E-Control: Tarifkalkulator, 2021. https://www.e-control.at/konsumenten/service-und-beratung/toolbox/tarifkalkulator#/

The flagship project Car2Flex (880780) has received funding from the 3rd call of the research and innovation programme Energy Model Region - Klima- und Energiefonds.

				=Revenue: 2 ct/kWh
Peak shaving - customer	- Reduction of the power-dependent grid fees	Peak Shaving local installation NE6/NE7 (NE5?)	Non-flat-rate end customers	- Grid usage fee (Netznutzungsentgelt) NE7 / Burgenland: 45,36 €/kW - Network provision fee (Netzbereitstellungsentgelt): NE7 / Burgenland 238 €/kW
Peak shaving DSO	- Avoided costs of grid expansion - Avoidance of curtailment costs	- Peak Shaving local installation NE6/NE7 (NE5) - Voltage regulation EN 50160	DSO	- Grid usage fee (Netznutzungsentgelt) NE7 / Burgenland: 45,36 €/kW - NE5 / Burgenland: 47,52 €/kW - Network provision fee (Netzbereitstellungsentgelt): - NE7 / Burgenland 238 €/kW - NE5 / Burgenland 107 €/kW Alterantive Approach: -Real grid expansion costs (Capex and Opex) -specific costs of grid expansion according to literature[34]
Peak shaving TSO	- Avoided costs of grid expansion - Avoidance of curtailment costs	- Voltage regulation EN 50160	TSO	- Grid usage fee (net component) NE1 930 €/kW - Network provision fee 8,70 €/kW Alterantive Approach: -Real grid expansion costs (Capex and Opex) -specific costs of grid expansion according to literature[35]

[34] Representing node-internal transmission and distribution grids in energy system models: https://doi.org/10.1016/j.renene.2017.10.041

[35] Cost/benefit analysis of transmission grid expansion to enable further integration of renewable electricity generation in Austria: https://doi.org/10.1016/j.renene.2016.05.073

Energy price optimization	- Price differences in the wholesales market	Trading: - Intra-Day - Day-Ahead	Energy supplier End customers with own procurement / flexible energy tariff	Average difference between highest and lowest Day-Ahead hourly price of a day in 2020 in bidding zone Austria: 28,25 €/MWh Data: ENTSO-E Transparency Platform[36]
Balancing energy	- Avoided energy balancing costs	Balancing energy	Balance group manager	Prices for activated balancing reserves according to ENTSO-E Transparency Platform[36] multiplied with avoided balancing energy of balancing group
Reserve energy	- Revenues on the reserve energy / power market	Balancing energy	- TSO - reserve energy / power pooler	- Prices for activated balancing reserves according to ENTSO-E Transparency Platform[36] multiplied with avoided reserve energy of control area
Integration in VPP	- Additional degree of freedom to improve the global optimum	All control strategies possible	- VPP-Operator	- Difference of global optimum with and without flexibility of Cars
Market premium models	- loading when electricity market prices are low and REN generation is high	Trading: - Intra-Day - Day-Ahead	- REN-Producer - Trader	Average difference between highest and lowest Day-Ahead hourly price of a day in 2020 in bidding zone Austria: 28,25 €/MWh Data: ENTSO-E Transparency Platform[37]

[36] ENTSO-E: Transparency Platform, 2021. https://transparency.entsoe.eu/dashboard/show
[37] ENTSO-E: Transparency Platform, 2021. https://transparency.entsoe.eu/dashboard/show

2.4.5 Revealed gaps concerning economic factors of eCars

Concerning economic factors for the adoption of electric vehicles, the previous chapters revealed barriers and motivators. It can be seen that economic factors, such as purchase price and charger subsidy, as well as charging infrastructure (charging time, charging station availability) are important factors for EV adoption. Furthermore, studies have shown that the EV penetration rate positively affects the EV preference, which implies that the externality effect can occur when neighbors use EVs [38]. Also, economic aspects such as the reduction of fuel costs are unanimously mentioned as a motivator.

However, there still exist hindering factors when it comes to EV adoption. Barriers are, e.g., the lack of charging infrastructure, technical restrictions, the lack of trust in environmental benefits, the electricity supply, the raw materials supply, and the limited availability of models. Furthermore, the ongoing price decrease due to technological progress might be neutralized by focusing on desirable higher humanitarian and environmental standards concerning lithium mining. A point that needs to be considered critically is that China dominates the market of battery production with a market share of 70%. Concerning economic aspects of market participation, there are various tariff models to bill customers for charging their EVs. The most popular one (among providers) is to charge per time, which means by every started minute of charging. Apart from the fact that this poses an advantage to eCars with higher charging performance, it is not very practicable for providing flexibility on spot- and balancing markets.

The following *Table 10* shows the examined economic factors and corresponding barriers and motivators for the diffusion of electric vehicles in three levels of formal social units[39]:

Table 10: Revealed gaps concerning economic factors of eCars:

Economic-Factors – Formal Social Unit Act as policy makers and/ or energy providers	
Barriers	**Motivators**
Higher price of electric cars in comparison to conventional cars	Emphasizing the lower charges of electricity compared to gasoline, in order to motivate potential EV buyers
EV prices are considerably higher, and there are no compensating benefits for users for lower pollution levels	Using night-time rates
	The total cost of ownership of electric vehicles is lower than in the case of conventional vehicles, due to fuel savings and lower maintenance costs
	Free electricity at some workplaces
EV buyers are not aware of the various government incentive programs	Using public charging
	Reduced fuel costs

[38] Jung, J., Yeo, S., Lee, Y., Moon, S., & Lee, D.-J. (2021). Factors affecting consumers' preferences for electric vehicle: A Korean case. Research in Transportation Business & Management, 100666. doi:10.1016/j.rtbm.2021.100666

[39] Biresselioglu, M. E., Demirbag Kaplan, M., & Yilmaz, B. K. (2018). Electric mobility in Europe: A comprehensive review of motivators and barriers in decision making processes. Transportation Research Part A: Policy and Practice, 109, 1–13. doi:10.1016/j.tra.2018.01.017

	Awareness is key to the successful market acceptance of EVs
Economic-Factors - Decision-making Unit Collective decision-making units, more formally structured and with relatively lower information and power asymmetries	
Barriers	**Motivators**
High procurement costs of electric vehicles	Low fuel costs and efficiency of operation
High procurement costs and slow acceptance in the mass market make it very challenging for new companies to enter the market	The efficiency of operation can be enhanced by policies that allow EV vehicles to be used in designated low emission zones, or to use bus lanes and special parking spaces
Limited loading capacity, as well as insufficient, unreliable and expensive after-sales support	Decreasing battery price is a further potential motivator
Using electric vehicles in the company fleet does not enhance the revenue flow, because customers do not pay the extra cost incurred by EV deliveries	
Uncertainty over oil and energy prices, If oil prices are low, but energy prices in general are increasing, the investment in EVs is not financially beneficial	
Economic Factors - Individual Unit Individual consumers engaging in joint contracts to increase their power of negotiation	
Barriers	**Motivators**
High purchasing price, coupled with high vehicle depreciation cost	Some users consider the EVs cost effective, mainly because of lower refueling costs compared to conventional vehicles
EVs lose a larger share of their purchase value, particularly due to rapid technological advances in the market	The option to use domestic electricity is very convenient
Many drivers are uncertain about the cost of recharging the car or how much electricity is needed	Recharging costs are also considered low
Lack of knowledge impedes the calculation of likely costs and savings	Although the initial purchasing price is higher than that of a conventional car, long term running costs are lower
Unprecise cost comparison	
The limited battery life span, many users fear that the replacement costs of batteries will exceed the lower running costs, and that purchasing an electric vehicle would not be economically beneficial	

2.5 Regulatory gaps and framework conditions

2.5.1 Legal framework conditions concerning construction and housing law

Concerning the construction of eCar charging points, the construction and housing law need to be evaluated. The operation of charging stations is not an activity that qualifies as the operation of an electricity undertaking within the meaning of the ElWOG. Electricity charging stations, if operated on a commercial basis, are therefore subject to the scope of application of Commercial Law (*Ger. Gewerbeordnung*). Whether an operating permit procedure is to be carried out depends on the extent to which specific unusual or dangerous local circumstances or specific unusual methods of execution arise in the intended project. These can be, for example, the location in a hazardous area (e.g., blocking of an emergency exit) or an unusual design (e.g., technically unsafe). If this is not the case, then the project is generally to be regarded as exempt from approval under commercial law. Additionally and depending on the federal state, there are different requirements in terms of building law (e.g., the issue of ventilation must be considered if lead-acid batteries are used). Moreover, the electrical installations for electric charging infrastructure for eCars must be carried out by a licensed electrical company [40].

In the following, the required steps and the legal framework for receiving a construction permit are described, whereas a distinction is made for private or commercial charging operation.

2.5.2 Legal framework for private charging points

In Austria, the current situation regarding the installation of an EVSE in a multi-party building can be described as difficult. According to current legislation, there is still the principle of unanimity among all apartment owners for the approval of a new single charging point and the principle of majority voting for community charging points. These principles have a restraining effect on the successful rollout of EV charging stations.

Even though the principle of unanimity is in place until now, the Supreme Court ruled in December 2019 that other apartment owners may not refuse the installation of an eCar charging station with a maximum power of 3.7 kW [41].

However, improvements in the legislation have anyhow been announced recently by the Austrian government for 2022 [42], with the aim to abrogate the necessity for unanimity/majority voting of all apartment owners (“right to plug”[43]). In the future, the majority of people responding to the request should be sufficient to approve the installation of charging stations. Relevant questions are yet unanswered, such as responsibility, questions regarding billing and potential involvement of companies and employers.

The following process diagram in Figure 23 shows the necessary official steps for the installation of a private charging point

[40] WKÖ: Ladeinfrastruktur für Elektrofahrzeuge, 2021. https://www.wko.at/service/umwelt-energie/ladeinfrastruktur-fuer-elektrofahrzeuge.html

[41] OGH-Entscheidung (5 Ob 173/19f). https://www2.deloitte.com/at/de/blog/deloitte-tax-blog/2021/die-errichtung-einer-e-ladestation-im-wohnungseigentumsrecht.html

[42] ORF.at : Gewessler: Mehr E-Tankstellen in Mehrparteienhäusern, 2021. https://orf.at/stories/3198361/

[43] BMK Infothek: “Right to Plug”: Ladestationen in Mehrparteienhäusern werden erleichtert, 2021. https://infothek.bmk.gv.at/right-to-plug-ladestationen-in-mehrparteienhaeusern-werden-erleichtert/

Figure 23: Official steps for the installation of a private charging point [44]

2.5.3 Legal framework for commercial charging points

In contrast to private charging stations, commercial ones are additionally subject to the Commercial Law (*Ger. Gewerbeordnung*). The process diagram in Figure 24 shows the necessary official steps for the installation of a commercial charging point.

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[44] BMVIT: Leitfaden für Private. Genehmigungsverfahren Ladeinfrastruktur für Elektrofahrzeuge, 2017.

Figure 24: Official steps for the installation of a commercial charging point [45]

2.5.4 Regulation on grid connection

The AC grid connection of the EVSE is regulated by national grid codes, whereby additional codes apply if V2G is to be used. In Figure 25, Figure 26, Figure 27 and Figure 28, the German regulations VDE AR N4100 and VDE ARN4105 are depicted at the grid connection.

If no national regulations apply, EN 50549-1 provides technical requirements for the connection of generating plants which can be operated in parallel with a public LV distribution network. They are intended to be used as a technical reference for connection agreements between DNOs and electricity producers and to demonstrate compliance with COMMISSION REGULATION (EU) 2016/631 (Requirements for Generators).

Additionally, there is the European Network Code on Requirements for Generators (RfG NC)[46] which establishes harmonized connection rules for power-generating modules. The code defines four categories

[45] BMVIT: Leitfaden für Betriebe. Genehmigungsverfahren Ladeinfrastruktur für Elektrofahrzeuge, 2017.
[46] Commission Regulation (EU) 2016/631

or ‘types’ A-D of generators, which are based on the maximum capacity of the power generating module and its connection voltage level.

Table 11: European Grid Codes relevant for EVSE

Country	Specifications
Europe	EN 50549-1 (valid if no national specification available), RfG NC
Germany	VDE AR N4105, N4100 and N4110
Austria	TOR
UK	ER G98/1; ER G99
Belgium	Elia - Proposition d’adaptation du Règlement Technique Fédéral; Synergrid - Technical Prescription C10/11
Denmark	Energinet - Technical Regulation 3.3.1 for Battery Plants
France	Enedis - Enedis-FOR-CF_11E
Italy	Norma Tecnica CEI 0-21 and CEI 0-16
Netherlands	ACM - Netcode elektriciteit
Norway	Statnett – FIKS; Statnett – NC-RfG; Olje - energilovforskriften
Sweden	Svenska Kraftnät - Affärsverket svenska kraftnäts föreskrifter; Energimarknads inspektionen - Energimarknadsinspektionens föreskrifter
Switzerland	Verband Schweizerischer Elektrizitätsunternehmen (VSE) – Several specifications
Spain	Red Eléctrica - PO12.2
Czech Republic	Energetický regulační úřad - pravidla provozování lokální distibuční soustavy

Most countries provide national grid codes which regulate generating and consuming plants. Table 11 shows the EVSE-relevant grid codes of selected European countries.
In Austria, the “Technische und Organisatorische Regeln für Betreiber und Benutzer von Netzen (TOR)” describe a set of grid codes which are relevant for EV charging and V2G discharging. Table 12 summarizes and describes the grid code set.

Table 12: Austrian Grid Codes relevant for EVSE

Specification	Description
TOR Teil D, Hauptabschnitt D1	Netzrückwirkungsrelevante elektrische Betriebsmittel; Schwellwerte für die notwendige Beurteilung durch den Netzbetreiber und Festlegungen zur elektromagnetischen Verträglichkeit
TOR Teil D, Hauptabschnitt D2	Richtlinie zur Beurteilung von Netzrückwirkungen
TOR Erzeuger Typ A ***required for V2G applications***	Anschluss und Parallelbetrieb von Stromerzeugungsanlagen des Typs A und von Kleinsterzeugungsanlagen (Maximalkapazität < 250 kW und Nennspannung < 110kV)

Regarding **electromagnetic compatibility** (EMC), additional regulations apply:

- Germany:
  - VDE AR N 4100 (flicker, rapid voltage changes, harmonics and interharmonics)
  - VDE 0124-100 5.2 (test procedure)
- Austria
  - TOR Teil D, Hauptabschnitt D2
- General EMC requirements (radiated HF etc.) are covered by Electromagnetic Compatibility Directive (EMC) 2014/30/EU: Article 14 and Annexes II and III
- Radio Equipment Directive (RED) 2014/53/EU: Article 17 and Annexes II and III
- IEC 61851-21-1: Electric vehicle on-board charger EMC requirements for conductive connection to an AC/DC supply
- Note:
  - Conformance of EMC is tested either internally or by an external accredited lab

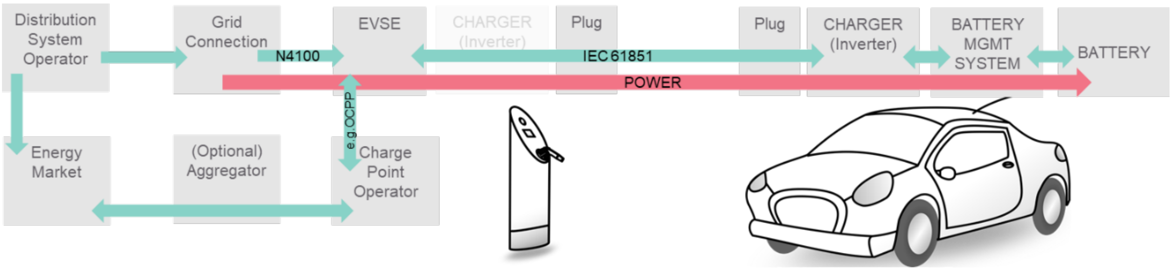

Figure 25: Onboard AC Charging

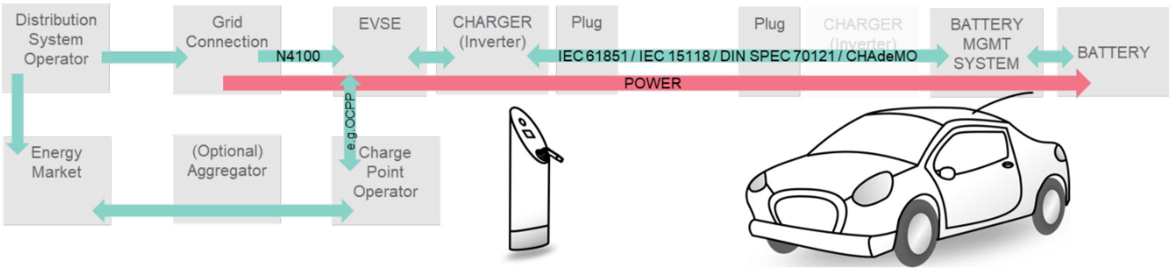

Figure 26: Offboard DC Charging

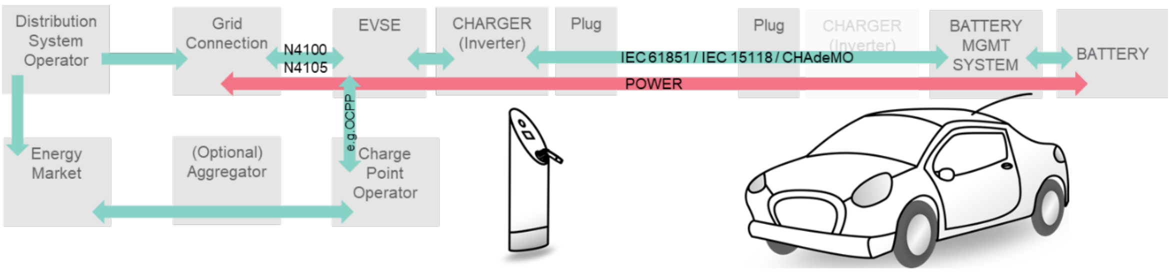

Figure 27: Offboard bidirectional V2G

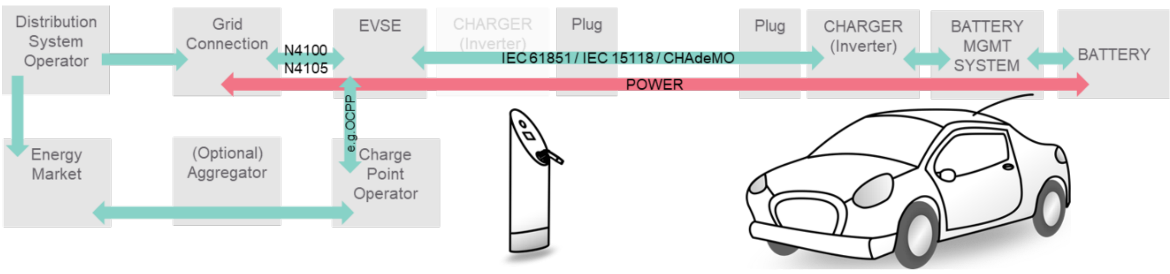

Figure 28: Onboard bidirectional V2G

2.5.5 Regulation on battery charger topologies

Many DC EVSEs (IEC 61851-1 mode 4) do not implement the full digital communication stack according to ISO 15118-2. Instead, they use a simplified communication stack defined in DIN SPEC 70121 which has been on the market for a longer time. This simplified EV-EVSE communication does not include a plug-and-charge functionality (which means there is no need for manual payment) and lacks a secure encrypted communication. A DC charging process can only be started if both the EV and the EVSE support the same communication protocol, so ISO 15118-2 is not backwards compatible to DIN SPEC 70121.

There are several technical use cases of EV charging: In a conventional charging process, a unidirectional battery charger rectifies the AC grid voltage and applies the appropriate DC voltage to the EV battery. The location of the utilized charger usually depends on the required charging power. EVs provide an on-board charger for “AC charging”, i.e. low-power charging with charging powers of up to 22 kW (depending on the EV model). This correlates to IEC 61851-1 modes 1, 2 and 3. Higher charging powers require larger and heavier power electronics for the voltage conversion, which is the reason why DC-EVSEs with integrated battery chargers are used (IEC 61851-1 mode 4). The rectifying process takes place in the EVSE and requires constant digital communication with the battery management system of the EV. For the CCS system this is accomplished by modulating a high-frequency Powerline communication on the pilot line (CP-line) of the charging cable. In contrast, the CHAdeMO system uses CAN communication for the transfer.

V2G charging use cases require a bidirectional charger located either within the EVSE or the EV. ISO 15118-20 (no final release yet) specifies these use cases and defines the respective communication between the EVSE and the EV for the CCS charging system. Since the currently effective ISO 15118-2 standard is not fully applicable for V2G use-cases it is going to be replaced by ISO 15118-20. This means that V2G charging is currently not yet standardized for CCS.

The CHAdeMO charging system is an alternative which is also present on the European market. It requires a different plug/socket and a different digital communication than the CCS system. However, it already provides a fully capable V2G functionality. Vehicles such as the Nissan Leaf already support V2G via CHAdeMO.

Figure 25, Figure 26, Figure 27 and Figure 28 summarize these points and depict the interrelations with other actors and standards. The figures show that the EVSE can communicate with the charge point operator, e.g. via the Open Charge Point Protocol (OCPP). This is necessary for public EVSEs to implement remote maintenance and set charging profiles which can be prescribed by the DSO or other regulators.

2.5.5.1 Isolated vs. non-isolated EVSE

ISO 17409:2020 [47] defines safety requirements for the connection of voltage class B electric vehicles to an external electric power supply. Inter alia, the standard defines how the EV chassis must be connected to the protective conductor of an isolated DC EVSE. However, requirements for the connection to non-isolated EVSEs (i.e. EVSEs with d.c. circuit on output side which is not electrically separated by at least basic insulation from the supply system) are not provided.

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[47] ISO 17409:2020 – https://www.iso.org/standard/72880.html

The informal Annex DD of IEC 61851-23:2014 defines examples for typical DC charging systems. Figure 29, Figure 30 and Figure 31 depict these systems. Although annex DD is informal it requires that a non-isolated system always provides a protective earth (PE) connection.

IEC 61851-23:2014 chapter 6.4.3.2 requires continuity checking of the protective conductor for both isolated and non-isolated systems. Non-isolated EVSEs *shall* be disconnected from the AC supply network after the loss of earthing conductor continuity (while isolated systems *can* be disconnected). Isolated chargers must perform an emergency shutdown within 10 s after a loss of electrical continuity of the protective conductor between d.c. EV charging station and EV. For non-isolated systems, the shutdown must be performed within 5 s.

Chapter 7.5.102 of IEC 61851-23:2014 mentions that protective measures for non-isolated DC EVSEs are under consideration. The committee draft for vote (CDV) version of the standard with a circulation date of Feb 7th, 2020 also mentions that the specific protection requirements for non-isolated systems are still under consideration (Chapter 8.101.1).

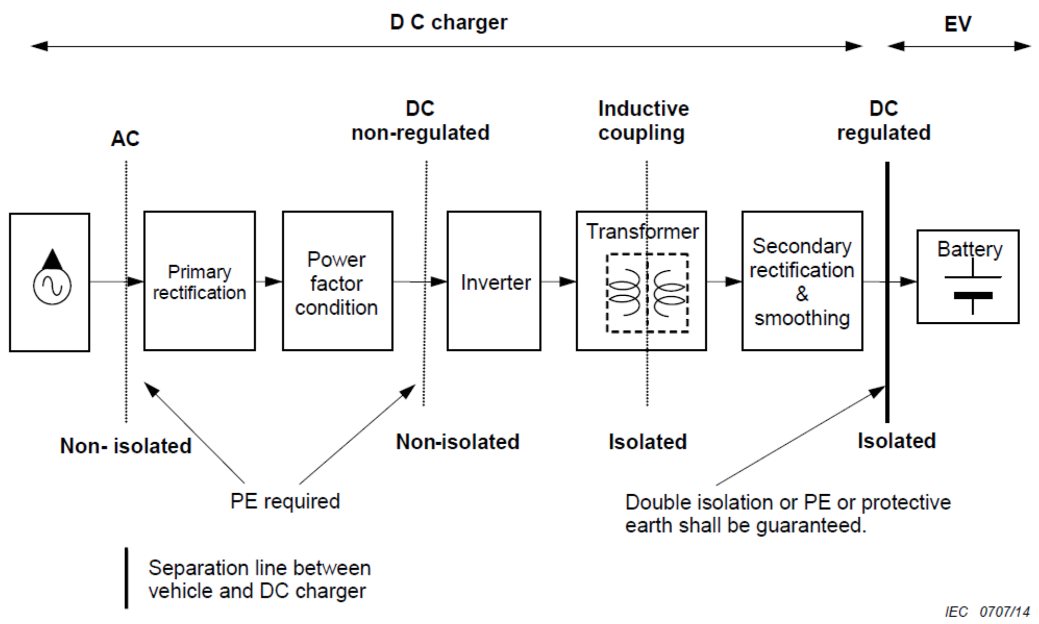

Figure D.1 – Example of typical isolated system

Figure 29: IEC 61851-23 Annex DD: Example of a typical isolated system

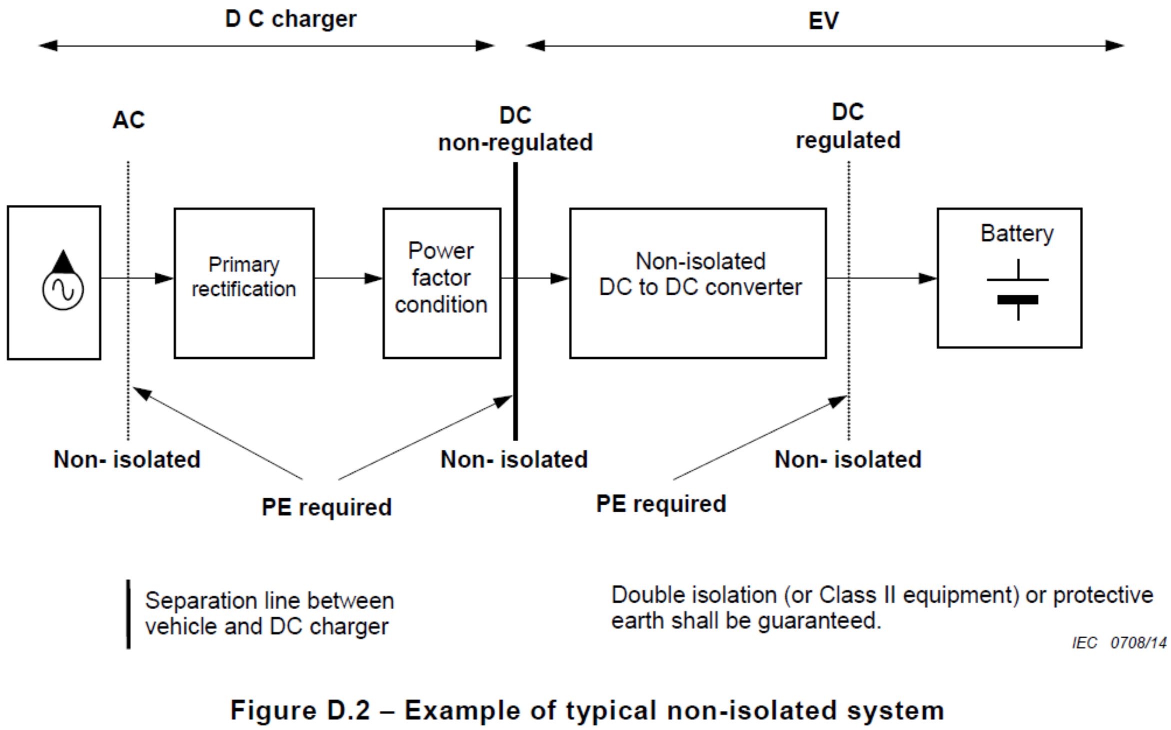

Figure 30: IEC 61851-23 Annex DD: Example of a typical non-isolated system

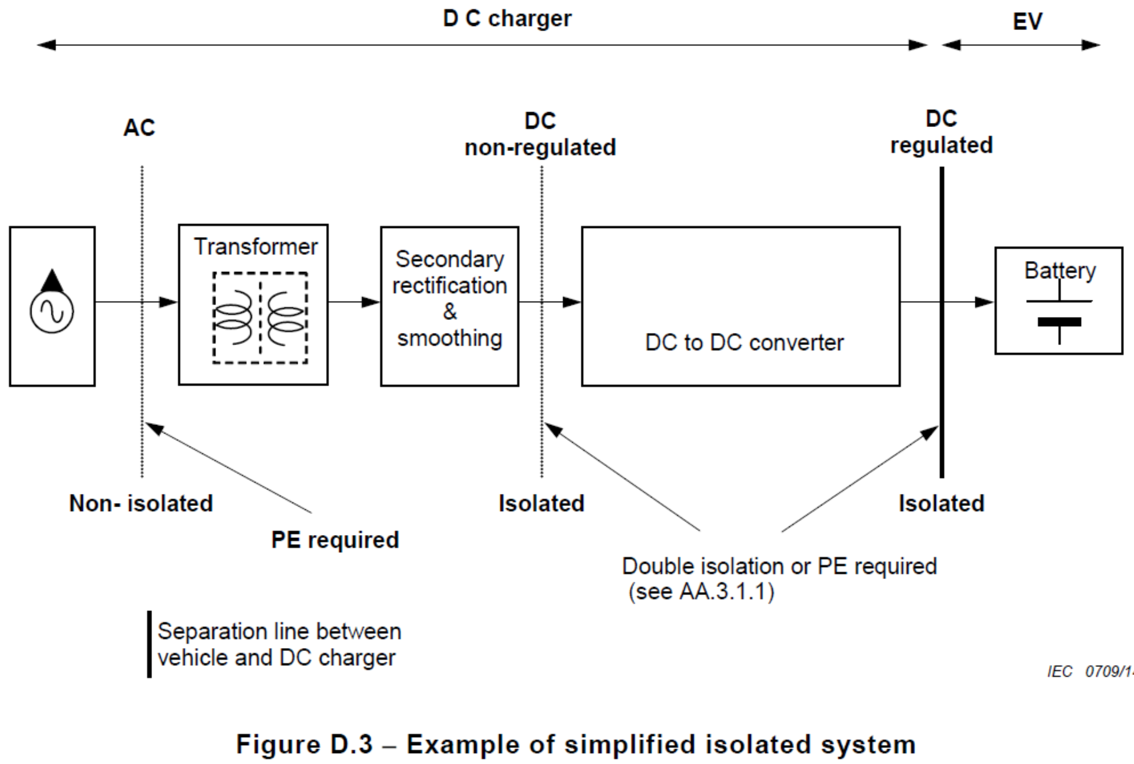

Figure 31: IEC 61851-23 Annex DD: Example of a simplified isolated system

AA.3 Specific safety requirements

AA.3.1 Fault protection in the secondary circuit

AA.3.1.1 General

For fault protection in the secondary circuit, system A station shall have the following measures:

a) reinforced isolating transformer;

b) earth leakage current measurement using a grounding resistor between the d.c. power lines DC+/DC- and earth (enclosure and chassis);

c) automatic disconnection of supply to d.c. power circuit at the first d.c. earth fault;

d) charging cable consisting of line conductors that are individually insulated.

When PE forms part of a charging cable, the cross-sectional area of PE shall be determined by the formula in 543.1.2 of IEC 60364-5-54:2011.

Figure 32: IEC 61851-23 Annex AA - Requirement for reinforced isolating transformer

2.5.6 Regulation concerning electricity market participation

2.5.6.1 Overview of electricity markets

Energy as a commodity can be traded in different timeframes either bilaterally (over the counter, OTC) or on power exchanges. Power exchanges for energy trade for delivery in Austria are the Austrian EXAA in Vienna, Nord Pool in Oslo, the German EEX in Leipzig and, as part of the EEX Group, EPEX Spot in Paris. Depending on the timeframes, different markets are available for trade.
The derivatives market is used to hedge against price volatility, whereas long-term contracts are concluded as futures (products on power exchanges), forwards (OTC products) or other products, such as options.
On spot markets (day-ahead and intraday market), energy is traded for shorter-term delivery. On the day-ahead market, electricity can be traded until one day before delivery. Additionally, on the intraday market, electricity can also be traded for delivery on the same day.
To guarantee power system stability, i.e., in order to keep the frequency of the electricity grid at 50 Hz, balancing capacity as increased or decreased generation or load is traded on the balancing market.
The following Figure 34 gives an overview over the time frame of the energy markets in Austria.

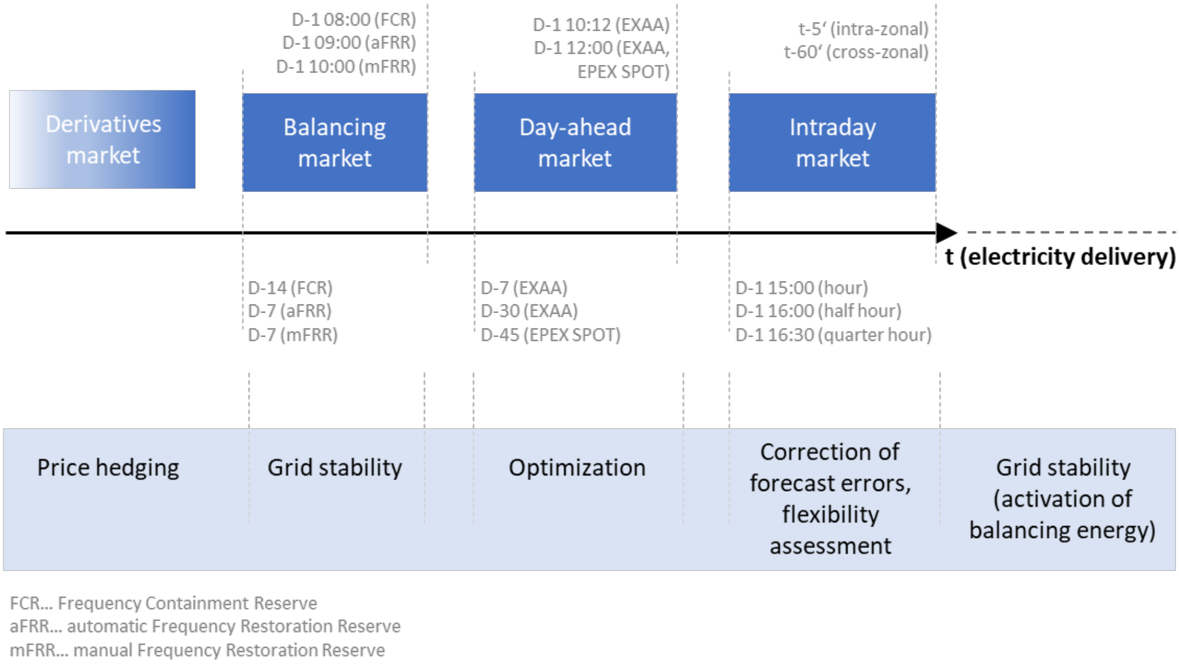

Figure 33: Timeline of electricity markets in Austria [48]

In Austria, for each balance group, the balance responsible party (BRP) must submit the schedule of the balance group's generation and load at 2:30 pm one day prior to delivery. As can be seen in Figure 34, the day-ahead market is used to optimize the portfolio, once more accurate information concerning generation (and/or load) is available. The intraday market is then used to correct the portfolio due to more accurate forecast information.

Due to the project's focus on flexibility from eCars, marketing on the derivatives market is considered out of scope. Therefore, in the following, the spot markets (day-ahead and intraday) and the balancing market is further discussed.

2.5.6.2 Electricity markets relevant for EV use cases

For electric vehicle charging (flexible or bidirectional), depending on the use case, the following electricity markets are of relevance:

Day-ahead market

On the day-ahead market, hourly and quarter-hourly products (and block products) can be traded in an auction-based manner. Bids on the supply side are ranked by their marginal price and the market clearing price (MCP), applicable to all bids, is then determined by the demand curve. The following Table 13 shows available products, allowed price spreads and the minimum volume for this market, whereas distinctions are made for the available power exchanges EXAA and EPEX SPOT.

Table 13: Parameters of the day-ahead market in Austria [49] [50]

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[48] S. Knötters et al., *D3.3: Definition of the optimization objective*, EDCSproof, 2020

[49] EPEX SPOT: Trading Brochure. Available at: https://www.epexspot.com/en/downloads#trading-products (last accessed on 28.06.2021)

[50] EXAA: Rules for the Trading of Spot Market Products for Electric Power on the Vienna Stock Exchange in its Function as a General Commodity Exchange –Trading Rules Spot Market Products Electric Power. Available at: https://www.exaa.at/site/assets/files/1/3_04_trading_rules_spot_market_products_electric_power.pdf (last accessed on 28.06.2021)

* Austria is already coupled in the European day-ahead market coupling project (single day-ahead coupling SDAC). The go-live of the merge of the two market coupling regions “multi-regional coupling (MRC)” and “4M market coupling (4M MC)” was June 2021[51]. The foreseen go-live of quarter hour products in the SDAC is 2024. SDAC shall also allow cross-product matching (e.g. four 15-minute products for one-hour product).

Parameter	Value
Available products	Hour (EXAA and EPEX SPOT) Quarter hour (EXAA)* Price spreads (EXAA) Block products (EXAA) Customized blocks (EPEX SPOT)
Gate opening time (GOT)	D-7 (EXAA 10:15 auction) D-30 (EXAA 12:00 market coupling auction) D-45 (EPEX SPOT)
Gate closure time (GCT)	10:12 D-1 (EXAA 10:15 auction) 12:00 D-1 (EXAA 12:00 market coupling auction) 12:00 D-1 (EPEX SPOT)
Floor price	-150 €/MWh (EXAA), -500 €/MWh (EPEX SPOT)
Cap price	3000 €/MWh (EXAA, EPEX SPOT)
Minimum tradable volume	0.1 MW

Intraday market

On the intraday market, short-term transactions can be carried out close to real-time delivery. This market is used to react to forecasting errors, power plant outages and other unforeseeable deviations from the load and generation schedule. Quarter-hourly, hourly and block products can be traded on EPEX SPOT. Until recently, this market was a continuous market only, where a trade was executed when a buy and sell order matched. However, EPEX SPOT introduced a quarter-hour auction for Austria, Belgium, France and the Netherlands in October 2020 [52]. Table 14 shows available products, allowed price spreads and the minimum volume for the intraday market.

[51] SDAC: Press release: Successful go-live of Interim Coupling, June 2021. https://eepublicdownloads.azureedge.net/clean-documents/Network%20codes%20documents/NC%20CACM/210617_Press_release_successful_go-live_ICP.pdf

[52] EPEX SPOT: EPEX SPOT and ECC successfully launch Intraday auctions in Austria, Belgium, France and the Netherlands. Available at: https://www.epexspot.com/en/news/epex-spot-and-ecc-successfully-launch-intraday-auctions-austria-belgium-france-and-netherlands (last accessed on 28.06.2021)

Table 14: Parameters of the intraday market in Austria [53]

* Austria is already coupled in the European market coupling project SIDC (single intraday coupling), formerly XBID. Until 2023, three intraday auctions shall be enabled in SIDC, also allowing cross-product matching (e.g., four 15-minute products for one-hour product).

Parameter	Value
Available products	Hour (EPEX SPOT continuous) Quarter hour (EPEX SPOT continuous and auction) Block/customized products (EPEX SPOT)*
Gate opening time (GOT)	15:00 D-1 (EPEX SPOT continuous)
Gate closure time (GCT)	15:00 D-1 (EPEX SPOT auction) t-5‘ (intra-zonal) t-60‘ (cross-zonal)
Floor price	-9999 €/MWh
Cap price	9999 €/MWh
Minimum tradable volume	0.1 MW

Balancing market

To guarantee stability of the Austrian (and European) electricity grid, the Austrian control area manager (CAM) and transmission system operator APG (Austrian Power Grid) procures three balancing products. The frequency containment reserve (FCR), the automated frequency restoration reserve (aFRR) and the manual frequency restoration reserve (mFRR) with different activation times are acquired in an auction-based manner. In contrast to the energy-only day-ahead and intraday markets, in the balancing market, bids were offered as both a capacity bid (MW) with a capacity price (€/MW) and with an energy price (€/MWh). This was and is not applicable for the FCR product, where only a capacity bid is offered.
The go-live of the balancing energy market (with explicit energy bids) was scheduled for November 2020 (German: *Regelarbeitsmarkt RAM*). Since then, aFRR and mFRR products are first procured through a capacity auction (merit-order based). The accepted bids must then also bid into the energy market (but can adapt price information) which is scheduled on the delivery day. Furthermore, separate bids that have not offered into the capacity market can still take part in the energy auction, which also functions merit-order based in a pay-as-bid regime. Table 15 summarizes available products, price structure, allowed price spreads and the minimum volumes for the balancing market, whereas the former regime and the current regime (not yet fully implemented European projects “MARI” and “PICASSO”*) are depicted.

[53] EPEX SPOT: Trading Brochure. Available at: https://www.epexspot.com/en/downloads#trading-products (last accessed on 28.06.2021)

Table 15: Parameters of the balancing market in Austria [54] [55]

Parameter	Value old	Value current ("MARI" and "PICASSO" not fully implemented*)
Available products*	FCR (six 4-hour products) aFRR (six 4-hour products, positive and negative) mFRR (six 4-hour products, positive and negative)	-"-
Gate opening time (GOT)	FCR: D-14 11:00 aFRR: D-7 10:00 mFRR: D-7 10:00	FCR: D-14 11:00 (capacity) aFRR: D-7 10:00 (capacity) mFRR: D-7 10:00 (capacity) t-60' (energy)
Gate closure time (GCT)	FCR: D-1 8:00 aFRR: D-1 09:00 mFRR: D-1 10:00	FCR: D-1 8:00 (capacity) aFRR: D-1 09:00 (capacity) mFRR: D-1 10:00 (capacity t-60' (energy)[56]
Price structure	FCR: capacity price aFRR, mFRR: capacity and energy price	FCR: capacity price aFRR, mFRR: capacity price in capacity auction, energy price in energy auction
Floor price	/	A floor and cap price for the energy bids were introduced in Germany (9999,99 €/MWh)[57].
Cap price	/	
Minimum tradable volume	1 MW	1 MW (capacity and energy)[58]
Full activation time frame	FCR: 30sec [59] aFRR: 5min [60] mFRR: 10min [61] (sometimes stated as 12.5min[62] due to 2.5min preparation time)	-"-

* The European projects for the joint procurement of balancing capacity, "PICASSO" and "MARI", shall be implemented end of 2021/beginning of 2022 and shall enable 15-minute tradable products[63].

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54 APG: Modalitäten für Regelreserveanbieter in Österreich, Version 1.0. Available at: https://www.e-control.at/documents/1785851/0/TC_EBGL_V1_2018.10.01_clean.pdf/34fd929d-d3d9-5506-3a05-75f079ca666a?t=1595331730917 (last accessed on 28.06.2021)

55 APG: Modalitäten für Regelreserveanbieter in Österreich, Version 1.2. Available at: https://www.e-control.at/documents/1785851/0/Anlage_1_TC_EBGL_V1.2_2020.03.12.pdf/3e75b3a2-32b4-a422-0406-ba098e03005f?t=1595332109823 (last accessed on 28.06.2021)

56 APG: Europ. aFRR Plattform (PICASSO), 20.10.2020

57 Energate Messenger: Regelarbeitsmarkt bekommt Preisobergrenze, December 2020. https://www.energate-messenger.de/news/208147/regelarbeitsmarkt-bekommt-preisobergrenze

58 APG: Weiterentwicklungen Regelreserven Teil 2: Roadmap to European Integration, 24.06.2020

59 A1 Energy Solutions, 2021. https://www.a1energysolutions.at/regelenergie-pool/

60 APG: Netzregelung, 2021. https://www.apg.at/de/markt/netzregelung

61 APG: Modalitäten für Regelreserveanbieter in Österreich, Version 1.2. https://www.e-control.at/documents/1785851/0/Anlage_1_TC_EBGL_V1.2_2020.03.12.pdf/3e75b3a2-32b4-a422-0406-ba098e03005f?t=1595332109823

62 APG: Weiterentwicklungen Regelreserven Teil 2: Roadmap to European Integration, 24.06.2020

63 APG: So helfen PICASSO und MARI Stromkosten zu senken und Erneuerbare zu integrieren, December 2020. https://www.apg.at/de/markt/2020/12/04/PICASSO-und-MARI-Stromkosten-zu-senken-und-Erneuerbare-zu-integrieren

2.5.7 Use Cases and their market objectives

Use Case 1 – Sharing

The objective of a car sharing company or housing association is to increase PV self-consumption and to reduce electricity costs by using charging flexibility. This reduction of costs can then be (partially) forwarded to the users if restrictions for the users are to be expected. The provider of the EVs has a contract with (or is) a charging point operator (CPO) who provides the charging infrastructure. Furthermore, the DSO has to be informed before EVSE installation to check physical grid capacities. As soon as the appropriate infrastructure is established, market participation is theoretically possible. However, even though the sharing company or housing association will usually provide various electric vehicles, it is unlikely that the required volumes of power can be supplied for the different markets. Therefore, the commercial provider and the housing association need a contract with an energy supply company (ESCo)/aggregator. It is possible that the sharing company itself or the cooperating CPO is already an ESCo or an aggregator themselves.

Use Case 2 – Fleet

As in Use Case 1, the provider and the owner of the EVs is the same entity. Here, a small or medium enterprise (SME) has the objective to reduce fleet costs by offering flexibility to the market. Additionally, available PV generation can be used to increase self-consumption. The cost savings generated by PV self-consumption and EV flexibility are direct profits for the SME and do not have to be passed on to the vehicle users. Again, a contract with a charging point operator for the provision of charging infrastructure and a contract with an ESCo/aggregator is needed for market participation. As before, it is possible that the CPO is already an ESCo or aggregator themselves.

Use Case 3 – Private/Individual

Depending on the charging location for private EVs, different objectives can be reached. On the one hand, PV self-consumption either profits the individual person owning a system at home or the employer that has a PV system on the company's roof (the employer could forward some of the savings to the employee). On the other hand, cost reductions through the offering of flexibility to the market are vital for both charging at home or at work. In case of charging at home, the user has to install a wallbox (usually 11 kW) that offers the possibility of smart charging. In this case, the individual themselves functions as the charging point operator. The installation of the wallbox has to be communicated to the respective DSO because of the physical grid capacity. There are wallbox solutions for companies too, in which case the employer is likely to want to minimize the effort managing the wallbox. At the same time, the company needs to know about charging data of every vehicle, it needs to get information about faults and there has to be a billing system[64]. The wallbox is the essential tool for providing flexibilities, it collects data on the charging behavior and can instruct the car on when to charge/discharge. However, market participation for the electric vehicle of an individual person is not possible, therefore a contract with an ESCo/aggregator has to be signed to enable the sale of flexibility.

The following Table 16 shows the steps to be taken and the responsible parties from EVSE installation to market participation for the three use cases.

[64] Wallbox installieren fürs E-Auto: Zuhause schnell laden (energieag.at) (last accessed on 27.10.2021)

Table 16: Responsible parties for each Use Case and step to market participation.

	Sharing	Fleet	Private/Individual
Installation EVSE	CPO	CPO	Individual
Grid Connection through DSO	Sharing Company / CPO	SME / CPO	Individual
Back-end	CPO / Aggregator	CPO / Aggregator	Aggregator
Market Participation	Aggregator*	Aggregator*	Aggregator*

*** note that CPO can function as an aggregator themselves.**

The charging point operator is responsible for installation and maintenance of the EVSEs. In Use Case 3, the individual is automatically the CPO of their wallbox. Before installing the charging infrastructure, permission has to be granted by the DSO to guarantee the corresponding grid capacity. Using smart charging points, the DSO will be updated regularly on the power consumption. The back-end system will be operated either by the CPO or the aggregator. This includes the communication with the EVSE to start/stop charging and discharging processes to enable market participation.

Market Participation

Regardless of the specific use case, the possibility of market participation must be established. As depicted in the previous Chapter 2.5.6.1, the current minimum trading volume is 0.1 MW for spot markets and 1 MW for balancing markets. Not every single individual or small fleet will be able to provide these capacities and therefore will not be able to participate in trading on their own. That is why electric vehicles will have to be pooled to be able to take an active part in providing flexibility on spot- and balancing energy markets. Due to the pooling concept, vehicle owners of the three use cases will most likely participate in different markets through an aggregator. On the one hand, an aggregator will take on the administrative effort of establishing the possibility for market participation on behalf of their clients and on the other hand will aggregate the flexibilities of all clients to be able to provide the required volumes for various markets.

Spot markets: Representative for all spot market participation processes, the following paragraph will concern the admission procedure for the EXAA [65, 66] day-ahead market. Before being able to participate in buying and bidding on EXAA's market, various steps must be undertaken to be permitted to the auctions. First, "only members of the commodity exchange whose companies are engaged in business activities related to the trading products are permitted to trade in the sport market for electric power products". They are also allowed to participate in the clearing and settlement of exchange transactions concluded at the spot market for electric power products. That means one has to be a member of the WBAG, the Wiener Börse AG. Furthermore, a settlement agreement with the EXAA has to be concluded which includes regulations regarding the following:

[65] https://www.exaa.at/site/assets/files/1/3_03_participation_rules_electric_power.pdf (last accessed on 27.10.2021)
[66] https://www.exaa.at/site/assets/files/1/3_06_clearing_and_settlement_rules_electric_power.pdf (last accessed on 27.10.2021)

- **Securities**: there will be a credit assessment, a collateral account or securities deposit has to be established at the OeKB, the Oesterreichische Kontrollbank and an additional cash collateral account may be set up at any Austrian Bank. These last two are deemed deposited as soon as a corresponding pledge declaration for cash and/or securities is forwarded to the Clearing and Settlement Agent.
- **Balance Group**: either one has to form a balance group or join an existing balance group. In the second case, there has to be an agreement between the balance group representative and the stock exchange member.
- **Technical Installations**: "proof of the adequate technical installations for the connection to the trading and settlement system that ensures smooth trading and/or clearing". Additionally, the settlement has to be documented electronically.
- **Transmission of Data**: the exchange member shall agree to the transmission of data by the clearing and settlement agent or by OeKB to the exchange operating company for purposes such as confirming or rejecting reported suspicious facts, pointing to grounds for expulsion or suspension and therefore releasing the OeKB from the bond to maintain banking secrecy and data secrecy.

Furthermore, the following documents need to be submitted:

- the register of commerce,
- the annual financial statements of the last two years,
- all official authorizations, permits and licenses,
- proof of membership in a balance group and proof of their authorization to exercise the function as a balance group issued by E-Control,
- proof of the balance group contract.

Balancing Market [67, 68]: Austria's control area manager (CAM) and transmission system operator (TSO) is the Austrian Power Grid AG (APG). They are responsible of keeping energy production and consumption in balance in order to keep the electricity grid's frequency at 50 Hz. To compensate for unexpected imbalance a balancing energy market is needed. As seen in Chapter 2.5.6.1, there are three different forms of balancing energy: the frequency containment reserve (FCR), the automatic frequency restoration reserve (aFRR) and the manual frequency restoration reserve (mFRR). To be accredited as a supplier of balancing energy, one has to specify the type of balancing energy product one wants to provide and then pass the respective technical prequalification (note that the prequalification procedure must be carried out separately for each type of balancing energy, it is also possible to supply just one or two balancing energy products). The framework conditions are based on the Operation Handbook of ENTSO-E, Policy 1[69] and are defined in detail in the prequalification guidelines by APG (there are separate guidelines for FCR[70], aFRR[71], mFRR[72]). Once the prequalification is achieved, it is valid for three years and must then be renewed. Therefore, the requirements have to be reconfirmed, then the prequalification will be extended for another three years. In case of significant changes to the plants of a supplier, a new prequalification will be required for the concerned plants. After passing the technical prequalification, a framework

67 https://www.apg.at/en/markt/netzregelung/teilnahmebedingungen (last accessed on 27.10.2021)

68 https://www.apg.at/de/markt/netzregelung/sekundaerregelung/ausschreibungen, Download: Ausschreibungsdetails Modalitäten Regelreserve, Technische Präqualifikation, Verkürztes Verfahren SRR (last accessed on 27.10.2021)

69 https://eepublicdownloads.entsoe.eu/clean-documents/pre2015/publications/entsoe/Operation_Handbook/Policy_1_final.pdf (last accessed on 27.10.2021)

70 https://www.apg.at/de/markt/netzregelung/primaerregelung/ausschreibungen (last accessed on 27.10.2021)

71 https://www.apg.at/de/markt/netzregelung/sekundaerregelung/ausschreibungen (last accessed on 27.10.2021)

72 https://www.apg.at/de/markt/netzregelung/tertiaerregelung/ausschreibungen (last accessed on 27.10.2021)

agreement has to be concluded to be accredited as a supplier for the balancing market. This framework agreement however does not oblige the supplier to FCR, aFRR or mFRR (a separate framework agreement has to be signed for each type of balancing energy). They simply gain the possibility to participate in all tenders for balancing energy for the APG control area.

In case of an aggregator, balancing energy would be provided in terms of a reserve pool of technical units, in the present case this would be electric vehicles. The technical units (the electric vehicles) are first aggregated according to their grid access point, these reserve units are in a next step combined to reserve groups and various reserve groups are then combined to a reserve pool. In case a technical unit is prequalified, a shortened prequalification procedure can be pursued as soon as the same or similar technical unit is supposed to be prequalified as addition to the pool.

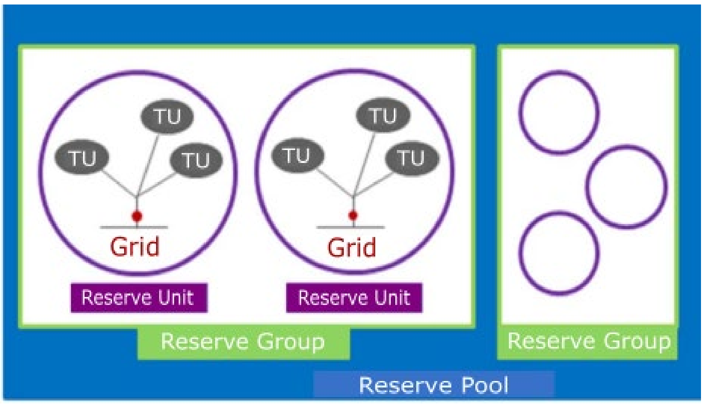

Figure 34: Scheme for structure of a reserve pool[73].

For the technical prequalification, an operating point has to be defined. The operating point defines the power target value, i.e., the power consumed in case no balancing energy is provided. No matter the type of balancing energy that is supposed to be provided, the operating point has to be smaller than the maximum effective power, otherwise no balancing energy can be supplied. The operating point can be defined either for each technical unit, reserve unit, reserve group or the whole reserve pool. Since the operating point defines the planned power consumption, it is easy to recognize and verify the supply of balancing energy, namely the deviation of consumption from schedule[74]. As for electric vehicles, there is no standardized procedure to define an operating point, that's why this issue is the most complex one for passing prequalification with a pool of EVs. So far, in Austria, there are no cases of reserve pools for electric vehicles yet. However, for example in Germany, there are first applications of reserve pools of electric vehicles established to provide balancing services[75, 76, 77]. There have been first field tests with up to 100 electric vehicles that revealed regulatory and technical challenges in balancing market participation. Even though there are no applications in Austria yet, the APG is open to adapt prequalification processes for unconventional forms of control energy provision. So far, there is an adjustment for technical units with limited storage capacity, such as large batteries[78].

Costs: Since there are no aggregators for electric vehicles in Austria yet, there is no data about costs for appointing an aggregator for eCars. Since clients will need an incentive to provide their EVs for spot- or

[73] https://www.apg.at/de/markt/netzregelung/sekundaerregelung/ausschreibungen, Download: Erläuterungen Präqualifikation (last accessed on 27.10.2021)
[74] https://www.apg.at/de/markt/netzregelung/sekundaerregelung/ausschreibungen, Download: Erläuterungen Präqualifikation (last accessed on 27.10.2021)
[75] Erstes Elektroauto nimmt am deutschen Markt für Primärregelenergie teil – pv magazine Deutschland (pv-magazine.de) (last accessed on 27.10.2021)
[76] Der (elektrische) Motor läuft – Wie E-Autos das Netz stabilisieren (next-kraftwerke.de) (last accessed on 27.10.2021)
[77] Feldversuch: Elektroautos als virtuelles Kraftwerk | EUWID Neue Energie Nachrichten (euwid-energie.de) (last accessed on 27.10.2021)
[78] https://www.apg.at/de/markt/netzregelung/sekundaerregelung/ausschreibungen, Download: Erläuterungen Präqualifikation (last accessed on 27.10.2021)

balancing markets, a possibility is that there are low or no investment costs for the aggregator themselves but rather that the aggregator will benefit to some percentage from the resulting profits.
As for market participation, there are various costs that need to be paid. In the following Table 17, there is an overview of the costs for the Austrian's EXAA day-ahead market, EPEX Spot day-ahead and intraday market as well as the balancing market managed by APG. For the EXAA and EPEX Spot markets, there are entrance, membership as well as transaction fees. As apparent from the table, there are no such costs for participating in balancing markets. Still, you have to pass the APG's prequalification process in order to participate. As for this process, there are no specific fees that have to be paid. The client is solely responsible for all expenses incurred in technical adaptions that have to be made to participate in balancing markets[79]. Another fact that can be highlighted is that in order to make green power more attractive, there are no entrance or membership fees at the EXAA in case only green power is traded on the day-ahead market (as a combined product of power and its renewable Guarantee of Origin).

Table 17: Market participation and trading costs for spot markets and balancing market

Costs	Day-Ahead Market[1] EXAA[80] (2021)	Day-Ahead & Intraday Market[1] EPEX Spot[81] (2020)	Balancing Market[1] PCR/aFRR/mFRR APG[82] (2021)
Participation:			
Entrance	10.000 EUR / 0 EUR[2]	25.000 EUR	–
Yearly Membership	10.000 EUR / 0 EUR[2]	10.000 EUR (DA & ID) 5.000 EUR (ID only)	–
Trading Fees	10:15 0.075 €/MWh 12:00 0.035 €/MWh	DA: 0.04 €/MWh ID: 0.09 €/MWh	–
Trading Volume min	0.1 MW	0.1 MW	1MW / 1MW / 1MW
Trading Volume max	–	–	25MW / – / 25MW[3]
Trading increment	0.1 MW	0.1 MW	1MW / 1MW / 1MW

[1] Grid tariffs and levies/taxes are to be paid for consumption and supply of electricity from/to the electricity grid. These vary depending on whether the electricity is purchased or supplied (see ElWOG 2010 and Grid Tariff Ordinance, Ger. Systemnutzungsentgelte-Verordnung SNE-VO 2018). For electricity consumption due to the provision of balancing energy (i.e. negative balancing energy), the grid use tariff as part of the entire grid tariff is reduced in accordance with SNE-VO 2018.
[2] In case only green power is traded, there are no entrance or yearly membership fees.
[3] Must not exceed prequalified amount.

[79] https://www.apg.at/de/markt/netzregelung/sekundaerregelung/ausschreibungen, Download: Modalitäten Regelreserve (TC_EBGL_V1.3_clean, last accessed on 27.10.2021)
[80] https://www.exaa.at/energiehandel/mitglied-werden/ (Handelsbedingungen Kassaprodukte Elektrische Energie & Gebührenordnung der Wiener Börse AG, 30.09.2021)
[81] https://www.epexspot.com/en/downloads (Trading Brochure 30.09.2021)
[82] https://www.apg.at/de/markt/netzregelung/primaerregelung/ausschreibungen (last accessed on 27.10.2021)
https://www.apg.at/de/markt/netzregelung/sekundaerregelung/ausschreibungen (last accessed on 27.10.2021)
https://www.apg.at/de/markt/netzregelung/tertiaerregelung/ausschreibungen (last accessed on 27.10.2021)

2.6 Social risk factors and framework conditions

The Car2Flex project foresees profound end-user integration within both demo sites and general public. As one preparatory step for the coming work packages dealing with end-user integration, a literature research is carried out to set the screen for social science guidance of the project.

The literature research focusses on scientific literature on customer perception and acceptance of V2X applications taking into account the main hurdles and motives amongst users when it comes to bidirectional charging applications. However, also basic information on general acceptance on electric vehicles as well as perception of controlled charging is considered. Especially users' perception of controlled charging shows similarities to the perception of V2X applications and is used by several studies as a starting point for their research on V2X. Further, V2X is a rather new concept, and limited body of research, especially in regard to fleet and car sharing is available.

This gap of research is highlighted when it comes to the connection of consumers' attitudes and social perception and bidirectional charging applications. Different studies find, that customer needs are underrepresented in V2G studies (Küfeoğlu et al. 2019[83], Reynolds et al. 2018[84], Sovacool et al. 2018[85], Andersen et al. 2019[86], Muhssin et al., 2021[87]). Their finding is, that most studies in this field are focusing solely on the technical and/or commercial aspects not taking into account that the consideration and integration of customers' needs are crucial for success of any upcoming business case (Andersen et al. 2019) and that customer acceptance is at same time one of the central challenges for V2G (Sovacool et al 2017[88], Tenton and Moura[89], Noel et al 2019[90], Tan et al. 2016). The results of Sovacool et al. (2018) underline the claim for stronger integration of social sciences, into V2G research: their meta-analysis showed that out of 200 studies dealing with V2G aspects, only 2.1% integrated user behaviour and routines. Information and education for potential end users was only covered by 0.5% of investigated studies.

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[83] Küfeoğlu, S., Melchiorre, D. A., & Kotilainen, K. (2019). Understanding tariff designs and consumer behaviour to employ electric vehicles for secondary purposes in the United Kingdom. The Electricity Journal, 32(6), 1–6.

[84] Reynolds, P., Jones, F., Lock, B., Rajavelu, N., Phillips, J., Redfern, R., Moorman, S., van Beek, T., & de Kerf, D. (2018). V2G Global Roadtrip Around the World in 50 Projects. Everoze, EV Consult, UK Power Networks and Innovate UK. https://innovation.ukpowernetworks.co.uk/wp-content/uploads/2018/12/V2G-Global-Roadtrip-Around-the-World-in-50-Projects.pdf

[85] Sovacool, B. K., Noel, L., Axsen, J., & Kempton, W. (2018). The neglected social dimensions to a vehicle-to-grid (V2G) transition: A critical and systematic review. Environmental Research Letters, 13(1), 013001. https://doi.org/10.1088/1748-9326/aa9c6d

[86] Andersen, P. B., Hashemi Toghroljerdi, S., Sørensen, T. M., Christensen, B. E., Høj, J. C. M. L., & Zecchino, A. (2019). The Parker Project: Final Report. Technical University of Denmark.

[87] Muhssin, M. T., Obaid, Z. A., Al-Anbarri, K., Cipcigan, L. M., & Ajaweed, M. N. (2021). Local dynamic frequency response using domestic electric vehicles. International Journal of Electrical Power & Energy Systems, 130, 106920. https://doi.org/10.1016/j.ijepes.2021.106920

[88] Sovacool, B. K., Axsen, J., & Kempton, W. (2017). Tempering the promise of electric mobility? A sociotechnical review and research agenda for vehicle-grid integration (VGI) and vehicle-to-grid (V2G). Annu. Rev. Environ. Resour, 42, 16–1.

[89] Turton, H., & Moura, F. (2008). Vehicle-to-grid systems for sustainable development: An integrated energy analysis. Technological Forecasting and Social Change, 75(8), 1091–1108. https://doi.org/10.1016/j.techfore.2007.11.013

[90] Noel, L., Zarazua de Rubens, G., Kester, J., & Sovacool, B. K. (2019b). Navigating expert skepticism and consumer distrust: Rethinking the barriers to vehicle-to-grid (V2G) in the Nordic region. Transport Policy, 76, 67–77. https://doi.org/10.1016/j.tranpol.2019.02.002

One reason for this research gap is, that currently the amount of real V2G demonstration sites and projects is limited in the amount of people that have real access to them. This poses an additional challenge to investigating broader public perception, as experience with a certain concept (e.g. electric vehicles itself) leads to changes in attitude towards these concepts (Jensen et al 2013[91], Bühler et al. 2014[92]).

2.6.1 Electric vehicles: user adoption and perception

A comprehensive examination of the key barriers and motivators to EV usage conducted by Biresselioglu et al. (2018) shows that the barriers predominate in relation to the motivators, which is an underlying reason for low adoption. Besides demographic factors, attitude, environmental values, beliefs and norms of an individual also social influences, the general awareness concerning e-mobility and the experience with EVs are crucial for a high acceptance (Biresselioglu et al., 2018). The latter is confirmed by Bühler et al. (2015), who investigated perception of EV before and after a 6-month field trial and found that experiencing driving with an EV significantly changes perception of EV-features. Especially experiential advantages such as low noise emission, fun and pleasant driving were stated more positively after the trial. Low refuelling costs and the possibility to charge at home were also perceived as an advantage after real-life experience. In addition, EV-users changed their view on possible barriers: they experience charging duration and infrastructure and concerns on the battery use as less restricting than before using an EV[93]. In addition, a survey conducted among members of EMC (Elektro-Mobilitäts-Club) Austria shows similar results indicating factors that EV users perceive more factors of using an e-vehicle as advantages rather than barriers (Maier et al., 2021)[94]. 74 EMC members took part in the survey, of whom 64 use an EV regularly. Several factors that are of importance for EV users and decision makers derived from Flämig et al. (2020)[95] were queried in terms of importance and rating (as either barrier or motivator for EV usage). The results are illustrated in an importance-performance matrix, which is divided in four quadrants, which can be used for managerial implications (s. Figure 36). Most of EMC members rate the queried factors as positive or neutral, whereas they perceive a large proportion of the factors as important. The environmental compatibility of EVs is particularly noteworthy as an important motivating factor for users, which supports former findings concerning influencing factors of EV adoption[96]. Other drivers that

[91] Jensen, A. F., Cherchi, E., & Mabit, S. L. (2013). On the stability of preferences and attitudes before and after experiencing an electric vehicle. Transportation Research Part D: Transport and Environment, 25, 24–32. https://doi.org/10.1016/j.trd.2013.07.006

[92] Bühler, F., Cocron, P., Neumann, I., Franke, T., & Krems, J. F. (2014). Is EV experience related to EV acceptance? Results from a German field study. Transportation Research Part F: Traffic Psychology and Behaviour, 25, 34–49. https://doi.org/10.1016/j.trf.2014.05.002

[93] Xu, G., Wang, S., Li, J., & Zhao, D. (2020). Moving towards sustainable purchase behavior: examining the determinants of consumers' intentions to adopt electric vehicles. Environmental Science and Pollution Research, 27(18), 22535-22546. https://doi.org/10.1007/s11356-020-08835-9

[94] Maier, C., Pfeiffer, C., Millendorfer, M. (2021). A User Perspective on current Drivers and Barriers for Electric Vehicle Usage in Austria. Proceedings of the 14th Conference on Sustainable Development of Energy, Water, and Environment Systems, SDEWES2021

[95] Flämig, H., Fieltsch, P., Matt, C., Rosenberger, K., & Steffen, M. (2020). Mobility behavior of companies in urban areas: a triangulation approach to explore the potential for battery electric vehicle. Urban Freight Transportation Systems (pp. 239-251). Elsevier. https://doi.org/10.1016/B978-0-12-817362-6.00013-6

[96] Haustein, S., & Jensen, A. F. (2018). Factors of electric vehicle adoption: A comparison of conventional and electric car users based on an extended theory of planned behavior. International Journal of Sustainable Transportation, 12(7), 484-496

are also considered important are cost effectiveness, usefulness, comfort/convenience and individuality. Factors that are perceived rather as barriers are transport capacity, dependency, flexibility, acquisition costs, range and time consumption, whereas acquisition costs, range and time consumption should be focused. Speed and public perception/image are more likely to be drivers of EV adoption; however, these are not that important for the respondents. Mental and emotional effort associated with EV usage is seen as barrier, but again with a rather low level of importance.

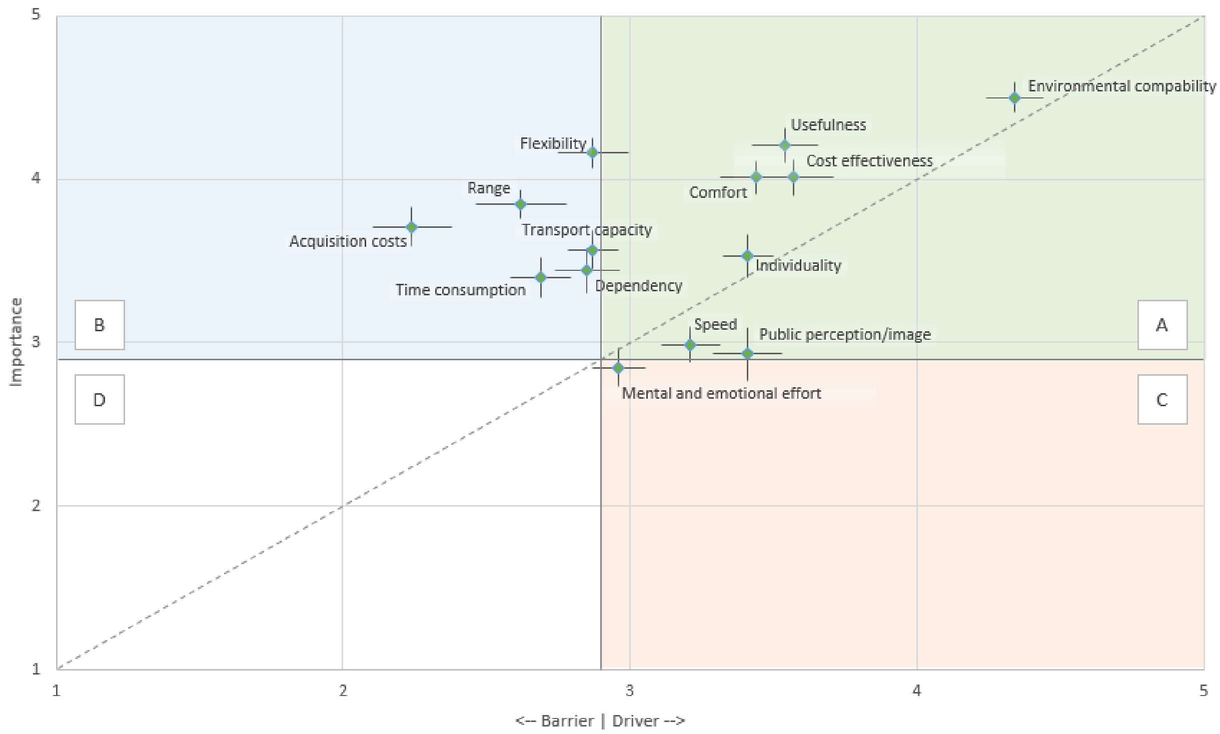

Figure 35: Importance-performance analysis of EV adoption factors

Chen et al. (2020)[97] studied personal characteristics positively affecting EV purchase, one characteristic being socio-demographics. They found that the typical EV buyers are "high earning, middle-aged males with high level of education who are environmentally and more importantly, technologically inclined across a variety of studies" (p.3). Further, EV-adoption shows positive relation with solar panel adoption, energy efficiency installations and high environmental values. More detailed it relates with a diet considering regionality and meat reduction and increased recycling measures. Other studies are highlighting the importance of interpersonal influence and social networks as well as lifestyle identities (such as "being green" or "being an early adopter") and innovativeness (see Chen et al 2020).

[97] Chen, C., Zarazua de Rubens, G., Noel, L., Kester, J., & Sovacool, B. K. (2020). Assessing the socio-demographic, technical, economic and behavioral factors of Nordic electric vehicle adoption and the influence of vehicle-to-grid preferences. Renewable and Sustainable Energy Reviews, 121, 109692. https://doi.org/10.1016/j.rser.2019.109692

2.6.2 Unidirectional controlled charging: user adoption and acceptance

Several studies state, that consumers in general are willing to participate in controlled charging (Krems et al. 2011[98], Schmalfuß et al. 2015[99], Bailey and Axsen 2015).

2.6.2.1 Motives & Concerns

Environmental and **financial benefits** are the main drivers for customers when it comes to smart charging. Which one is at first place differs between different studies (Fisher et al 2015[100], Schmalfuß et al. 2015, Delmonte et al. 2020[101], Huber et al. 2019[102], Will and Schuller 2016[103]). Contribution to grid stability and the social environment seems to play a minor role, but still are of importance. One Barrier are **perceived costs** (such as effort for making settings and plan ahead) which felt not to be compensated, neither financially nor through environmental benefit (Krems et al. 2011). Further, customers perceive a **loss of control** (Bailey and Axsen 2015)[104]. They fear that their car will not be fully charged when needed, or not available for unexpected trips (Delmonte et al. 2020). Privacy issues are also a concern among users (Bailey and Axsen 2015).

2.6.2.2 Controlled Charging: customer perspective on contract terms & incentives

Kinnear et al. (2017)[105] investigated different tariffs in a customer trial. First, they encountered a lack of understanding of controlled charging and time-of-use tariffs. Despite a previous explanation, most respondents could not sufficiently distinguish between the two schemes. For customers, direct load control in return for a lower flat rate was preferred, whereas dynamic pricing (day to day) was least popular for customers. People already allowing remote control of their electric storage heaters were more likely to accept time-of-use tariffs. Still, there should be the possibility to override automation. In the study of Delmonte et al. (2020), customers preferred user managed charging over supplier managed charging.

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[98] Krems, J. F., Bartholdt, L., Cocron, P., Dielmann, B., Franke, T., Henning, M., Ischebeck, M., Schleinitz, K., & Žilytė-Lennertz, M. (2011). Schlusbericht Verbundprojekt: MINI E powered by Vattenfall V2.0. TU Chemnitz. https://www.erneuerbar-mobil.de/sites/default/files/2016-09/Schlussbericht_Vattenfall_MINI_E_2.0.pdf

[99] Schmalfuß, F., Mair, C., Döbelt, S., Kämpfe, B., Wüstemann, R., Krems, J. F., & Keinath, A. (2015). User responses to a smart charging system in Germany: Battery electric vehicle driver motivation, attitudes and acceptance. In Energy Research & Social Science (Bd. 9, S. 60–71). https://doi.org/10.1016/j.erss.2015.08.019

[100] Fisher, J., Gammon, R., & Irvine, K. N. (2015). SDRC 9.6: An assessment of the public acceptance of Demand Side Response of EV charging using Esprit [Report]. My Electric Avenue.

[101] Delmonte, E., Kinnear, N., Jenkins, B., & Skippon, S. (2020). What do consumers think of smart charging? Perceptions among actual and potential plug-in electric vehicle adopters in the United Kingdom. Energy Research & Social Science, 60, 101318. https://doi.org/10.1016/j.erss.2019.101318

[102] Huber, J., Schaule, E., Jung, D., & Weinhardt, C. (2019). Quo vadis smart charging? A literature review and expert survey on technical potentials and user acceptance of smart charging systems. In World Electric Vehicle Journal (Bd. 10, Nummer 4, S. 85).

[103] Will, C., & Schuller, A. (2016). Understanding user acceptance factors of electric vehicle smart charging. Transportation Research Part C: Emerging Technologies, 71, 198–214. https://doi.org/10.1016/j.trc.2016.07.006

[104] Bailey, J., & Axsen, J. (2015). Anticipating PEV buyers' acceptance of utility controlled charging. Transportation Research Part A: Policy and Practice, 82, 29–46. https://doi.org/10.1016/j.tra.2015.09.004

[105] Kinnear, N., Anable, J., Delmonte, E., Tailor, A., & Skippon, S. (2017). Transport Reserach Laboratory.

However, latter one was seen more positively if it leads to an overall positive benefit for society. It remains open, whether travel patterns affect the acceptance of tariffs (Kinnear et al. 2017).

Smart Charging Business Models have to be as easy as possible for customers, as they do not wish to spend additional time and effort when charging their car. The use of smartphone apps for charging is seen differently by customers. Some groups remain sceptical due to e.g., coverage or the need to always carry around the charged smartphone (Kinnear et al. 2017, Delmonte et al. 2020)

Bailey and Axsen (215)[106] conducted a choice experiment on unidirectional controlled charging (UCC) business models, taking into account the factors "percentage of green electricity", "Source of green electricity", "guaranteed minimum charge" and "monthly electricity bill". According to these factors, they defined 4 customer segments for controlled charging:

Table 18: Customer types for UCC (Bailey and Axsen 2015)

Customer Segment	*WTP*	*characterization*
Renewable focused (19% of respondents)	$98 p.a. to increase share of renewables by 10%	want to increase share of renewables higher environmental consciousness lesser concern on privacy issues well-educated
Cost-motivated (27% of respondents)	$49 for 10km increase in min. SOC $6 p.a. to increase share of renewables by 10%	more technologically oriented less altruistic
Charge-focused (33% of respondents)	$317 for 10km increase in min. SOC	no siginifcant vaule on environmental benefits of UCC
Anti-UCC (21% of respondents)		negative towards UCC, negative preference for using renewables, elder and lower level of education

2.6.3 Bidirectional Charging: user adoption and acceptance

On the one hand, end-user want to contribute to society (covering grid stability, reduction of CO_2 emission) (Jensen et al 2013). On the other hand, mainly personal benefits are of importance. According to Payne (2018)[107] customers are interested in V2X at first because of **independence**, second are **environmental reasons** and third **financial** reasons. However, this applies to early adopters taking part in V2X trials and

[106] Bailey, J., & Axsen, J. (2015). Anticipating PEV buyers' acceptance of utility controlled charging. Transportation Research Part A: Policy and Practice, 82, 29–46. https://doi.org/10.1016/j.tra.2015.09.004

[107] Payne, G. (2018). Understanding the TrueValue of V2G. An analysis of the customers and valuestreams for V2G in the UK. Cenex: Loughborough. Available at: https://www.cenex.co.uk/app/uploads/2019/10/True-Value-of-V2G-Report.pdf [07.06.2021)

can be compared to average end-users only to a limited degree, as the motives of early adopters differ from those of other end-users (Axsen et al. 2016[108], Will and Schuller 2016). Sovacool et al. (2017) [109] state, that environmental reasons might be decisive for buying an EV but are not sufficient for enrolment to V2G contracts.

Users are afraid of losing **flexibility** in their own EV-use (Bierman et al. 2016)[110]. The perceived loss of control can be addressed, if customers have the possibility to overrule the system, e.g. Gschwendtner et al (2021)[111] propose an “immediate charge button”. This offer will not be used by all customers but will provide them with the possibility to charge in case of unexpected mobility need. Related to this concern is customer’s **lack of trust in the technology**. They are concerned that their car will not be charged when needed (Andersen et al. 2019, Fraunhofer et al. 2015, Geske and Schumann 2018). A minimum SOC has to be ensured to enhance acceptance (Tan et al. 2016)[112]. Further, for V2G range anxiety still is a challenge (Geske & Schumann 2018[113], Jensen et al 2013[114]).

The biggest concern of private end-users are range and **battery degradation** (Reynolds et al. 2018, Jensen et al 2013), however, Noel et al. (2019)[115] state, that both, experts and customers are overestimating the extent of battery degradation and that this concern could be addressed with intense education measures.

Plug-in behavior remains a central challenge for V2X (Gschwendtner et al 2021, Payne 2018[116]). Commonly, users plug in their EV on need basis (Sovacool et al 2020)[117], except new EV-users which in the first months plug in whenever possible due to range anxiety (Gschwendtner et al. 2021, Payne et al.

[108] Axsen, J., Goldberg, S., & Bailey, J. (2016). How might potential future plug-in electric vehicle buyers differ from current “Pioneer” owners? Transportation Research Part D: Transport and Environment, 47, 357–370. https://doi.org/10.1016/j.trd.2016.05.015

[109] Sovacool, B. K., Axsen, J., & Kempton, W. (2017). The Future Promise of Vehicle-to-Grid (V2G) Integration: A Sociotechnical Review and Research Agenda. *Annual Review of Environment and Resources*, *42*(1), 377–406. https://doi.org/10.1146/annurev-environ-030117-020220

[110] Bierman, P., Kroon, C., von Loon, R., & Arghi, Y. (2016). Key Innovation Forms—Integration of Electric Vehicles and Vehicle to Grid (V2G). Hespul. http://www.cityzen-smartcity.eu/wp-content/uploads/2016/01/cityzen-kif-lian-integration-v2g.pdf

[111] Gschwendtner, C., Sinsel, S. R., & Stephan, A. (2021). Vehicle-to-X (V2X) implementation: An overview of predominate trial configurations and technical, social and regulatory challenges. Renewable and Sustainable Energy Reviews, 145, 110977. https://doi.org/10.1016/j.rser.2021.110977

[112] Tan, K. M., Ramachandaramurthy, V. K., & Yong, J. Y. (2016). Integration of electric vehicles in smart grid: A review on vehicle to grid technologies and optimization techniques. Renewable and Sustainable Energy Reviews, 53, 720–732. https://doi.org/10.1016/j.rser.2015.09.012

[113] Geske, J., & Schumann, D. (2018). Willing to participate in vehicle-to-grid (V2G)? Why not! In Energy Policy (Bd. 120, S. 392–401). https://doi.org/10.1016/j.enpol.2018.05.004

[114] Jensen, A. F., Cherchi, E., & Mabit, S. L. (2013). On the stability of preferences and attitudes before and after experiencing an electric vehicle. Transportation Research Part D: Transport and Environment, 25, 24–32. https://doi.org/10.1016/j.trd.2013.07.006

[115] Noel, L., Zarazua de Rubens, G., Kester, J., & Sovacool, B. K. (2019). Navigating expert skepticism and consumer distrust: Rethinking the barriers to vehicle-to-grid (V2G) in the Nordic region. Transport Policy, 76, 67–77. https://doi.org/10.1016/j.tranpol.2019.02.002

[116] Payne, G. (2018). Understanding the TrueValue of V2G. An analysis of the customers and valuestreams for V2G in the UK. Cenex: Loughborough. Available at: https://www.cenex.co.uk/app/uploads/2019/10/True-Value-of-V2G-Report.pdf [07.06.2021)

[117] Sovacool, B. K., Kester, J., Noel, L., & Zarazua de Rubens, G. (2020). Actors, business models, and innovation activity systems for vehicle-to-grid (V2G) technology: A comprehensive review. Renewable and Sustainable Energy Reviews, 131, 109963. https://doi.org/10.1016/j.rser.2020.109963

2018). Until plugging-in ones' car whenever not using it becomes a general habit, incentives are needed for longer plug-in rates.

Information and transparency: On the one hand, there are highly interested drivers who want to always be informed about the status of charging and discharging and they would prefer for a user interface at the charging station displaying charging information and setting a minimum SOC (Jensen et al 2013[118], van Heuvlen et al. 2021). On the other hand, users state that a weekly or monthly overview would be sufficient. Nevertheless, transparency concerning the use of the battery and information on the benefits and risks, which comes with this use, were highlighted by customers (van Heuveln et al. 2021).

The usage of a user interface related to V2X technology implies an exchange of data, which may be considered as **privacy issue** for users. Schmidt et al. (2016)[119] found that beside safety and control, privacy is a prioritized criterion for the use of V2X technology. Users are rather not willing to share information about their physiological data (e.g., reaction rate), demographic data, information of past trips and their intention to move (e.g., planned route in navigation system) with e.g., car manufacturers. Providing information about their current motion data (e.g., position) and what type of road user (e.g., bus, pedestrian) they are does not pose a problem. In the context of data sharing, the authors also state that prior experience with driver assistance systems as well as technical affinity are essential for the willingness to share any data in a V2X network.

Most authors claim for intense **education** and information in order to increase knowledge, awareness and acceptance (e.g., Andersen et al. 2019, Noel et al. 2019a[120], Noel et al. 2019b, Payne 2018, Kester et al. 2018). Further, there are unrealistic expectations on the monetary benefit of V2G (Parsons et al 2014)[121], which should be also addressed to avoid disappointment (Kester et al. 2018)[122].

2.6.4 Bidirectional Charging: customer perspective on contract terms & incentives

Overall, end-users claim for easy business models with little impact on their everyday EV use and low effort for themselves (Andersen et al. 2019). In addition, they want to have the possibility to end their V2G-contract anytime and unsubscribe of contract terms (Parsons et al. 2014). Regarding the concern of battery degradation, customers demand for an extended battery warranty as a pre-condition for enrolment (Sovacool et al. 2017).

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[118] Jensen, A. F., Cherchi, E., & Mabit, S. L. (2013). On the stability of preferences and attitudes before and after experiencing an electric vehicle. Transportation Research Part D: Transport and Environment, 25, 24–32. https://doi.org/10.1016/j.trd.2013.07.006

[119] Schmidt, T., Philipsen, R., Ziefle M. (2016). User Diverse Privacy Requirements for V2X-Technology. Quantitative Research on Context-Based Privacy Aspects. Proceedings of the International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS 2016), 60-67

[120] Noel, L., Papu Carrone, A., Jensen, A. F., Zarazua de Rubens, G., Kester, J., & Sovacool, B. K. (2019a). Willingness to pay for electric vehicles and vehicle-to-grid applications: A Nordic choice experiment. Energy Economics, 78, 525–534. https://doi.org/10.1016/j.eneco.2018.12.014

[121] Parsons, G. R., Hidrue, M. K., Kempton, W., & Gardner, M. P. (2014). Willingness to pay for vehicle-to-grid (V2G) electric vehicles and their contract terms. Energy Economics, 42, 313–324. https://doi.org/10.1016/j.eneco.2013.12.018

[122] Kester, J., Noel, L., Zarazua de Rubens, G., & Sovacool, B. K. (2018). Promoting Vehicle to Grid (V2G) in the Nordic region: Expert advice on policy mechanisms for accelerated diffusion. Energy Policy, 116, 422–432. https://doi.org/10.1016/j.enpol.2018.02.024

Taking into account the above-mentioned concerns of users, business cases and contract terms were tested in different studies. A stated-preference experiment by Zonnevelt (2019)[123] found, that remuneration was the most important element to customers, followed by security of energy supply for the battery, contract duration, discharging cycles and plug-in duration. The choice experiment of Meijssen (2019)[124] revealed that the importance to customers of all these contract attributes is dependent on the recharging speed of the EV. Faster recharging can therefore lead to higher willingness to enrol to V2G contracts. Parsons et al (2014) propose, that customers have higher preference for upfront incentives or charging in a pay-as-you-go basis and lesser preferences for V2G contracts limiting them to specific charging behaviour (as specific minimum plug-in time required). According to Jensen et al. (2013), customers' acceptance depends on the frequency of discharging. People owning an EV are more concerned about discharging applications that those, leasing an EV. Arnold et al. (2015)[125] found in their study, that a remuneration of 15€ per month would be attractive to customers, but up to 10€ per month customers state their main motive to be environmentally.
Van Heuveln et al. (2021)[126] built, based on the theory of planned behaviour, a conceptual model for factors influencing the acceptance of V2G (see Figure 37), which gives a good overview about the complexity and variety of aspects, customers do consider when it comes to V2G.

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[123] Zonneveld, J. (2019). Increasing participation in V2G through contract elements: Examining the preferences of Dutch EV users regarding V2G contracts using a stated choice experiment.

[124] Meijssen, A. (2019). Dutch electric vehicle drivers' preferences regarding vehicle-to-grid contracts: Examining the willingness to participate in vehicle-to-grid contracts by conducting a context-dependent stated choice experiment taking into account the EV recharging speed.

[125] Arnold, G., Brandl, R., Degner, T., Gerhardt, N., Landau, M., Nestle, D., Portula, M., Scheidler, A., Schwinn, R., & Baumbusch, K. (2015). Intelligente Netzanbindung von Elektrofahrzeugen zur Erbringung von Systemdienstleistungen–INEES. In Wolfsburg, Hamburg, Niestetal, Kassel: Volkswagen AG, LichtBlick SE, SMA Technology AG, Fraunhofer IWES. https://www.erneuerbar-mobil.de/sites/default/files/2016-09/INEES_Abschlussbericht.pdf

[126] van Heuveln, K., Ghotge, R., Annema, J. A., van Bergen, E., van Wee, B., & Pesch, U. (2021). Factors influencing consumer acceptance of vehicle-to-grid by electric vehicle drivers in the Netherlands. Travel Behaviour and Society, 24, 34–45. https://doi.org/10.1016/j.tbs.2020.12.008.

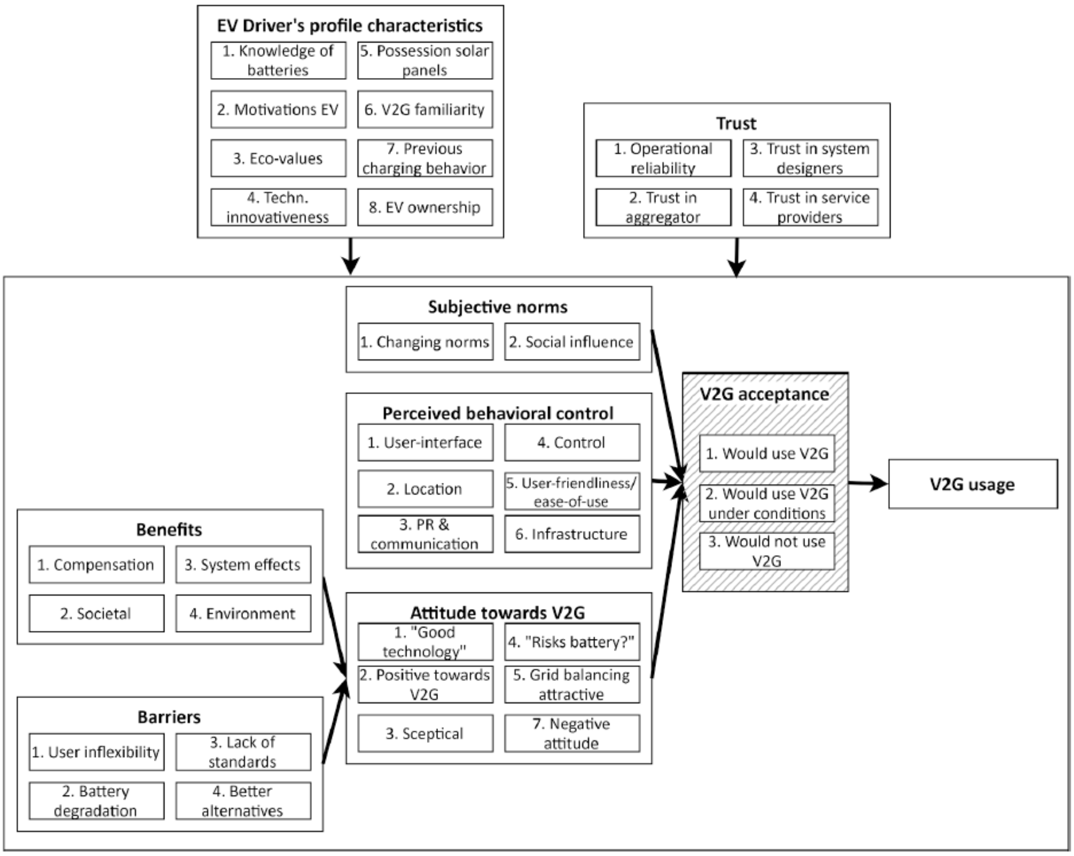

Figure 36: Theory of planned behaviour model (source: van Heuveln et al. 2021)

2.6.5 Social Framework conditions: Use Case "Fleet"

In the case of a corporate EV fleet, it must be taken into account that several parties play a role in the decision-making process. On the one hand, needs of the users, i.e. the employees, must be addressed. Their reaction to the electrification of the company fleet is essential for the purchase decision (Globisch et al. 2018)[127]. If employees are involved early in the process of converting the company fleet from conventional vehicles to EVs, and if information about the conversion is kept transparent, they are more likely to accept the change; especially if the conversion has no impact on their daily work (Wikström et al. 2016)[128].

In addition to the employees, procurement agents, fleet managers and/or company owners must be considered; this group even as key stakeholders (Corchero & Sanmarti 2018)[129]. However, the needs of these two stakeholder groups differ from each other and one group does perceive some factors as more

[127] Globisch, Joachim, Elisabeth Dütschke, and Joachim Schleich. "Acceptance of electric passenger cars in commercial fleets." Transportation Research Part A: Policy and Practice 116 (2018): 122-129. https://doi.org/10.1016/j.tra.2018.06.004

[128] Wikström, M., Hansson, L., & Alvfors, P. (2016). Investigating barriers for plug-in electric vehicle deployment in fleets. Transportation Research Part D: Transport and Environment, 49, 59-67. https://doi.org/10.1016/j.trd.2016.08.008

[129] Corchero, C., & Sanmarti, M. (2018). Vehicle-to-everything (V2X): Benefits and barriers. In 2018 15th International Conference on the European Energy Market (EEM) (pp. 1-4). IEEE.

important than the other group. While individual users rank mental and emotional effort regarding EV usage as most important, for company fleet decision makers this is one of the least important factors. They place greater value on public perception and company image as well as on cost effectiveness (Flämig et al. 2020). Hence, these two factors should be emphasized when addressing companies. The monetary factor is an essential driver for companies to include V2G vehicles in their fleets, as they can use them to participate in the wholesale electricity market and thus generate additional revenue, which increases the profitability of EVs (Corchero & Sanmarti 2018). The presentation of the company to the public as environmentally friendly and innovative, which is attributed to V2X technology, is also a motivating factor, as it has a positive effect on the company's image (Biresselioglu et al. 2018).

2.6.6 Social Framework conditions: Use Case "Sharing"

Car Sharing is a rising market in Austria and customer stock is still to grow[130]. Simultaneously, the number of eCars for sharing is increasing[131].

For Car2Flex, the social framework is of station-based two-way carsharing is assessed. Two-way car sharing and one-way car sharing serve different customer groups and are complementary but not competing business models (Becker el al. 2017)[132]

Carsharing customers are mostly young, well educated, affluent and environmentally conscious people, who are already well informed about the concept. They are mostly members of the working population or students. (Rotaris and Danielis 2018[133], Becker et al. 2017). In contrary to one-way carsharing, where most customers are male, two-way carsharing is equally used by male and female persons. Additionally, customers of two-way carsharing are slightly elder. These customers mostly possess 0 or 1 car (Becker et al. 2017). The car is for fulfilling a mobility need and no status symbol for two-way carsharing customers (Millard-Ball 2005)[134].

The main reasons for using sharing services are monetary (cheaper than owning a car) and environmentally (more efficient use of resources due to sharing, especially when it comes to eCar sharing). Further, they enjoy not to take care of an own car and not to be dependent on possessing a car (Loose 2010)[135]. For customers of two-way carsharing monetary and environmental reasons are even stronger than for one-way carsharing users (Lempert et al 2019)[136].

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[130] VCÖ (2018). Mehr als 100.000 Car-Sharing Haushalte in Österreich - Potential um ein Vielfaches höher. Pressemitteilung. Available at: https://www.vcoe.at/presse/presseaussendungen/detail/carsharing-haushalte-potential-2018, [12.07.2021]

[131] ORF.at: Carsharing-Anbieter setzen auf E-Autos, April 2021. https://wien.orf.at/stories/3100134/

[132] Becker, H., Ciari, F., & Axhausen, K. W. (2017). Comparing car-sharing schemes in Switzerland: User groups and usage patterns. Transportation Research Part A: Policy and Practice, 97, 17–29. https://doi.org/10.1016/j.tra.2017.01.004

[133] Rotaris, L., & Danielis, R. (2018). The role for carsharing in medium to small-sized towns and in less-densely populated rural areas. Transportation Research Part A: Policy and Practice, 115, 49–62. https://doi.org/10.1016/j.tra.2017.07.006

[134] Millard-Ball, A. (2005). Car-sharing: Where and how it Succeeds. Transportation Research Board.

[135] Loose, W. (2010). Aktueller Stand des Car-Sharing in Europa—Endbericht. Bundesverband CarSharing e.V. http://www.carsharing.info/images/stories/pdf_dateien/wp2_endbericht_deutsch_final_4.pdf

[136] Lempert, R., Zhao, J., & Dowlatabadi, H. (2019). Convenience, savings, or lifestyle? Distinct motivations and travel patterns of one-way and two-way carsharing members in Vancouver, Canada. Transportation Research Part D: Transport and Environment, 71, 141–152. https://doi.org/10.1016/j.trd.2018.12.010

When deciding for a carsharing service, monetary factors are most important to customers, namely membership fees and usage fees (Zoepf 2015). Access distance is also found to be pivotal, as well as the availability and the age of the vehicle (Lorimier and El-Geneidy 2012[137], Zoepf 2015)[138]. Regarding eCar sharing the above-mentioned fear of range anxiety within individual drivers is not of importance (Krauss and Gschwendtner 2020)[139].

There are few literatures available on customers' perception on unidirectional and bidirectional controlled charging. On the one hand, few researches have been conducted on this rather new concept, on the other hand, both concepts do not affect the end-users (drivers) in their car use. However, additional functionalities can have an impact on customer's motives: Krauss and Gschwendtner (2020) found, that eCar sharing including V2G is more attractive to customers than eCar sharing without V2G and more attractive than sharing of cars with combustion engines. Customers do not claim for renumeration using V2G-capable car-sharing offers.

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[137] Lorimier, A., & El-Geneidy, A. (2012). Understanding the Factors Affecting Vehicle Usage and Availability in Carsharing Networks: A Case Study of Communauto Carsharing System From Montréal, Canada. International Journal of Sustainable Transportation - INT J SUSTAIN TRANSP, 7. https://doi.org/10.1080/15568318.2012.660104

[138] Zoepf, S. (2015). Plug-in vehicles and carsharing: User references, energy consumption and potential for growth.

[139] Krauss, K., & Gschwendtner, C. (2020). How can vehicle-to-grid enhance the business model of car sharing compared to electric and conventional schemes?: A customer perspective. Arbeitsberichte Verkehrs-und Raumplanung, 1565.

3 Stakeholder Perspective on Business Models

3.1 Use Case 1 – Perspective of the Sharing Fleet Operator

The integration of V2G charging schemes into existing EV-sharing business models has yet to be widely investigated. V2G charging is expected to increase the profitability of EV-sharing business models (Zhang & Shen 2021)[140]. Similar improvements can be expected for fleet operators.

From a socio-economic point of view, service providers will benefit from the increased integration of V2G applications, as this will result in increased deployment of EVs and increase energy storage available to the electric grid. With this improved framework, users will be more willing to forego their own cars and use sharing services instead (Zhang & Shen 2021).

In order to gain knowledge on how Austrian sharing fleet operators face this topic, semi-structured interviews with Austrian carsharing operators were conducted. Eighteen sharing companies were contacted with the request for an interview. Eight agreed, one declined as V2G is not relevant for that company and nine did not respond. The interviews were conducted in October and November of 2021. These eight carsharing companies vary in their business strategies and their emphasis on V2G. Table 19 shows an overview of the interview partners.

Table 19: Overview: Interviewed Sharing Providers

	Type of Sharing Provider	Number of EVs in Sharing Program
I3, I4, I7	Small regional initiatives, driven by clubs	2-5
I2, I8	Small to medium regional initiatives, driven by (not-for-profit) companies	6-12
I1, I5, I6	Large initiatives incl. full-service offer	30+

3.1.1 V2X: Current State & Interest of Sharing Operator

All interview partners were **generally aware** of the topic; however, no one considered it currently viable for their own business. Only one interviewee stated that the company already did research on how to integrate V2G into their own business model, but declined its implementation due to technical and legal issues (I1). The others, especially smaller sharing providers, mentioned private interest and awareness of the general principle of operation, however their companies have yet to implement a V2G installation. The level of knowledge varied among the interviewees. Some respondents were well informed on potential use cases, benefits (e.g., grid-support, marketing of flexibilities, self-consumption optimization), technical and financial aspects (e.g., range of revenue achievable) (I1, I4, I6, I7, I8), which demonstrates an

[140] Zhang, Y., Lu, M., & Shen, S. (2021). On the values of vehicle-to-grid electricity selling in electric vehicle sharing. Manufacturing & Service Operations Management, 23(2), 488-507.

understanding of the energy sector. Others had only basic information on the concept, and were not aware of possible applications and overall benefits (I2, I3, I5). Still, all operators were interested into V2G.

All respondents expressed a positive **attitude towards V2G**. However, three respondents were **sceptical** that carsharing is an appropriate application for V2G and would at present reject implementing it. This is mainly due to the high occupancy rates within carsharing, which limits the availability of the battery for any other use other than driving (I3, I4, I5). They would be open towards V2G for their fleets, if the viability of V2G for carsharing is proven. The other five respondents showed an overall positive attitude on V2G and are interested in its implementation. Gschwendtner et al. (2021) found the same varying opinions among stakeholders.

Respondents were quite open towards different applications of V2G. Using EV batteries for the optimization of self-consumption (for municipality, company or multi-apartment building) was of particular interest (I1, I2, I4, I5, I6). Flexibility services offered to third parties to support the grid were also rated positively. However, challenges exist in explaining these services to customers. A better understanding of these concepts could increase acceptance of e-mobility and carsharing (I1, I4). Two respondents were interested in using V2G as an emergency power supply (I4, I5), and one respondent expressed interest in integrating V2G charging into energy communities (I3).

Motives and Challenges

The **main benefits** for sharing operators include: contributing to the energy transition (Energiewende) and the **positive environmental impacts** (efficient use of renewable energy, increase share of renewables) (I1, I2, I5, I7). Only one operator explicitly mentioned financial benefit as their sole motivation – this operator expects to enhance the profitability of cars that have a low occupancy rate (I7).

Opinion regarding the challenges of V2G differ among the interviewees. While some do not see any challenges at all (once a legal framework is established) (I7), others believe that V2G will not be feasible with carsharing fleets due to the unpredictability of availability, the need for flexibility of bookings and high occupancy rates of the EVs (I3, I5). As a counter argument, some operators point to their data base of past bookings which can facilitate planning of charging management (I6).

Despite the overall positive attitude towards V2G, operators desire **more information** on certain aspects of V2G for example: technical procedures, eligible areas for deployment, and possible benefits. In addition, the extent of cost savings (I4) and the impact on resale-value is not fully understood (I1, I8). The actual environmental benefit still has to be proven (I4), especially as most operators already supply their fleets with green electricity, which minimizes potential for further improvement in CO_2 emissions.

Six operators were concerned, that the **driving function** of their fleet would suffer from V2G. Their primary business model and thus top priority is ensuring that vehicles can be rented. As such, a charged car must be available when needed (I2, I3, I4, I5, I6, I8).

Three respondents consider their **fleet too small** or too dispersed for an efficient implementation of V2G. They are concerned that their small vehicle fleet cannot recuperate the initial investments of time and money (I3, I6, I8). Furthermore, any additional **administrative burden** in daily business would be troublesome (I8).

Company and site-specific aspects can also pose a challenge to V2G. Existing partnerships may limit a carsharing provider's ability to implement new business models such as V2G. Such limits might include: existing contracts with charging infrastructure providers, space constraints and parking contracts (I4). For

example, some car sharing providers already utilise an existing public charging network free of charge. As such, it is unlikely that the provider would purchase and maintain its own V2G infrastructure (I8).
For most interviewees, V2G is still a **future endeavor** as there are several technological and regulatory aspects that require further clarification. Additional insights and first-hand experience are need to demonstrate the viable implementation of these business models. Such information may include: financial analysis, site implementation guides, best practices, and acquiring/maintaining a customer base. Furthermore, the majority of sharing operators do not apply controlled charging mechanisms. Controlled charging could be an entry point for V2G.
Capacity loss of the battery can be a challenge. Information and evidence on the extent of battery degradation is needed (I1, I2, I4, I8), especially for older vehicles with lower initial battery capacity. Others however are not concerned about capacity loss (I7).
The **compatibility** of different charging systems must be ensured; different charging systems at different sharing sites may confuse the end user (I4). Some concern exists regarding the **reliability** of V2G technology and its control systems (I8). Awareness building and education is needed.
The development of a sufficient **regulatory framework** is a precondition for all respondents. They see the challenge to integrate V2G into the already complex standards of the energy and mobility sector. The matter of warranty is relevant for some operators.
All except for two operators are non-for-profit organisations. Financial aspects therefore are of minor importance to them. A **cost-covering** V2G operation would be an option for all interviewees. Three respondents would be willing to accept **additional costs,** if environmental benefits of V2G charging can be demonstrated (I2, I5, I7).

Question: Is carsharing a suitable use case for V2G?
Three respondents were **sceptical, whether Carsharing can be an appropriate application for V2G**. Ensuring adequate flexibility in bookings (short-term bookings and unpredictability of bookings) as well as guaranteeing an adequate vehicle SOC present significant challenges (I3, I4, I5). Even if customers were obliged to state the length of their planned trip, driving style and road conditions may still greatly affect actual battery consumption and range. For one interviewee the idea of V2G actually contradicts the idea of carsharing fundamentally: carsharing aims for high occupancy rates and low downtime -users are educated to minimize downtime during their rental period. In order to reduce such conflicts, a transparent communication would be necessary (I3).
Governance & Requirements
Historical data for planned trips can aid in the implementation of efficient V2G charging strategies.
Question: What is the minimum range that operators want to offer their customers for driving?
The general tendency is that operators want to ensure a minimum SOC of 70%.
70% is a general average. The minimum SOC is car and time (time of day) dependent for V2G charging and the respective markets/services that V2G should support (I2, I6, I7).
In particular, the following estimations were given for regular business hours: 50 km at any time (I3); 100 km at any time; higher range before scheduled bookings (I4); never beyond 50%, regular SOC of 70 – 80% (I6); 80% (I7, I8), 100% (I5)
Question: Which capacity would operators reserve for V2G markets/services?
There is a strong difference between night and day applications (regular business hours).

For night-time usage, most respondents would not limit the discharging capacity, so long as the vehicle reaches approximately 80% SOC for its first booking (typically in the morning).

Within the regular business hours, operators estimate about 20-30% of battery capacity could be used for V2G (I6, I7, I8). One interviewee found it unnecessary to define a maximum SOC-reserve for V2G markets/services so long as the customer (driver) is ensured to have enough energy for their next trip (I3).

Question: Which information is of interest for operators and which settings do they require?

As V2G is still an abstract topic for most, these answers can only serve as initial ideas regarding an adequate user interface for operators. Further research, prototypes and intense testing are needed.

The following **information** would be of interest to operators:

Predicted range at the start of a renting period (I2)

Overview on charging and discharging periods (duration, amount of electricity) (I6, I7)

Overview on environmental effects of bidirectional charging (I6)

Financial effect of each bidirectional charge/discharge operation (I7, I8)

Relatively little interest concerning discharging power (I3) and the number of discharge cycles (I3, I4). A live overview is not needed (I7)

The following **settings** would be of interest for operators:

Day- and car-dependent control of all settings

General minimum SOC

Maximum battery capacity reserved for V2G (I1, I6, I7, I8)

Min. SOC before start of each renting period (I6, I7, I8), ideally in combination with planned trip length (I1)

Dedicate / block times for discharging (I4, I7)

Minimum remuneration (e.g., based on electricity prices), based on this setting, bidirectional use would be permitted or locked (I6).

Fixed time slots or durations for bidirectional use of the EVs cannot be guaranteed (I6)

Customers from the Operator’s Perspective

At present, carsharing is still a niche product and not widely used by the general public. The assessment of driver's interests is somewhat hampered by the fact that **few operators can define a "typical" customer** in terms of his/her motivation (e.g. environmental and financial) and usage (e.g. rental frequency and trip length). Most interviewees agree, that V2G will be an additional asset for customers with strong environmental motives (I1, I3, I5, I6, I7), but expect little no effect on others customers. Three respondents believe, that V2G will not be of interest to any customer, unless there is a financial benefit (I2, I5, I8). As an add-on feature V2G is not a decisive argument for the choice of a particular vehicle within a sharing-pool, as other aspects such as price, vehicle range or trunk capacity are of greater importance(I3).

Most operators do not believe that customers are willing to pay extra for vehicles participating in V2G programs, even if environmental or societal advantage are proven and communicated effectively (I1, I2, I6, I7, I8). Only a marginal share of customers, which have very strong ecological values are expected to be willing to pay extra for V2G (I1, I2, I6, I7).

According to one respondent, customers have high standards and expect a minimal effort on their own behalf. Other respondents responded similar:

Any additional effort required by the customer will hinder the acceptance of V2G (I1, I4, I5, I6).

If V2G affects the customer in any manner, the benefit for the end-user must be evident and clearly communicated (I6).

The “anonymous” selling of flexibility, can pose a challenge (I1).

Customers’ **range anxiety** may be a challenge. Some customers are already sceptical of using EV due to their actual or perceived limited driving range. Reducing it via V2G services may exacerbate range anxiety (I4, I8). On the other hand, battery ranges continue to increase; one operator believes that customers will not mind any reduced range (I6, I7). A lack of trust or certainty in V2G technology might lead drivers to fear that their vehicle will not be adequately charged when it's needed (I4).

So-called Full Service Providers, offering townships/counties (DE: Gemeinde) complete car-sharing services, believe that its customers are interested in V2G charging (I6). As these townships/counties often have an existing PV installation, V2G could provide additional environmental and economic benefits by increasing self-consumption. However, smaller townships/counties have already turned down car-sharing projects (without V2G), based on their real and perceived complexity (I5). This highlights the importance of keeping V2G solutions simple. Any additional financial or administrative burden due to V2G could risk the viability of these projects.

Perspective of Sharing Operators: Summary

The most important findings from the expert interviews are summarized here.

Operators are aware of V2G. Attitudes towards V2G are generally positive.

There is scepticism on the viability of carsharing as an application for V2G as both concepts aim at increased vehicle use and may exhibit mutually adverse effects.

Environmental benefits and the increased use of renewables are the most important motives for operators. As such, scientific evidence on the actual impact of V2G is needed.

Additional education and information on V2G concepts will likely increase acceptance and willingness to implement V2G within sharing fleets. Operators must be assured that their core-business will not be negatively affected by the addition of V2X to their fleet.

Operators are primarily concerned with:

Proof of actual environmental impact

Evidence on the actual financial impact with regard to different use cases

Fleet size necessary for viable V2X operation

Evidence regarding any additional loss of capacity to the vehicle’s battery

3.2 Use Case 2 – Perspective of the Company Fleet Operator

As opposed to individual EV users (private citizens), fleet managers may be better-informed and better inclined to make rational decisions concerning the procurement of EVs (Meelen et al. 2021)[141]. Therefore, fleet managers and decision makers, respectively should be addressed differently as compared to individual users. Although similar factors play a role in the procurement decision as in the individual case, there are further components that have to be considered (Biresselioglu et al., 2018)[142]. Besides

[141] Meelen, T., Doody, B., & Schwanen, T. (2021). Vehicle-to-Grid in the UK fleet market: An analysis of upscaling potential in a changing environment. *Journal of Cleaner Production*, *290*, 125203.

[142] Biresselioglu, M. E., Kaplan, M. D., & Yilmaz, B. K. (2018). Electric mobility in Europe: A comprehensive review of motivators and barriers in decision making processes. Transportation Research Part A: Policy and Practice, 109, 1-13.

environmental and economic aspects, companies profit from a positive public perception by converting their fleet to EVs (Biresselioglu et al., 2018). However, if the company's objective is to improve its image through zero-emission mobility, EV charging stations should be powered by renewable energy. This may call for the addition of on-site generation of renewable energy, which could act as a further barrier to the purchase of EVs (Laurischkat et al., 2016)[143]

The expense of changing out an existing company fleet for EVs may be a significant barrier for commercial fleet owners. Companies face several challenges in such a comprehensive change process. This starts with the composition of the fleet, designing an appropriate charging infrastructure and the management of the fleet through a functional, easily accessible information system (Laurischka et al., 2016; Biresselioglu et al., 2018). Deciding to switch to an EV fleet as well the conversion process itself are both complex processes. Fleet managers are often unable to evaluate the various technologies on the market in order to find the most appropriate solution for their company (Di Foggia 2021)[144]. This could have a negative impact on the adoption of V2G technologies in EV fleets.

Challenges for fleet managers regarding the adoption of EVs were also investigated in the project e-flex (2020)[145]. The main barriers for EV adoption for commercial fleets are the initial purchase price and the concern about rising energy costs. Furthermore, about 50% of respondents worry about battery life. However, they also recognize that more environmentally friendly fleets can serve as an incentive for customers. Regarding V2G within commercial fleets, the main benefits for fleet managers are cost savings and additional revenues through selling energy back to the grid. About 50% believe that these savings could compensate for the higher investment costs. Only 9% are concerned about the cyber security of V2G.

Besides the monetary factor, fleet managers perceive scarcity of charging infrastructure as a serious barrier. In addition, the lack of information about long-term political activities hinders EV adoption for companies. Public companies and companies that work closely with governments are more willing to introduce EV fleets than private companies. In general, larger organizations have more resources available for planning, implementation and maintenance of fleets and are thus better able to deal with the various challenges associated with electrifying their fleets (Demeulenaere 2019)[146].

3.3 Use Case 3 – Perspective of the Individual Car Driver

The acceptance of different business models and tariff systems is highly dependent on the sample of customers and the factors included in the respective study. No single business model will fulfill the needs

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[143] Laurischkat, K., Viertelhausen, A., & Jandt, D. (2016). Business models for electric mobility. *Procedia Cirp*, *47*, 483-488.

[144] Di Foggia, G. (2021). Drivers and challenges of electric vehicles integration in corporate fleet: An empirical survey. Research in Transportation Business & Management, 100627.

[145] e-flex. (2020). Moving towards more sustainable fleet management with vehicle-to-grid systems. https://static1.squarespace.com/static/5c06a9175cfd79e695c47abc/t/5e296b928dd05752c90ae19f/1579772819667/CIS119F-79+E-Flex+Report_v6.pdf, 13.07.2021

[146] Demeulenaere, X. (2019). The use of automotive fleets to support the diffusion of Alternative Fuel Vehicles: A Rapid Evidence Assessment of barriers and decision mechanisms. Research in Transportation Economics, 76, 100738. (no UCC, BCC)

of each customer. However, any successful business model must be easy to use for its end customers. In addition, customer training is needed to explain the workings of bidirectional charging and any other complex issues that may arise as part of these new business models. Researchers also agree, that customers should be allowed to override automation if they feel the necessity to do so. Customer's perspective on contract terms for unidirectional and bidirectional charging are outlined above.

4 Framework and Requirements for Interfaces

Figure 38 provides a framework including interfaces for the V2G demo sites in car2flex. Additional information on each component can be found in their respective sections. Car2flex demo sites will use off-board (DC) bidirectional V2G charging.

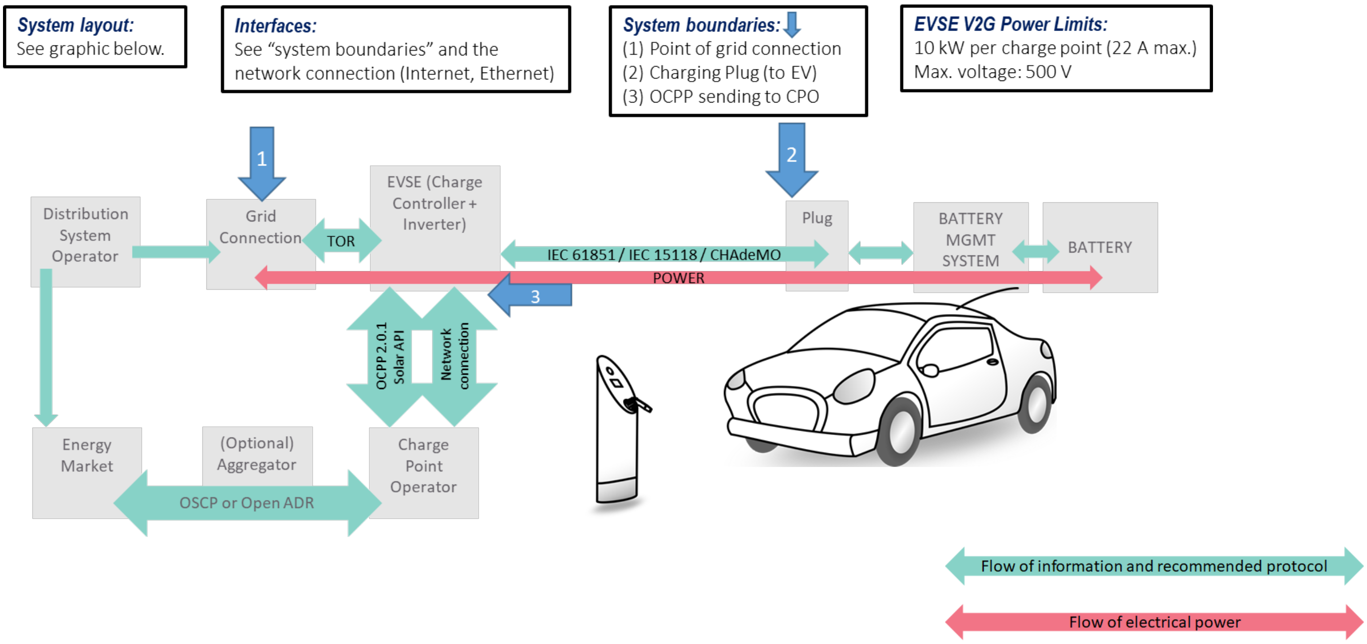


Figure 37: System layout, interfaces and system boundaries for V2G charging stations at demo sites.

4.1 Components

4.1.1 Electric Vehicle and Battery

Electric vehicles participating in V2G charging must support a suitable communication protocol e.g. CHAdeMO. Extensions to the IEC 15118 (as well as an expected revision) also enable V2G charging. For the long term success of V2G services, car manufactures must implement these features (via the aforementioned protocols) as well as guarantee the warranty of the vehicle's battery.

4.1.2 Battery Management System (BMS)

The battery management system must adopt its software to appropriately support V2G functions. Special consideration of minimum charging currents is relevant for both the vehicle's BMS as well as the Electric Vehicle Supply Equipment (EVSE). Minimum and maximum electric currents of these devices must be understood and coordinated. For example, the minimum charging current of the EV and the maximum output current of the various power electronic devices used in photovoltaic installations are critical in the context of directly charging an EV via a PV installation. In addition, the BMS must be prepared to handle possible surges/sags that may result from V2G services, especially if the EV is used in a back-up power application. These power fluctuations and resulting electric currents may lay outside the typical demand seen by the battery during driving.

4.1.3 EV Charging Plug

Demo-sites will be equipped with a CHAdeMO plug, as CHAdeMO already supports V2G charging. Support for CCS via ISO 15118 is currently under review.

4.1.4 Electric Vehicle Supply Equipment (EVSE)

V2G capable Electric Vehicle Supply Equipment i.e. charge points will be supplied by Fronius. These prototypes utilize a modified 3 phase hybrid PV/Battery inverter.

4.1.5 Grid Connection

The electrical connection of the V2G EVSE is to be installed in accordance with national regulations:

- TAEV (2020) Technische Anschlussbedingungen für den Anschluss an öffentliche Versorgungsnetze mit Betriebsspannungen bis 1000 Volt.
  EN: Technical connection conditions for connection to public supply networks with operating voltages of up to 1000 volts.
- OVE E 8101 Low-voltage electrical installations
- TOR (Parts D1, D2) relevant for charging G2V
- Tor Erzeuger Typ A relevant for discharging V2G
  EN: TOR Generation Type A
- Additional requirements as per the DSO

4.2 Actors/Organizations

Coordination of the various actors is important as each actor may use its own algorithms and optimization strategies. Fulfilling the requirements of one actor may conflict with another. Some coordination of the following services/goals are necessary:

- System demand as dictated by a local energy management system
- Services sold to various energy markets and aggregators
- Preventing disruptions and maintaining power quality on the LV grid

Long term, coordination between the DSO and TSO must also be strengthened. Several of the important actors/organizations involved in V2G charging are listed below.

4.2.1 Distribution System Operator DSO

Several distribution system operators belong to the various demo sites in car2flex. V2G charging can be used to support voltage requirements on the LV grid (EN 50160) as well as other power quality metrics.

4.2.2 Energy Market

V2G charging can support various energy markets such as:

- Derivative markets
- Balancing market
- Day-ahead market
- Intra-day market

4.2.3 Aggregator

An aggregator buys and sells energy or energy related services in bulk either for its various customers and for their own use. Aggregators typically participate in the energy markets listed above as well as via bilateral agreements with their partners/customers. Using so called virtual power plants, aggregators can bid into these larger markets, by connecting and coordinating smaller actors (both generation and demand response), thus enabling their participation in such markets.

4.2.4 Charge Point Operator

The charge point operator (CPO) is the party that organizes and operates the charging point. They are responsible for its upkeep as well as service and maintenance. In some cases, the CPO also owns the equipment.

4.2.5 eMSP/MSP

An e-mobility service provider (eMSP) or a mobility service provider (MSP) handles the communication and billing services necessary to bill the EV customer.

4.3 Interfaces and Protocols

Figure 39 shows some common interfaces and protocols used in EV charging. The specific framework used for the V2G demo sites is shown in Figure 38.

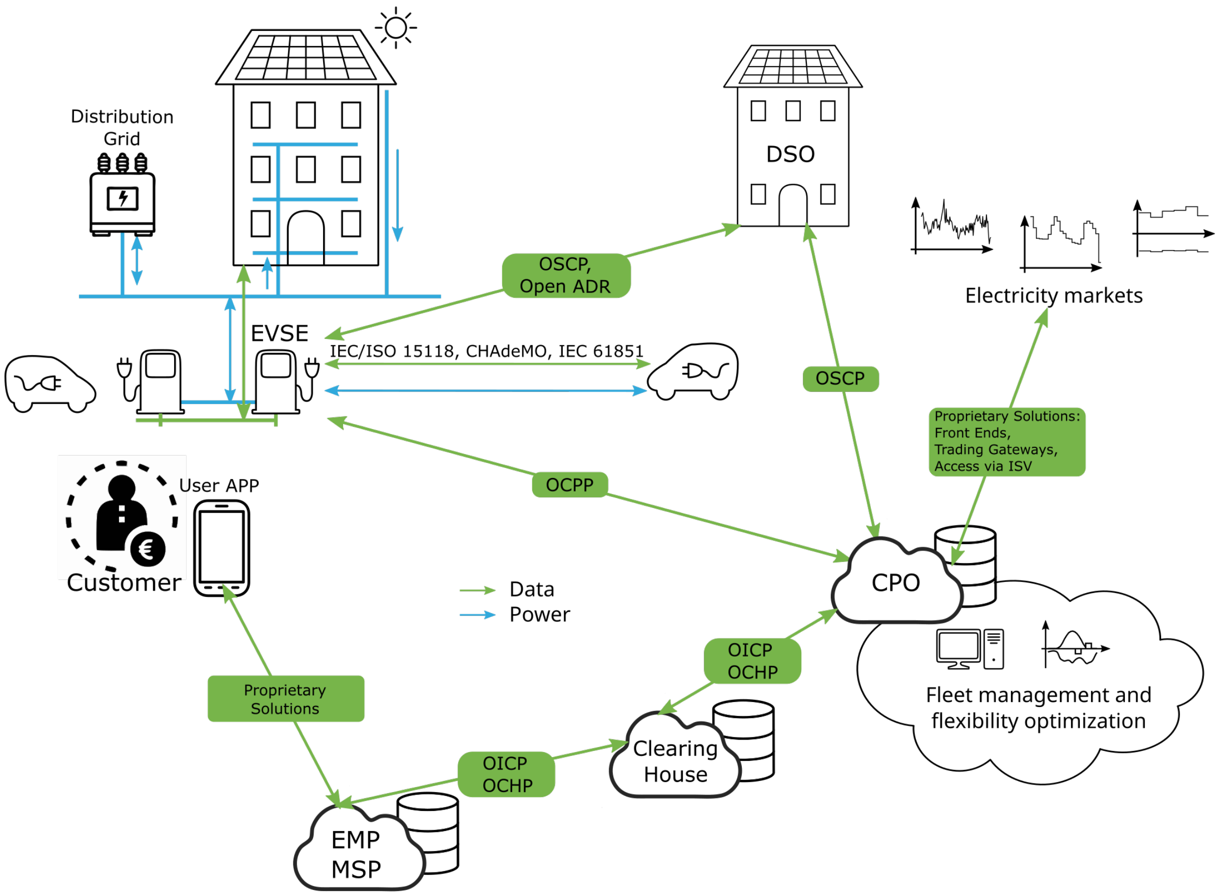


Figure 38: Common interfaces and protocols in EV charging.

4.3.1 OSCP: Open Smart Charging Protocol[147]

This protocol was originally designed to communicate the physical net capacity from the DSO to the charge point operator. Charging profiles can be adapted based on the available charging capacity. The protocol has been expanded to integrate DER, battery storage, heat pumps, and other devices for a larger energy management eco-system.

4.3.2 OpenADR[148]

OpenADR is a standardized automated demand response program. Aggregators and DSOs can use this to control demand of many devices on the electrical grid.

4.3.3 OCPP: Open Charge Point Protocol[149]

The open charge point protocol supports communication between charge point operators and a back-end system for central control. It supports ISO15118 and smart charging.
An example of an OCPP ChargingProfile is shown in Figure 40. Such a profile can be used to control power flow in and out of the grid/EV.

The following data structure describes a daily default profile that limits the power to 6 kW between 08:00h and 20:00h and to 11 kW between 00:00h and 08:00h and between 20:00h and 00:00h.

ChargingProfile			
chargingProfileId	**100**		
stackLevel	**0**		
chargingProfilePurpose	**TxDefaultProfile**		
chargingProfileKind	**Recurring**		
recurrencyKind	**Daily**		
chargingSchedule	*(List of 1 ChargingSchedule elements)*		
	ChargingSchedule		
	duration	**86400 (= 24 hours)**	
	startSchedule	**2013-01-01T00:00Z**	
	chargingRateUnit	**W**	
	chargingSchedulePeriod	*(List of 3 ChargingSchedulePeriod elements)*	
		ChargingSchedulePeriod	
		startPeriod	**0 (=00:00)**
		limit	**11000**
		numberPhases	3
		startPeriod	**28800 (=08:00)**
		limit	**6000**
		numberPhases	3
		startPeriod	**72000 (=20:00)**
		limit	**11000**

Figure 39: Example of an OCPP Charging Profile.

[147] https://www.openchargealliance.org/protocols/

[148] https://www.openadr.org/

[149] https://www.openchargealliance.org/protocols/

4.3.4 OICP: Open Interface Charge Protocol[150]

The open interface charge protocol was designed by Hubject and offers a roaming platform for electric vehicles. Hubject is a joint venture of the BMW Group, Bosch, Daimler, EnBW, Innogy, Siemens and the Volkswagen Group.

4.3.5 OCHP: Open Clearing House Protocol[151]

The open clearing house protocol was designed to help connect back-end systems to clearing houses. It is an open-source protocol.

[150] https://solidstudio.io/blog/ev-roaming-with-open-standards-oicp-emip

[151] http://www.ochp.eu/

5 Simulation of the Use Cases

5.1 Economic Simulation

5.1.1 Use Case 1 – Car Sharing

The scenarios investigated to evaluate the economic potential of residential on-site e-car-sharing. Each scenario is distinguished by different objective functions and, therefore, by different investment decisions. Figure 41 shows the set-up of the five investigated scenarios. It is important to note that the scenarios are characterized by different local optimums, with the only exception of the "Fully Integrated E-Car-Sharing Company", which represents the global optimum and thus allows the lowest total costs.
In the "baseline" scenario, as shown in Figure 41, the residential building tenants are characterized by a residential load and a driving need. They don't have the opportunity to invest in PVs or BSs, but only in optimal CSs. Furthermore, the tenants optimize their electricity consumption and their investment individually.

In the "individual" scenario, the residential building tenants have the opportunity to invest in PVs and BSs to reduce their yearly costs. In this scenario, again the tenants optimize their electricity consumption and investment individually, as illustrated in Figure 41.

The scenario "External E-Car-Sharing Company" is characterized by an external e-car-sharing company, which covers the driving need of the tenants J, as depicted in Figure 41. The tenants have the opportunity to invest in PVs and BSs without taking into account their driving needs. At the same time, the external e-car-sharing company optimizes the EVs' and CSs' operation and investment, and the tenants share the EVs made available by the e-car-sharing company. The non-simultaneous tenants' need for EVs allows, possibly, the e-car-sharing company to cover their driving needs with fewer cars. Hence, the tenants and the e-car-sharing company optimize their electricity consumption and investment individually.

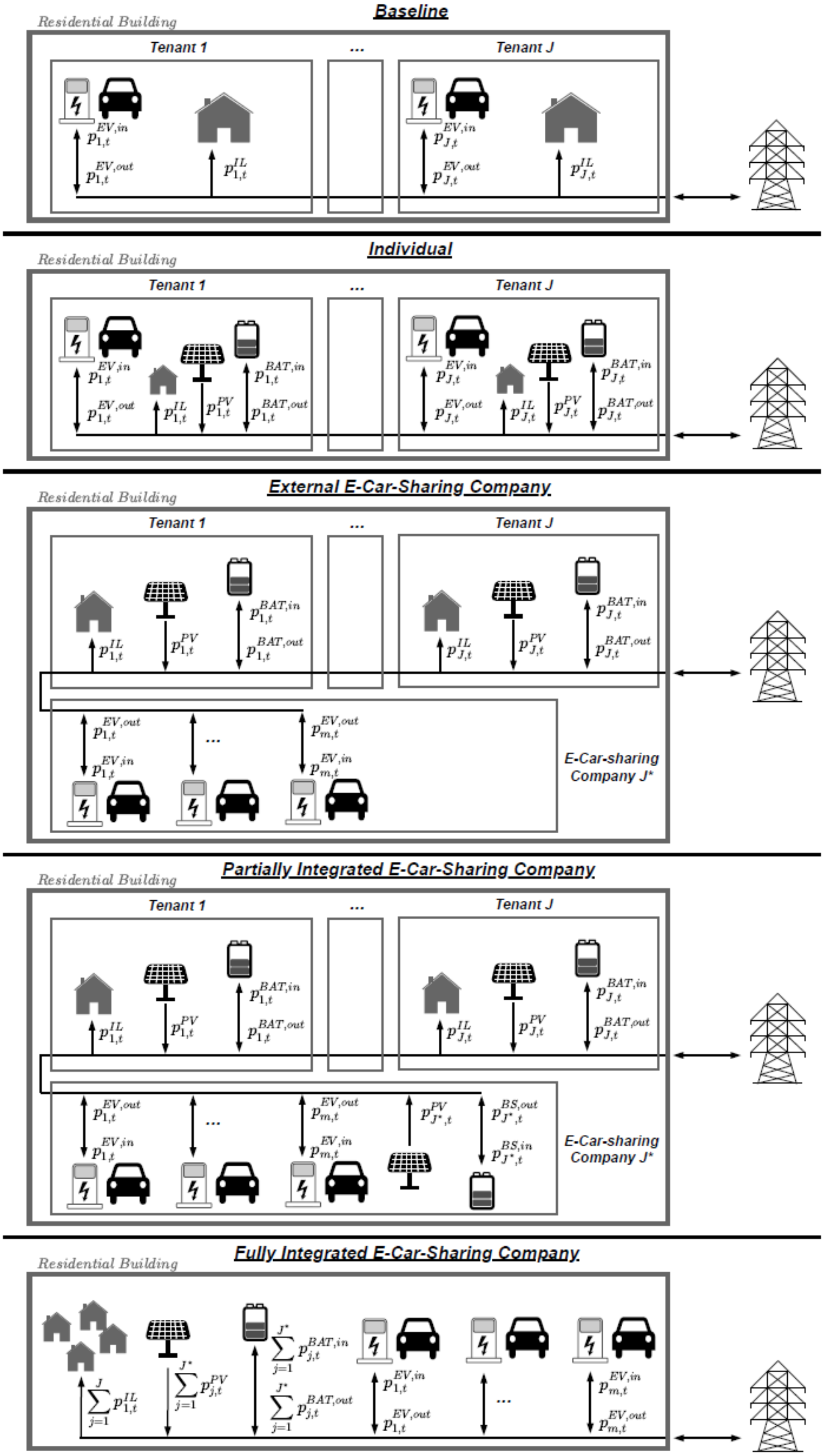


Figure 40: Set-ups of the investigated scenarios

In this work, we consider a generic Austrian residential building with eight tenants. The simulated period covers one year: from 01.01.2019 to 31.12.2019. The residential load of the tenants is modeled with the "LoadprofileGenerator" software and the driving need with the "Python" toolbox "emobpy". The "emobpy" toolbox considers empirical mobility statistics of different types of drivers to deliver EVs' consumption profiles. The tenants' annual consumption and driven kilometers are resumed in Figure 42.

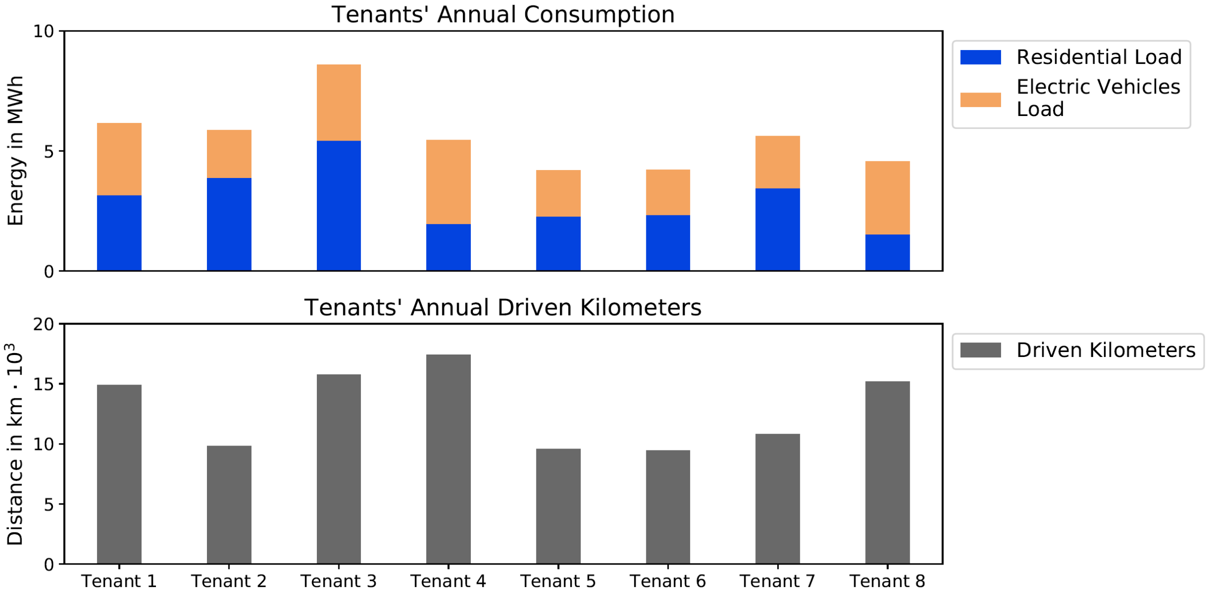


Figure 41: Tenants' annual consumption and driven kilometers.

The grid tariffs considered are given by the Austrian electricity regulator. The DA prices (of the European Power Exchange) and the PV time-series of specific generation considered are those of the ENTSO-E Transparency Platform. The rooftop of the investigated residential building is limited to 30 kW_P of installed PV and is equally distributed among the tenants. The tenants also have the opportunity to invest in a lithium-ion BS to reduce their total costs. Besides, the EV considered is the model "Nissan Leaf" with a capacity of 40 kWh and a consumption rate of $0.2 kWh/km. The tenants and the e-car-sharing company can invest in one of 8 different CSs with different nominal power: 3.7 kW, 7.4 kW, 11 kW, 22 kW, bidirectional, or not.

In the investigated case study, it has been assumed that the tenants invest in EVs and not in other conventional vehicles to cover their driving needs. Furthermore, perfect forecast for the residential load, the driving need and PV generation are assumed. The operational strategy of the technologies, which are implemented in the mixed-integer linear optimization framework using the *Python* toolbox *Pyomo*, is defined by the *Gurobi* solver. The annual total costs for the residential building tenants $\mathcal{J}$ in the five different scenarios are resumed in Figure 43.

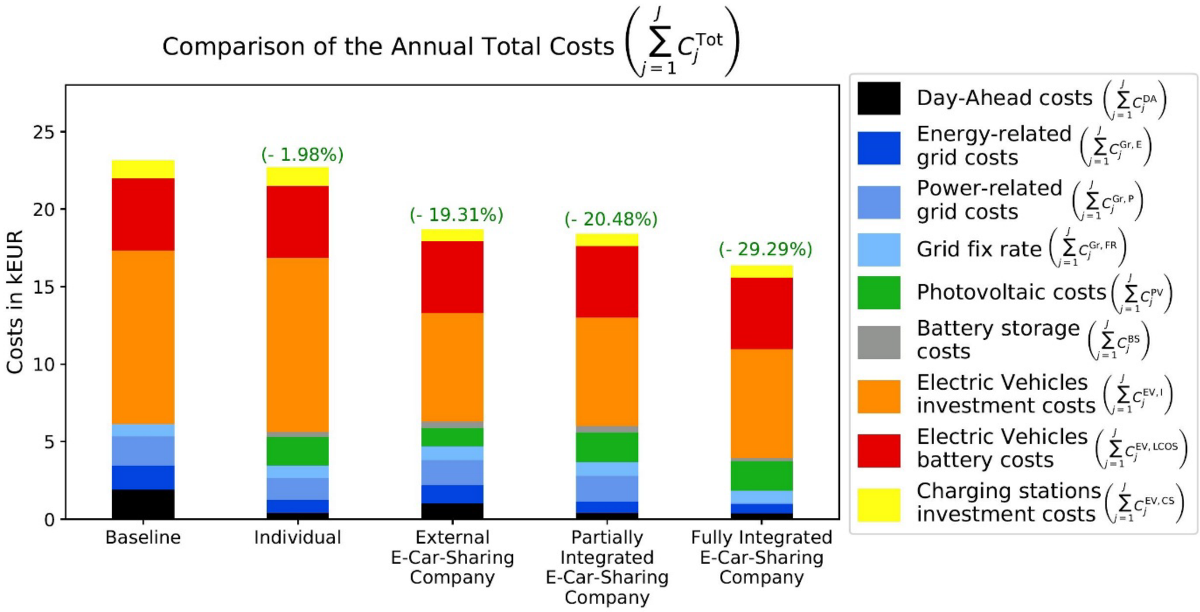


Figure 42 Comparison of the tenants' annual total costs

In the *baseline* scenario, the tenants optimize their electricity consumption and investment in CSs to cover their residential and driving needs. Hence, in this simulation, no investment in PVs, BSs, or e-car-sharing system is considered. The availability of the EV batteries allows the tenants to flexibilize their consumption patterns to optimize their electricity withdrawals and minimize their total costs. In this case, 47.2 MWh were bought at the DA for an average price of 40€ / MWh. The grid costs represent 18 % of the total costs, of which 37 % are energy-related, 44 % power-related and 19 % are the fixed rate. The EVs' costs make up 73 % of the total costs, as shown in Figure 43. The optimal investment for the tenants is for each a 3.7 kW CS without implementing a bidirectional inverter.

In the *individual* scenario the tenants have the opportunity to invest in PVs and BSs. Figure 44 presents the overall installed BS capacity, the total installed PV power and the autarky and self-consumption rates. The self-consumption rate describes the relationship between the energy used, which is produced from the photovoltaic plant, and the total energy produced by the photovoltaic plant itself. The autarky rate is the relationship between the energy used generated by the photovoltaic plant and the total amount of electricity required by the tenants. It is observable that in the *individual* scenario, the residential building's tenants utilize almost the entire rooftop area installing 28.6 kWp PV power. Also, the further investment in 18.7 kWh BS capacity leads the tenants to a total costs reduction of 1.98 %, as shown in Figure 42. In this case, the DA costs represent only 2 % of the total costs. In total, 37.8 MWh were negotiated at the DA, of which 25 MWh bought and 12.8 MWh sold. The operation of the BSs allows the tenants to purchase energy when the DA prices are low and to sell it again when prices are high. The self-production of energy through PV leads to a significant reduction of energy-related grid costs. In fact, the grid costs are 27 % lower in comparison to the *baseline* scenario. On the other hand, the PV and BS costs represent 10 % of the total costs. The opportunity to invest in PV and BS does not affect the investment in CSs. In fact, as in the *baseline* scenario, each tenant invest in a not bidirectional 3.7 kW CS. However, it should be noted that the availability of the EV batteries allows the tenants to achieve a noteworthy self-consumption rate (65 %), as shown in Figure 44.

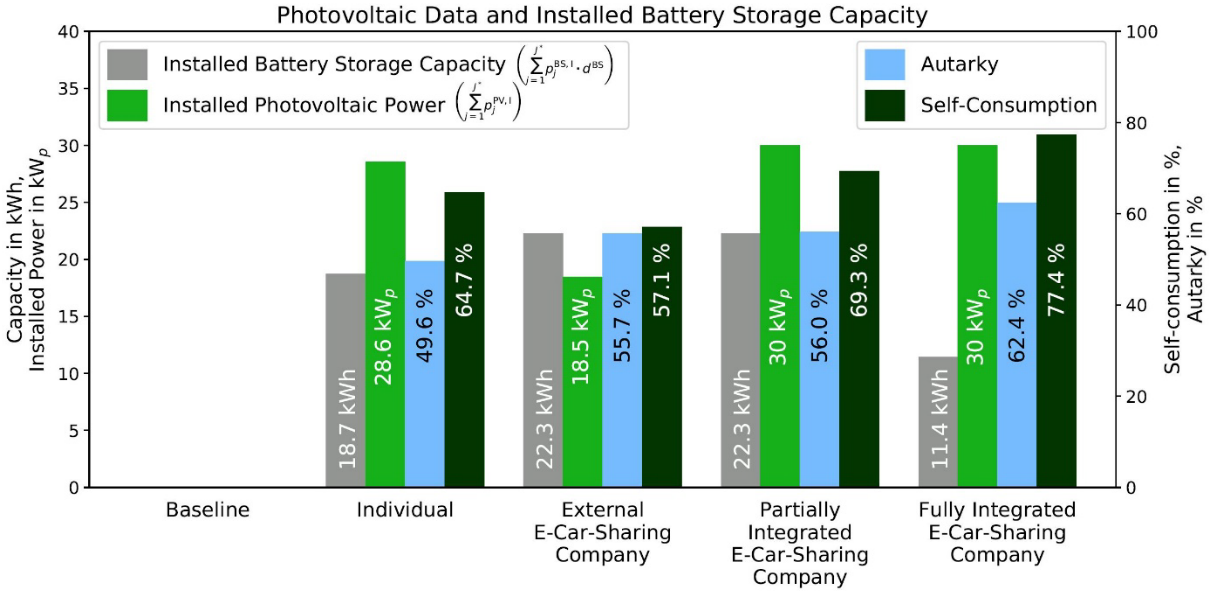


Figure 43 Photovoltaic data and installed battery storage capacity

In the *external e-car-sharing company* scenario, an external e-car-sharing company covers the driving needs of the tenants, which invest in PVs and BSs, taking into account only their residential load. In this scenario, the e-car-sharing company does not have the opportunity to invest in PVs and BSs. As shown in Figure 43, the total costs drop by over 19 %. The non-simultaneous use of EVs allows the e-car-sharing company to cover the tenants' driving needs with five. This leads to a significant reduction of the EVs' costs of 26 %. Also in this case, the CSs are not bidirectional, but have different nominal charging powers. In fact, the e-car-sharing company invest in 1 CS with 3.7 kW nominal power, 3 with 7.4 kW and 1 with 11 kW. The reduced number of EVs causes a lower amount of flexibility, leading to higher DA and grid costs. As a result, the DA and the grid costs are, respectively, 148 % and 20 % higher in comparison to the *individual* scenario. It is important to note that, since the residential building tenants no longer have to cover their driving needs, they optimally invest in less PV power (only 18.5 kWp), as illustrated in Figure 44. Nevertheless, the non-availability of the EV batteries makes it more convenient for the tenants to invest in batteries, which are installed for more than 22 kWh. These facts lead the tenants to have an autarky rate of 56 % and a self-consumption rate of 57 %.

The *partially integrated e-car-sharing company* scenario is characterized by an e-car-sharing company, which covers the driving needs of the tenants and has the opportunity to invest in PVs and BSs. As observable in Figure 43, the total costs drop by over 20 % in comparison to the *baseline* scenario. Also in this case, the non-simultaneous usage of EVs allows the e-car-sharing company to cover the tenants' driving needs with five cars, investing in the same type of CSs used in the *external e-car-sharing company* scenario. The e-car-sharing company invests in the remaining 11.5 kWp of PV available on the rooftop without investing in BS. This investment involves the maximum exploitation of the available PV power on the rooftop (30 kWp), reducing the DA and grid costs by 78 % and 23 %, respectively, in comparison to the *baseline* scenario. Since the e-car-sharing company can invest in PV, its consumption patterns are considered in the calculation of the autarky and self-consumption rates. Figure 44 shows how the opportunity for the e-car-sharing company to invest in PV leads to an overall self-consumption rate of 69 %.

In the *fully integrated e-car-sharing company*} scenario, the tenants and the e-car-sharing company build up an energy community to make joint investments in BSs, PVs, EVs and CSs. This scenario represents the most ideal one and leads to a total costs reduction of 29 %, as illustrated in Figure 43. In this case, the optimization aims to minimize the total costs, as described in the objective function, and not to minimize the costs of each player individually. The tenants' driving needs are covered with five cars and 5 non-bidirectional CSs: 1 with 3.7 kW nominal power, 3 with 7.4 kW and 1 with 11 kW. The optimization considers all residential loads and driving needs simultaneously, which lead to optimal dispatching of the PV-generated electricity, optimal BS capacity usage, and optimal operation of the CSs. In fact, the DA costs fall by 80 %, and the grid costs fall by 66 % compared to the *baseline* scenario. Moreover, the decrease of the installed BS (11.4 kWh) and the increase of the autarky and self-consumption rates are remarkable, which in this scenario are 62 % and 77 %, respectively.

Since the optimization framework optimizes the residential building as a single agent and the costs are distributed among the tenants based on their residential loads and driving, the cost savings are not shared equally. Figure 45 compares the tenants annual total costs in the five investigated scenarios.

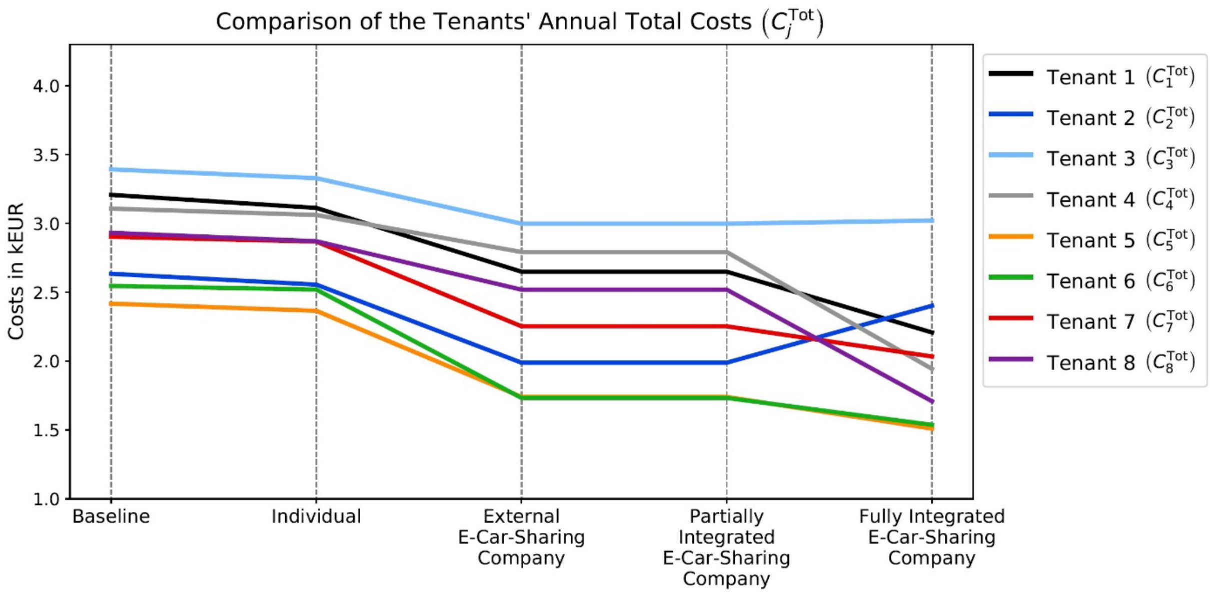


Figure 44 Comparison of the tenants' annual total costs

It is observable that in the scenarios where the e-car-sharing company costs are distributed on the basis of the tenants' driving needs, the tenants with the higher driving need (tenants 3, 4 and 8) have slighter cost reductions compared to the tenants with a low driving need. In particular, in the *fully integrated e-car-sharing company* scenario, where both the residential load and driving need are considered to share the cost savings, there are tenants for whom this set-up may not be economically advantageous. In fact, in this case study, tenants 2 and 3 minimize their costs in the *partially integrated e-car-sharing company* scenario, as illustrated in Figure 45. This happens because of their high residential load. A more sophisticated approach to share the total costs is required to make this scenario the most economically convenient for all the tenants, such as the Shapley value, the Nash bargaining solution, and different reinforcement learning-based mechanisms.

5.1.2 Use Case 2 – Company Fleet

Two use cases were optimized, whereby a UC case in which bidirectionality is made as an investment decision in the model. Since it turns out that V2G applications are not economical, a second UC case was calculated in which the V2G application is fixed.

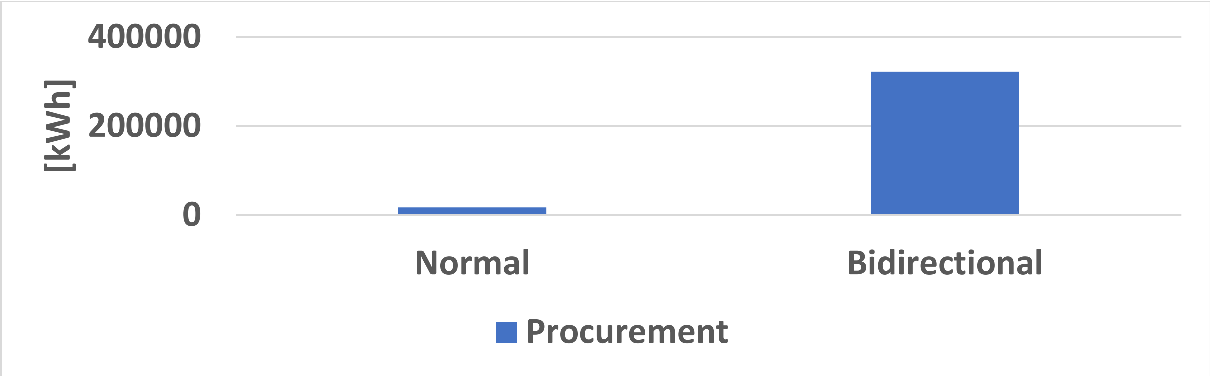


Figure 45 Comparison of the procured energy for the two modeled use cases

Figure 3 shows that the load on the network is much greater in bidirectional UC.

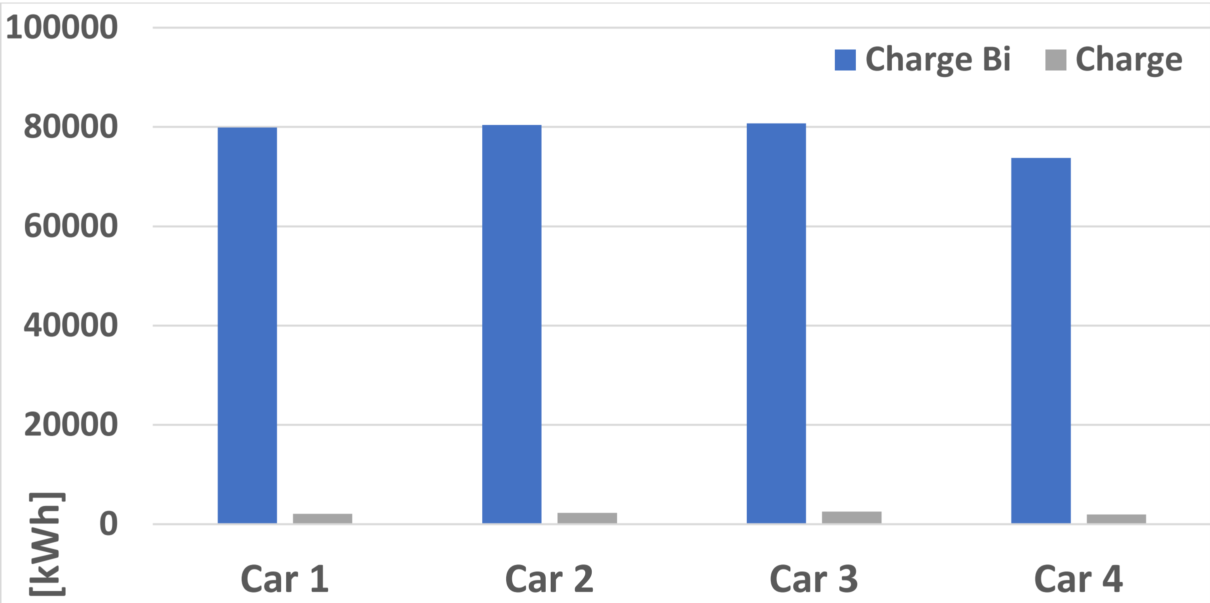


Figure 46 charged energy for the two different use cases

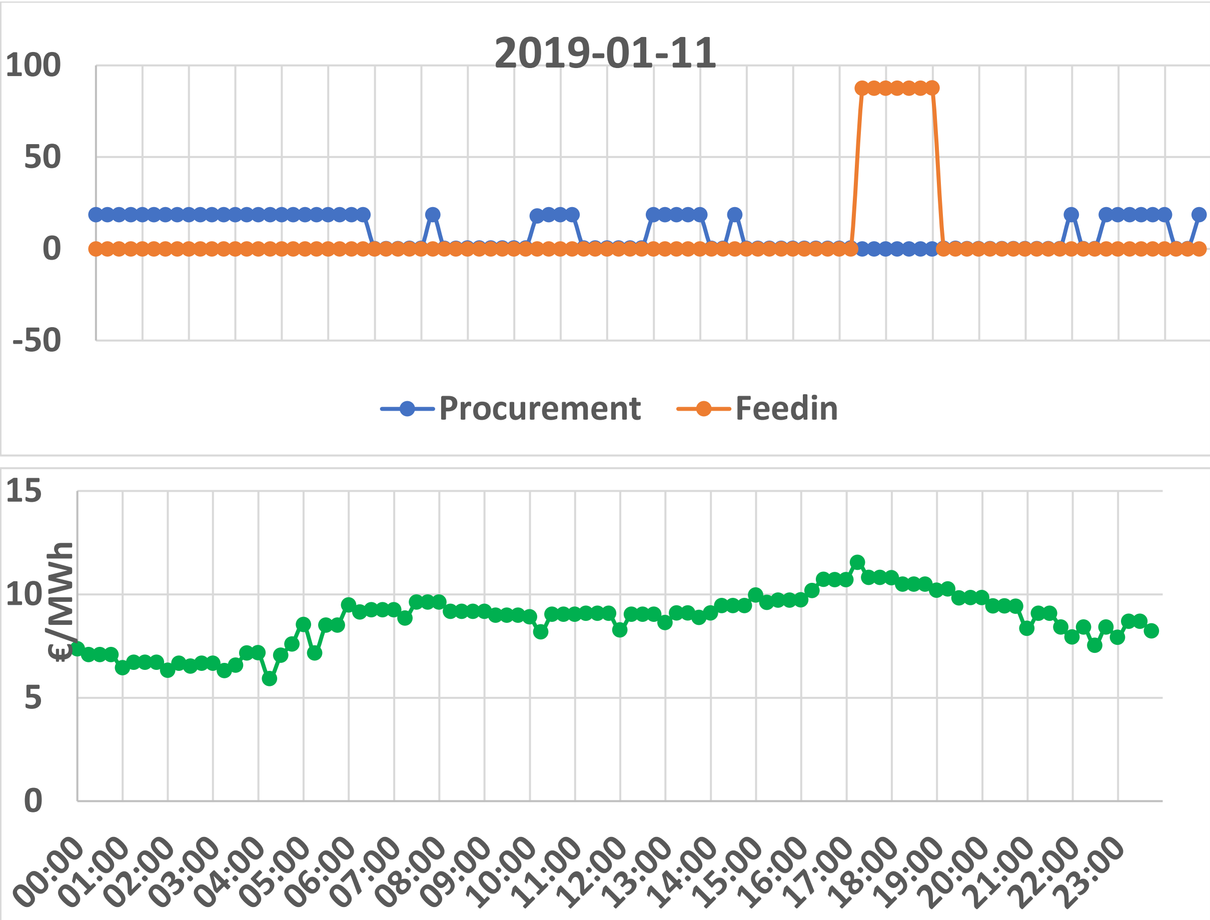


Figure 47 procurement and feed and the according day ahead price

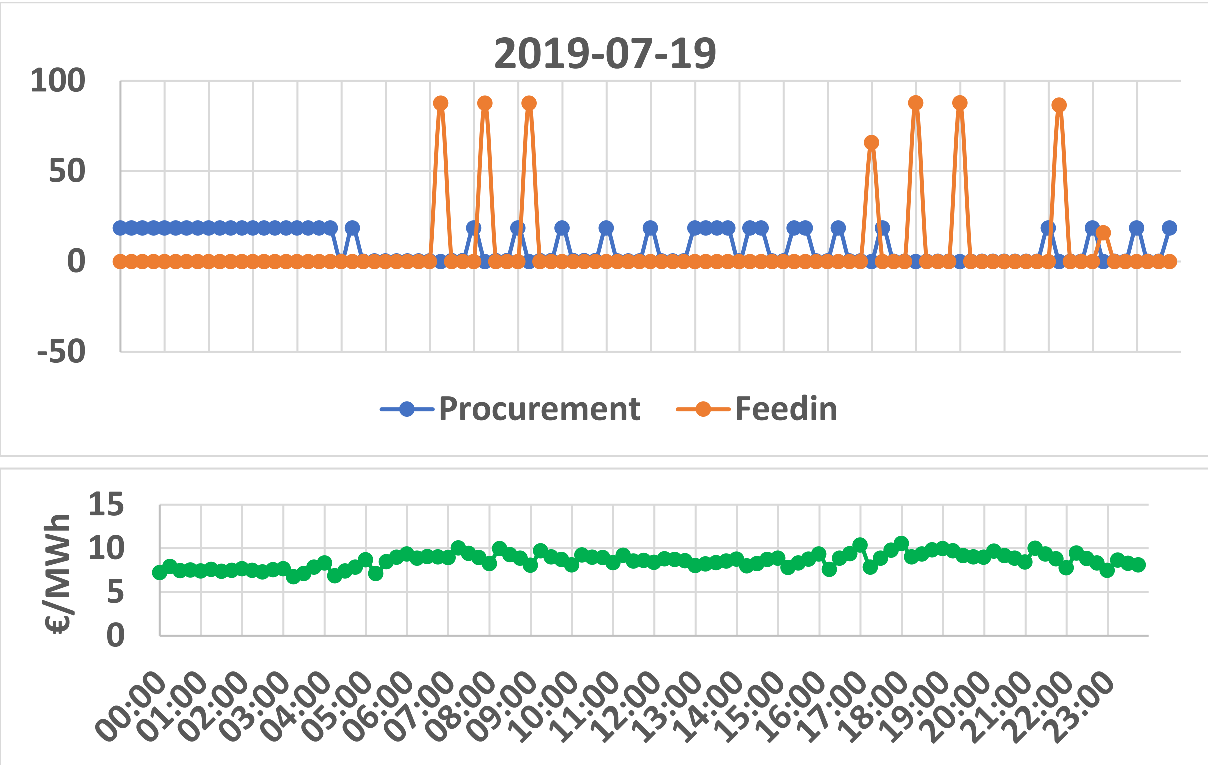


Figure 48 procurement and feed in based on the day ahead price

5.1.3 Use Case 3 – Private

A multi-objective optimisation model has been developed for private charging of electric vehicles, enabling vehicle to grid (V2G) functionality. The optimisation model aims to minimize costs and grid load, whereby the influence of the respective minimization is determined via weighting factors. This means, that the current energy consumption or self-generation is considered when determining the minimum costs or minimum power. Only the charging and discharging of the electric vehicle is considered as a controllable variable. Depending on the weighting, the vehicle is therefore charged when the costs on the spot market or the residual load at transformer level are low. Conversely, the vehicle is discharged when spot market prices are high, and the residual load is low. The load profile of the household demand and the PV generation profile are predefined for each time step and cannot be changed.

As a programming language, Python was chosen due to the wide availability of open source resources. The Pyomo optimisation module was used for modelling. The optimisation problem was solved using the commercial solver Gurobi, which was selected for its high efficiency and stability for large-scale linear and mixed-integer optimisation problems.

A spot market tariff was applied for the economic assessment, whereas on the grid side a fixed power limit at the household connection point was introduced as grid constraint. Consequently, the analysis concentrates specifically on the economic utilisation of V2G. The simulation uses an hourly time resolution and covers a full year. The study considers a single-family household equipped with an electric vehicle and a photovoltaic system, with only the charging and discharging behaviour of the vehicle being considered as a variable.

Identical basic technical parameters were used for all scenarios. These include:

Household

- Annual household energy consumption: ~4.9 MWh/a
- Time-resolved annual load profile (modelled with “LoadProfileGenerator” software)

Electric vehicle (EV)

- Maximum charging and discharging power (bidirectional): 3.7 kW
- Battery size: 64 kWh
- Annual driving energy demand: ~3.2 MWh/a (without charging losses)
- Time-resolved charging profile for uncontrolled charging without V2G (as a reference)

Photovoltaic system

- Installed capacity: 6 kWp
- Annual generation: ~5.9 MWh/a
- Time-resolved measured PV generation profile of a private household

Three price scenarios were considered to analyse the impact of V2G, each including grid fees, levies, taxes and a variable energy price based on the spot market. Scenario 1 is based on historical spot market prices from 2021 and the grid fees and levies applicable at that time. The future scenarios for 2030 and

2040 are based on price forecasts[152] that rely on assumptions in the TYNDP 2022[153] report. All three scenarios are compared with an uncontrolled charging profile without V2G operation.

Analysis of the charging and discharging profiles of the electric vehicles in the three price scenarios shows that the V2G potential is highest when applying the spot market tariff for 2021. This can be seen in Figure 50 (left panel), where the number of battery cycles caused by V2G is significantly higher than in the scenarios for 2030 and 2040. In the 2030 scenario, only limited V2G activity is observed, particularly during the summer months, indicating that the vehicle battery is rarely discharged to the grid. A key factor contributing to this behaviour is the assumed availability of the vehicle: the model assumes that the electric vehicle is mainly connected to the private charging station in the afternoon and at night. As a result, the typical midday peaks in PV generation and low or even negative spot market prices cannot be used. Instead, charging mainly takes place at night when electricity prices are lower, which excludes simultaneous V2G operation during these hours.

This behaviour is reflected both in the number of battery cycles and in the amount of energy fed back into the grid (Figure 50, right). Depending on the scenario, the annual discharge energy ranges between 1.25 MWh and 0.37 MWh. It is important to note that the energy charged minus the energy discharged in V2G operation is not directly comparable to the energy charged under uncontrolled charging conditions. This difference is due to additional charging and discharging losses resulting from the number of battery cycles in the V2G scenarios, which increases the total energy throughput.

Despite these limitations, all scenarios achieve cost reductions compared to uncontrolled charging. The savings amount to approximately 22 % in the 2021 scenario, around 11 % in the 2030 scenario, and about 14 % in the 2040 scenario. For comparison purposes, energy consumption at the household connection point was evaluated using the respective electricity price structures in all scenarios, including the uncontrolled charging case.

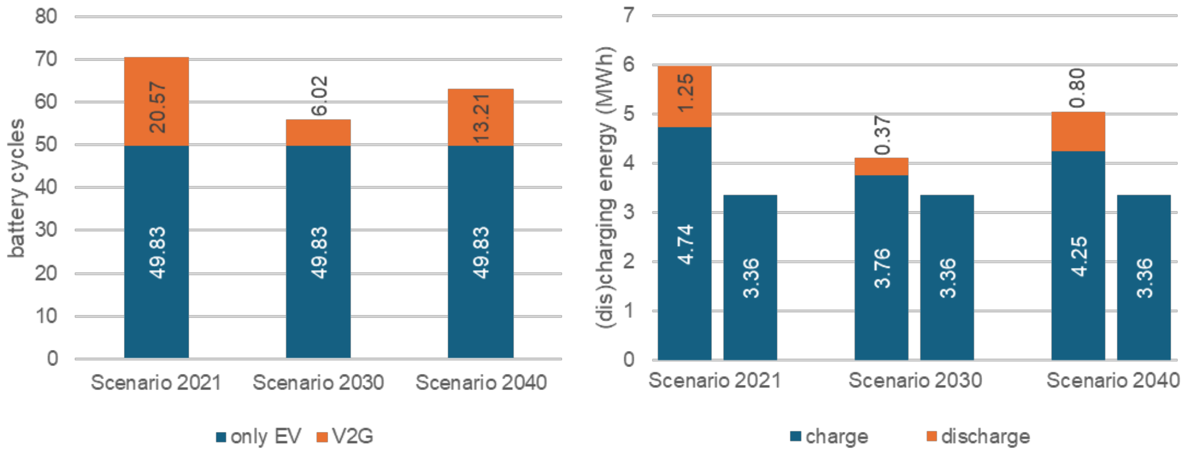


Figure 49 (left) Comparison of battery cycles per scenario; (right) Comparison of charging and discharging energy per scenario – left bar with V2G; right bar uncontrolled charging

As illustrated by the electricity price profiles in Figure 51, lower price volatility and a reduced seasonal pattern are expected for 2030 and especially for 2040. Consequently, the economic potential of V2G

[152] Loschan, Christoph ; Schwabeneder, Daniel ; Maldet, Matthias ; Lettner, Georg ; Auer, Hans: Hydrogen as Short-Term Flexibility and Seasonal Storage in a Sector-Coupled Electricity Market. In: *Energies* Bd. 16, Multidisciplinary Digital Publishing Institute (MDPI) (2023), Nr. 14
[153] ENTSOG ; ENTSO-E: *TYNDP 2022 Scenario Report – Introduction and Executive Summary*. In: *ENTSO-E AISBL | European Network of Transmission System Operators for Gas (ENTSOG)* (2021-09-27)

decreases, as the optimisation algorithm, under perfect foresight, consistently selects the lowest-cost charging and discharging strategy. Due to the limited price differences, V2G usage is therefore reduced and only the energy required for vehicle operation is supplied. Nevertheless, charging processes are optimised in terms of time, which differs from uncontrolled charging in the optimised scenarios. The evaluation of annual energy costs at the house connection point shows a reduction of almost 10% from 2021 to the scenarios for 2030 and 2040. However, this reduction is primarily due to the lower overall electricity prices in the future scenarios and not to increased V2G benefits.

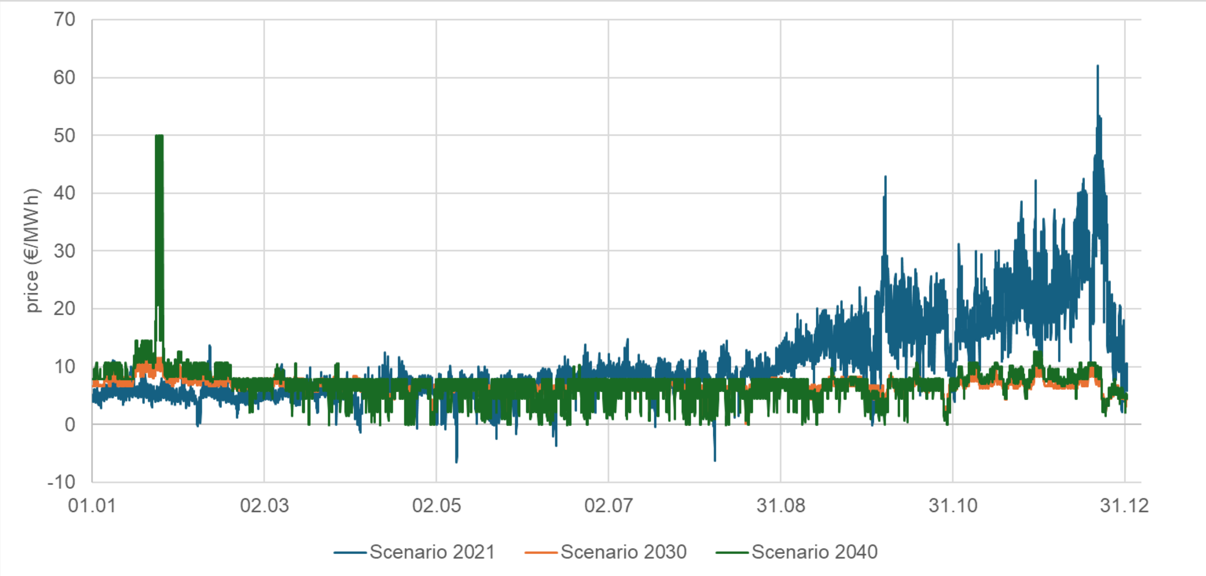


Figure 50 Spot market prices for 2021, 2030 and 2040

Figure 52 shows an example week in April with comparatively high V2G activity. The time shift in charging processes is clearly visible. It should also be noted that the vehicle does not need to be charged every day and that daily charging requirements may differ from the uncontrolled scenario. A minimum state of charge of 10% has been defined as a boundary condition, which means the vehicle must be charged enough before departure for this threshold to still be met at the next arrival at the charging station. In practice, this threshold can be adjusted to the individual requirements of users.

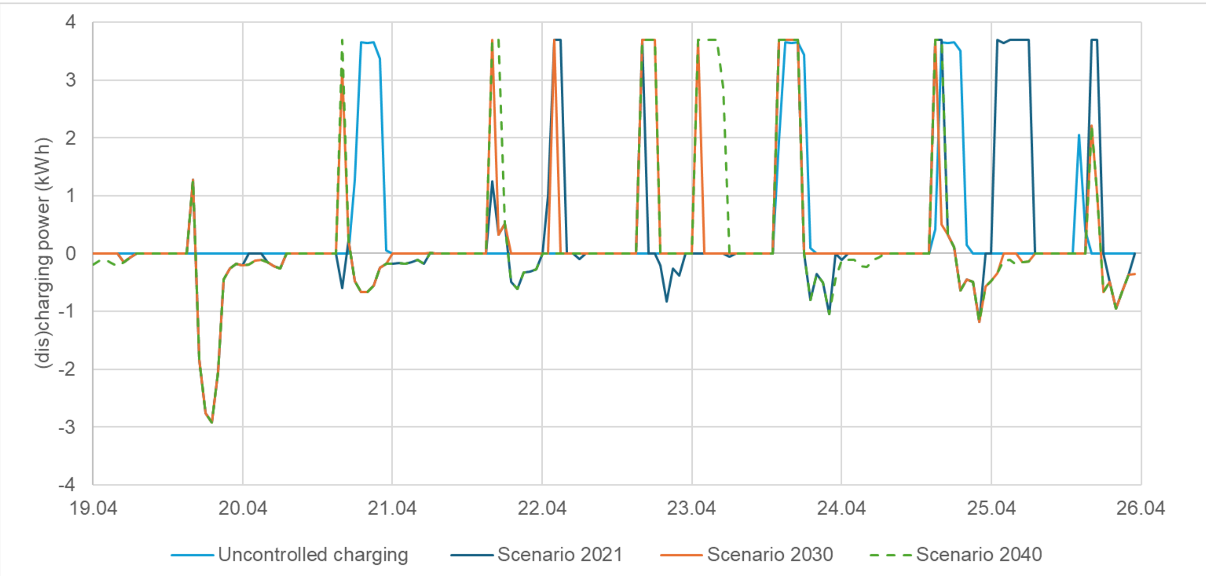


Figure 51 Charging and discharging curve of the EV for the different scenarios (Example week: 19.04. to 26.04)

5.2 Technical Simulation

The simulation results of the economic optimization of the Car2Flex use cases have been analyzed and prepared for the technical simulations. This includes the active power schedule, the connection state of each EV, and the initial and target SOC of each EV.

In the first set of simulations, the grid impact of different control strategies has been evaluated for the sharing use case and the fleet use case. In order to enable comparisons, a baseline scenario without any EVs has been defined for both use cases. Table 20 gives an overview of the simulation scenarios. The X in the scenario number is a placeholder for a set of permutations when EV control is enabled. These permutations are described in Table 21. E.g., scen_2_3 means *Sharing Use Case with EVs and P(U) control enabled*.

Table 20 Description of the simulation scenarios

Scenario Number	Use Case
scen_1	Sharing Baseline without EVs
scen_2_X	Sharing with EVs
scen_3	Fleet Baseline without EVs
scen_4_X	Fleet with EVs

Table 21 Permutations of the EV scenarios

Scenario Number	Description
scen_X_1	No droop control
scen_X_2	Q(U)
scen_X_3	P(U)
scen_X_4	Q(U) and P(U)

5.2.1 Use Case 1 and 3 – Car Sharing and Private

For the Sharing use case, multiple EV sharing communities have been deployed in the chosen LV grid. The simulation time span is one week, and the time series figures below show the results for a selected day. The nomenclature of the scenarios is described in Table 20 and Table 21.

Figure 50 shows the summed charging power of all EVs of all sharing communities. The scen_2_1 has no voltage-dependent charge control, and the resulting charging power is the highest. The three variants Q(U) (scen_2_2), P(U) (scen_2_3) and QP(U) (scen_2_4) show a lower charging power at some points in time. This is also reflected in the resulting minimum node voltages depicted in Figure 51.

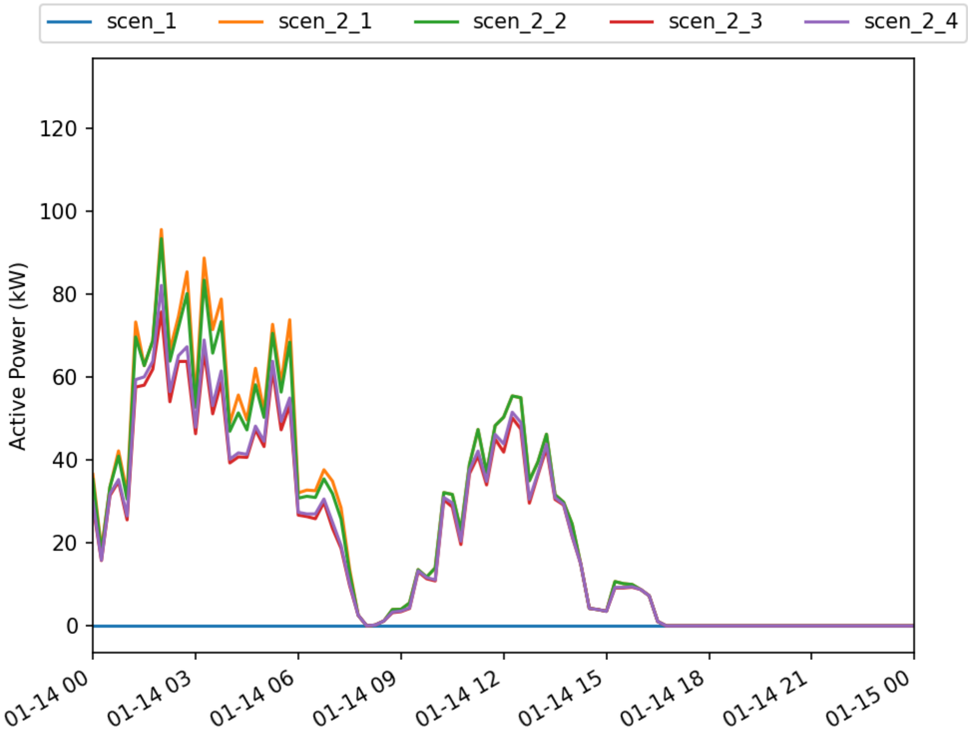


Figure 52 UC Sharing - Summed power of all EVs in the evaluated LV grid

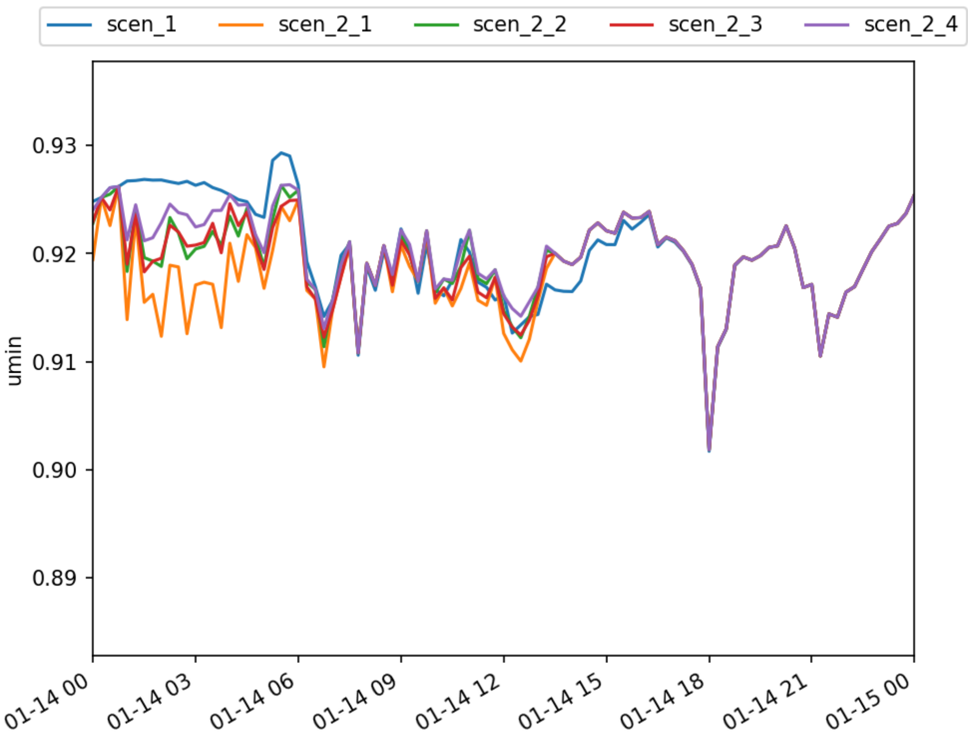


Figure 53 UC Sharing - Minimum node voltages of all node elements

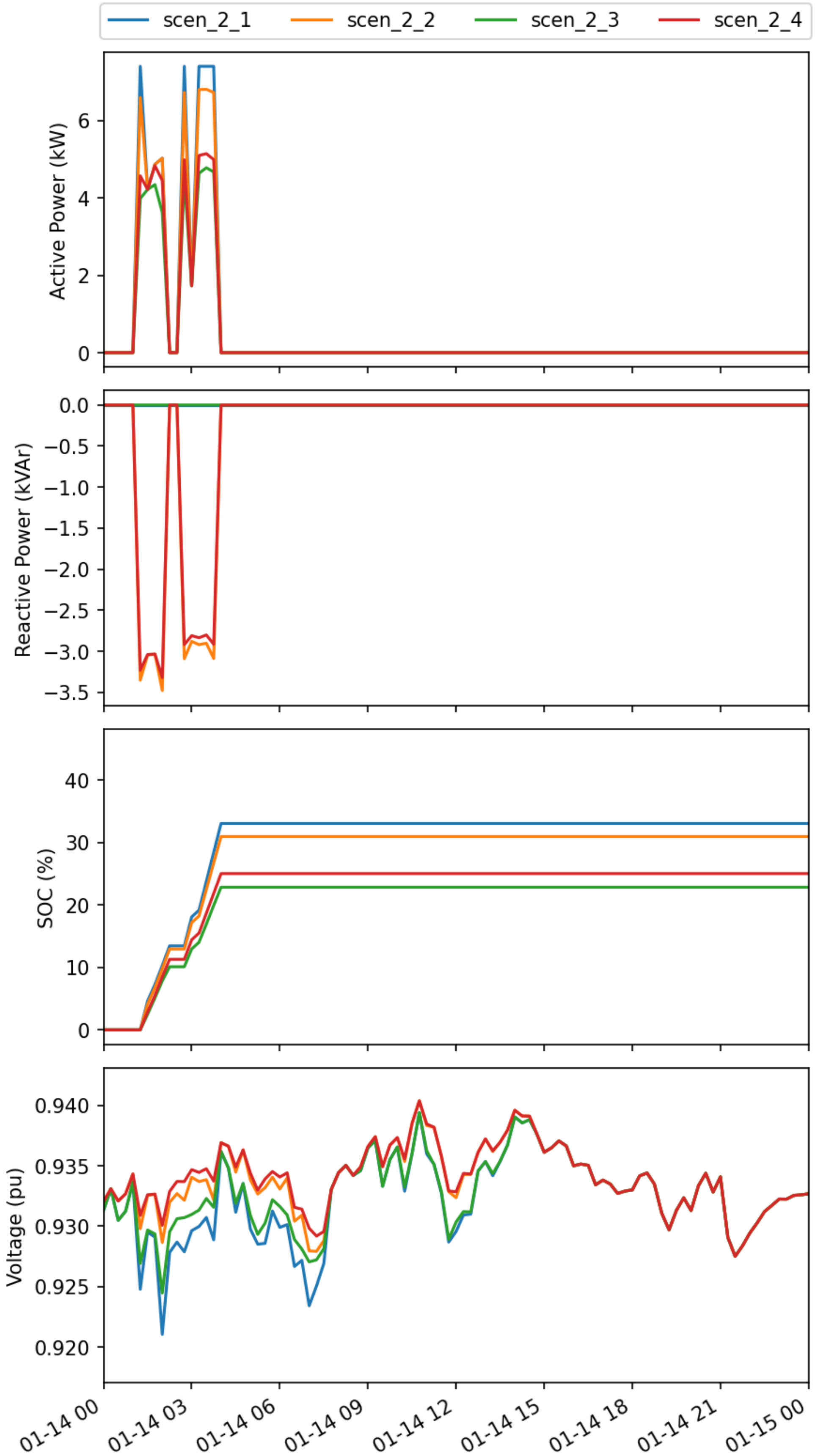


Figure 54 UC Sharing - Active power, reactive power, SOC of one EV, and the node voltage which the EV is connected to

In order to evaluate the detailed differences between the charging management approaches, Figure 52 depicts information about a single EV which is connected at a certain network node. As can be seen, the reactive power control activated in scen_2_2 and scen_2_4 helps to increase the node voltage. An interesting observation is the comparison of the different SOCs: The Q(U) scenario (scen_2_2) almost keeps up with the uncontrolled case but manages to increase the node voltage as well as scen_2_4. It should be mentioned that the node voltage is also influenced by many other nearby components. Interestingly, the P(U) scen_2_3 shows the worst voltage stabilization behavior but at the same time has the lowest charging power and lowest SOCs.

Figure 53 and Figure 54 show duration curves of the minimum voltages of all network nodes and the average SOCs. The curves describe which share of the simulation time a line is below a certain value. For example, it can be seen in Figure 54 that the Q(U) scen_2_2 does not heavily influence the average SOCs. In future simulations in Task 5.2, different setpoints for the droop algorithms can be chosen to optimize the control performance.

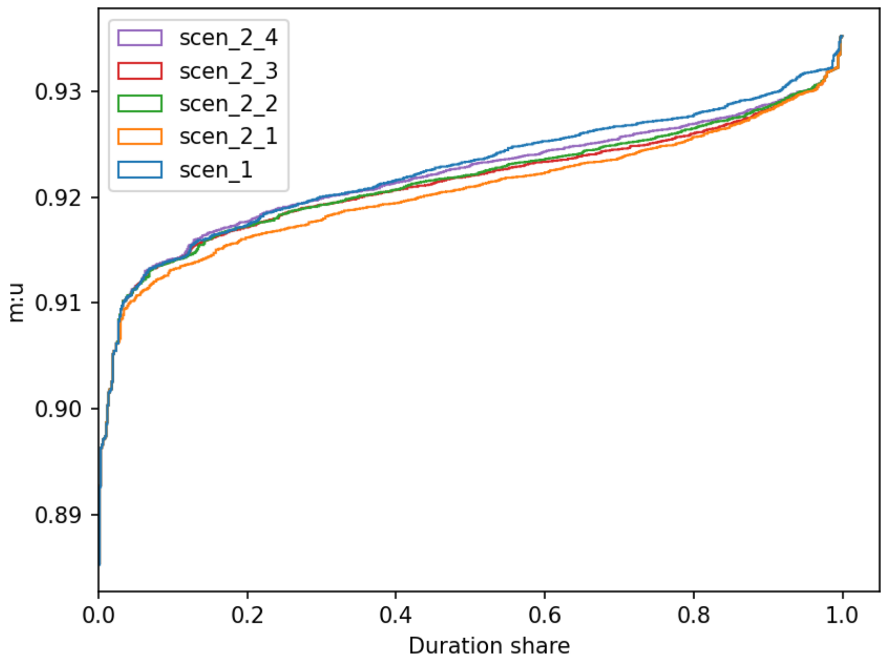


Figure 55 UC Sharing - Duration curve of the minimum voltage of all network nodes

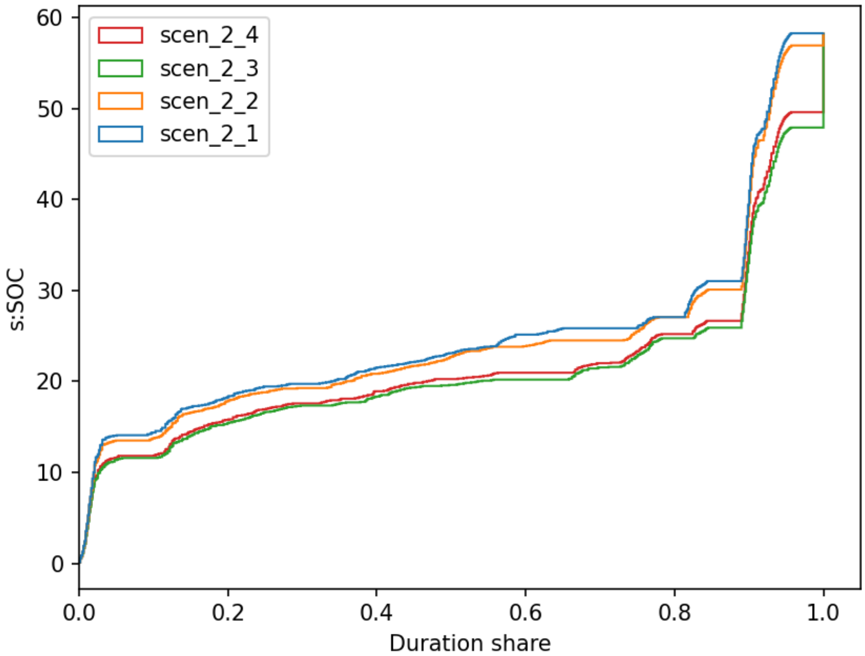


Figure 56 UC Sharing - Duration curve of the average SOC of all EVs

The results for the demo site in Lower Austria can be seen in Figure 55.

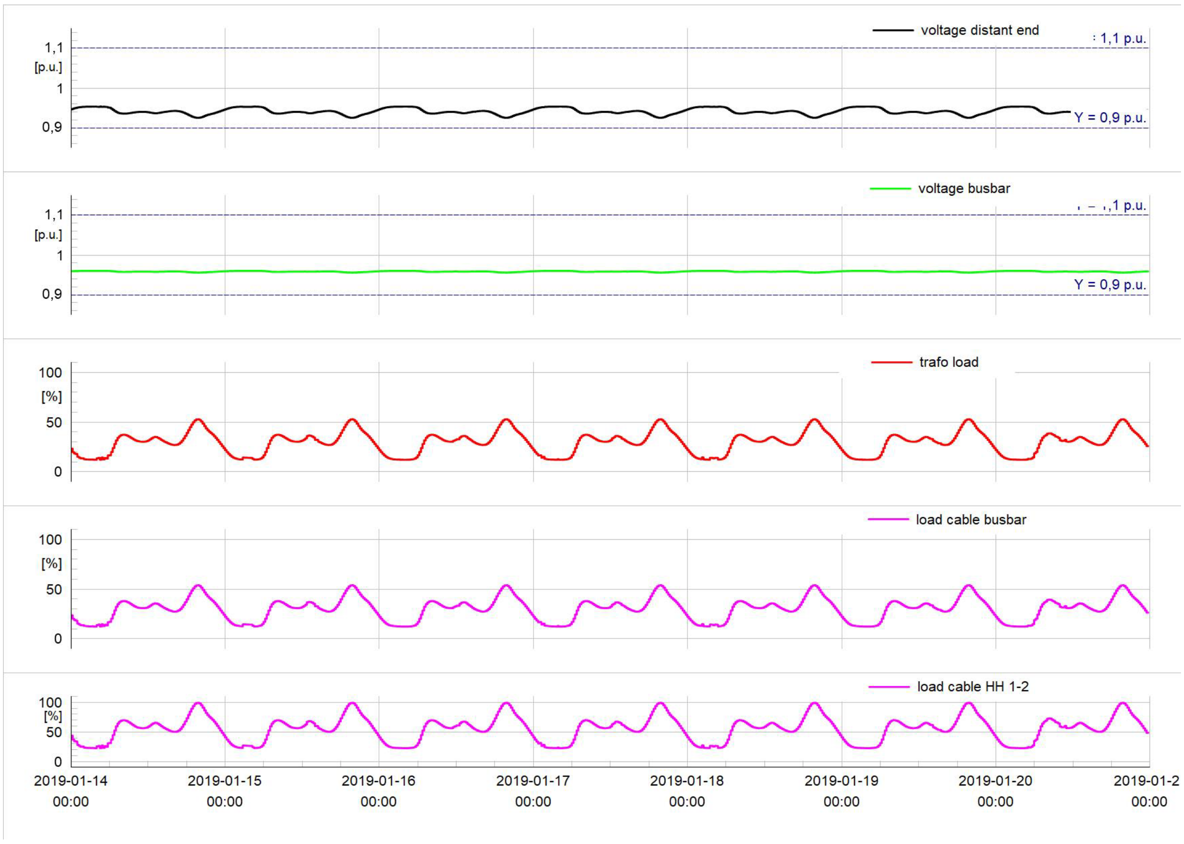


Figure 57: Results of load flow calculation, use case sharing (TUW)

The cable between the households 1 and 2 reaches the rated current. This was not expected and will be checked with measurements on the demo sites. With the measurements the model may be improved, especially the household load might be estimated too high with the standard load profile “H0”.
As only one branch of interest is modelled in the simulation, excluding other branches connected to the transformer, the rated current of the transformer is not reached. This result can therefore not be used to estimate the real load of the transformer.
The results can be seen as worst-case scenario because of two reasons. First, the simultaneity of the household loads is estimated high, with a maximum of up to 92% of the sum of the nominal loads. Secondly, the voltage set in the medium voltage grid and the transformer setup lead to a voltage of around 96% at the bus bar in the low voltage grid. Since the loads are modelled as P/Q-loads with constant power, the low voltage leads to higher currents and higher load of the cables. If the transformer has a tap changer, the real voltage will most likely be higher, leading to lower load of the cables.
The low secondary voltage of around 96% on the transformer, combined with the voltage drop along the cable, may lead to under-voltage on the distant nodes. Therefore, the voltage at the demo site will also be measured to check the plausibility of the model and improve it if necessary. The voltage at the primary winding of the transformer is set to 100% of the rated voltage. According to the Austrian TOR [1], the voltage in the medium voltage grid may be as low as 95% of the rated voltage. With the voltage of the primary winding set to 95% of the rated voltage, the voltage at the distant node is below the allowed value of 90% of the rated voltage. It is most likely, that the transformer has a off load tap changer, which is set to increase the open circuit voltage. Therefore, the measurements at the demo site will be used to verify the model and possibly adapt it afterwards.
Figure 56 shows the detailed time series for the realization of a schedule including P(U) and Q(U) control.

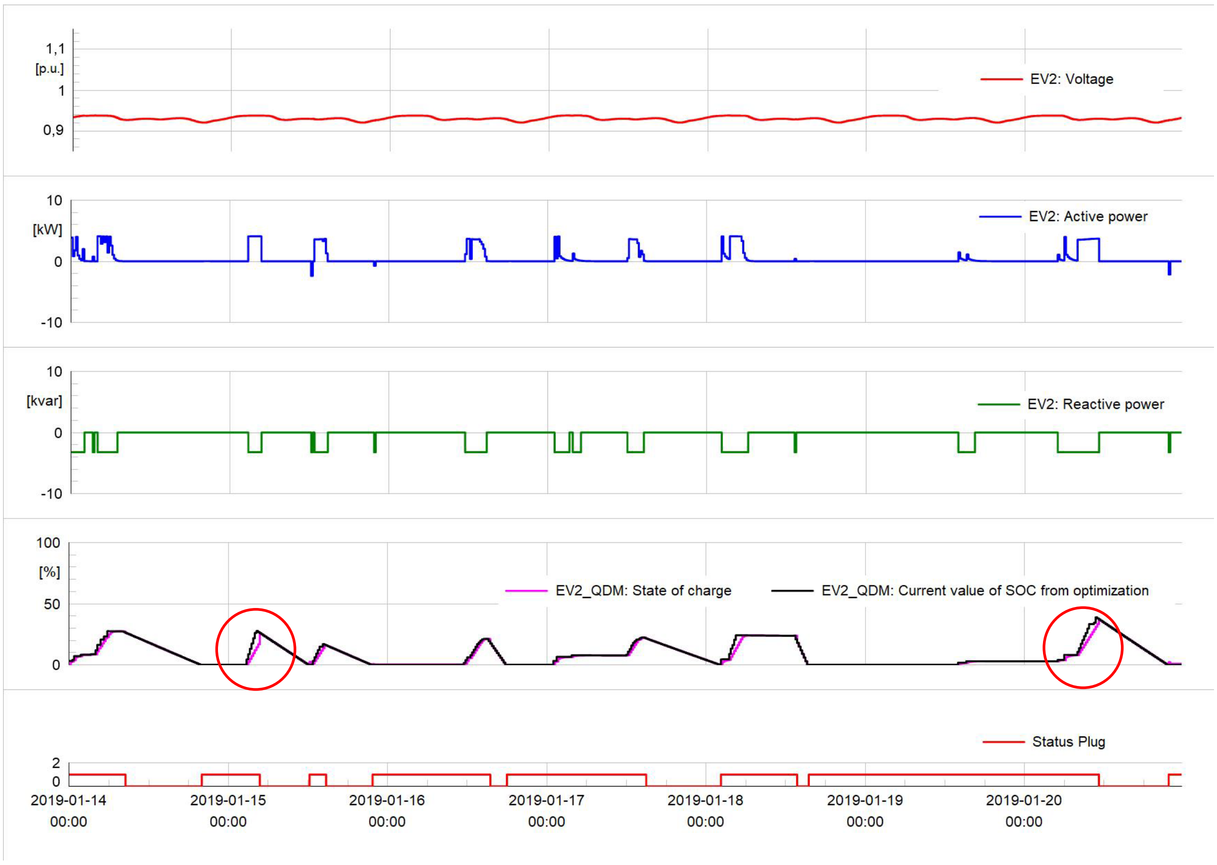


Figure 58: Realizing a schedule with P(U) control activated

In order to activate the P(U) control significantly, the voltage on the medium voltage grid was set to 98% of the nominal voltage and the threshold for the P(U) control was set adapted so the control is activated under 100% of the nominal voltage. The activation of the P(U) control can be examined since the active power is lower than the nominal power of 7,4kW used for charging.

A problem with the desired schedule is that in most cases the EV will be charged shortly before it leaves and will only be charged exactly to the necessary SOC. This is a result of the optimization to minimize the losses due to self-discharge of the battery. This leads to a problem when trying to reach the admired SOC, since sometimes the admired active power cannot be reached and there is no possibility to charge later, since the EV has already left the EVSE. In the examined week there were two occurrences of a not fulfilled SOC demand, which are marked in Figure 56 with red circles. In all other cases, the admired SOC could be reached by charging the battery later than desired.

The problem with not reaching the admired SOC does not only occur with P(U) control, but may also appear because of the reasons described in the section EV Charge Control Strategies. These circumstances must be considered at the implementation of the Car2Flex platform. To avoid these problems, a possibility would be to add a specific amount of energy to the requested SOC in the optimization up front. In addition, it would be reasonable to keep the battery at a minimum SOC to be able to fulfill spontaneous driving requests and to avoid the battery taking damage from under-voltage.

5.2.2 Use Case 2 – Company Fleet

The optimization results of the company fleet use case have also been prepared for the technical simulations. In this use case, bidirectional power transfer has also been simulated. Figure 57 shows the summed power of all EVs for one selected day. The corresponding minimum node voltages are depicted in Figure 58. Similar to the Sharing use case, the scenarios where active power droop control activated show a reduced overall EV power. In contrast to the Sharing use case, the difference is much higher because the grid is heavier loaded (higher EV penetration).

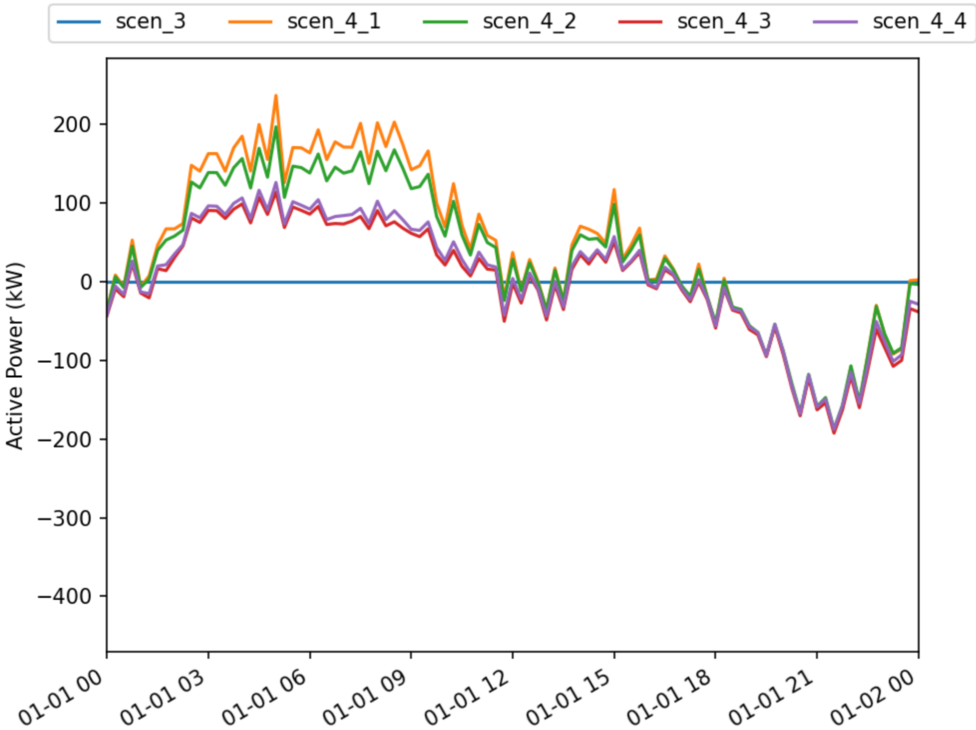


Figure 59 UC Fleet - Summed power of all EVs in the evaluated LV grid

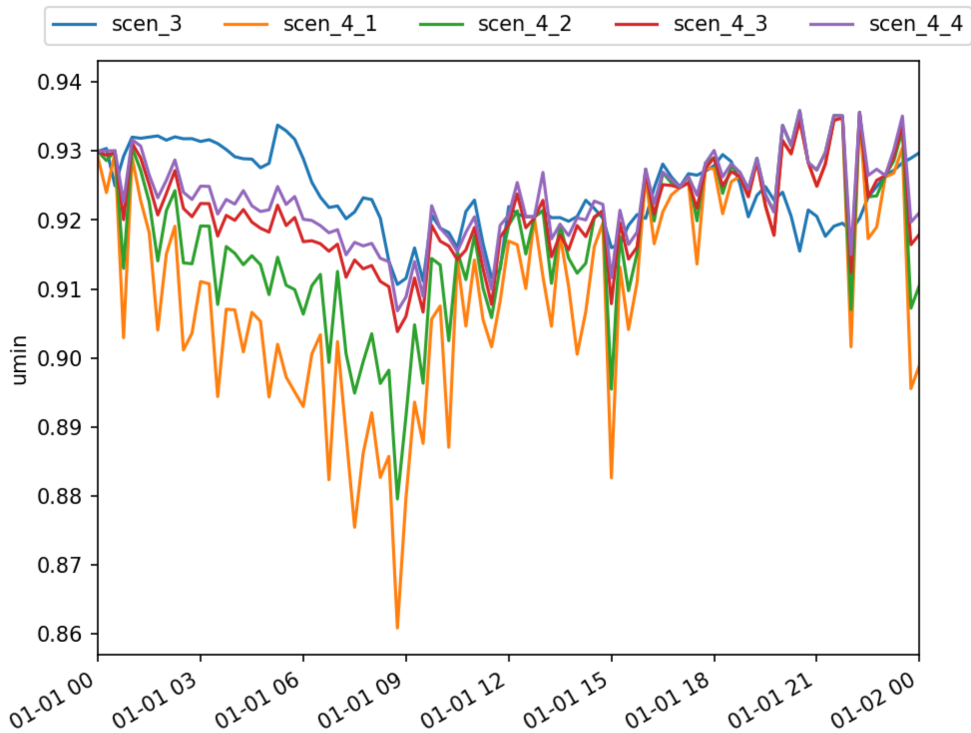


Figure 60 UC Fleet - Minimum node voltages of all node elements

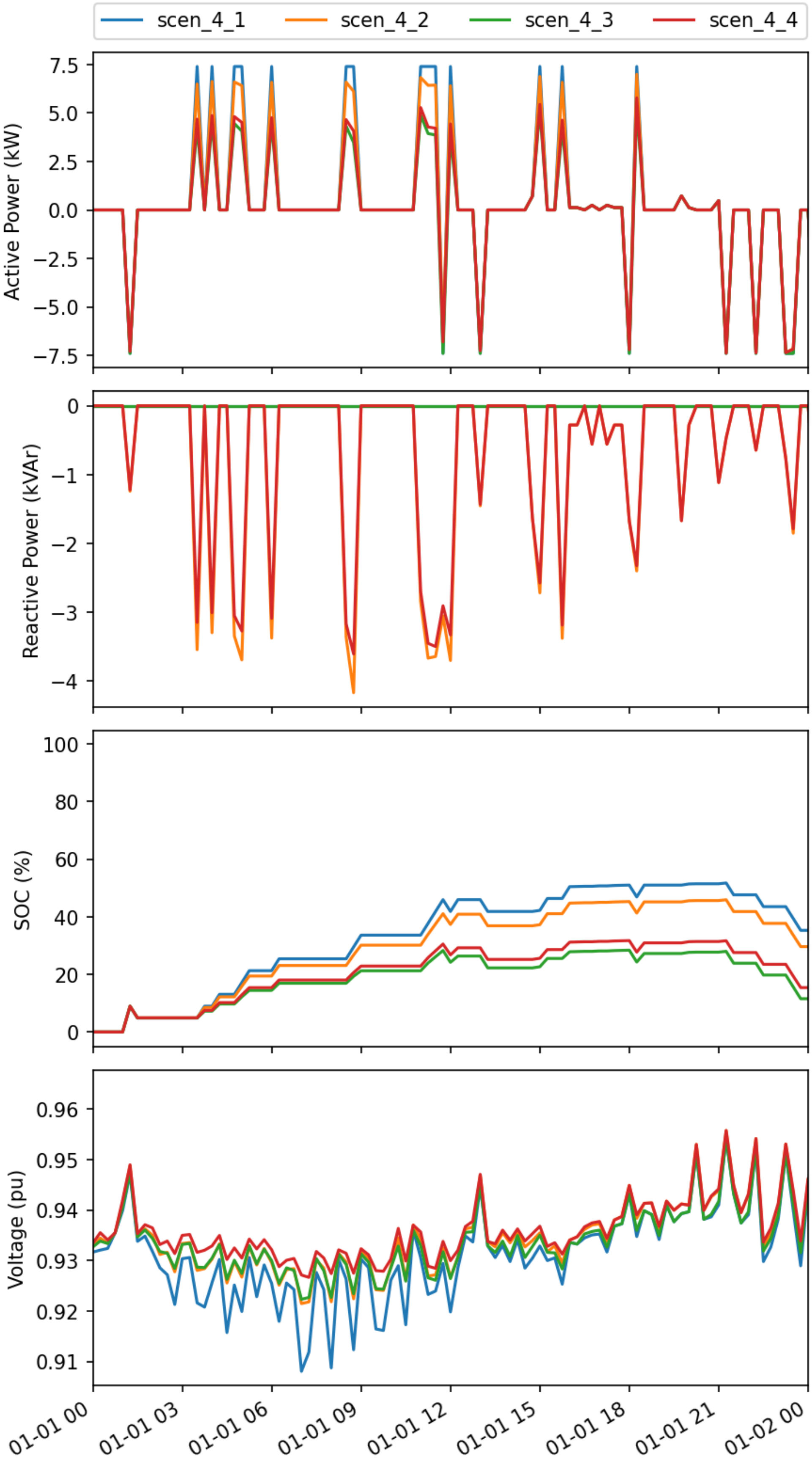


Figure 61 UC Fleet - Active power, reactive power, SOC of one EV, and the node voltage which the EV is connected to

Figure 59, Figure 60 and Figure 61 show that in severe undervoltage situations, the active power control enabled in scen_4_3 and scen_4_4 leads to a heavily reduced SOC of the cars. Again, the Q(U) control in scen_4_2 provides good voltage stabilization while only marginally influencing the SOCs. An increased loading of the cables and transformer has not been observed because the nominal apparent power of the EVSE cannot be exceeded even with Q(U) enabled.

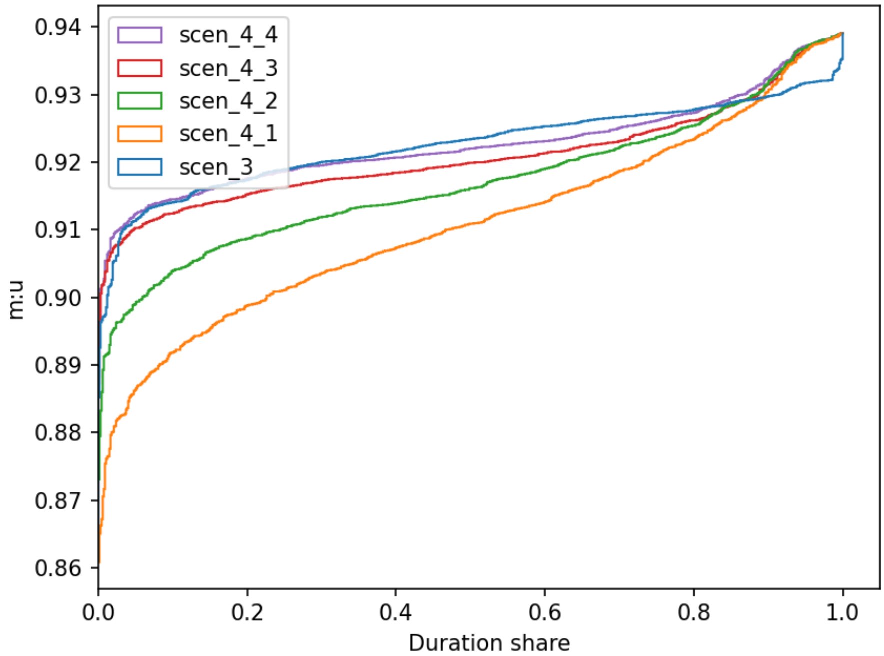


Figure 62 UC Fleet - Duration curve of the minimum voltage of all network nodes

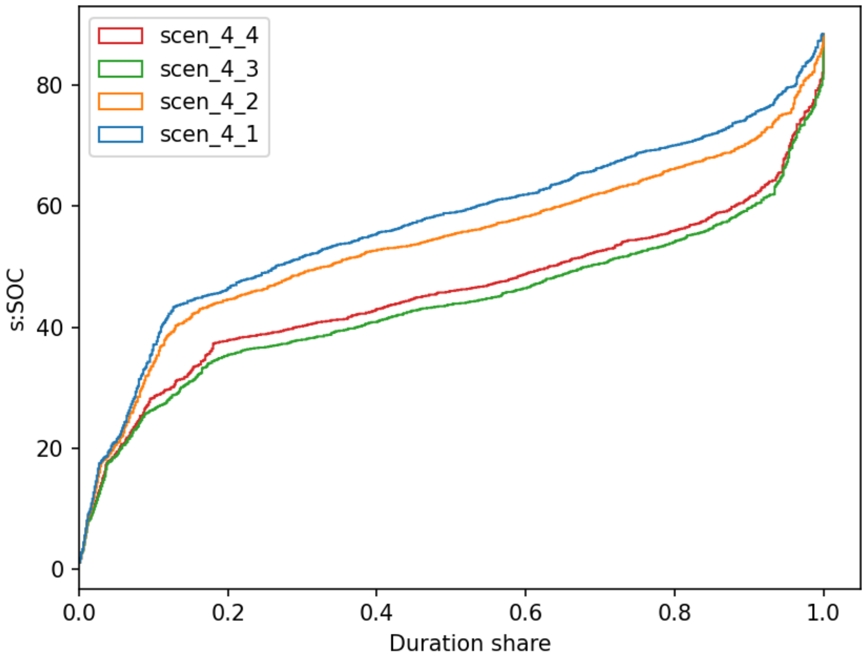


Figure 63 UC Fleet - Duration curve of the average SOC of all EVs

6 Car2Flex Demonstration-sites

Based on the framework conditions developed for the three e-mobility use cases (car sharing, company fleet, individual/privat), which are described in more detail above, the Car2Flex demos are defined. As the publication of the ISO 15118-20 standard and its implementation were continuously delayed, it was not possible to define which vehicle models would be required for the Car2Flex demos. Consequently, the identification of suitable sites was made difficult by the need to ensure that the existing e-vehicle (EV) models would allow bi-directional charging in practice. The demos are designed, for example, to test the developed technical concept, to validate the communication between the power grid and the EV driver, and to collect empirical values and measurement data for validation.

6.1 Use Case 1 – Car Sharing

6.1.1 Absdorf

The charging station at Absdorf was put into operation with significant public visibility in April 2024, while the carsharing service was launched in August 2024.

v.l.n.r. DI Stefan Czamutzian MA (Region Wagram), Bgm. Franz Aigner (Obmann Region Wagram), DI Matthias Komarek (Energie- und Umweltagentur des Landes Niederösterreich), Ing. Mag. Ludwig Fliesser (Forschungsinitiative Green Energy Lab), Bgm. Dir. Franz Dam (Bürgermeister Absdorf), DI Matthias Zawichowski (Verein fahrvergnügen.at / im-plan-tat Raumplanungs GmbH & CoKG)

The following framework conditions provided the basis for the testing phase concerning bidirectional charging:

- The vehicle was characterized by a 40 kWh battery which is always charged by at least 45%.
- Depending on booking demands, the battery can optionally be used to supply electricity to the stairwell.
- As soon as bookings are made via the platform, an assessment is carried out of how much electricity is required for mobility and how much remains available for the stairwell supply.

- If grid consumption exceeds 12 kW, the vehicle discharges so that a maximum of 12 kW is drawn; if grid consumption is below 12 kW, the vehicle is recharged accordingly (functioning similar to a zero-feed-in system).

The following graphic provides an overview of total consumption and feed-in since the commissioning of the smart meter, which has been recording data since June 2024.
It can be clearly seen that until around mid-September, consumption was covered by PV to about 50%, as consumption and feed-in rose equally. After that, however, consumption definitely exceeded generation, while feed-in stagnated. This suggests that the PV electricity was either consumed directly or temporarily stored in the vehicle and later used locally. This pattern flattened with the increasing PV yield in April–May 2025, since in addition to higher generation, the heat pump as the main consumer was less active.
Since the start of data recording, approx. 51.4 MWh have been drawn from the grid and around 4.1 MWh have been fed into the grid.

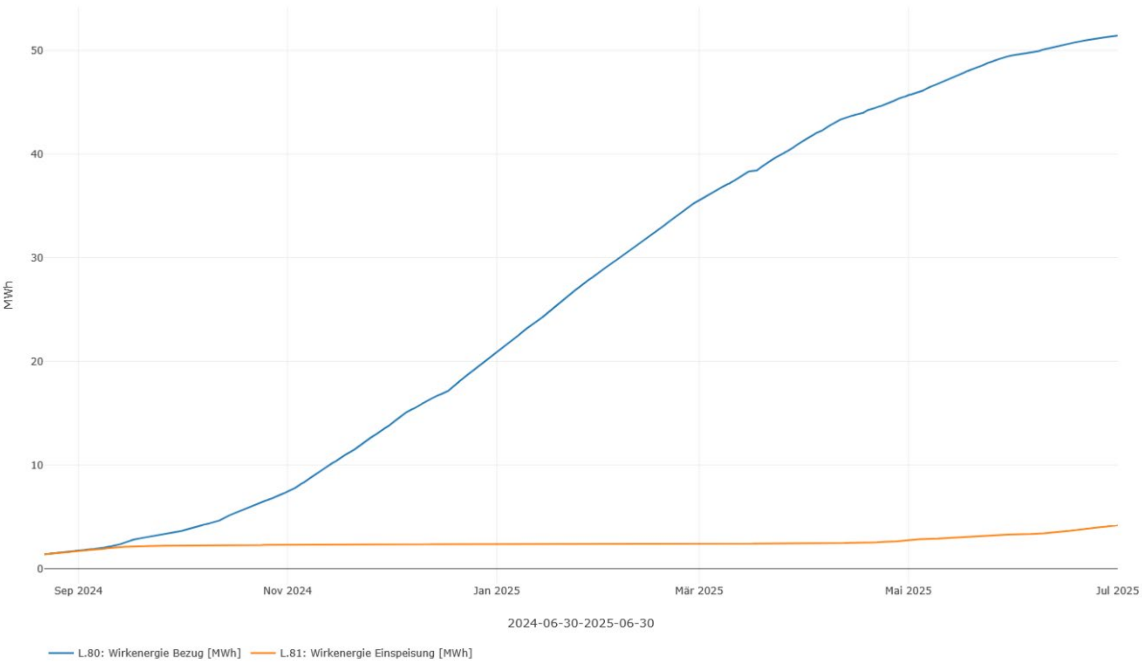


Figure 64 Total consumption/feed-in at Absdorf

Another graphic now shows the real data of the carsharing vehicle at the Absdorf site in October 2024. During this month, the e-carsharing vehicle was absent from the site for about 1.5 days. This difference is clearly visible in the grid consumption (green) – it becomes evident that grid activity increases when the vehicle reaches charging limits.
In addition, it can be observed that peaks in relation to the grid (grid consumption peaks – aggregated 15-minute values) are capped. Grid activity is, for example, more intensive due to the constant switching on and off of the heat pump, but likely also due to other consumers such as lighting.
This provides evidence that the electric vehicle, when used bidirectionally, is indeed capable of smoothing grid consumption peaks (consumption is at times around 12 kW, while the EV can offset up to 8 kW –

since the charging station is limited to 9 kW output/input capacity – so that the actual grid draw partly falls below 5 kW within the observed period, provided that system and charging limits can be maintained).

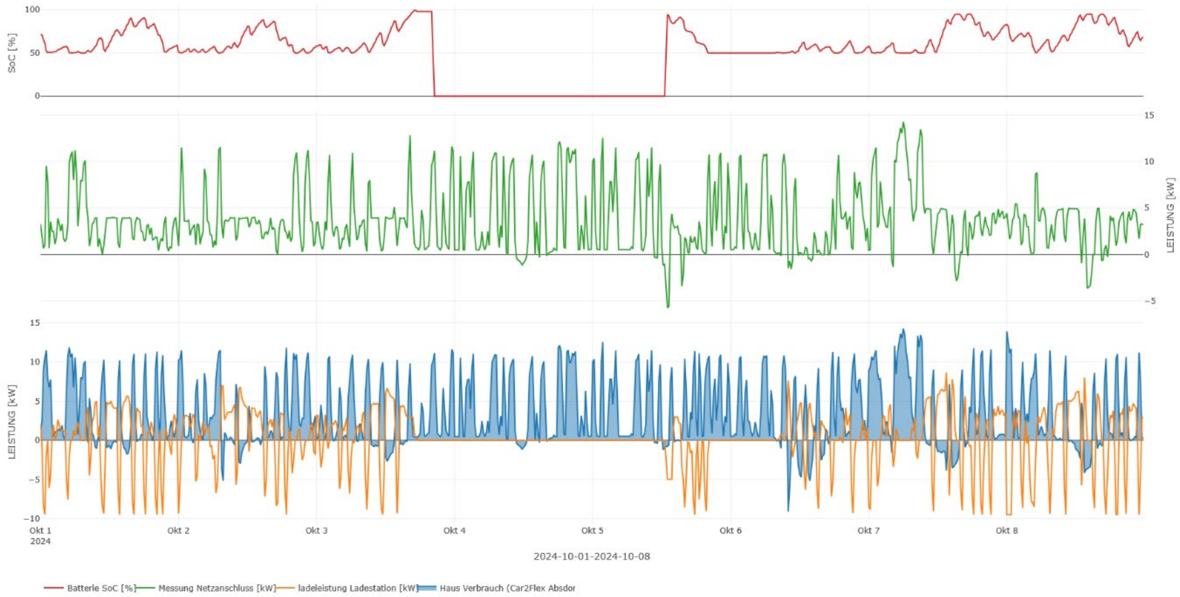


Figure 65 Real test data from the first week of October 2024 at Absdorf

Further valuable practical insights that were gained at the Absdorf site are provided in Figure 64, which shows real test data from January 2025.

A clear baseload can be observed here, most likely attributable to the consumption of the heat pump. The additional peaks that can be seen are likely caused by lighting and the elevator. Due to the seasonally lower PV production, little to no PV electricity could be stored. The car therefore served as much as possible for load smoothing. This clearly demonstrates that the heat pump is a distinctly cyclical, but not constant, consumer.

In this case, the vehicle was primarily charged with electricity from the grid – with grid peak values (heat pump and charging station combined) reaching up to 18 kW. On January 21, the charging limit was experimentally raised from 80% to 85% in the morning only. In this way, more energy could be stored and subsequently released.

Figure 66 Real test data from the second and third week of January 2025 at Absdorf

Figure 65 illustrates real operation in March 2025.The **red line** represents the state of charge (SoC). The charging limits here are always between 45% and 85%, which corresponds to a storage capacity of 16 kWh.

The **green line** indicates the value measured at the main metering point, i.e. the power drawn from the grid.

The **blue line** shows the building's consumption, in this case that of staircase 3 (consumption/feed-in). The **orange line** depicts the activities of the charging station, which attempts to counterbalance fluctuations. The objective is to maintain grid consumption at 8 kW, provided the maximum charging power of ±9 kW is not exceeded and the charging limits are not under- or overshot.

During colder periods, grid consumption is set to around 12 kW, for example, in order to avoid an empty vehicle and to ensure charging in general. In this way, it can be guaranteed that sufficient residual charge (SoC) is always available so that the vehicle can be charged quickly if required, without the need for excessively high power draw. (Heat pump approx. 15 kW and charging station approx. 10 kW – max.)

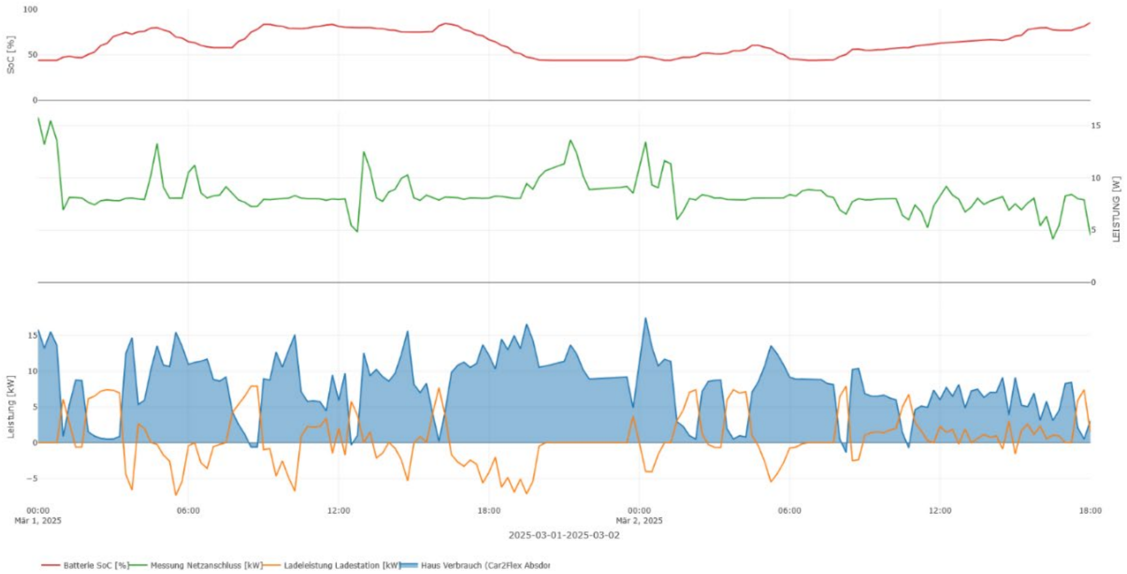


Figure 67 Real test data from March 2025 at Absdorf

Figure 4: Real test data from March 2025 at Absdorf

Figure 66 shows the cumulative power values of the charging station. Since the beginning of the recordings, approx. 1,640 kWh of electricity have been required for carsharing trips (as of June 30, 2025).

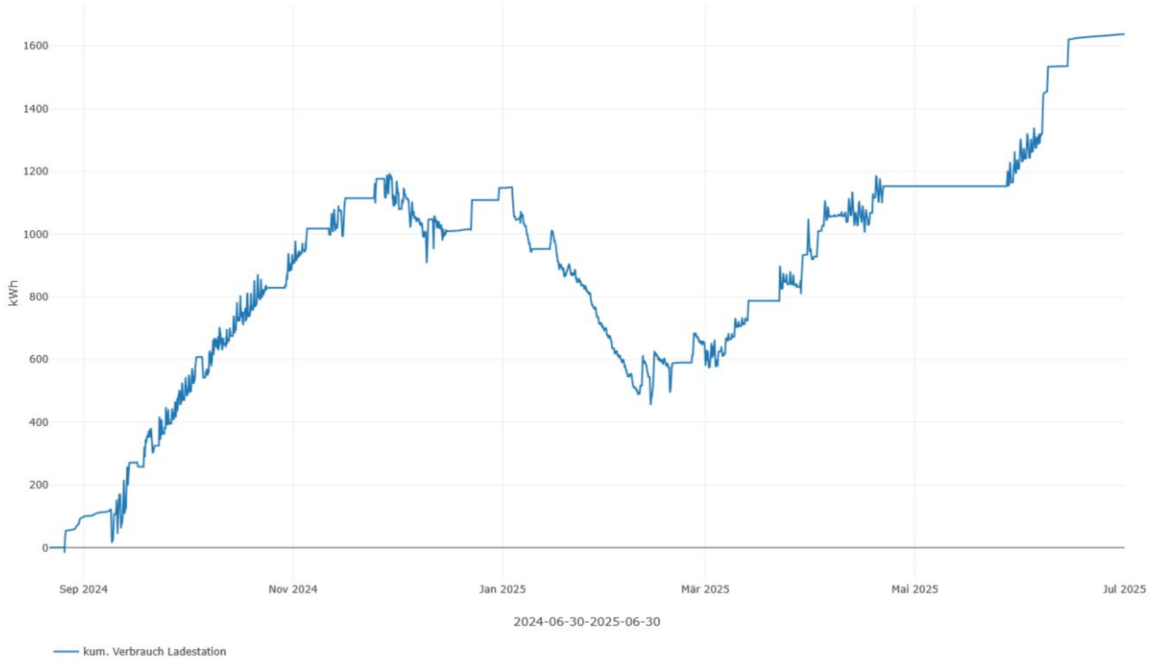


Figure 68 Total electricity consumption concerning carsharing

6.1.2 Stockerau

The charging station at Stockerau was also put into operation with strong media coverage in April 2024. The sharing service itself was launched in August 2024.

The framework conditions defined for the pilot site at Stockerau were as follows:

- The vehicle is equipped with a 40 kWh battery, which is always charged to at least 45%.

- Depending on booking demands, the battery can optionally be used to supply electricity to the stairwell.
- As soon as bookings are made via the platform, an assessment is carried out of how much electricity is required for mobility and how much remains available for the stairwell supply.

The carsharing vehicle, a Nissan Leaf, is located – as already mentioned in the previous report – at Gustav Mahler-Promenade 4. The multi-unit residential building is equipped with an 8 kWp PV system installed on the roof.

In bidirectional operation, the vehicle supplies both stairwell 2 (general electricity) and the elevator. A dedicated smart meter IP additionally provides data to the EMS, ensuring that maximum values for consumption and feed-in are not exceeded.

Figure 69 DI Matthias Zawichowski (Verein fahrvergnügen.at / im-plan-tat Raumplanungs GmbH & CoKG), DI Matthias Komarek (Energie- und Umweltagentur des Landes Niederösterreich), Dir. Martin Schuster (Obmann und Vorstandsvorsitzender der NÖ Bau- und Siedlungsgenossenschaft), Ing. Mag. Ludwig Fliesser (Forschungsinitiative Green Energy Lab

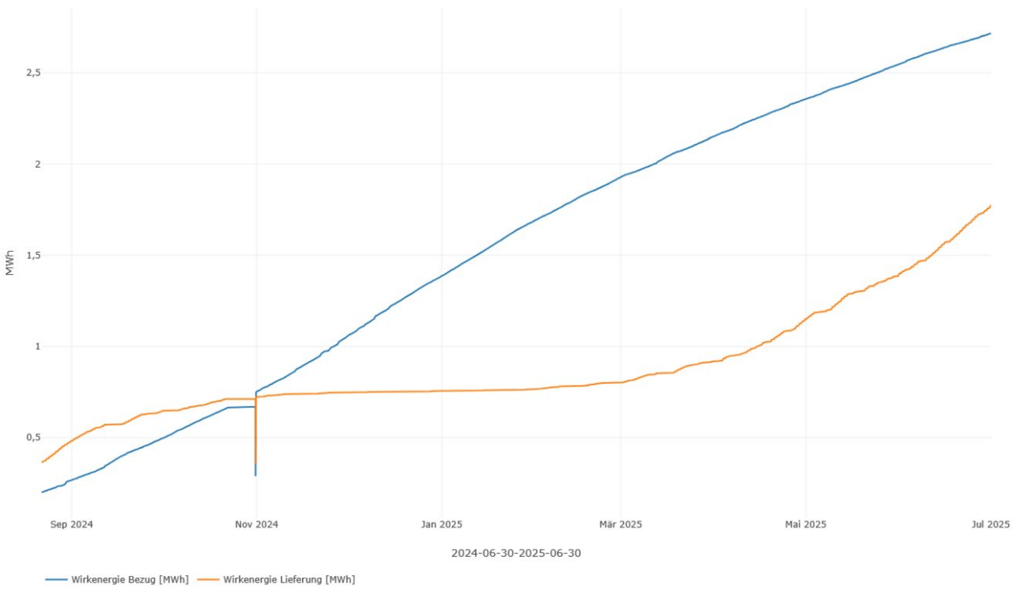


Figure 70 Total grid consumption/feed-in at Stairwell 3

Figure 68 illustrates the total grid consumption and feed-in achieved during the test operation. Specifically, grid consumption amounted to approximately 2.7 MWh, while around 1.7 MWh were fed back into the grid. At the beginning, production exceeded consumption, a trend observable until around mid-September (the curve stagnates just as quickly or even faster than consumption). Between the end of October and the beginning of November, a change can be noticed, visible in the figure as a "kink." At that time, however, no data were available – once the charging station was connected and operational, this was interpreted as an issue with data storage.

Afterwards, consumption developed relatively steadily, indicating that the vehicle successfully functioned as an electricity storage unit. Since March 2025, production has again consistently exceeded consumption, suggesting that surpluses were fed into the grid and that measured consumption slightly decreased.

It can also be concluded that the available storage (SoC 45–95%) was sufficiently large to cover most of the consumption, except during periods of poor weather.

Figure 69 now provides further exciting insights into the practical application possibilities of bidirectional charging:

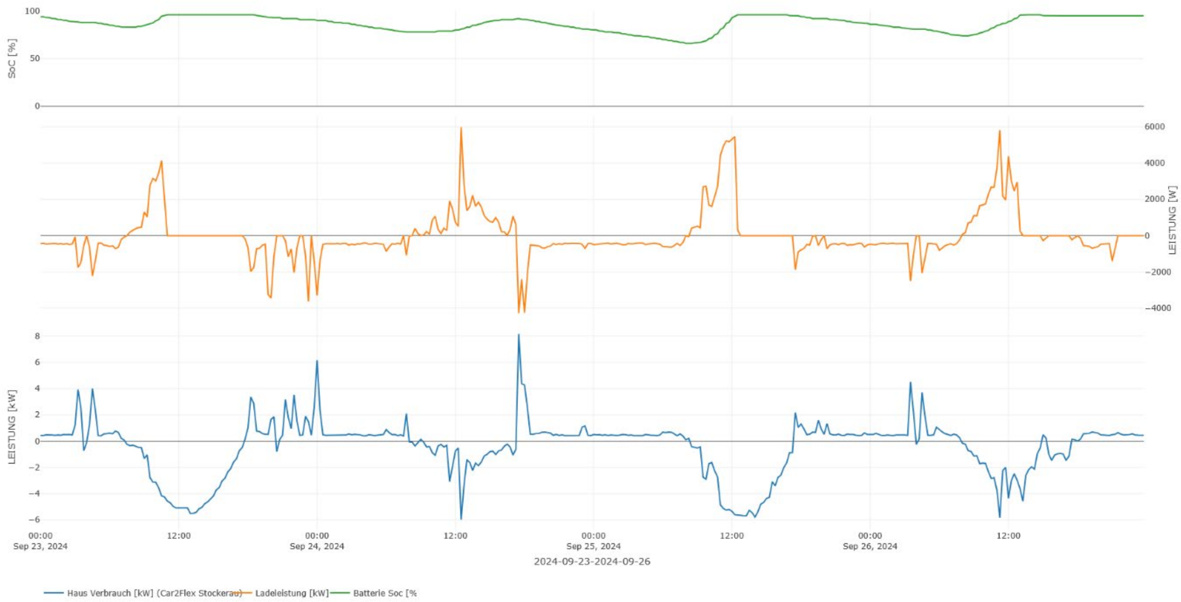


Figure 71 Real test data, fourth week of September 2024

A closer look at Figure 69 reveals that the vehicle was able to cover consumption almost entirely through the bidirectional use of its battery. It is noteworthy that the discharge limit was hardly ever reached, while the charge limit was often reached by midday – meaning the vehicle was frequently fully charged at that time.

The subsequent Figure 70 illustrates the potential of different operating modes tested during the research project. Particularly in November – when PV generation is typically lower – the electric vehicle occasionally had to be charged from the grid. To ensure a valid data basis, various strategies were applied, such as dynamic spot market charging and discharging. Without these approaches, no relevant energy exchange would have been measurable. Instead, constant low charging levels were used to maintain continuous operation and enable meaningful analysis.

Figure 72 Real test data, fourth week of November 2024

In contrast, the following figure again focuses on a springtime period, specifically March 2024. It is evident that the battery, due to charging with PV electricity, is usually full by late morning. This suggests that night-time consumption is too low to allow for additional energy storage. In this case, discharging is therefore mostly inefficient, which can also be explained by the low consumption of the building, with a base load of just 0.2 kW.

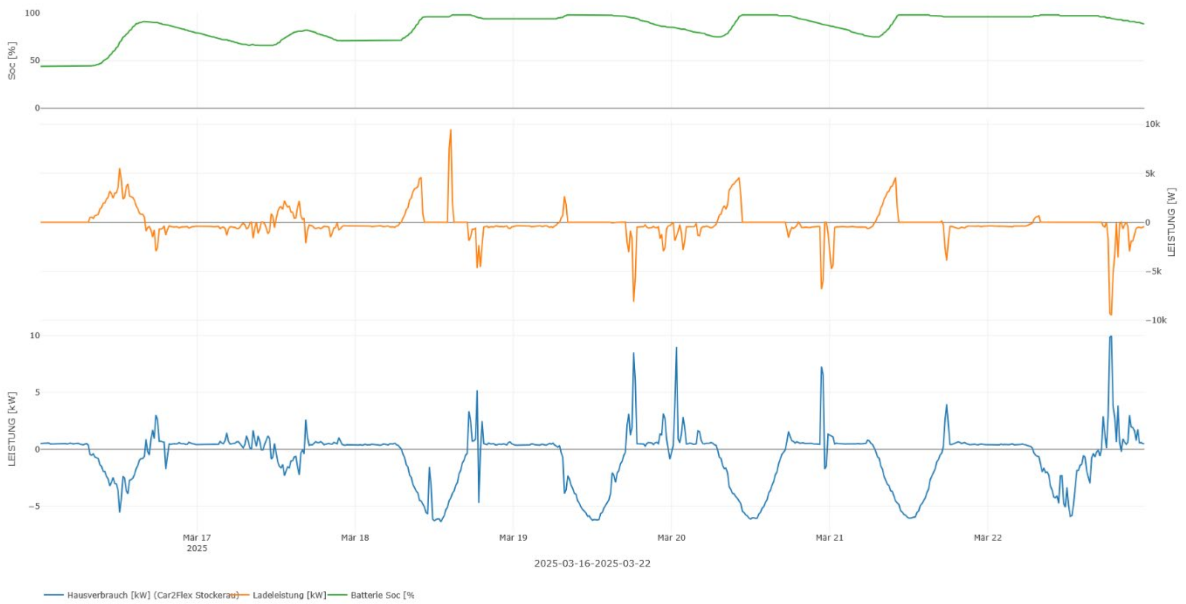


Figure 73 Real test data, second and third week of March 2025

Figure 9: Real test data, second and third week of March 2025

Finally, Figure 72 illustrates the overall electricity consumption of the carsharing vehicle during the trial operation from summer 2024 to the end of June 2025. Since the beginning of the recordings (noting that several delays had occurred), more PV electricity was stored and released by the carsharing vehicle than was actually needed for the trips themselves. This can be observed in the fact that after the winter months, PV output increased, but the vehicle was used less frequently for driving. As a result, the car battery often served as a storage unit for local consumers. Cumulatively, more electricity was stored over the testing period than was required for carsharing trips.

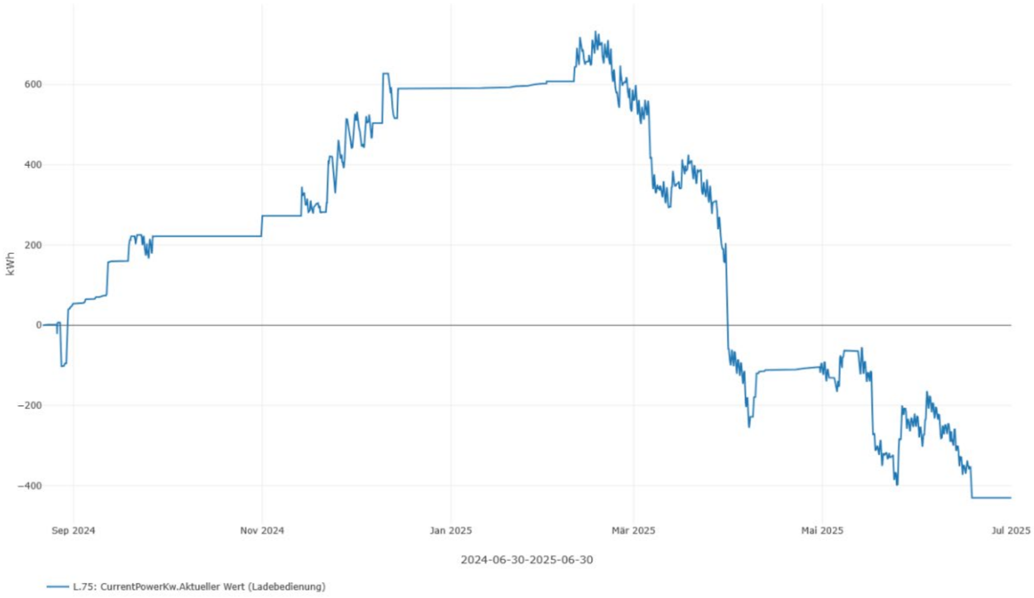


Figure 74 Power demand carsharing

6.1.3 Korneuburg

At Kreuzensteinerstraße 2–4 in Korneuburg, a Fronius prototype (bidirectional DC charging station for CCS plug) was installed on the northeast house wall in front of the garage driveway in early June. This setup consists of two devices connected to each other: a Fronius Symo GEN24 10.0 Plus and the actual Fronius prototype, which mainly handles communication. The charging station has implemented ISO 15118-20, the standard required for bidirectional charging via CCS. However, due to current vehicle-side limitations, the station could only provide controlled charging (PV surplus and spot market charging).
The prototype is connected to the building's general electricity supply. Consumers at the metering point (transformer measurement) include a 25 kW electric heat pump, an elevator and lighting. On the generation side, the building has a 70 kWp PV system with a 90 kWh battery installed on the roof. For energy management, a Fronius Smart Meter IP was once again installed for root measurement. In total, the building has 32 residential units. A collective generation system (GEA) was implemented and is currently in operation.

Figure 75 Charging station at Korneuburg

The following graph provides an overview of total electricity consumption and feed-in since the commissioning of the smart meter, which has been recording data since late June 2024. It can be clearly seen that until about mid-September, around 50% of consumption was covered by PV, as consumption and feed-in increased at roughly the same rate. After that, however, consumption was definitively higher, while feed-in stagnated. This suggests that PV electricity was either consumed directly or temporarily stored in the vehicle battery and then used locally. With increasing PV yield from March 2025 onward, this pattern flattened out again, as in addition to the higher generation, the heat pump – the main consumer – was less active.

Since the beginning of the recordings, approx. 28.4 MWh have been drawn from the grid and around 19.3 MWh have been fed into the grid.

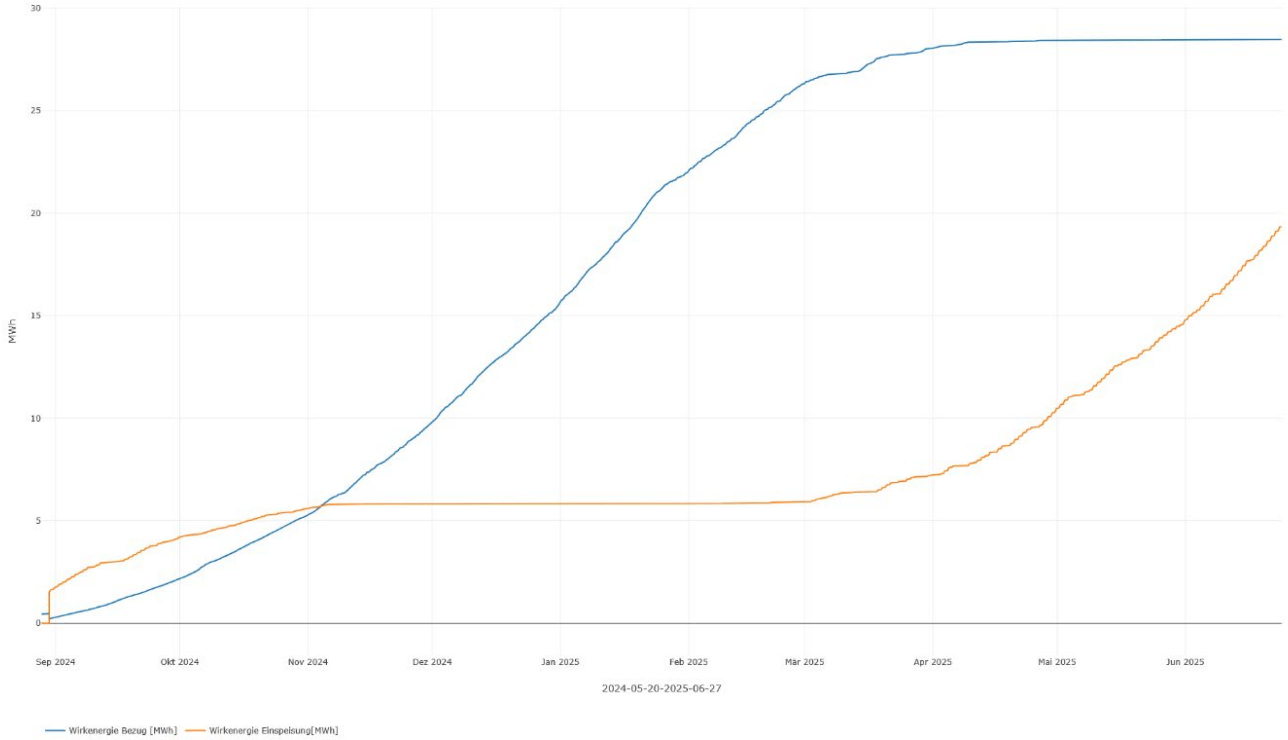


Figure 76 Total consumption/feed-in at Korneuburg

6.2 Use Case 2 – Company Fleet

6.2.1 Fuhrpark Burgenland Energie

Figure 75 shows an overview of a site of Burgenland Energie with an optional photovoltaic system. The goal can be to reduce the site's total peak loads (e.g., from warehouse, charging stations), also interesting to many companies whose energy costs depend essentially on peak loads. An additional EV fleet can push these costly power peaks significantly. Hence, dynamic load management becomes an important topic in many residential complexes to stabilize the site connection to the grid.

Figure 77: Overview Fuhrpark Burgenland Energie

6.2.2 FH Burgenland

The University of Applied Sciences Burgenland in Eisenstadt locates several KEBA wall boxes under a photovoltaic carport as PV energy receivers. An overview of the site can be seen in Figure 76. The KEBA wall boxes are public charging stations and thus available to visitors of the University of Applied Sciences. Additional pool EVs for, e.g., employees of the surrounding companies (“Technologiezentrum”, Forschung Burgenland, University of Applied Sciences Burgenland) with bidirectional charging capability shall optimize the energy yield from the site’s PV system.

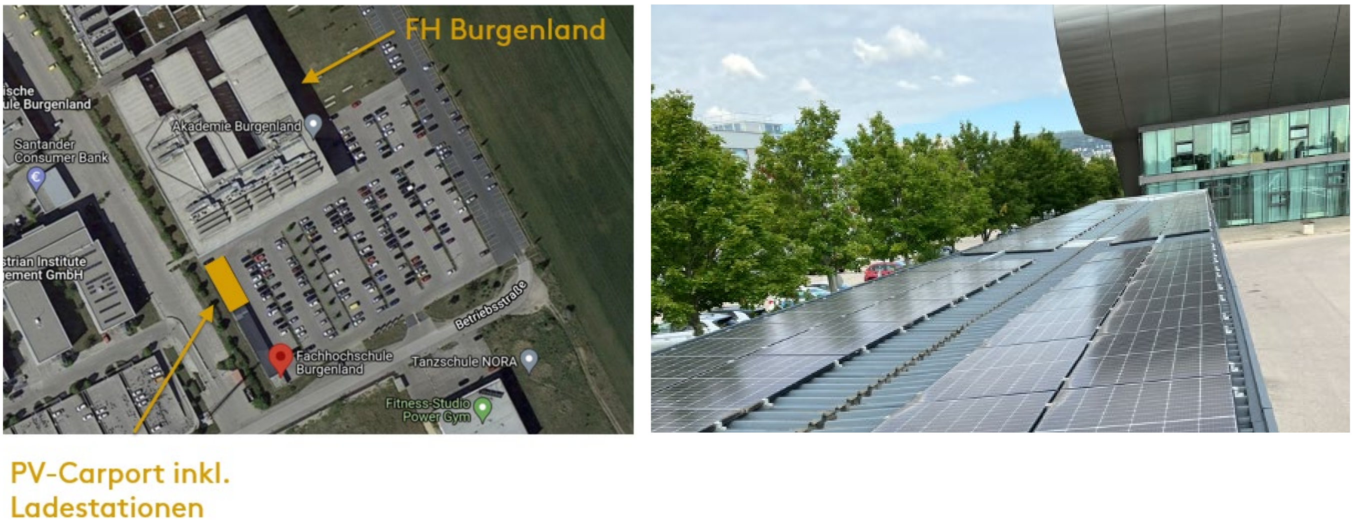


Figure 78: Overview FH Burgenland

This figure shows the bidirectional charging station from Fronius was installed at the demo site of FH Burgenland. Two Kia e-niro from the FH Burgenland vehicle fleet with 64 kWh batteries and one VW e-Golf with a 31 kWh battery were assigned to this charging station (Figure 80). However, the fleet vehicles were predominantly charged at conventional FH Burgenland charging stations.

Figure 79: Charging station at FH Burgenland

The company fleet is used on an average of 102 days per year. Most business trips take place within one hour in the morning and within a short distance of up to 10 km. As a result, even on days when they are in use, the vehicles are available at the FH Burgenland for controlled or bidirectional charging for an average of 80% of the time.

Between October 2024 and May 2025, 143 recharges were carried out, leading to a total of 1372 kWh charged over 325 hours. On average, a car was charged for 2 hours and 16 minutes and charged 9.6 kWh. The longest charging sessions was 9 hours and 17 minutes. A summary of the charging processes is shown in Figure 81.

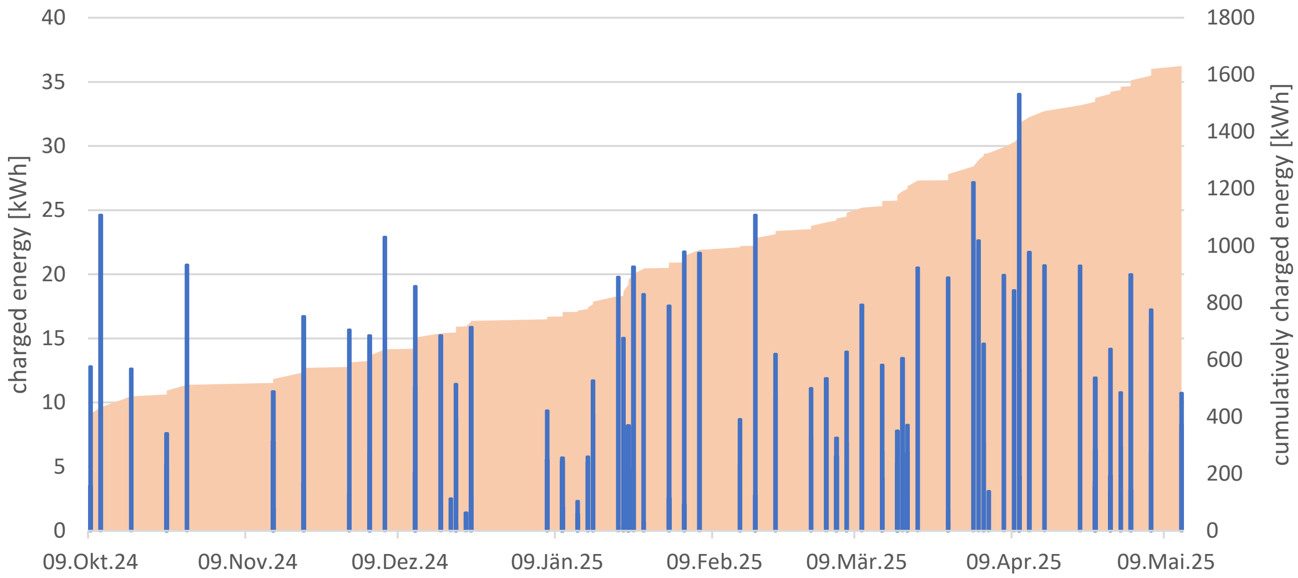


Figure 80: Real test data from October 2024 to May 2025 at FH Burgenland

6.2.3 EVN Direktion Garage bidirectional charging station

A bidirectional charging station from Fronius will be installed in the EVN head office. A VW id 3 from the EVN vehicle fleet is assigned exclusively to this charging station.

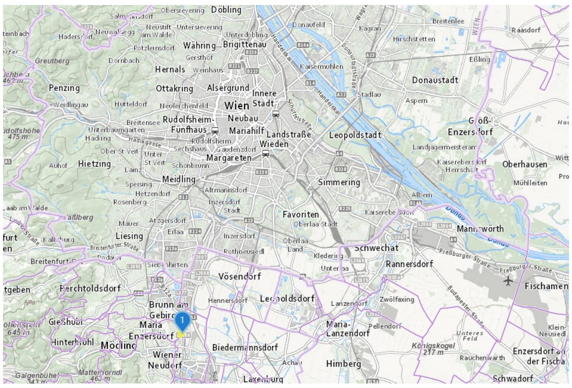


Figure 81: Overview EVN Maria Enzersdorf

For the demo site in Maria Enzersdorf, a parking space in the EVN fleet garage was selected. The primary use case was analyzing user behavior and exploring possible integration into fleet management for electric vehicles.

A senior sales employee was chosen as the test user. The vehicle used was a VW ID.3 with a 77 kWh battery. Due to the highly variable driving profile—between office and off-site trips—an atypical charging behavior regarding charging times and duration was expected.

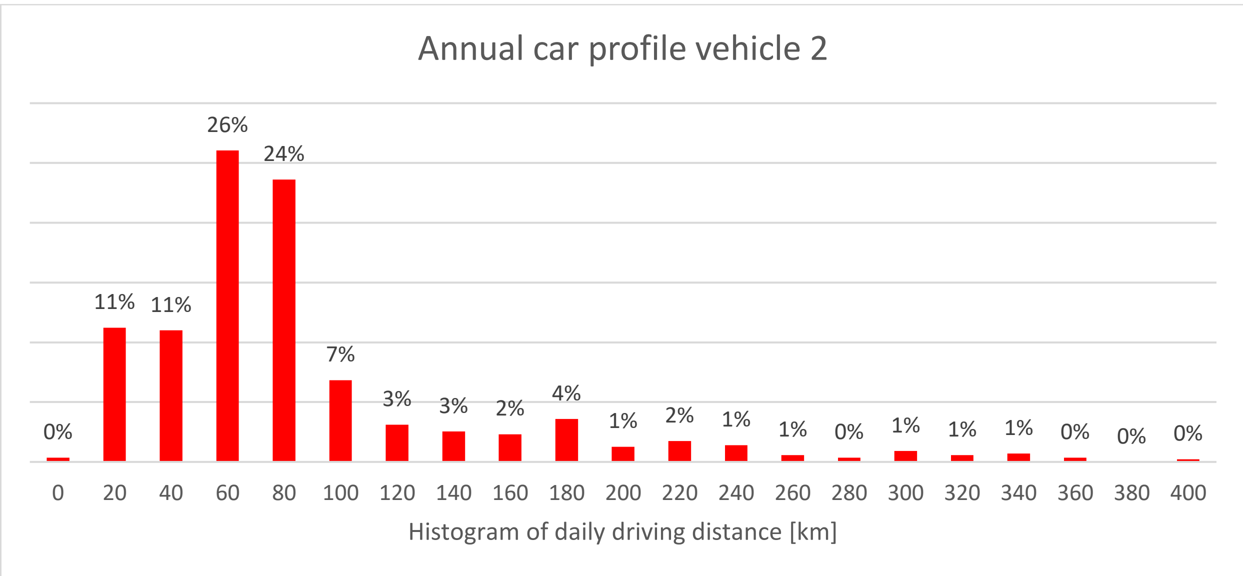


Abbildung 1: Annual Vehicle Profile

Additionally, the site offered the opportunity to test compatibility with various vehicle brands and models.

Figure 82: Charging Point EVN Garage

The charging station was commissioned on 18 October 2023 by Fronius and Elin. Subsequently, the employee used the station, and the charging behaviour was monitored via the portal provided by Reisenbauer.
Usage was not consistently smooth due to technical and connectivity issues. Various test scenarios and troubleshooting efforts were required. Software adjustments were made to resolve the problems, but only partially succeeded before the station was dismantled. This affected user behaviour: charging attempts were often abandoned after the first failure because restarting the system took more than five minutes. Additionally, charging sessions were interrupted, leaving the vehicle without the desired state of charge (SoC).
Regarding smart charging (V1G), the Reisenbauer portal was used to conceptually examine the specification of power data and potential integration into the existing smart charging infrastructure.

With the announcement that VW vehicles could be discharged, discharge tests with Fronius were prepared starting in December 2024. Fleet vehicles were identified by model and firmware version, and the charging station was prepared. On 9 December 2024, the first test was conducted after a software update, and on 19 December 2024, the discharge process was demonstrated live during a Car2Flex jour fixe. Further tests were carried out until 21 January 2025 to improve the timing of charge retention during discharge. Charging could be initiated at the vehicle and controlled via the Reisenbauer portal after authorization. After the firmware upgrade from version 3.5 to 3.7, discharge was no longer possible for end users.

In addition, 40 charging stations at the site were equipped with V1G technology for controlled charging. Across all locations, a total of 100 V1G-enabled charging stations were available.

The analysis revealed typical charging patterns during **07:00–11:00** and **17:00–06:00**, as shown in the following graphic:

Figure 78: EVN car pool – 2 weeks total

The time window from 07:00 to 11:00 was mainly caused by fleet vehicles used privately or vehicles that remained off-site overnight due to operational requirements. A detailed view illustrates the power peaks caused by simultaneous user behavior.

Figure 79: 3 selected vehicles – one day

6.3 Use Case 3 - Individual

6.3.1 Demo Steiermark

The demonstrators in styria are three private households. The participating persons will presumably be employees of Energie Steiermark who already have experience with e-mobility as well as a technical background.
Basic requirements for participation are:

- VW ID3, ID4 or ID5 with 77 kWh battery capacity and software version 3.1 (bidirectional charging with CCS) as EV
- Regular use of the EV for private and professional purposes
- Own PV- system at home
- Possibility to install a bidirectional charging station (prototype) at home
- Motivation for active participation

The bidirectional charging stations were successfully installed at all three demonstration sites. Figure 77-80 shows the installation and locations of the different demo sites. The installation consists of two interconnected components: a Fronius Symo GEN24 10.0 Plus and the Fronius prototype itself, which primarily manages communication functions. The charging station supports ISO 15118-20, the standard that enables bidirectional charging via CCS. While the bidirectional charging stations at the Feldbach and St. Radegund demonstration sites were mounted on the wall in the garage, the bidirectional charging station at the Premstätten demonstration site was mounted and installed outdoors on a special stainless steel stand due to lack of space. The charging station was thus exposed to the weather all year round, but this did not cause any technical difficulties.

The local photovoltaic (PV) systems and smart meter data were fully integrated into the setup. Demo participants received comprehensive training on both the software platform and the mobile application.

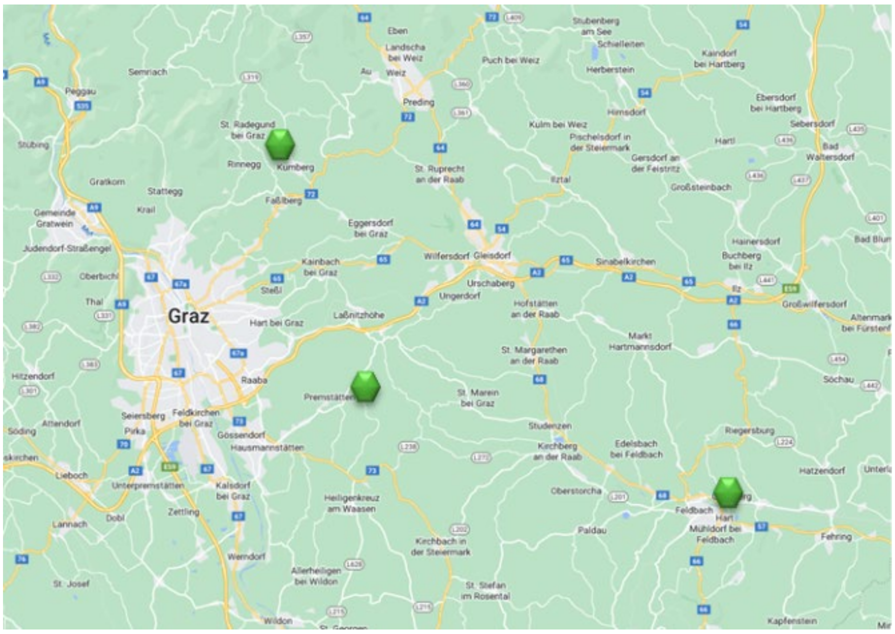


Figure 83 Demo site Locations

Figure 84 Demo site Feldbach

Figure 85 Demo Site Premstätten

Figure 86 Demo Site St.Radegund

During the initial phase, the focus was primarily on conducting charging sessions, collecting data, and addressing early technical issues related to software and hardware. Gradually, additional functionalities were introduced, such as PV surplus charging.

Furthermore, exclusively at the demonstration sites in Styria, live power grid signals were integrated to enhance system optimization. For this purpose, six so-called Enhanced Grid Sensors (EGS) were installed at local transformer stations and distribution boxes. Figure 81 shows the the grid sensors and transfomer installations.

In the course of the project, a so-called grid controller (see Figure 82) was developed, capable of responding to live grid signals. Through the software platform, it could dynamically adjust charging processes in near real-time—either increasing or decreasing charging power as needed—to help prevent potential grid overloads. This marked the first successful practical test of a “digital interface” that enables communication and control between the distribution grid operator (DSO) and an external energy management system.

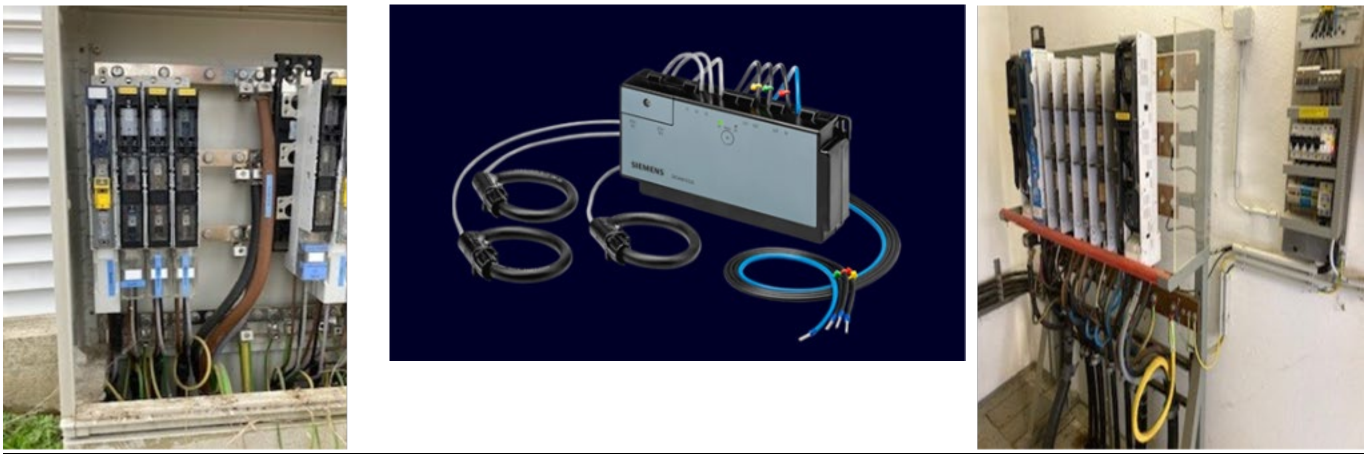


Figure 87 Grid Senors and Transformator-Installations

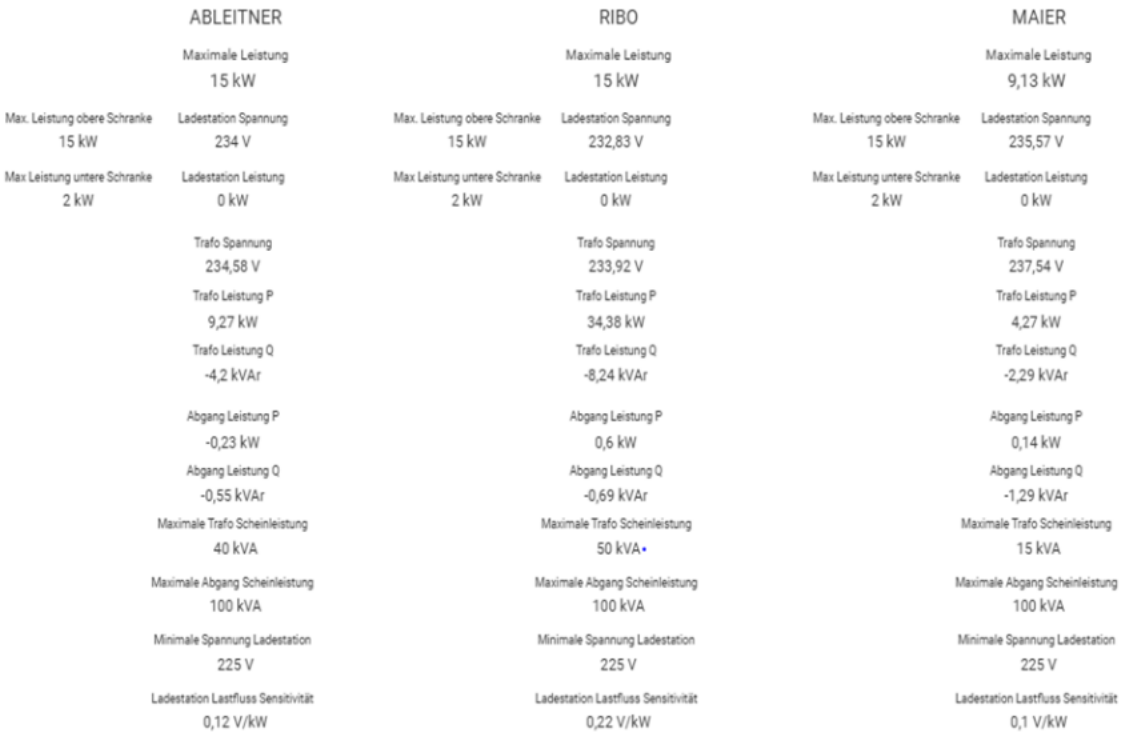


Figure 88 Grid-Controller Interface

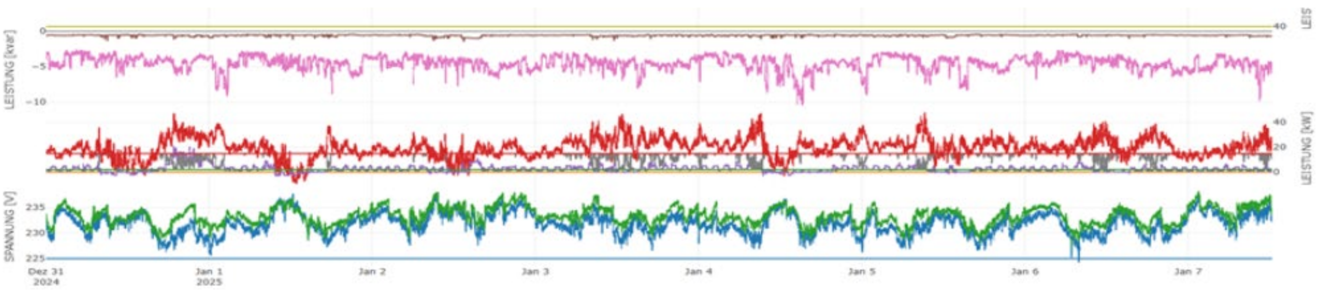


Figure 89 Measured Values (Transformators, Chargiung station, Home Consumption)

Subsequently, vehicle discharging was also tested in practice. This functionality was first successfully demonstrated at the Feldbach demo site, where the vehicle discharged energy back into the household (Vehicle-to-Home, V2H). Unfortunately, after a routine workshop visit, a new software version was installed on the vehicle, which rendered the previously developed workaround for discharging incompatible and thus no longer functional.

Finally, the discharging functionality and the overall system architecture were tested intensively over several days at the Premstätten demo site, where a vehicle with a compatible software version was available. Although there were occasional interruptions in the discharging process initiated by the vehicle itself, these issues were successfully resolved both remotely and on-site. As a result, various V2H (Vehicle-to-Home) concepts as well as discharging into the public grid (Vehicle-to-Grid, V2G) could be successfully demonstrated (see Figure 84 an 85). During V2H mode, the car was primarily charged using surplus photovoltaic energy. In the evening and night hours, the car then covered household consumption and operated the heat pump by discharging. The software regulated the house power-connection (smart meter) to zero as best as possible during both charging and discharging. This meant that no PV electricity was fed into the grid at midday and hardly any electricity was drawn from the public grid in the evening. The result is a grid-friendly mode of operation, as both the grid-loading feed-in peak at midday and the grid-loading consumption peak in the evening were reduced. Furthermore, a minimum SOC of 30% was taken into account.

The V2G mode was only tested to the extent that the car fed different amounts of power (2-8 kW) back into the grid, depending on the power specifications in the software, until a certain minimum SOC was reached. The V2G feed-in followed the logic of the grid controller and was theoretically tested to feed in according to a SPOT market price principle, which would require a flexible feed-in tariff.

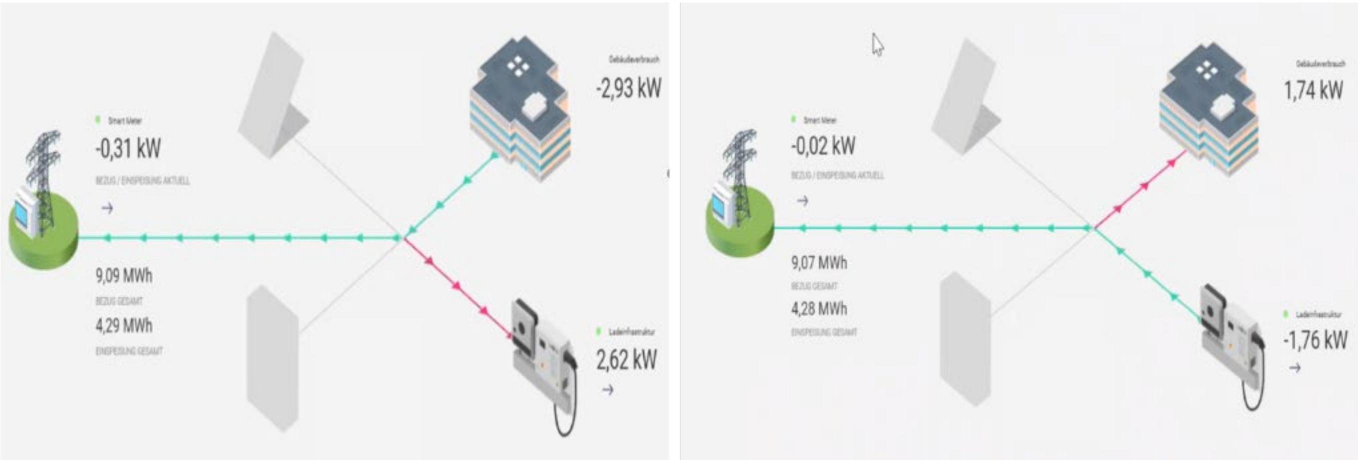


Figure 90 V2H-Modus at Demo Premstätten

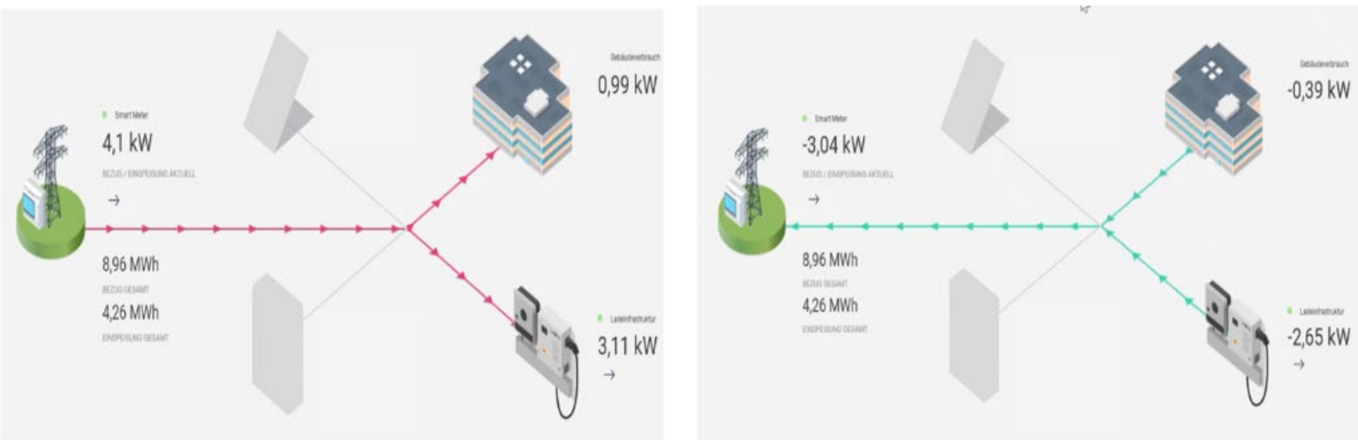


Figure 91 V2G-Modus at Demo Premstätten

Particular emphasis was placed on the practical interaction and communication between the software/app, the charging station, the smart meter, the PV system, and the power grid. The grid controller, in its final version, was also successfully demonstrated during this phase.

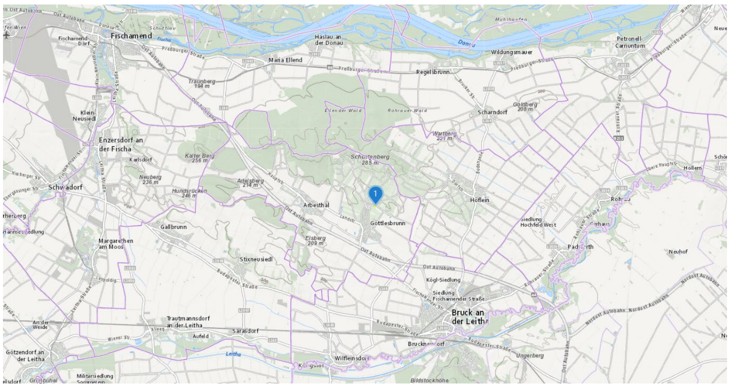
Only at the St. Radegund demo site was discharging not tested in practice, as the vehicle was not authorized for this functionality. The bidirectional charging station there was used exclusively for controlled charging; nevertheless, valuable insights were still gained from this setup.

6.3.2 EVN

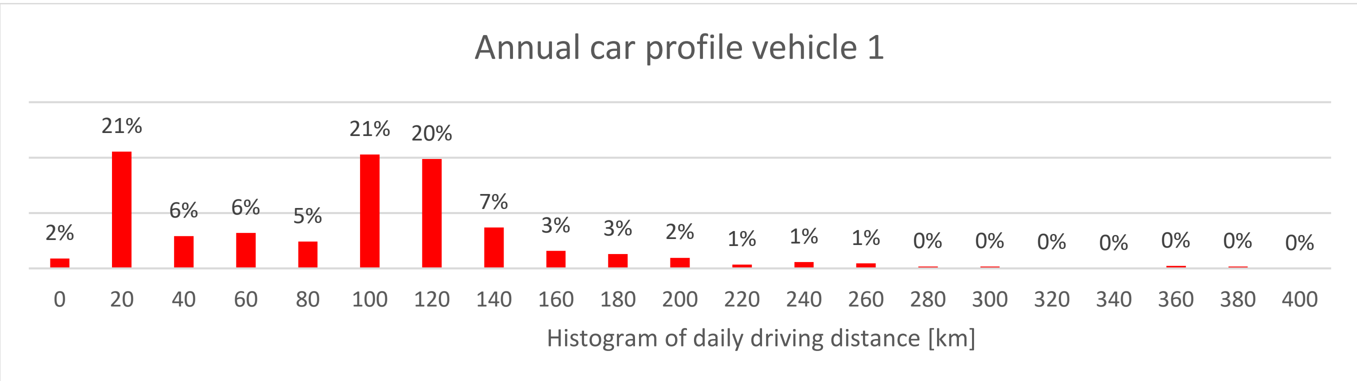
Two bi-directional charging stations from Fronius will be installed at private households from EVN employees who are experienced with e-mobility.
Basic requirements for participation are:

- VW ID3, ID4 or ID5 with 77 kWh battery capacity and software version 3.1 (bidirectional charging with CCS) as EV
- Regular use of the EV for private and professional purposes
- Possibility to install a bidirectional charging station (prototype) at home
- Motivation for active participation

Demosite Göttlesbrunn



This demo site was selected because it featured a modern house equipped with a photovoltaic system and a heat pump. The vehicle, a VW ID.4 with a 77 kWh battery, was charged in a garage using the installed charging station.



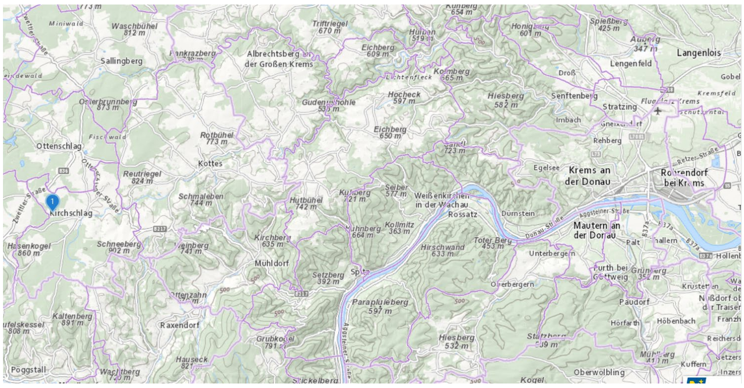
Since the garage was separate from the main house, extensive additional work was required. The power supply line to the garage had to be newly laid, which involved excavation. Two wall penetrations and the additional installation of a data cable caused further delays.

Like the EVN garage, user experience was affected by charging errors, interruptions, and long restart times for the charging station. In the initial phase, the system was restarted by disconnecting and restoring the power supply—a method criticized by Fronius. Subsequently, a restart option via the Reisenbauer portal was implemented.

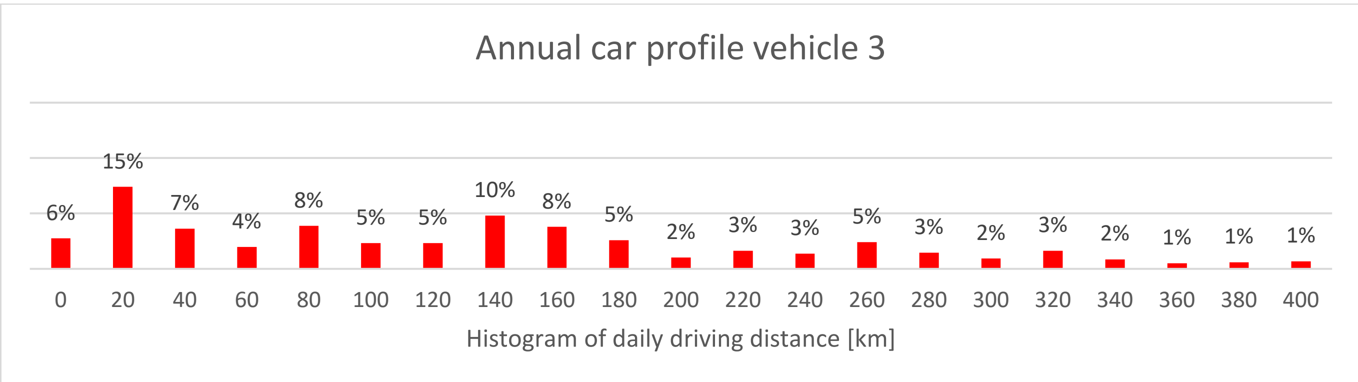
For internal company processes, accurate billing of charging sessions was necessary. The user was accustomed to retrieving billing data via software using the previous solution (an NRGkick charging cable). Therefore, an alternative solution had to be found. Since the Reisenbauer portal allows exporting consumption data, billing was handled through manual data export and processing in Excel. After this adjustment, the user was able to use the charging station without losing reimbursement for self-generated electricity.

Various approaches to optimize the interaction between consumption and generation were tested. Since the vehicle was mostly connected overnight, opportunities were limited to a few home office days and weekends.

Demosite Kirchschlag



This user was selected due to their driving profile: as a senior executive of a regional unit with frequent trips to the headquarters, a user profile with significant SoC variations was expected compared to other users.



However, the charging point was rarely used. The reasons were the technical difficulties described, the confined installation situation, and the need to always keep the vehicle ready for use. Acceptance was therefore very low. Requests to charge, modify, or dismantle the station were delayed, as the user only made a few additional charging attempts.

6.4 Requirements for Integration of Car2Flex Bi-DC charging Prototype

This section describes and documents the technical solution for bidirectional DC-charging developed within der Car2Flex project in order to enable a demo operation in the field.
It also describes the challenges and hurdles the Car2Flex Project faced during the preparation and implementation of the demos.
Due to the lack of standards for bidirectional charging, various gaps had to be closed within the research project to enable the desired field test for bidirectional charging based on CCS, which is the only remaining relevant charging standard for passenger cars in Europe.

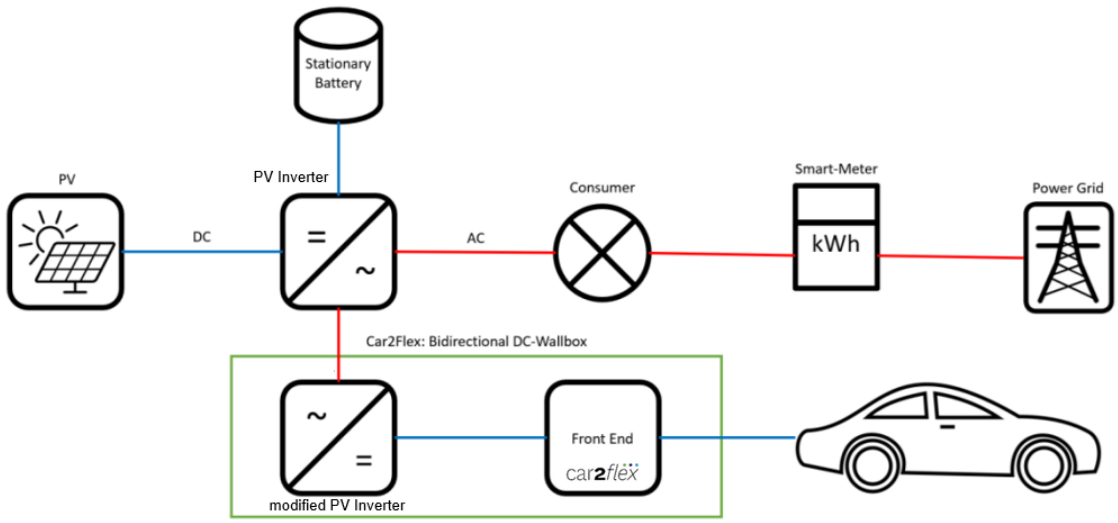


Figure 92 System diagram Car2Flex bidirectional DC-Wallbox

6.4.1 Norms and Standards

6.4.1.1 General

The electric vehicle (EV) charging ecosystem is governed by a complex set of international standards that ensure safety, interoperability, and performance across all system components—from the vehicle to the grid.
Vehicle Interfaces and Connectors: Standards such as **IEC 62196-1, -2, and -3** define the physical characteristics of plugs, sockets, and vehicle inlets for both AC and DC charging. High-power charging (HPC) is addressed by **IEC TS 62196-3-1**, enabling faster energy transfer.
Communication Between EV and Charging Station (EVSE): The **ISO 15118** series (Parts 1–5 and the new 15118-20) and **DIN 70121** define the digital communication protocols that enable smart charging, Plug & Charge, and bidirectional energy flow (Vehicle-to-Grid, V2G). These protocols allow seamless interaction between the EV and the charging station.
Charging Station Standards (EVSE): The **IEC 61851** series specifies general and DC-specific requirements for EVSE, including communication (Part 24), electromagnetic compatibility (Part 21-2), and safety features like residual current detection (**IEC 62955**) and low-voltage switchgear (**IEC 61439-7**).

Grid Integration and On-Board Charging: Grid-side safety and installation requirements are covered by **IEC 60364-7-722** and **IEC 62909-1/2**, while vehicle-side safety and EMC are addressed by **ISO 17409**, **ISO 5474**, **ISO 6469-3**, and **IEC 61851-21-1**.

Backend Communication and Management: Protocols such as **OCPP 1.6 / 2.0**, **IEC 63110**, and **IEC 63119-1** define how charging stations communicate with central management systems, enabling remote monitoring, billing, and load balancing.

Together, these standards form a robust framework that supports the safe and scalable deployment of EV charging infrastructure worldwide.

The following illustration gives an overview on the EV charging infrastructure standards. The most relevant standards for the development of the Car2Flex Prototype are highlighted with yellow color and listed in the table below.

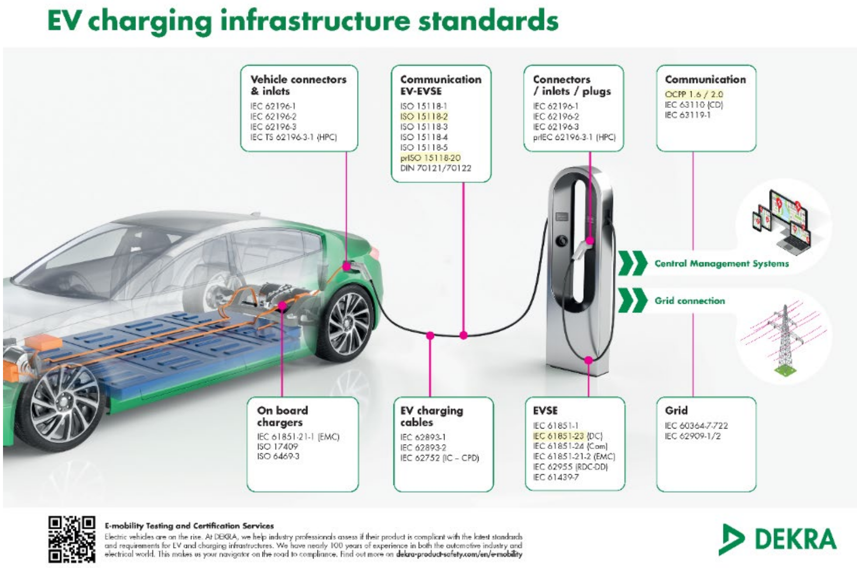


Figure 93: Overview of EV charging standards. Highlighted the most relevant standards for the development of the Car2Flex Prototype.[154]

Standard	Description
ISO 15118-2	Road vehicles – Vehicle to grid communication interface – Part 2: Network and application protocol requirements
ISO 15118-20	Road vehicles – Vehicle to grid communication interface – Part 20: 2nd generation network and application protocol requirements
IEC 61851-23	Electric vehicle conductive charging system – Part 23: DC electric vehicle charging station
OCPP 1.6 /2.0	Open Charge Point Protocol Version 1.6 / 2.0

Table 22: most relevant standards for the development of the Car2Flex Prototype

[154] Dekra, 2023. EV charging infrastructure standards. [online] Available at: <https://image.info.dekra.com/lib/fe3b157075640578721171/m/2/6b11875b-dc2a-44c7-827a-0e1fd405b73b.pdf> [Accessed 10 Apr. 2024].

6.4.1.2 Communication EV-EVSE

The ISO 15118 standard series define the communication interface between electric vehicles (EVs) and the electric vehicle supply equipment (EVSE). ISO 15118-2 and ISO 15118-20 are key parts of this series, with ISO 15118-20 introducing significant advancements, particularly in the area of bidirectional charging. This table provides a comparative overview of these two standards, focusing on their support for Vehicle-to-Grid (V2G) and related functionalities.

Feature	ISO 15118-2	ISO 15118-20
Publication Year	2014	2022
Charging Types	AC and DC charging	AC, DC, Wireless, and Pantograph charging
Plug & Charge	Supported	Enhanced with multi-contract management
Smart Charging	Supported	Extended profiles (dynamic, scheduled)
Bidirectional Charging (V2G)	Basic support, not fully specified	Fully specified (V2G, V2H, V2B, V2L) with new message formats
Communication Channels	Single channel	Multiplexing: parallel communication channels
Automatic Connection Device (ACD)	Not included	Supported (e.g., pantograph for buses)
Wireless Power Transfer (WPT)	Not included	Supported (in combination with IEC 61980)
Security Features	Basic cryptography	Enhanced cryptography and security mechanisms
Contract Management	Single contract possible	Multiple Plug & Charge contracts per vehicle
Energy Flow Direction	Charging only (Unidirectional)	Charging and discharging (Bidirectional)

Table 23: Feature Comparison ISO 15118-2 and -20 [155] [156]

ISO 15118-20 represents a significant evolution from ISO 15118-2, especially in the context of bidirectional charging. It introduces comprehensive support for V2G and related applications such as Vehicle-to-Home (V2H), Vehicle-to-Building (V2B), and Vehicle-to-Load (V2L). These enhancements make ISO 15118-20 a critical standard for the future of smart and sustainable electric mobility.[157]

Availability of the ISO 15118-20 in Series EVs and EVSE

At the start of development of the Car2Flex DC wallbox prototype in the year 2020 and during the hole project period, no series vehicle with implemented ISO 15118-20 was available.

[155] DIN, 2014. ISO 15118-2:2014 Road vehicles — Vehicle to grid communication interface — Part 2: Network and application protocol requirements. Berlin: Deutsches Institut für Normung.
[156] DIN, 2022. ISO 15118-20:2022 Road vehicles — Vehicle to grid communication interface — Part 20: 2nd generation network and application protocol requirements. Berlin: Deutsches Institut für Normung.
[157] Hubject, 2023. Plug & Charge according to ISO 15118. [online] Available at: <https://www.hubject.com/plug-charge> [Accessed 10 Apr. 2024].

Now at the time of the project completion mid-2025, ISO 15118-20 is gradually being adopted in series electric vehicles and charging infrastructure, driven largely by regulatory developments such as the EU's Alternative Fuels Infrastructure Regulation (AFIR). According to the latest AFIR updates, support for ISO 15118-20—including bidirectional charging and enhanced Plug & Charge capabilities—will become mandatory for all newly installed or renovated public and private chargers starting January 1, 2027
While some early-adopting EV OEMs and charging station manufacturers have already begun implementing ISO 15118-20 features, widespread availability across the EV market is expected to accelerate in the next 12–24 months. However, technical and legal readiness still varies across regions, and full interoperability remains a work in progress
The Alternative Fuels Infrastructure Regulation (AFIR) is a key component of the EU's "Fit for 55" climate package, aimed at reducing greenhouse gas emissions by at least 55% by 2030. It replaces the older Alternative Fuels Infrastructure Directive (AFID) and introduces legally binding targets for the deployment of charging infrastructure.
From January 1, 2027, all newly installed or renovated public and private charging stations in the EU must support EN ISO 15118-20:2022, including[158]:

- Plug & Charge
- Bidirectional charging (V2G)
- Smart charging capabilities

6.4.1.3 EVSE

The most relevant EVSE standard for the development of the Car2Flex bidirectional charging prototype is the "IEC 61851-23 Electric vehicle conductive charging system –DC electric vehicle charging station"
The IEC 61851-23 specifies the requirements for DC electric vehicle charging stations, focusing on safety, interoperability, and performance. The standard outlines the electrical characteristics and control communication protocols necessary for conductive DC charging. Key requirements include:

- Protection against electric shock, overcurrent, and thermal hazards.
- Requirements for system monitoring, fault detection, and emergency shutdown.
- Specifications for charging modes, voltage levels, and current ratings.
- Integration with vehicle communication systems for charging control and status feedback.
- Compatibility with various EV types and battery systems.
- Use of standardized connectors and communication interfaces.

The interoperability of the developed prototype with EVs according to the IEC 61851-23 was a crucial requirement for ensuring safe and reliable operation during the field test.

6.4.1.4 Backend Communication

The Open Charge Point Protocol (OCPP) is a widely adopted open communication standard for electric vehicle (EV) charging stations and central management systems (Backend). OCPP 1.6 and OCPP 2.1 are

[158] Pionix, 2025. AFIR Regulation Update – Spring 2025
. [online] Available at: < https://www.pionix.com/news/afir-regulation-update-spring-2025> [Accessed 31. July 2025].

two major versions of the protocol, each offering different levels of functionality, particularly in the context of bidirectional charging (Vehicle-to-Grid, V2G).

OCPP 1.6

OCPP 1.6, released in 2015, introduced support for smart charging and WebSocket-based communication. It allows for remote control of charging sessions, status monitoring, and basic load balancing. However, OCPP 1.6 has limited support for bidirectional charging. While it can report energy flow and control charging sessions, it lacks native support for energy discharge from the vehicle back to the grid.[159]

OCPP 2.1

OCPP 2.1, released in 2023, builds upon OCPP 2.0.1 and introduces enhanced support for bidirectional energy flow. It includes features such as improved energy management, support for ISO 15118-20, and advanced charging profiles. OCPP 2.1 enables charging stations to manage both charging and discharging operations, making it suitable for V2G applications. It also supports enhanced security, device management, and extensibility for future energy services.[160]

	OCPP 1.6	OCPP 2.1
Release Year	2015	2023
Smart Charging	Supported	Enhanced with profiles
Bidirectional Charging	Limited (no native support)	Fully supported
ISO 15118 Integration	Partial (Plug & Charge only)	Full (incl. ISO 15118-20)
Security	Basic TLS	Advanced security model
Energy Management	Basic load balancing	Advanced energy flow control

Table 24: Comparison of OCPP 1.6 and OCPP 2.1

During the runtime of the Car2Flex Project beginning with 2020, OCPP 2.1 was not yet available. The protocol was still under development, and the industry was primarily focused on OCPP 1.6, which had become the de facto standard for EV charging communication. OCPP 2.0, released in 2018, was just beginning to gain attention, but its adoption was limited due to the lack of implementation-ready hardware and software.

At that time, bidirectional charging was not a mainstream requirement, and OCPP 1.6 offered only basic support for smart charging without native capabilities for energy discharge (Vehicle-to-Grid). OCPP 2.0 introduced some foundational elements for advanced energy management, but it lacked the full feature set and maturity that OCPP 2.1 would later provide.

[159] Open Charge Alliance, 2025. Open charge point protocol. [online] Available at: https://openchargealliance.org/protocols/open-charge-point-protocol/ [Accessed 27 Apr. 2024].
[160] Open Charge Alliance, 2025. OCPP 2.1. [online] Available at: https://openchargealliance.org/protocols/ocpp-protocols/ocpp-2-1/ [Accessed 27 Apr. 2024].

In summary, OCPP 2.1 was not available in 2020, and the ecosystem was still transitioning from OCPP 1.6 to the early stages of OCPP 2.0. The technical and regulatory environment for bidirectional charging was also not yet in place.
Due to this lack of availability, we had to implement a workaround for the bidirectional charging based on the OCPP 1.6 standard for the Car2Flex prototype.

6.4.2 Car2Flex Prototype

6.4.2.1 Technical description

The following illustration gives an overview on the Car2Flex system architecture which was developed within the project and implemented at the 10 demo sites.

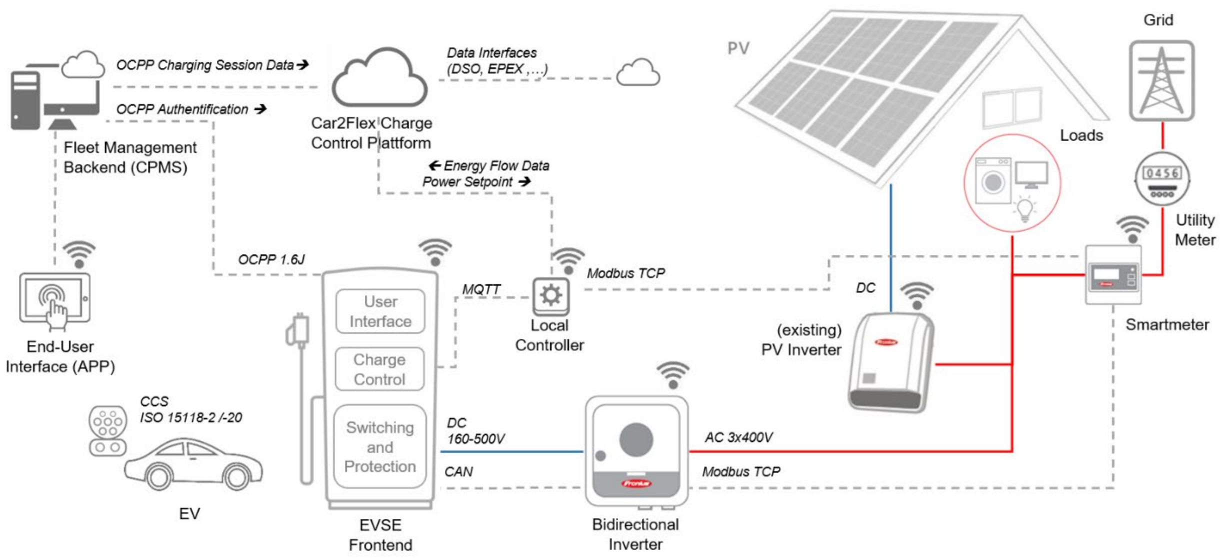


Figure 94: Car2Flex System Architecture

Key components and their roles:

- **End-User Interface (App)**: Allows users to interact with the system, authenticate, and manage charging sessions via OCPP protocols. The users need to define the departure time and the desired SOC at the departure time before starting a charging session.
- **Fleet Management Backend (CPMS)**: Acts as the central backend system, handling session data and authentication, and interfacing with the charge control platform.
- **Car2Flex Charge Control Platform**: Serves as the core logic unit, managing energy flow, power setpoints, and communication between backend systems and local hardware.
- **EV and EVSE Frontend**: The EV connects to the charging station using **CCS and ISO 15118-2/20** protocols, enabling bidirectional communication and charging. The EVSE includes user interface, switching, protection, and charge control modules.
- **Bidirectional Inverter**: Enables both charging and discharging of the EV battery, converting DC from the EV to AC for household use or grid export. It also ensures compliance with **grid**

codes and **technical operational requirements (TOR)**, supporting safe and grid-compatible energy exchange.

- **Local Controller**: Communicates with the EVSE, the Smartmeter and the Charge Control Platform using **MQTT and Modbus TCP**, coordinating local energy flows. The local controller is necessary since the OCPP 1.6 protocol does not support negative values for the power-setpoint which is necessary for discharging.
- **PV System and Inverter**: Generates solar energy, which is converted and distributed to household loads, the EV, or the grid.
- **Loads**: Represent household or building energy consumption.
- **Utility Meter and Smart Meter**: Monitor energy flows to and from the grid, ensuring accurate billing and energy balancing.

The system supports **bidirectional charging**, **smart energy distribution**, and **renewable integration**, making it suitable for future-ready, grid-interactive EV infrastructure.

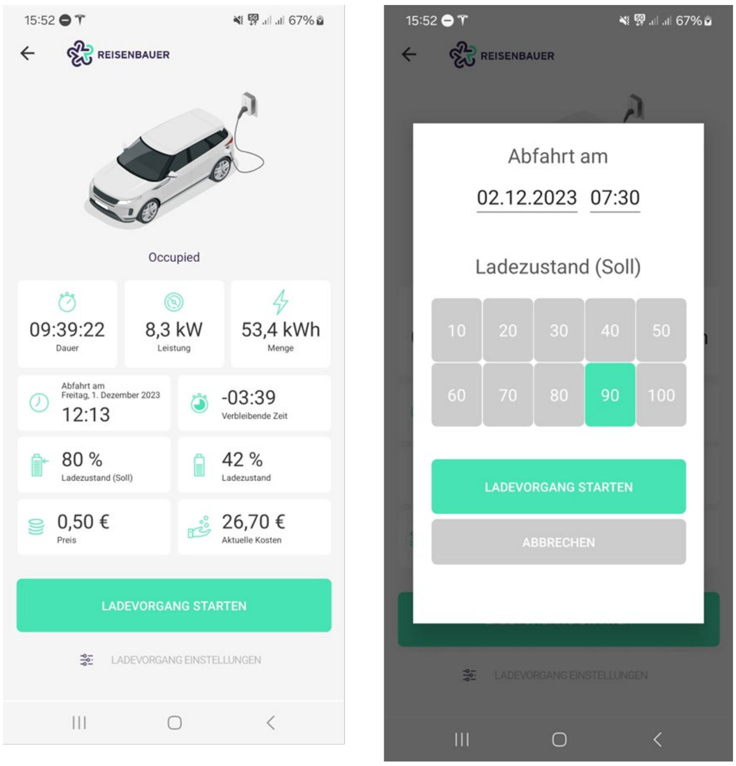


Figure 95: End-User Interface (App)

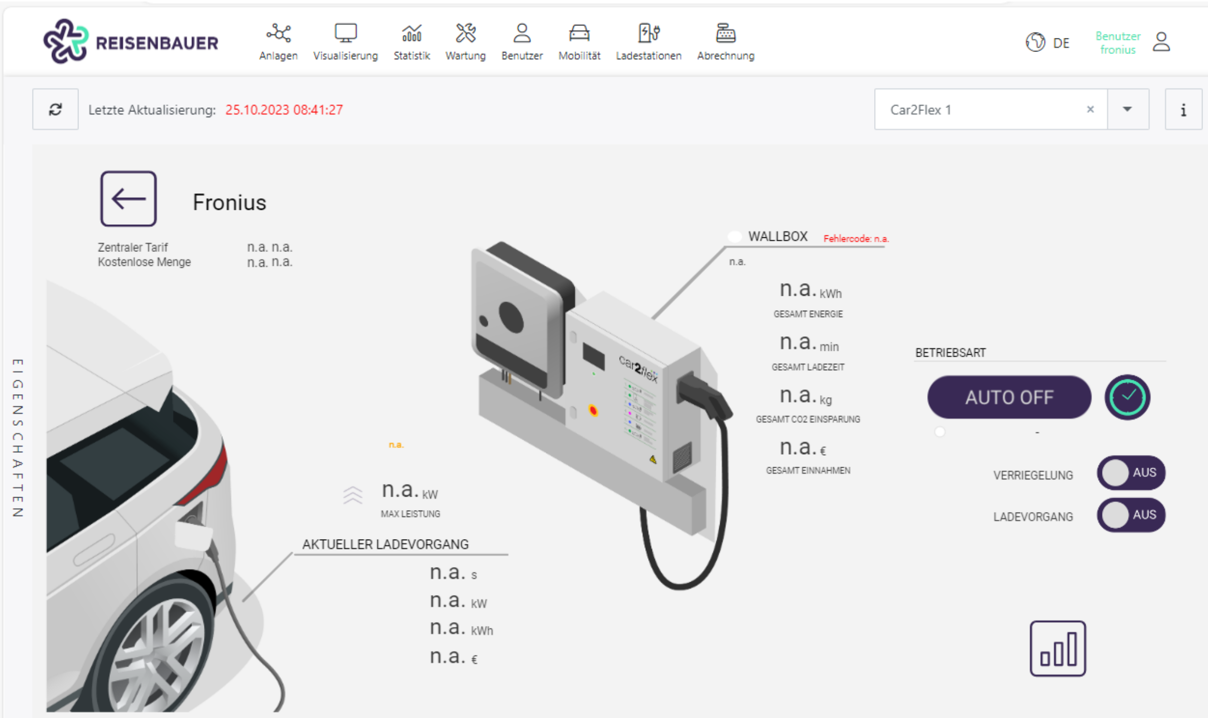


Figure 96: Fleet Management Backend (CPMS) and Car2Flex Charge Control Platform

6.4.2.2 Technical Requirements for Demo-site Implementation

The following requirements were defined prior to the demo site installation and had to be ensured by those responsible for the demo.

General:

- Access must be possible up to the installation site.
- The Fronius Smart Meter is installed on-site at the measurement point (grid connection point).
- Connection cables (AC, equipotential bonding conductor, LAN cable from the Smart Meter) must be laid on-site up to the installation location.
- A test report according to ÖVE E8001/E8101 (as per local conditions) for the connection cables must be available — especially the measurement-based verification of low-resistance continuity of protective grounding, equipotential bonding conductors, and grounding connections.
- The installation site must be suitable for the system (e.g., wall load-bearing capacity).
- LTE mobile connection must be available at the installation site for backend connectivity.
- The electric vehicle must be available for commissioning.

AC Connection:

- 3x400V per 10 kW charging point (Recommendation: 5x6mm² cable).
- Recommended protection: Circuit breaker C 32A 3+N.
    - If deviating: cables and circuit breakers must be dimensioned accordingly.

- Residual current device (RCD) Type A with 30 mA tripping current.
- Equipotential bonding conductor: PE conductor with a minimum cross-section of 10mm² copper from the local equipotential bonding bar to the charging point.

Data Connectivity:

- An LTE modem is installed at the charging point for backend communication.
- A SIM card with an unlimited LTE data plan must be provided by the demo project partner.

PV Connection:

- Coupling of a PV system is done on the AC side via a separate (existing) inverter.

Surface for Wall Mounting or Suitable Stand Console:

- Inverter and extension module each 600x600mm (see sketch below).
- Weight: Inverter and extension module each 30 kg.
- Distance between inverter and extension module: max. 2m.
- Installation possible indoors or outdoors.
    - Outdoors only in protected areas, without direct sunlight and splash-proof (e.g., under a rain cover).

Figure 97: Impressions from Demo-site installations

6.4.3 Data exchange and backend

A total of 32 data points were monitored and recorded during the runtime of demo installations. Here is an extract of the measured values:

- DC-Voltage
- DC Current
- State of Charge (SOC)
- OCPP-status
- Actual Session Energy Charged
- Actual Session Energy Discharged
- Actual Frequency
- Inverter Temperature
- Power Setpoint

The resolution of the data recording and exchange with the backend was one second.

The following illustration shows the time series data of 3 example data points (red: DC-Voltage in Volts, yellow: State of Charge in Percent, blue: DC-Current in Ampere). In the shown example at first the car was charged (positive value of the blue line), then followed by a standby phase (zero value of the blue line) and afterwards the car was discharged (negative value of the blue line).

Figure 98: Example data monitoring of a charging/discharging session

6.4.3.1 Special features of the prototype

Transformerless topology

A transformerless topology in power electronics refers to the absence of a galvanic isolation transformer between the input and the output side. Instead, power conversion is achieved through semiconductor switching devices and control algorithms that handle voltage adaptation, waveform shaping, and safety measures electronically.

In photovoltaic (PV) inverters, transformerless designs have been the state of the art for almost two decades, driven by the push for higher efficiency, lower cost, and compact designs. Safety is ensured through careful grounding concepts, residual current detection, and insulation monitoring.

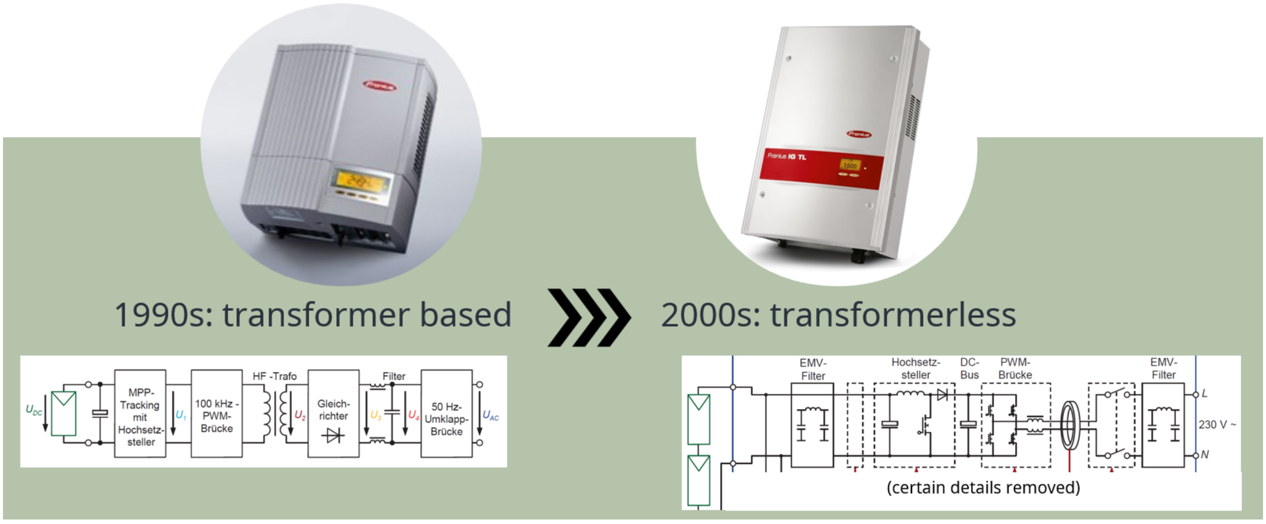


Figure 99: Comparison of transformer based and transformerless PV-Inverter

In DC EV chargers, transformerless topologies are still beyond the current mainstream state of the art, as actually all market available chargers still employ isolation transformers for grid compliance and safety. However, the technical and economic advantages of the transformerless topologies are highly relevant for the successful market penetration of bidirectional charging, especially for prosumer application, where the price of equipment and installation is crucial.

Advantages

- Weight
  Removing the transformer eliminates one of the heaviest components in the system. This is especially relevant for a power range used in the private sector (“prosumer”), where weight constraints may apply in existing building infrastructure and ease of installation is desirable.
- Volume
  Transformers are bulky. Transformerless designs can be up to 40–60% smaller in footprint, enabling denser installations, easier integration into constrained spaces. High frequency transformers are significantly smaller than line frequency transformers but demand an additional high frequency AC semiconductor stage.
- Efficiency
  Transformers introduce copper and core losses, which are especially noticeable at partial load

(typical in PV systems under varying irradiance, and in EV chargers during PV surplus charging). Transformerless systems can achieve >98% peak efficiency and maintain high efficiency at partial load, significantly improving annual energy yield or reducing charging energy losses.

- Cost and Price
  Without a transformer, material costs (copper, core , additional electronic stages) and manufacturing complexity are reduced. The overall system can be produced and sold at a lower price, with additional savings from reduced shipping weight, simpler installation, and higher lifetime energy throughput. The investment-cost is of utmost importance for enabling bidirectional charging in the private sector.

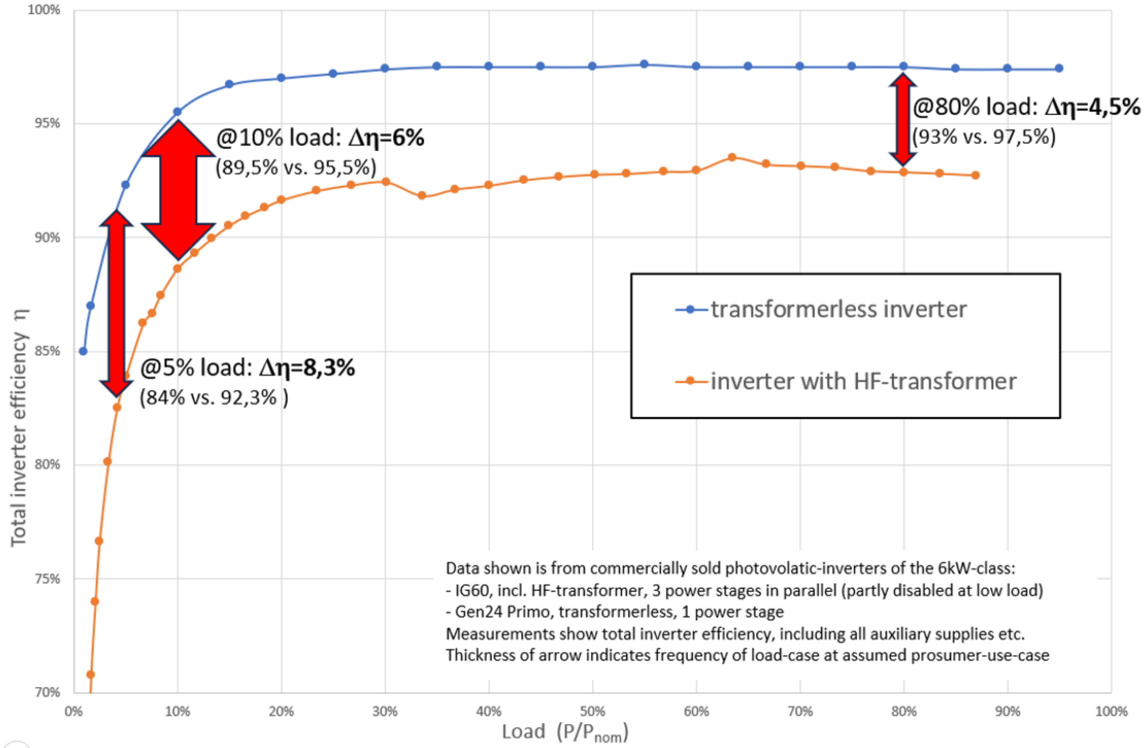


Figure 100: Comparison of the efficiency of a transformerless inverter with a transformer-based inverter

Transformerless topology represents a mature, proven approach in PV inverters and an emerging option for DC EV chargers to penetrate especially the prosumer sector. Its strengths in weight, volume, efficiency—especially under partial load—and cost make it an attractive solution wherever safety can be assured through modern electronic and system-level protections.

Challenges

- Controlling the potential of the EV battery versus ground
- Protection against faults such as ground faults, grid overvoltage

- Safety & Galvanic Isolation Requirements
  - Challenges:
    In the progress of the car2flex project, it became apparent, that the high voltage cabling of EVs only provide basic insulation by EV-manufacturing standards like ISO 6469. By cancelling the transformer, the necessity of establishing a new concept for fault protection arose.
    In most grid and EV standards, galvanic isolation is mandatory to prevent dangerous DC leakage currents to the grid or vehicle chassis. Without a transformer, touch currents must be managed otherwise.
  - Implication:
    Thorough analysis of minimal EV architectures which are guaranteed by standards had to be made. Out of this, first concepts for alternative fault protection were developed.
    Requires robust insulation monitoring devices (IMD) and fault detection to ensure equivalent protection to existing, transformer-based safety regulations (IEC 61851, IEC 62196, UL standards).

- DC Leakage Currents
  - Challenge: Transformerless systems are prone to DC leakage into the grid, which can saturate distribution transformers and provoke malfunction of RCDs.
  - Implication: Advanced control algorithms and highly sensitive residual current detection (AC + DC) are essential.

- Fault Ride-Through & Protection
  - Challenge: In fault conditions (e.g., short circuits or insulation failures), there is a direct path from the grid to the vehicle battery.
  - Implication: Protection circuits must be extremely fast and reliable, with coordinated operation between charger, grid, and vehicle systems.

- Controlling the Potential of the EV Battery vs. Ground
  - Challenge: without isolation, the EV Battery DC bus can float at high voltages relative to earth. Dangerous touch voltages, insulation stress, increased common-mode noise can apply.
  - Implication: active common mode control, high speed insulation monitoring, controlled grounding strategies

- Market Perception & Reliability
  - Challenge: Transformerless chargers are still seen as “cutting-edge” in DC-EV- charging. Utilities, Standard comitees charging network operators and EV OEMs may be cautious about early adoption.
  - Implication: Requires proven field data to build trust and demonstrate long-term reliability.

Relevant standards for implementation of transformerless topology

The relevant product standard for DC electric vehicle supply equipment is the IEC 61851 – 23 Electric vehicle conductive charging system – Part 23: DC electric vehicle charging station.

In the currently valid Edition 2 from 2023, transformerless charging (="non-separated EVSE") is mentioned as „under consideration".

1 Scope

Requirements for systems not providing simple separation or protective separation between side A and side B are under consideration.

5.101.1 Separation type

The EV supply equipment shall be classified according to the type of separation between side A and side B:

– separated EV supply equipment;
– non-separated EV supply equipment (under consideration)

8 Protection against electric shock

8.101 General provisions

8.101.1 General

Specific requirements for protective measures for non-separated EV supply equipment are under consideration.

Figure 101: Extract from the IEC 61851 – 23 concerning transformerless charging regulation

Compliance to EU Directives

EU directives allow in general a deviation to the known standards. Recital 16 of the European Commission's General Product Safety Directive (Directive 2001/95/EC) defines the following procedure for this case:

"Where no specific provisions exist and no European standards established in the context of standardisation mandates of the Commission are applied, the safety of products should be assessed, in particular taking into account national standards aimed at implementing other relevant European or international standards, recommendations from the Commission or national standards bodies, international standards, codes of practice, the current state of knowledge and technology, as well as the safety that consumers can reasonably be expected to have."[161]

Carried out Compliance process for the Car2Flex project

- Risc-assessment with determination of criticality for the safety functions (SIL or ASIL)
- Specification of safety requirements
- Validation & verification plan
- Optional: Application to a Notified Body
- Test and review process (at AIT and / or Notified Body)

[161] Directive 2001/95/EC of the European Parliament and of the Council of 3 December 2001 on general product safety. [online] Available at: < https://eur-lex.europa.eu/eli/dir/2001/95/oj/eng > [Accessed 11 Aug. 2025].

- Certificate of Conformity from Notified Body
- Declaration of Conformity from Fronius
- A Notified Body is not mandatory according to the EU Directives bot highly recommended because we are outside of the known standards

Functional safety requirements

Primary Objectives:

- Protect life and limb – Implement protective measures against earth faults
- Protect equipment – Implement protective measures against short circuits.

Protection Measures per IEC 61851 – Transformer Topology

- Cable check before charging: Achieved via insulation measurement.
- Insulation monitoring during charging: not possible with transformer topology.

Protection Measures for Transformerless Topology

Insulation monitoring during the charging process is not possible in a purely transformerless design. Therefore, additional safety measures are required to protect against:

1. High-impedance earth faults
2. Low-impedance earth faults
3. Short circuits
4.

High-Impedance Earth Fault

- Cause: Minor insulation damage in the EV, EVSE, or charging cable (e.g., small rupture in DC– cable insulation).
- Prevention:
    - Residual current monitoring (RCMU) in the inverter to monitor the power path of the EVSE up to the EV.
    - Additional 6 mA RCMU for DC-leakage-current monitoring to prevent malfunction of Type A-RCD in installation.
    - Automatic disconnection of the EVSE when residual current is detected.

Low-Impedance Earth Fault

- Relevance: In transformerless topology, a low-impedance earth fault is equivalent to a short circuit.
- Cause: Severe insulation damage in the EV, EVSE, or cable (e.g., DC– contact with EV chassis via PE).
- Risk:

  - High currents driven by the EV battery (up to 10 kA).
  - Theoretically high touch voltages possible on EV parts which are not protectively grounded
- Prevention:
  - Selectively dimensioned DC fuses in both EV and EVSE.
  - Appropriately dimensioned PE conductor (e.g., 10 mm²).
  - High speed disconnect mesaures within EVSE, triggered by e.g. the RCMU

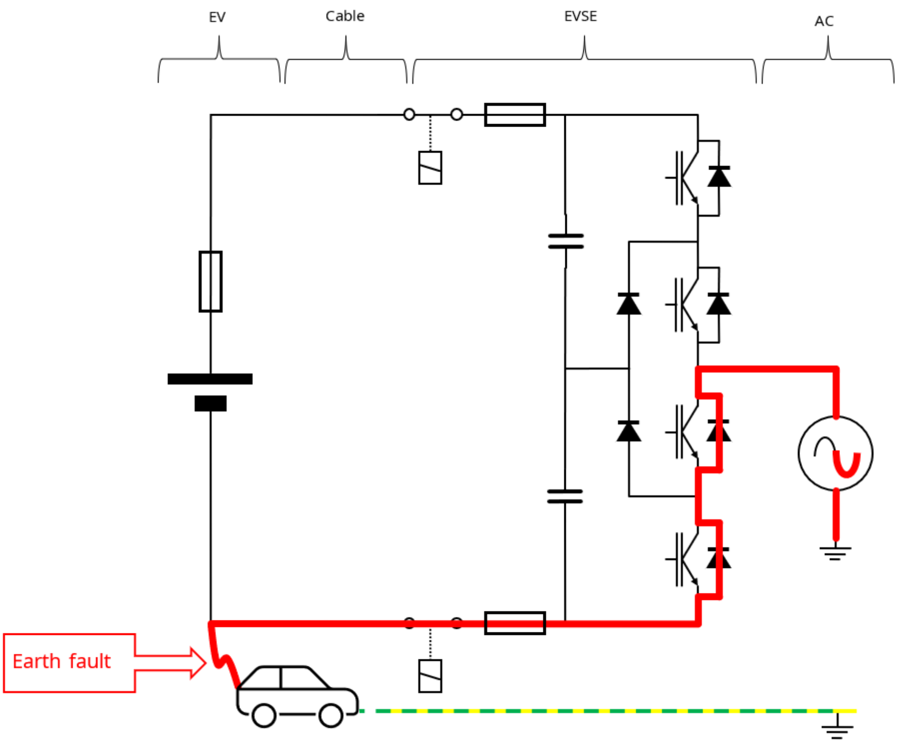


Figure 102: Illustration of an earth fault scenario

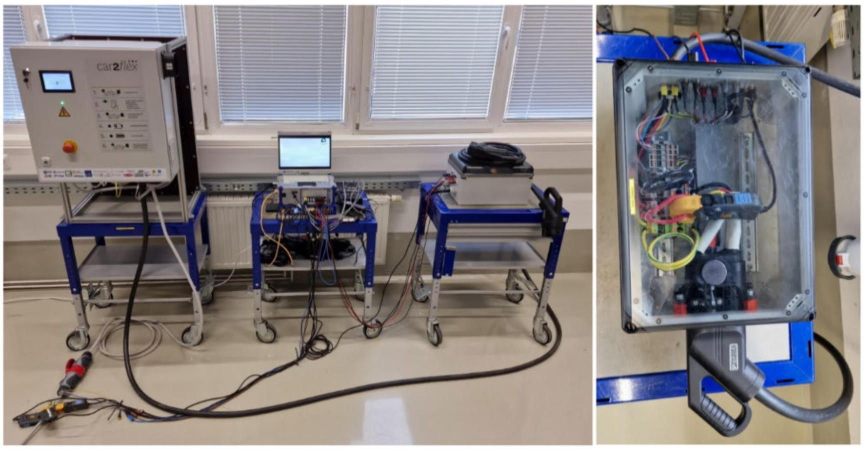


Figure 103: Testing equipment for comprehensive testing of different failure scenarios

6.4.3.2 Workarounds during the project

Workaround for Discharging with Serial EVs based on ISO 15118-2

At the start of development of the Car2Flex DC wallbox prototype in the year 2020 and during the hole project period, no series vehicle with implemented ISO 15118-20 was available.

So, the challenge was to find a solution based on available series EVs with the ISO 15118-2 standard.

Although ISO 15118-2 is not inherently designed to support vehicle-to-grid (V2G) discharging, experimental findings from the Car2Flex project revealed a practical workaround. During laboratory tests, it was observed that many commercially available electric vehicles permit continuous discharging if a brief charging pulse of approximately one second is sent at least once per minute. This behavior enables a stable discharge mode, even in the absence of officially supported V2G functionality. Using this method, researchers within the Car2Flex project successfully implemented discharging operations both in controlled lab environments and the real-world field tests, demonstrating a viable interim solution for demonstrating the Use-Cases which were defined for the project.

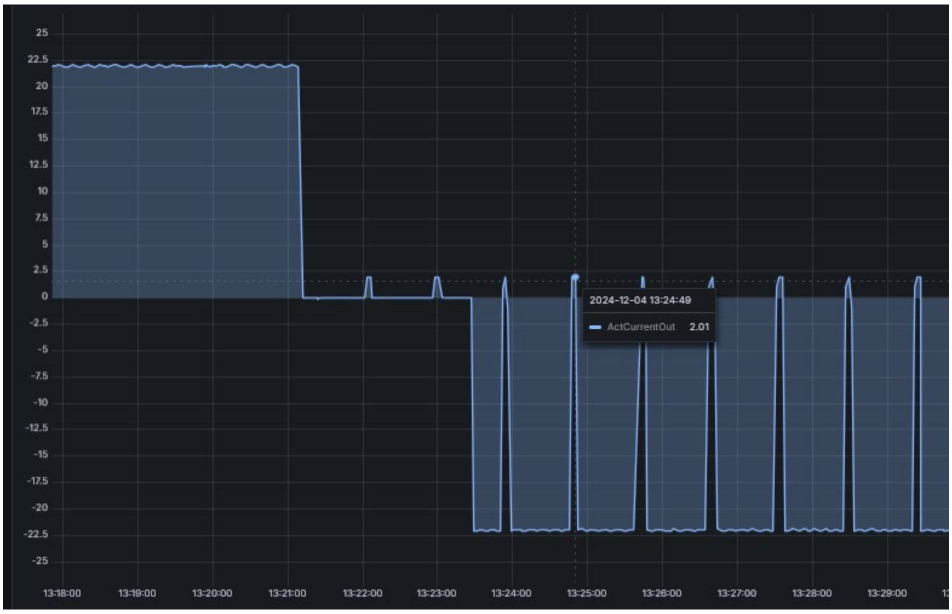


Figure 104: Current flow within the workaround for Discharging

7 End-User Analysis

The chapter addresses the role of bidirectional electric vehicle (EV) charging, also termed as Vehicle-to-Grid (V2G), in Austria, at the level of individual private households and within Renewable Energy Communities (RECs). The scope of this report is within the broader European strategy to enhance grid flexibility and integrate renewable energy, where V2G is expected to play a pivotal role in climate change mitigation and energy security. Despite the ecological and economic potential, large-scale adoption of V2G is highly dependent on user acceptance and supportive regional policies. With this background, the report investigates how private (Austrian) EV owners perceive bidirectional charging, highlighting their demographic, environmental, and technological attitudes while outlining barriers and opportunities for broader V2G adoption.

The methodological framework used in this analysis relies on a hybrid approach, combining both quantitative and qualitative data collection. Two major surveys were conducted: one survey focused on private EV owners, and another on EV owners, who are also members of RECs. To assess the trade-offs in user preferences for charging infrastructure attributes, including acquisition costs, battery warranties, charging management options, and acceptable charging durations, both the surveys used discrete-choice experiments. Furthermore, sociodemographic data, environmental values, technological affinity, and mobility behavior were additionally collected to contextualize acceptance patterns. While challenges such as limited accessibility to energy communities and non-representative sampling were acknowledged, the surveys were designed for careful data quality checks and simpler explanatory material to ensure that the participants had a shared understanding of bidirectional charging concepts.

7.1 Methodology

This section highlights the methodological framework laid out in the project. For the end-user analysis different stakeholder groups were originally included in the project.

The methodology used in the analysis combines quantitative and qualitative approaches to capture the user preferences and attitudes towards bi-directional EV charging. The Data collection is carried out primarily through online surveys targeting EV-owners in Austria and members of Renewable Energy Communities, complimented by discrete-choice experiments to systematically evaluate trade-offs between the different technical and economical attributes identified. In addition, the demographic information, user attitudes toward technology and the environment, and the existing renewable energy adoption are also assessed to contextualize the findings. The analysis in the scope of the report employs statistical methods to identify significant determinants of acceptance and willingness to adopt V2G, while comparative assessments between individual EV owners and REC members highlights differences in priorities and motivations. This mixed-method approach ensures that both practical preferences and underlying behavioral drivers are captured to develop policy and business model recommendations.

7.1.1 Research design - tools and data collection for end-user studies

The surveys/ interviews captured respondents' attitudes and perceptions toward bidirectional charging highlighting acceptance or reservations and skepticism towards its use under specific conditions and its future application. The aim was to identify, at an early stage, the potential, opportunities, and needs for socio-technical developments for V2G/V2X in Austria. In addition to highlighting factors that influence the acceptance of the technology and its application, the study's findings also contribute to the development and improvement of national regulations.

In conducting the V2G study in Austria, several practical constraints influenced the scope of the analysis. The sampling approach proved difficult to classify and likely reflected elements of convenience sampling. Participant recruitment was further affected by gatekeeper dynamics: energy communities (EEGs) with centralised management structures were generally inaccessible. In addition, many EEGs were perceived as "over-researched" and, despite expressing interest, did not proceed with concrete cooperation. These factors limited the size and diversity of the dataset, making it feasible to conduct robust analysis only for two user groups. While this necessarily reduced the breadth of the study, the results obtained are both meaningful and insightful, offering a valuable contribution to understanding user perspectives on V2G in the Austrian context.

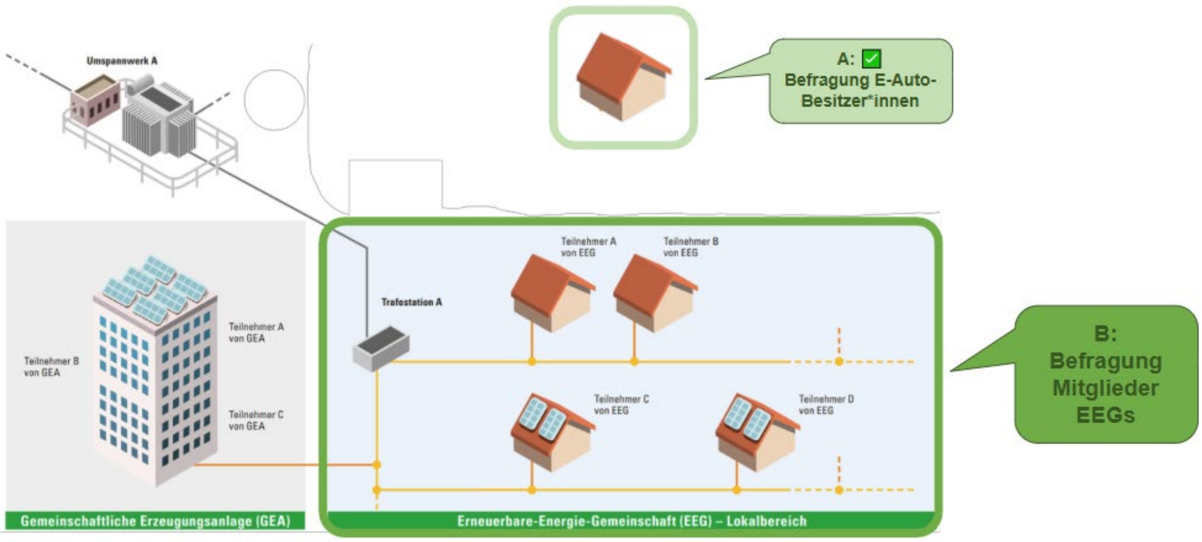


Figure 105: Template of a figure or picture

A survey among 2 user groups a.) private e-car owners and b.) e-car owners who are members of an energy community was conducted. The focus was to gather detailed insights and a better understanding of financial and technical framework needed in support for bidirectional charging in Austria. The general interest and "willingness to pay" (resp. "willingness to accept") for bidirectional charging applications had been determined by means of a conjoint analysis. The results provide a basis for further detailed development of business cases and tariff structures. In addition, this survey investigates the expectations with regard to the monetary compensation through V2G as well as the motivating factors that could increase its adoption. Additionally, data on environmental and technological values were gathered to support a broader understanding of customer needs.

7.1.2 Survey Design Acceptance of EV users

The first survey targeted EV users as potential private end users of bidirectional charging and was mainly distributed via the newsletter of the *Environment Agency of Lower Austria* and via contacts from the extended network of the project consortium. The survey was distributed via multiple channels, including newsletters from energy and environmental agencies, contacts from funding agencies, and e-mobility clubs. Reminders were sent periodically to encourage participation. The survey period for the first survey ran from December 19, 2022, to May 17, 2023. It was conducted using *Unipark s*urvey software. Data management involved rigorous cleaning processes, including plausibility checks and duplicate checks, to ensure the integrity of the data. Incomplete responses were deleted to maintain the quality and reliability of the dataset.

First, the participants were asked about socio-demographic characteristics such as gender, age, salary and their living situation. In addition, questions were included about existing vehicles in the household and the mobility behavior of the participants.

In an additional section of the survey, participants were also asked about their attitudes toward environmental issues, as well as their trust and affinity for technology and innovation. This part aimed to explore potential correlations between these attitudes and the acceptance or usage behavior related to bidirectional charging infrastructure.

The main part of the survey consisted of a discrete choice experiment[162]. Unlike traditional valuation methods, the choice experiment allows services (in general) to be described as a combination of distinct attributes[163]. The method was used as an assessment of the relative importance of each feature to the EV end-users. The aim was to explore the influence of Vehicle-to-Grid (V2G/V2X) capabilities on decisions related to the adoption of electric vehicle charging infrastructure.

Respondents were asked to compare and evaluate various fictitious e-charging infrastructure profiles, each of which consisted of five features (purchase costs, charging process, guaranteed battery life, charging management, minimum charge level) with two to five different specifications. The attributes and specifications used (table 1) were usually derived from the current state of research on the acceptance characteristics (see Deliverable D2.1). In contrast, the specifications for the acquisition cost feature were determined with experts and the unidirectional e-charging infrastructure currently available on the market.

[162] Hainmüller, J., Hopkins, D.J. & Yamamoto, T. (2014): Causal Inference in conjoint Analysis: Under-standing Multidimensional Choices via Stated preference Experiments. Political Analysis, 22, 1-30.

[163] Holmes, Thomas & Adamowicz, Wiktor & Carlsson, Fredrik. (2017). Choice Experiments. In: A Primer on Nonmarket Valuation (pp.133-186)., https://www.researchgate.net/publication/313534641_Choice_Experiments; Weller, P., Oehlmann, M., Mariel, P. & Meyerhoff, J. (2014): Stated and inferred attribute non-attendance in a design of designs approach. Journal of Choice Modelling, 11: 43-56.

Table 25: Features of the charging infrastructure

Attributes	Specifications
Acquisition Costs	2000 €, 3000 €, 4000 €, 5000 €, 6000 €
Charging process	unidirectional, bidirectional
Battery Guarantee	7 years, 8 years, 9 years
Charging Management	cost-optimized, grid-optimized, climate-friendly
Minimum Charge	20%, 30%, 50%

An explanatory text on bidirectional charging was provided beforehand, along with a detailed explanation of the task. This ensured that all respondents shared a common understanding of the functions and potential applications of bidirectional charging. Following this, participants were presented with two e-charging infrastructure profiles in each of six rounds. These profiles were randomly generated using different combinations of feature specifications. Figure 1 illustrates an example of such a comparison.

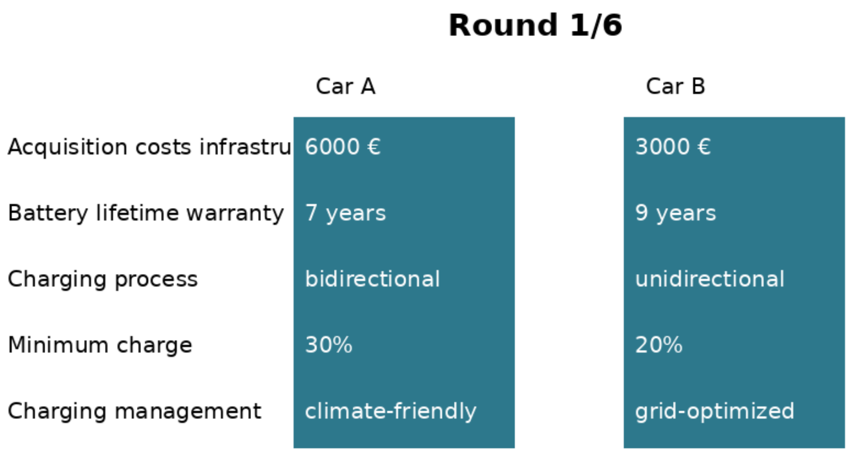


Figure 106: Choice experiment in the survey

In each round, participants were asked to choose which of the two profiles they preferred. Additionally, they rated both e-charging infrastructure profiles on a 7-point scale, ranging from “I like it very much” (rating = 7) to “I don't like it at all” (rating = 1). This approach allowed the collection of both preference choices and evaluative ratings[164] in order to cross-validate the respective responses.

As another part of the survey, EV users were asked to specify the charging durations that they personally consider “not feasible”, “just feasible”, and “feasible”. This approach was designed to capture users' subjective thresholds and tolerances for charging times. Rather than imposing fixed time limits, the method allowed respondents to express their own perceptions of acceptable durations. By analyzing these categorizations, the study aims to identify practical boundaries from the user’s perspective and gain insights into the expectations and real-world usability of bidirectional charging technologies.

[164] Hainmüller, J., Hopkins, D.J. & Yamamoto, T. (2014): Causal Inference in conjoint Analysis: Under-standing Multidimensional Choices via Stated preference Experiments. Political Analysis, 22, 1-30.

7.1.3 Survey Design Acceptance of EV users in Renewable Energy Communities

The second survey was largely based on the same design and methodological framework as the first survey to ensure comparability and to allow contrasting the results from both groups. It retained the core structure of the questionnaire, including the discrete choice experiment, the explanatory introduction to bidirectional charging, and the combination of preference choices and 7-point evaluative ratings for fictitious e-charging infrastructure profiles. As in the first survey, the instrument was implemented using UniPark and followed the same data quality procedures (plausibility checks, duplicate screening, exclusion of incomplete responses).

This second round specifically targeted EV users who are members of renewable energy communities, aiming to gather insights from a group with potentially greater engagement in sustainable energy systems. While the overall structure of the survey and the choice experiment remained the same, one adjustment was made to include in the charging management attribute the specification 'cost-optimized for the energy community', to better reflect the context and expectations of this user group. Another adjustment concerned the question about the user group's attitudes: specifically, their views on bidirectional charging, their assessment of its benefits for the energy community, and their perceived role in the expansion of renewable energy.

In the second survey, the 27-item online questionnaire was distributed via email to representatives of renewable energy community (REC) initiatives in Austria between May 16 and May 27, 2024. The representatives were asked to distribute the questionnaire among the members of their respective energy community. As an incentive for survey participation, respondents could partake in a lottery for 30 gift vouchers each worth 30 Euro. The survey yielded 88 valid responses.

To supplement the sample, additional data from electric car users was collected in December 2024 via an online panel by the market research institute Bilendi. Neither sample was designed to be representative of the Austrian population, as there are significant demographic differences in the prevalence of electric vehicles[165].

Table 2 presents the attributes of the charging infrastructure along with their corresponding specifications. In contrast to the initial survey, the current version includes an updated specification for charging management. While the previous version only featured cost optimization for the individual user, the revised specifications now also encompass cost optimization for the energy community. The specifications on climate-friendly and grid-optimized charging remained as in the first survey.

[165] Chen, C., Zarazua de Rubens, G., Noel, L., Kester, J. & Sovacool, B. (2020) Assessing the socio-demographic, technical, economic and behavioral factors of Nordic electric vehicle adaption and the influence of vehicle-to-grid preferences. Renewable and Sustainable Energy Reviews, 121, 109692

Table 26: Features of the charging infrastructure

Attributes	Specifications
Acquisition Costs	2000 €, 3000 €, 4000 €, 5000 €, 6000 €
Charging Process	unidirectional, bidirectional
Battery Guarantee	7 years, 8 years, 9 years
Charging Management	cost-optimized, grid-optimized, climate-friendly, cost optimized for the energy community
Minimum Charge	20%, 30%, 50%

To better understand participants’ willingness to engage in bidirectional charging activities, the study—specifically both surveys—investigated various influencing factors. As already described in the previous section, one central aspect was the assessment of tolerable charging durations, which reflect users' subjective thresholds for what they consider acceptable. Building on this, the survey on REC participants further examines feasible charging durations for EV users who are members of renewable energy communities.

7.2 Results: Individual EV users

This chapter presents the key findings from the survey of EV users, with a focus on their acceptance of attributes of charging infrastructure.

7.2.1 Sample characteristics of EV users

The survey sample consisted of n=1181 participants, of whom 794 completed the questionnaire, providing a detailed overview of their demographic, economic, and mobility characteristics. The vast majority of respondents were male (88.4%), the average age was 53 years (SD=12.49). Regarding educational attainment, 40.1% of respondents hold a tertiary degree. Employment status reveals that 63.5% are employed full-time, while 22.9% are retired. Respondents tend to live in higher-income households, with 30.8% reporting a net household income exceeding €4,900 per month. Household sizes are generally small, as 42.9% of participants live in two-person households. Geographically, respondents predominantly reside in rural areas, with 29.7% living in municipalities with fewer than 2,000 inhabitants. The housing situation of respondents shows a majority of single-family homes (75.5%). Additionally, 11.6% reside in apartments, and 12.9% in two- or multi-family houses. A significant majority (91.5%) live in owner-occupied properties. These characteristics align closely with the profile of electric vehicle (EV) owners, suggesting that EV drivers or those interested in EVs differ notably from the general population of private car owners. When examining mobility behavior and the adoption of renewable technologies, the data reveals that most respondents own both a first and a second car. Among first cars, 83% are electric vehicles, while 32% of second cars are electric. This indicates that the majority of respondents have substantial experience with EVs. Beyond vehicle ownership, the integration of renewable energy technologies is noteworthy. A significant proportion (70.3%) of respondents own a photovoltaic (PV) system, and an additional 15.7% are planning to install one. Furthermore, 27.5% of participants own an electricity storage unit. The average annual electricity demand among respondents is 7293.63 kWh (SD = 2019.53).
Table 3 provides a detailed overview of the sociodemographic characteristics of the survey participants. The sample is predominantly male (88.4%), with females representing only 11.4% and a very small proportion identifying as diverse (0.2%). Educational attainment among respondents is relatively high, with 40.1% holding a tertiary degree, while 30.5% have not completed high school.
In terms of employment status, the majority is employed full-time (63.5%), and nearly a quarter are retired (22.9%). Income levels are fairly evenly distributed across the mid and upper brackets: 30.9% earn between €3,301 and €4,900, and 30.8% earn above €4,900, while only 6.3% report earning €2,000 or less.

Table 27: Sociodemographic attributes of survey participants

Attribute	%	Attribute	%
Gender		**Population of the residence**	
Female	11.4	<2,000	29.7
Male	88.4	2,000-4,999	23.8
Diverse	0.2	5,000-19,999	17.8
Education		≥20,000	28.7
No high school diploma	30.5	**Housing type**	
High school diploma	29.4	Single-family house	75.5
Tertiary degree	40.1	Apartment	11.6
Employment		Two- and multi-family house	12.9
Full-time	63.5	**Housing situation**	
Retired	22.9	Owner-occupied	91.5
Other	13.6	Rented	8.5
Income		**EV use**	
≤€2,000	6.3	Yes	89.4
€2,001-€3,300	23.1	**Photovoltaics**	
€3,301-€4,900	30.9	Yes	70.3
>€4,900	30.8	No, but planned	15.7
No response	8.8	No	14.0
Household size		**Electricity storage**	
1 Person	8.1	Yes	27.5
2 People	42.9	No	72.5
3 People	21.7		
4 or more people	27.3		

Household composition shows that most participants live in two-person households (42.9%), with 27.3% living in households of four or more people. Housing characteristics reveal that 75.5% reside in single-family homes, and 91.5% are owner-occupiers, indicating a high level of residential stability and private homeownership.

Geographically, respondents are well distributed across settlement sizes, with 29.7% living in communities with fewer than 2,000 inhabitants and 28.7% in cities with over 20,000 residents.

Regarding energy-related attributes, a significant majority already use electric vehicles (89.4%), and 70.3% have installed photovoltaic systems. However, only 27.5% report using electricity storage systems, suggesting room for expansion in this area. Notably, 15.7% plan to adopt photovoltaics in the future.

The data indicates a predominantly male, well-educated, and financially secure sample, largely consisting of homeowners in rural or semi-rural settings. High rates of EV and PV adoption suggest strong engagement with sustainable technologies, though lower uptake of electricity storage may reflect cost or awareness barriers. The results point to a progressive and relatively affluent participant base with strong interest in energy self-sufficiency.

7.2.2 Acceptance

Mobility behavior, as illustrated in Figure 3, reveals distinct usage patterns between first and second cars, an important consideration for assessing the potential and user acceptance of bidirectional charging. For first cars, 56% of trips are related to work and education, while only 16% are for leisure activities. In contrast, second cars are used for work and education in 36% of cases and for leisure in 32% of cases. The average annual mileage for first cars is approximately 18,000 kilometers, whereas second cars are driven an average of 9,600 kilometers per year. These findings underscore the differences in usage patterns between primary and secondary vehicles. First cars might be more accessible to bidirectional charging, as the planned schedules of work trips facilitate the integration of charging times in the daily mobility patterns. The brands of the cars are also shown in Figure 94.

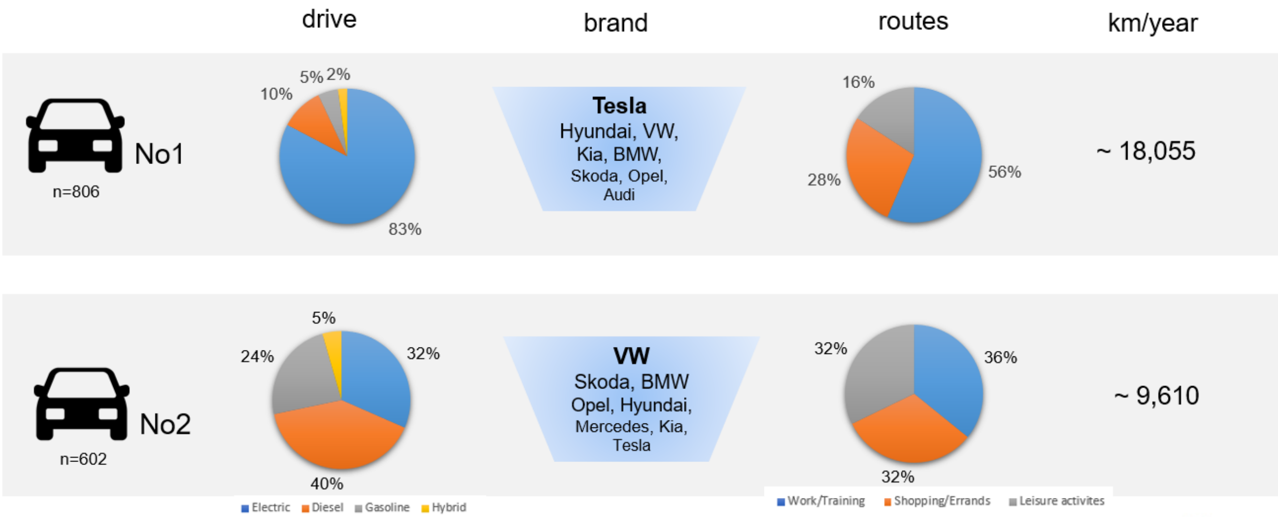


Figure 107: Mobility Behavior

In addition to mobility patterns, individual attitudes toward environmental issues also play a key role in the acceptance of bidirectional charging technologies. Questions Q1 to Q16 consist of statements that participants were asked to evaluate for accuracy. The results for the questions on *Environmental Value Orientation* are presented in Figure 95.

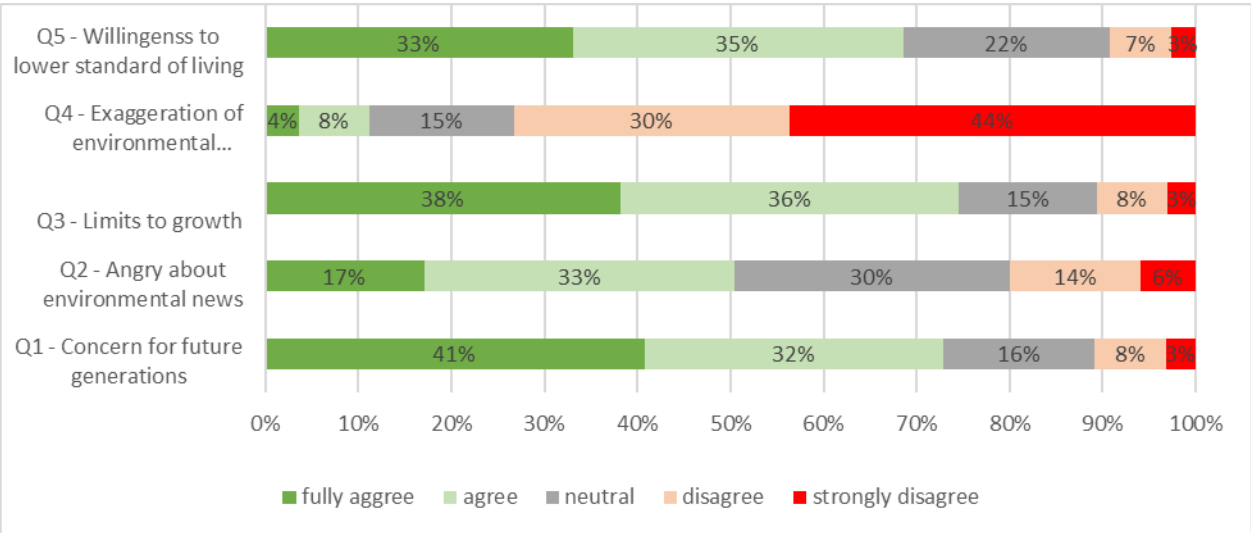


Figure 108: Environmental Value Orientation of Users

The survey results reveal a strong overall concern among respondents regarding environmental issues and their long-term consequences. A clear majority (73%) expressed worry about the living conditions of future generations, while only a small minority (11%) disagreed. Similarly, broad recognition of ecological limits was observed, with 74% agreeing that industrialized societies have already exceeded or will soon exceed growth boundaries.

Emotional engagement with environmental information appears more varied. While 50% reported feelings of outrage and anger when confronted with environmental problems in media, a notable 30% remained neutral and 20% disagreed, indicating differing levels of affective response. Skepticism toward environmental concerns was largely absent, with 74% rejecting the claim that environmental problems are exaggerated. Furthermore, a substantial majority (68%) indicated a willingness to reduce their standard of living for the sake of environmental protection, suggesting openness to behavioral change in support of sustainability goals.

The results for the questions on *Confidence in Technology* are presented in Figure 96.

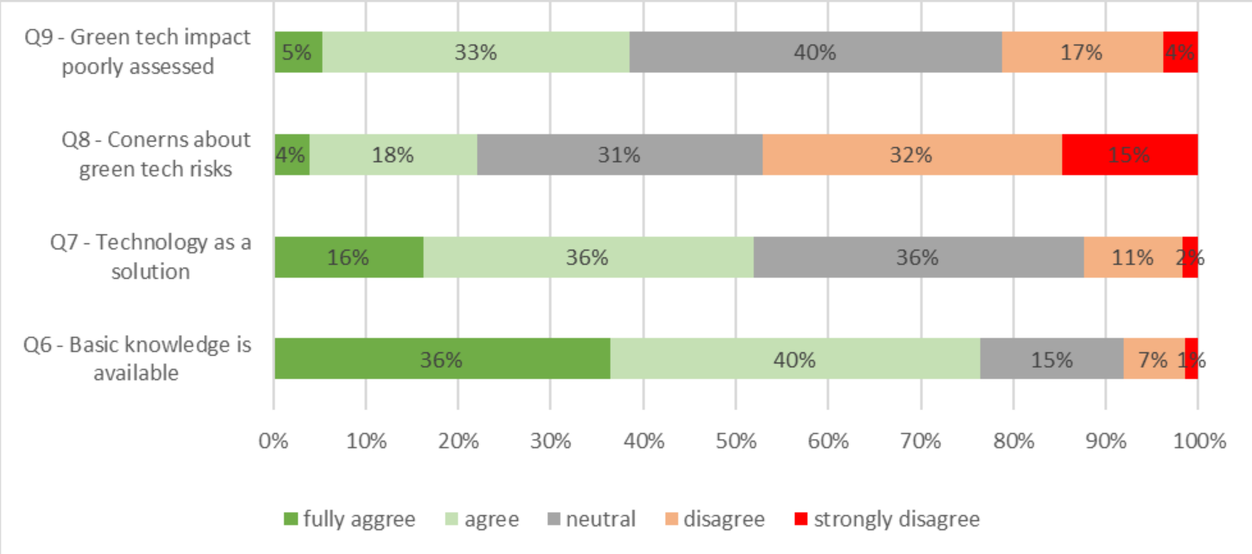


Figure 109: Confidence in Technology

The survey results also indicate that respondents generally perceive the scientific and technical knowledge required to address climate change as already available, with a majority either fully agreeing (36%) or agreeing (40%) to this statement, while only a small minority expressed disagreement. A similar tendency is observed in the view that technology will assist in addressing climate change, though opinions are more evenly distributed: 52% agreed to some extent, whereas a notable 36% remained neutral and 13% expressed disagreement.

Concerns about potential drawbacks of climate-friendly technologies are also evident. Just over half of respondents (52%) agreed that such innovations may introduce ecological, social, or economic risks, while 36% remained neutral and only 13% disagreed. In contrast, when asked whether new technologies are often implemented without sufficient impact assessment, responses were more skeptical: only 21% agreed, while a combined 38% disagreed and 40% remained neutral. These results highlight a nuanced perception of green technologies—acknowledging their availability and potential while simultaneously expressing reservations regarding their risks and deployment processes.

The results for the questions on *Technological Innovation* are presented in Figure 97.

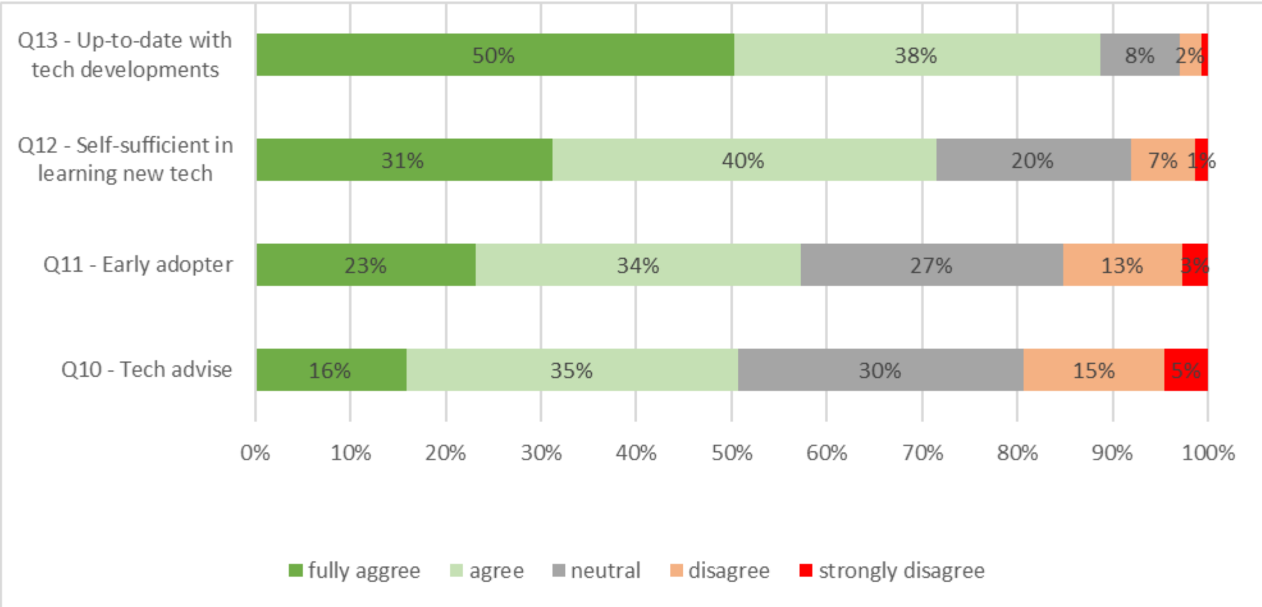


Figure 110: Technological Innovation

Further results from the survey indicate a generally high level of technological affinity among respondents. Approximately half of participants (51%) reported that others seek their advice on new technologies, suggesting that a considerable proportion are perceived as knowledgeable within their social environment. Similarly, 57% of respondents identified themselves as early adopters, typically among the first in their peer groups to purchase new technology, while 27% expressed neutrality on this statement.

Self-assessed competence in handling advanced technologies was also pronounced. A clear majority (71%) stated that they can learn to use high-tech products and services without external assistance, with only a small minority (8%) indicating difficulty in doing so. The strongest consensus was observed regarding staying informed: 88% of respondents agreed or fully agreed that they actively keep up with technological developments in their areas of interest. Collectively, these findings highlight a respondent group characterized by above-average openness to innovation, high self-efficacy in adopting new technologies, and strong engagement with technological progress.

Overall, the responses indicate a strong sense of confidence and engagement with technology, particularly in staying updated with developments and learning new technologies independently.

The results for the questions on *Energy Security Concerns* are presented in Figure 98. Questions Q14 to Q16 included statements about specific concerns, which participants were asked to evaluate based on their level of worry. The response options were: not at all worried, rather not worried, neutral, rather worried and very worried.

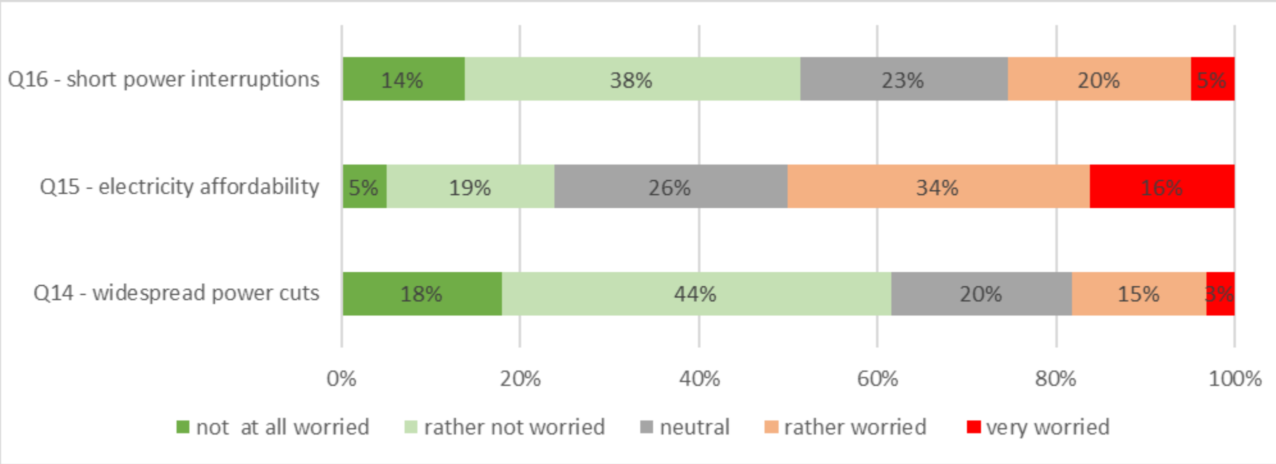


Figure 111: Energy Security Concerns

Survey results for the final questions indicate a considerable level of concern among respondents regarding the reliability of electricity supply in Austria. With respect to potential long-lasting power outages, 62% of participants reported being worried (18% very worried, 44% rather worried), whereas only 18% expressed little or no concern. In contrast, the affordability of electricity raised comparatively fewer worries, with only 24% of respondents indicating concern, while the majority were either neutral (26%) or not worried (50%). Concerns about short-term supply interruptions were somewhat in between these two extremes: 52% of respondents reported being worried about power cuts lasting a few hours, while 25% expressed little or no concern.

Overall, the findings suggest that prolonged power outages are perceived as the most pressing risk, while electricity affordability is less of an immediate concern. Short-term supply interruptions are acknowledged as a potential issue but are viewed with less urgency than the prospect of extended blackouts. This indicates that public perception is primarily shaped by the severity and duration of potential disruptions, with longer-lasting outages evoking significantly higher levels of anxiety.

7.2.3 Results for EV users from the choice experiment

This section presents the results of the discrete choice experiment conducted with private EV users. The aim of the experiment was to quantify user preferences for various features of bidirectional charging systems and to identify the relative importance of individual attributes in the decision-making process.

The table shows that bidirectional charging is preferred across all the presented demographic groups. Respondents identifying as female or male favor bidirectional over unidirectional charging, with a slightly higher preference among male respondents (58.9% vs. 55.7%). Among respondents identifying as diverse, the pattern is somewhat reversed; however, the number of responses in this group was low and should be interpreted with caution. Educational level appears to have little influence, as support for bidirectional charging remains consistent at around 58–59% across all levels.

Table 29 Specification Attributes and Choice” shows a descriptive evaluation of the aggregated results, reporting both the frequency with which specific attribute levels were chosen and the corresponding means in the evaluative ratings on a 7-step scale from “I like it very much” (rating = 7) to “I don't like it at all” (rating

= 1). This dual analysis offers insights into how certain technical and economic parameters influence user acceptance and perceived attractiveness of bidirectional charging solutions.

Table 28 reveals a crosstabulation of sociodemographic characteristics and preferences for the charging process (unidirectional vs. bidirectional). The table shows that bidirectional charging is preferred across all the presented demographic groups. Respondents identifying as female or male favor bidirectional over unidirectional charging, with a slightly higher preference among male respondents (58.9% vs. 55.7%). Among respondents identifying as diverse, the pattern is somewhat reversed; however, the number of responses in this group was low and should be interpreted with caution. Educational level appears to have little influence, as support for bidirectional charging remains consistent at around 58–59% across all levels. Table 29 Specification Attributes and Choice" shows a descriptive evaluation of the aggregated results, reporting both the frequency with which specific attribute levels were chosen and the corresponding means in the evaluative ratings on a 7-step scale from "I like it very much" (rating = 7) to "I don't like it at all" (rating = 1). This dual analysis offers insights into how certain technical and economic parameters influence user acceptance and perceived attractiveness of bidirectional charging solutions.

Table 28: Sociodemographic characteristics and choice of charging process

Attribute	Charging process		
	Specification	**unidirectional**	**bidirectional**
Gender	**female**	44.2%	55.7%
	male	41.1%	58.9%
	divers	53.8%	46.1%
Education	**no high school diploma**	41.6%	58.4%
	high school diploma	41.4%	58.6%
	tertiary	41.4%	58.6%

Table 29 Specification Attributes and ChoiceThe results reveal a clear and consistent negative relationship between acquisition costs and both the probability of choice and the average rating. As acquisition costs increase the share of participants selecting the corresponding option decreases steadily from 64.6% to 41.0%. This indicates price sensitivity among respondents. Similarly, average ratings decline with rising costs, from 4.9 at €2000 to 4.2 at €6000.

Battery life exerts a positive influence on both choices and ratings. Options with a longer battery warranty are more likely to be chosen. Specifically, choice shares rise from 42.7% (7 years) to 60.5% (9 years), while average ratings increase slightly from 4.4 to 4.7. These findings suggest that longer battery warranties enhance product appeal.

Preferences regarding the charging process reveal a divergence between choice behavior and ratings. While bidirectional charging achieves the highest choice share (63.7%), it is rated lower (4.3) than unidirectional charging (4.9), which is selected less frequently (44.4%). This discrepancy may reflect a gap between the functional appeal and the awareness of bidirectional charging. Participants may choose bidirectional options for their added utility, even if they rate them lower due to uncertainty or unfamiliarity.

The results for charging management show that the climate-friendly option achieves the highest choice share (57.0%). The cost-optimized variant is chosen slightly less frequently (54.6%). Interestingly, the grid-optimized option receives the highest rating (4.9) but the lowest choice share (50.4%).
For minimum charge level, a reverse relationship between choice shares and ratings emerges. While the lowest minimum charge (20%) is rated highest (4.7), it is chosen least often (43.7%). Conversely, a higher minimum charge of 50% is most frequently chosen (63.9%) but rated lowest (4.5). This suggests that although lower minimum thresholds may be preferred conceptually (perhaps for greater battery flexibility), higher thresholds are more appealing when making actual selections.

Table 29 Specification Attributes and Choice EV user

Attribute	Specification	Choice	Rating
Acquisition costs	**€ 2000**	64.6%	4.9
	€ 3000	62.2%	4.8
	€ 4000	54.4%	4.6
	€ 5000	48.2%	4.5
	€ 6000	41.0%	4.2
Battery life	**7 years**	42.7%	4.4
	8 years	54.3%	4.6
	9 years	60.5%	4.7
Charging process	**unidirectional**	44.4%	4.9
	bidirectional	63.7%	4.3
Charging management	**cost optimized**	54.6%	4.2
	climate friendly	57.0%	4.6
	grid optimized	50.4%	4.9
Minimum charge	**20%**	43.7%	4.7
	30%	54.1%	4.6
	50%	63.9%	4.5

Table 30 shows a Crosstab of specifications of charging process and charging management (choice in %)

Table 30: Charging process and charging management EV user

	Charging management		
Charging process	**Cost optimized**	**Grid optimized**	**Climate friendly**
unidirectional	33.1%	36.2%	30.9%
bidirectional	34.3%	33.9%	32.6%

For unidirectional charging, the highest share of preferences (36.2%) is observed when it is framed as grid-optimized, suggesting that respondents are more inclined to choose this configuration. In contrast, the climate-friendly variant of unidirectional charging is the least preferred option, receiving only 30.9% of the choices. For bidirectional charging, preferences are more evenly distributed across the three management strategies, with the cost-optimized option slightly leading at 34.3%, followed closely by grid-optimized and climate-friendly alternatives.

7.2.4 Acceptable charging hours for EV users

This section explores the range of charging durations that participants consider acceptable for bidirectional charging. Specifically, EV users were asked to assess what charging durations they deem not feasible, just feasible, and feasible. We applied an adjusted Van Westendorp's Price Sensitivity Meter (PSM)[166] to assess the acceptable charging duration. By understanding their perceptions of acceptable charging times, this analysis provides insight into the practical limits and expectations of EV users regarding bidirectional charging technologies.

Figure 99 shows the distribution of charging hours across three feasibility categories: not feasible, just feasible, and feasible.

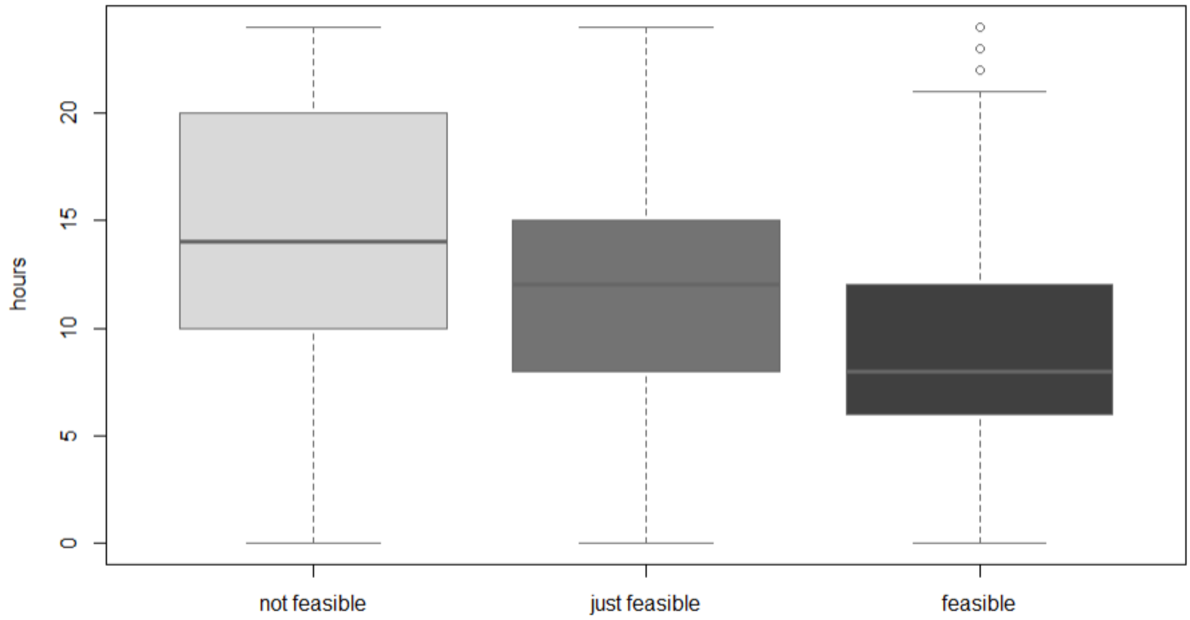


Figure 112: Acceptable charging hours for EV users

Not feasible: The mean charging duration is 13.98 hours (SD = 6.18), indicating that users perceive this duration as too long for bidirectional charging. The relatively high standard deviation suggests considerable variation in responses regarding what is considered unfeasible.

Just feasible: The mean is 11.61 hours (SD = 5.52). This lower standard deviation suggests less variability in responses, indicating more agreement on what is considered the upper limit of acceptable charging duration.

Feasible: In this category, participants report a mean of 9.27 hours (SD = 4.99), reflecting a more widely accepted and practical duration for bidirectional charging.

166 Van Westendorp, P.H. (1976), "NSS-Price Sensitivity-Meter (PSM) – a new approach to study consumer perception of prices", Proceedings of the 29th ESOMAR Congress, pp. 139-167.

7.3 Results: EV users in Renewable Energy Communities

This chapter presents the key findings from the survey of the second end user category, members of renewable energy communities (RECs), focusing on their acceptance of various attributes of electric vehicle charging infrastructure. Section 4.1 outlines the sample characteristics, providing insights into respondents' demographic, economic, and mobility profiles. Section 4.2 details the results of the choice experiment, while Section 4.3 examines preferences related to acceptable charging durations.

7.3.1 Sample characteristics of EV users in RECs

The survey resulted in 124 responses from their REC members and is listed in detail in Table 6a. The survey sample is composed primarily of male participants (74.7%), with female respondents representing 25.3% of the total. In terms of age distribution, the largest group falls within the 35–49 age range (37.8%), followed by those aged 50–64 (31.6%). Younger participants under 35 years make up 22.4%, while only 8.2% are 65 years or older.

Educational attainment varies, with 67.0% of respondents holding at least a school-leaving certificate, while 33.0% do not possess such a qualification. A significant majority of participants (82.0%) own their homes, whereas 18.0% are renters.

The sample is largely rural, with 78.0% residing in rural areas and only 22.0% in urban settings. Additionally, a substantial proportion of respondents reported having photovoltaic systems at home (78.3%), and half of the sample (50.0%) also have battery storage systems installed. Participants report an annual electricity consumption of mean = 6,753.82 kWh (SD = 4,046.15)

Table 31: The Sample Characteristics of EV users in RECs

Attribute		%		Attribute		%
Gender				**Population of the residence**		
Female		25.3		<2,000		22.7
Male		74.7		2,000-4,999		33.3
Diverse		-		5,000-19,999		18.2
Education				≥20,000		25.8
No high school diploma		68.2		**Housing type**		
High school diploma		31.8		Single-family house		88.3
Tertiary degree		-		Apartment		10.1
Employment				Two- and multi-family house		1.4
Full-time		36.6		**Housing situation**		
Retired		49.2		Owner-occupied		77.8
Other		14.2		Rented		22.2
€2,001-€3,300		25.6		**Photovoltaics**		
€3,301-€4,900		25.6		Yes		67.0
>€4,900		21.1		No, but planned		5.6
No response		-		No		27.4
Household size				**Electricity storage**		
1 Person		10.6		Yes		43.4
2 People		35.9		No, but planend		45.5
3 People		24.7		No		11.1
4 or more people		22.4				

7.3.2 Acceptance

For first cars, 61.2% of trips are related to work and education, while only 16% are for leisure activities. In contrast, second cars are used for work and education in 23.0% of cases and for leisure in 15.7% of cases. The average annual mileage for first cars is approximately 16,414 kilometers, whereas second cars are driven an average of 5,766 kilometers per year.

The results for the questions on Attitudes towards Bidirectional Charging and its role in Renewable Energy Communities (RECs) are presented in Figure 92 and Figure 101. Questions Q1 to Q11 consisted of statements that participants were asked to evaluate for accuracy (fully agree to strongly disagree).

Figure 9 shows the results for the questions on “Attitudes towards Bidirectional Charging” (Figure 100).

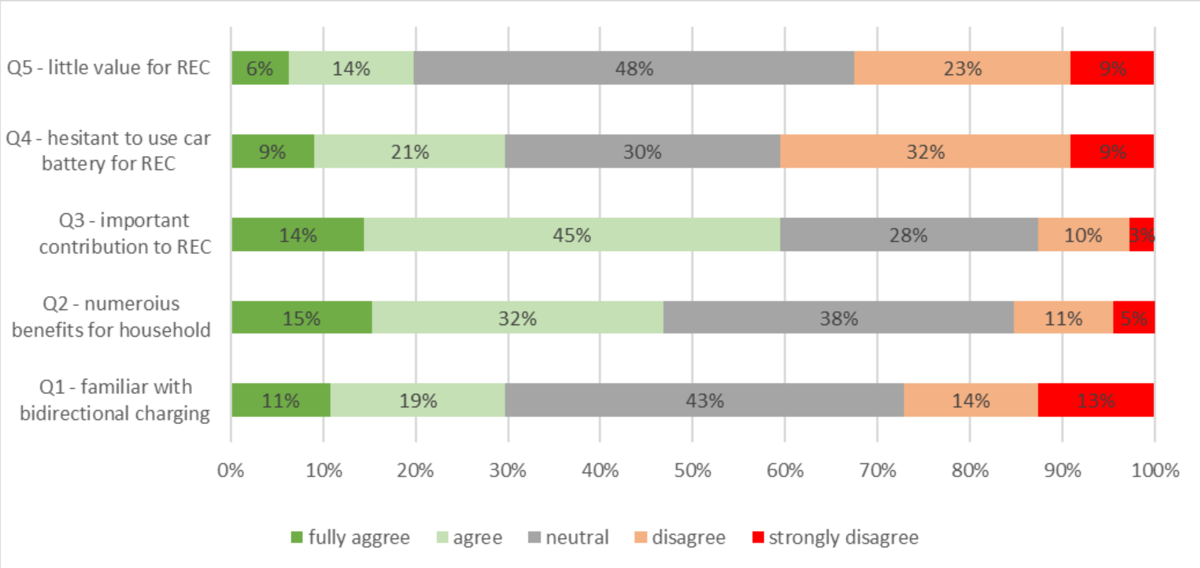


Figure 113: Attitude toward Bidirectional Charging

The survey results indicate that awareness of bidirectional charging among participants remains limited, with only 30% expressing familiarity, while 43% reported neutrality and 27% indicated unfamiliarity. Despite this knowledge gap, nearly half of the respondents (47%) acknowledged household benefits associated with bidirectional charging, though a significant portion (38%) remained undecided, highlighting both cautious optimism and the need for further information and practical demonstrations.

Perceived benefits at the community level were even more pronounced. A majority of 59% agreed that bidirectional charging could provide an important contribution to renewable energy communities (RECs), with only 13% disagreeing. Nevertheless, concerns regarding the use of private vehicle batteries for shared storage were evident: approximately one-third of participants expressed reluctance, while another third opposed such use, and 30% remained undecided. Finally, opinions on the overall potential of bidirectional charging for RECs were divided, with 20% considering it negligible, 32% disagreeing with this view, and nearly half (48%) remaining neutral. These results suggest that while bidirectional charging is broadly recognized as a promising concept, its practical application continues to face skepticism, particularly in relation to battery sharing within communities and the lack of demonstrable benefits.

The results for the questions on Attitudes toward the Role of Bidirectional Charging in RECs (Figure 101).

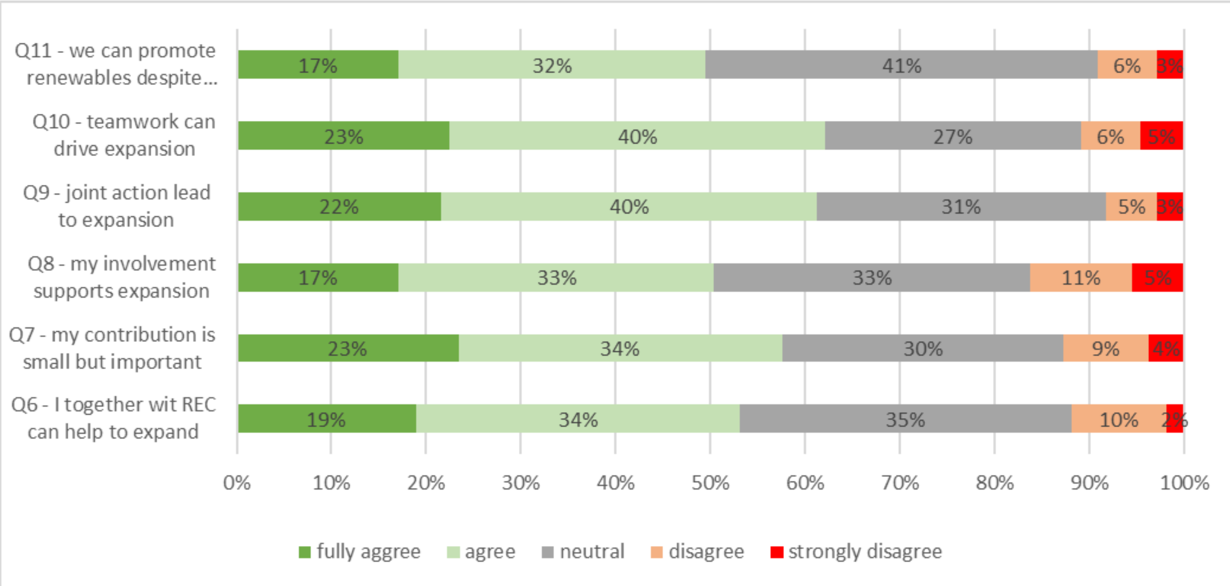


Figure 114: Attitude toward the Role of Bidirectional Charging in RECs

The survey results demonstrate a generally positive attitude among respondents toward their role in supporting the expansion of renewable energies through participation in energy communities. Across several questions, between 49% and 63% of participants expressed agreement that individual or collective involvement within renewable energy communities (RECs) can effectively advance renewable energy deployment. In particular, the strongest agreement was observed regarding the importance of collaborative action: 62%–63% of respondents endorsed the view that working together within their community is a key driver of renewable energy growth.

At the same time, a substantial proportion of respondents (27%–41%) remained neutral across multiple items, suggesting a degree of uncertainty about the effectiveness of both individual and collective contributions. Disagreement levels were consistently low (8%–16%), indicating only limited skepticism. Notably, when asked about overcoming resistance and difficulties, support declined somewhat, with nearly half (49%) in agreement but over 40% neutral. Overall, the findings highlight a strong belief in the value of cooperation within RECs, while also revealing ambivalence about the scale of personal impact and the ability to overcome external challenges.

7.3.3 Results of the choice experiment for EV users in REC

The comparison of sociodemographic characteristics of renewable energy community (REC) members with their choice of charging process (unidirectional vs. bidirectional) can be seen illustrated in Table 7. The results indicate that both male and female respondents show a higher preference for bidirectional charging, with 54.5% of women and 58.0% of men opting for this option, compared to 46.9% and 53.1% respectively for unidirectional charging. No responses were recorded for participants identifying as diverse.

In terms of education, a majority of REC users in both groups had not completed a high school diploma (68.3% for unidirectional and 72.0% for bidirectional). A smaller proportion reported holding a high school diploma (31.7% and 28.0%, respectively), while no respondents indicated tertiary education. Overall, the data suggest that within the surveyed REC sample, both men and women lean slightly toward bidirectional charging, and the majority of users—regardless of charging preference—belong to the lower educational attainment group.

Table 32: Sociodemographic characteristics and choice of charging process REC users

Attribute	Charging process		
	Specification	**unidirectional**	**bidirectional**
Gender	**female**	46.9%	54.5%
	male	53.1%	58.0%
	divers	0.0%	0.0%
Education	**no high school diploma**	68.3%	72.0%
	highschool diploma	31.7%	28.0%
	tertiary	0.0%	0.0%

Table 33 shows a descriptive evaluation of the aggregated results, reporting both the frequency with which specific attribute levels were chosen and the corresponding mean ratings. This dual analysis offers insights into how certain technical and economic parameters influence user acceptance and perceived attractiveness of bidirectional charging solutions.

Also, for this survey, preferences decline as acquisition costs increase. The highest choice rate (64.0%) was for a cost of €3000, with a high rating of 4.6. Even at €2000, the choice rate was slightly lower (59.3%) but still well-rated (4.6). As costs rise to €4000 and €5000, the choice rate dropped to 56.4% and 52.2% respectively, with ratings also decreasing slightly (4.5 and 4.4). At the highest price point of €6000, the choice rate fell significantly to 42.7%, with the lowest rating of 4.2, indicating a clear sensitivity to price.

Battery life exerts a positive influence on both choices and ratings. Options with a longer battery warranty are more likely to be chosen. Specifically, choice shares rise from 51.8% (7 years) to 56.8% (9 years), while average ratings increase slightly from 4.2 to 4.6.

The bidirectional charging option was more popular, with 57.0% of respondents choosing it, compared to 52.4% for unidirectional charging. The mean ratings were equally 4.4.

The charging management specifications in this survey included a cost-optimized option specifically for energy communities (RECs). This option received the highest share of preferences, with 61.4% of participants selecting it. The general cost-optimized option (50.9%) and the climate-friendly option (50.0%) received considerably less acceptance. The grid-optimized option received the lowest rating (4.2), while both the cost-optimized for REC and the climate-friendly options achieved the highest average rating of 4.5.

For minimum charge level, a reverse relationship between choice shares and ratings emerges. The lowest minimum charge (20%) is chosen (48.4%) and rated lowest (4.7), A higher minimum charge of 50% is most frequently chosen (59.6%) and rated (4.6).

Table 33: Specification Attributes and Choice REC user

Attribute	Specification	Choice	Rating
Acquisition costs	**€ 2000**	59.3%	4.6
	€ 3000	64.0%	4.6
	€ 4000	56.4%	4.5
	€ 5000	52.2%	4.4
	€ 6000	42.7%	4.2
Battery life	**7 years**	51.8%	4.2
	8 years	55.8%	4.5
	9 years	56.8%	4.6
Charging process	**unidirectional**	52.4%	4.4
	bidirectional	57.0%	4.4
Charging management	**cost optimized**	50.9%	4.4
	climate friendly	50.0%	4.5
	cost optimized for REC	61.4%	4.5
	grid optimized	42.7	4.2
Minimum charge	**20%**	48.4%	4.3
	30%	56.3%	4.4
	50%	59.6%	4.6

Table 34 Crosstab of specifications of charging process and charging management (choice in %)

Table 34: Charging process and charging management REC user

	Charging management			
Charging process	**Cost optimized**	**Climate friendly**	**Cost optimized for REC**	**Grid optimized**
unidirectional	16.0%	16.0%	56.9%	11.1%
bidirectional	15.5%	18.1%	62.4%	14.6%

For both unidirectional and bidirectional charging, the highest share of preferences is observed when the specification is cost-optimized for REC (56.9% and 62.4%), suggesting that respondents are more inclined to choose this configuration. In contrast, the grid-optimized variant of unidirectional charging is the least preferred option, receiving only 11.1% (unidirectional) and 14.6 % (bidirectional) of the choices

7.3.4 Acceptable charging hours for EV users in REC

In this section, the results of a survey are presented in which EV users from Renewable Energy Communities (RECs) were asked to assess how many charging hours they consider acceptable. This analysis employed the same Price Sensitivity Meter method as for EV users. Respondents evaluated different durations as “not feasible,” “just feasible,” or “feasible,” providing insight into their preferences and practical expectations for participation in bidirectional charging.
As shown in Figure 102, the data reveals the following means and standard deviations for each category of charging hours:

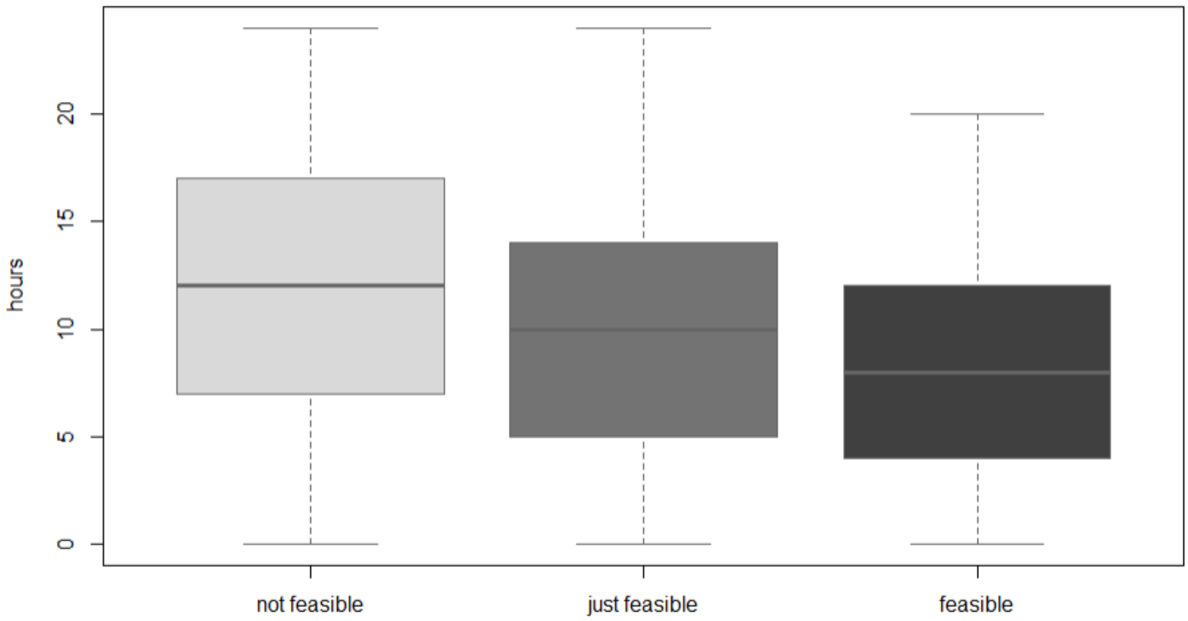


Figure 115: Acceptable charging hours for EV users in REC

Not feasible: The mean reported duration is 12.16 hours (SD = 6.41). The boxplot for this category shows a higher median and a wider spread, reflecting substantial variability in what users perceive as unacceptably long charging times.
Just feasible: The mean decreases to 10.02 hours (SD = 5.47), with slightly less variability, suggesting a moderate level of agreement among users on the upper boundary of acceptable charging time.
Feasible: The mean reported for this category is 7.88 hours (SD = 4.90). The narrower spread in this category indicates a stronger consensus among users regarding what they consider a practical and convenient charging duration.
These results suggest that shorter charging times are clearly preferred and viewed as more realistic for participation.

7.4 Key findings and recommendations

7.4.1 Individual EV users

The sample of EV users in the first survey is not representative of the Austrian population; however, this comes as no surprise as the adoption of electric vehicles has not (yet) reached all population segments. EV users in the sample were mostly male (percentage in comparison to female respondents), well-educated, and affluent. They are homeowners in rural or semi-rural settings. Thus, this socio-demographic profile also characterizes the potential target group for products and services related to bidirectional charging. EV users show a broader affinity to sustainable technologies, since, according to the survey results, most of them own a PV or plan to install one. Thus, this group seems open to adopting smart energy technologies such as bidirectional charging. Their first cars might be more accessible for bidirectional charging purposes, as their work and education trips occur at quite similar, pre-planned times of day which facilitate the integration of charging and discharging times into energy profiles. EV users hold strong environmental value orientations and are quite confident in technology. They picture themselves as technologically innovative and as open towards staying informed and familiarizing themselves with new technologies. This suggests that marketing messages framed towards these attitudes might be effective in reaching this target group. However, they do not voice strong energy security concerns that would make them accessible for arguments that promote bidirectional charging as an element of (local) blackout prevention systems that integrate energy storage such as car batteries.

EV users prefer bi- over unidirectional charging, regardless of their gender and education. Although small gender differences can be observed in the sample, these are to small to be generalized to the population of all Austrian EV users. Naturally, respondents aim for low acquisition costs, long battery life and high minimum charge. However, the variability in responses points to a certain degree of sensitivity that may be leveraged in specific business models that incentivize, for example, lower minimum charges with higher payments. As a guideline, acquisition costs of €4000 or less, battery life of 8+ years and a minimum charge of 30%+ are accepted by the majority, i.e. more than half of the sample. This guideline could inform the dimensioning of general business models that aim for broad acceptance among EV users.

EV users do not voice a clear preference for a specific form of charging management. However, a slight priority for climate friendly charging management can be observed, indicating that this aspect should be emphasised in marketing messages. Charging duration should not exceed 11 hours and should preferably stay below 9 hours. Similarly to the other attributes, large variability within the responses suggests that there is leeway for different business models that could be tailored to different target groups within the EV user population and that could incentivise longer charging durations.

7.4.2 EV users in REC

The sociodemographic distribution in the sample mirrors the first survey, since male and rural homeowners stand out. However, the role of income and education is less pronounced, indicating that RECs have already broader diffusion in the Austrian Population that EVs.

The results of the second survey among EV users who are also members in REC reveal mixed levels of awareness and attitudes toward bidirectional charging of electric vehicles. While only 30% of respondents reported familiarity with the concept, 47% believed it could bring tangible benefits to their household, indicating cautious optimism. The strongest agreement emerged regarding its role in energy communities, with 59% recognizing its importance for renewable energy integration. However, 30% expressed reluctance to use their vehicle battery as a shared storage unit, and opinions were divided on whether the potential for such applications is negligible—20% agreed, 32% disagreed, and nearly half remained neutral. Overall, the findings point to a general openness toward bidirectional charging, tempered by uncertainty and a need for further information and practical demonstration.

The results for EV users in RECs indicate generally positive attitudes toward contributing to the expansion of renewable energies within energy communities. A majority of respondents agreed that both individual and collective actions can drive progress, reflecting a strong belief in the power of collaboration. Personal contributions were recognized as meaningful, with 57% agreeing they could play a small but important role. Confidence was highest in the potential of joint efforts, particularly when working together (Q9: 62%, Q10: 63%). However, a consistent share of neutral responses—ranging from 27% to 41%—suggests some uncertainty about the extent of personal impact and the ability to overcome challenges. Overall, the findings reflect optimism tempered by a need for clearer understanding of how individual and collective efforts translate into real-world outcomes.

A clear preference for bi- directional charging over unidirectional charging is observed in the analysis. However, the thresholds in the desired specification of charging attributes tend to be higher: The majority, i.e. more than half of the sample, would accept acquisition costs of € 5000 or less and a battery life of 7+ years, thus they seem less restrictive than general EV users. Minimum charge, however, should not drop below 30%. Charging management that is cost-optimized for the REC meets the highest acceptance, underlining that the population of EV users in RECs take not just their own, but also their energy community's interests into account.

In terms of charging duration, the second survey sample is more restrictive than the first sample. Charging duration should not exceed 10 hours and should preferably stay below 8 hours. However, as in the first survey sample, high variability suggests options for products and services tailored to specific target groups within the population of EV users and REC members.

Our results show a broad preference for bidirectional over unidirectional charging across all sociodemographic groups, indicating strong potential for V2G adoption. However, users remain highly price-sensitive, and lower acquisition costs, along with extended battery warranties, clearly increase acceptance. While bidirectional charging is valued for its functional benefits, it is often rated lower than unidirectional options, suggesting that limited familiarity or perceived complexity may hinder full user confidence.

The preferences in charging management lean toward climate-friendly and cost-optimized options, while grid-optimized solutions—though highly rated—are chosen less often, pointing to a need for better communication of their benefits.

Overall, companies and policymakers should focus on reducing costs, offering warranty incentives, ensuring clear user information, and expanding accessible, interoperable infrastructure to strengthen trust and accelerate the adoption of V2G technologies.

7.4.3 Conclusion

The end-user analysis conducted in the Car2Flex project provides concrete evidence that while bidirectional charging of EVs is generally perceived as a promising and valuable innovation. However, the widespread adoption of bidirectional charging in Austria remains dependent on overcoming barriers such as cost, battery warranty, and informational barriers.

The findings from the analysis indicate a strong environmental and technological orientation among both EV user groups (private EV users and EV users in RECs), coupled with a willingness to contribute to renewable integration. However, concerns regarding acquisition costs, battery durability, acceptable charging durations, and unfamiliarity with V2G applications underline the need for specifically designed communication strategies, supportive policy frameworks, and business models that align financial incentives with user expectations. By addressing these barriers, policymakers, industry stakeholders, and energy community actors can further improve public trust, minimize adoption barriers, and successfully facilitate the integration of bidirectional charging technologies as a key enabler of Austria’s transition to a more flexible and resilient energy system.

8 Impact Analysis

8.1 Grid Impact

This section explores the increasing adoption of electric vehicle (EV) charging and theirimpact on low-voltage (LV) grids in Styria, Salzburg, and Graz, revealing insights into the resilience and capacity . The investigation extends its scope to encompass the integration of heat pumps (HPs) and photovoltaic (PV) systems, to gain more insights into the impacts of these technology rollouts on the grid infrastructure. These technologies will constitute a substantial proportion of energy generation and consumption in the energy transition from traditional, fossil fuel-based energy sources to more sustainable, low-carbon, and renewable energy sources. It is, therefore, essential to assess how their operation, in conjunction with EVs, will affect the low-voltage grid.

Three distinct EV use cases are examined: private EV, car sharing, and fleet. The car-sharing use case, is based on an adaptation of private EV usage, specifically focusing on optimizing charging resource utilization within the context of shared mobility.

The work analyses the significant impacts of these assets on the low voltage grids and the influence of varying assumptions of different EV charging behaviour.

8.1.1 Simulation methodology

8.1.1.1 Implementation of future technologies

This section provides a comprehensive overview of how future technologies were integrated into the networks.

In the private EV use case, the charging points were randomly allocated to the households, with each EV having a charging point, while in the car sharing use case, at some grid nodes where car sharing was applicable, the shared charging points were allocated to the nodes instead of private charging points. In the fleet use case, the designated charging station was allocated to the node accommodating the commercial load with the highest annual energy consumption within the network. All EVs/charging points were modelled as constant current loads with a rated power of 11 kW, while all other loads/generators were modelled as constant power loads. Like the private EV use case, the allocation of heat pumps in each network followed a random distribution among households.

The allocation of PV systems was intricately tied to the annual energy consumption of the metering points at each node. Thus, if a node was allocated a PV system, all metering points at the node were assumed to share a fraction of the PV system according to the proportion of their energy consumption. Initially, the existing PV system sizes (in kW_p) within the network were assessed. If the total fell short of the forecasted value, the deficit was supplemented. However, if the existing PV system size was equal to or surpassed the forecasted value, no additional PV capacity was introduced.

Assuming 1000 full-load hours for the PV systems, the PV size for each node was determined by dividing the annual energy consumption of the loads connected to it by 1000. Nodes were then randomly chosen until the cumulative PV size approached the forecasted value for the network. Subsequently, the forecasted PV size for the network was distributed to these nodes proportionately and scaled such that the cumulative sum was equivalent to the forecasted PV size for the network. If the computed PV size using the annual energy consumption of metering points within the network fell short of the forecasted PV size, the distribution was carried out among all nodes with metering points in accordance with their annual energy consumption proportions and scaled such that the cumulative sum was equivalent to the forecasted PV size for the network. If, on the other hand, the computed PV size for a single selected node was greater than the forecasted PV size for the network, the forecasted PV size was distributed to all nodes with metering points. This measure was implemented to guarantee that no individual node would receive a PV size exceeding 100 kWp. However, in cases where PV sizes per node surpassed 100 kWp, they were capped at 100 kWp with the assumption that an LV network cannot accommodate larger PV systems at a single node in network level 7.

8.1.1.2 Time series load flow simulations

Quasi-dynamic load flow simulations (QDSs) were used to evaluate the impacts of the EV, PV and HP scenarios on the networks. The simulations were conducted for both a winter and summer week (the third week of January and the first week of July, respectively). These weeks were considered to effectively capture the impact of these assets on the grid during the two extreme seasons of the year while avoiding the computing overhead associated with running simulations for each day of the year.

In order to perform the QDSs, the integration of EVs, HPs and PV systems in the networks was followed by the allocation of load profiles to all loads in the networks. The annual energy consumption percentiles (ranging from 0 to 100) of all households in the Styria grid with an annual energy consumption greater than 500 kWh were used as a reference to determine the load profile that was allocated to each household having an EV; EVs were allocated with separate load profiles. If a household was allocated an EV, it was also assigned a specific load profile tailored to scale with the median of the percentile interval corresponding to its annual energy consumption prior to the allocation of the EV. To illustrate, if the annual energy consumption of the household fell within the range of the 20th and 21st percentiles, it was allocated a load profile scaled to the median of these percentiles, specifically the 20.5th percentile. The percentile approach was used to streamline the allocation of load profiles to households with EVs, limiting the set to 100 profiles. This strategic choice aimed to minimize the optimization effort for EV charging profiles, given that household load profiles were integral inputs in the optimization process.

Figure 103 shows the percentile medians of all households in the Styrian grid with an annual energy consumption greater than 500 kWh. The Styrian grid, comprising more than 6000 networks, was presumed to provide a comprehensive representation of the distribution pattern of household energy consumption across all grids.

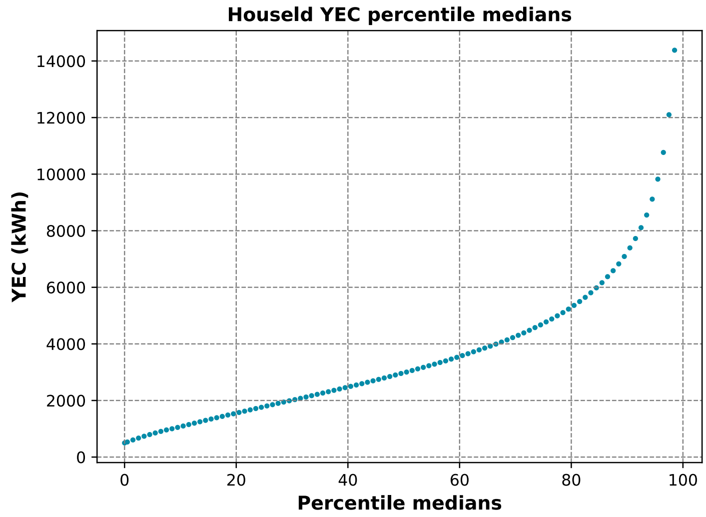


Figure 116 Percentile medians of the yearly energy consumption of Styrian households

Individual private or car-sharing EVs were assigned random load profiles selected from the set of 11 kW-rated EV charging profiles. Likewise, each HP was assigned a load profile randomly chosen from the set of HP profiles. For the fleet, the fleet charging profile was allocated and scaled based on the rated power corresponding to the total number of EVs in the fleet. Other loads were assigned profiles corresponding to their load types, scaled proportionally to their annual energy consumption. Generator profiles were scaled in alignment with the nominal powers of the generators.

Employing DIgSILENT PowerFactory[167] the new assets were integrated into the networks with their respective load/generator profiles for each simulation. Firstly, a reference scenario simulation was performed to assess the pre-existing state of the grid, serving as a baseline for subsequent evaluations of grid changes. Each of the private EV, car sharing, fleet, PV, and heat pump simulation scenarios underwent independent evaluation, and a comprehensive all-in-one scenario, encompassing PV, heat pump, car sharing, and fleet was also simulated.

Additionally, scenarios with optimised EV charging profiles for the private EV and car sharing use cases, which also incorporated fleets, HPs and PV were simulated. The monitored network parameters were voltage levels, line loading, and transformer loading.

8.1.1.3 Worst-case load flow simulations

Performing quasi-dynamic load flow simulations for only two weeks in a year has a limitation: it does not ensure the comprehensive capture of worst-case scenarios of the impacts of the new assets on the grid. Hence, quasi-dynamic load flow simulations were only relevant to assess the impacts of the new assets in terms of uncontrolled and optimised EV charging. Therefore, in addition to the quasi-dynamic load flow simulations, worst-case load flow simulations were also carried out.

The worst-case load flow simulations were divided into two scenarios: “high load no infeed”, and “low load high infeed”. In the high load no infeed scenario, generation was set to zero, while all loads, except for interruptible loads, were scaled to their peak power. Interruptible loads (hot water tanks, night storage

[167] Xgboost Developers, “XGBoost Documentation,” 2022. [Online]. Available: https://xgboost.readthedocs.io/en/stable/index.html. [Accessed 2023].

heater, etc) were not considered in worst-case load flow analysis because during grid peak hours (typically late afternoon or early evening of a winter working day), they are often out of service. In supply areas where transformer peak loading measurements were available, the peak value of the load power was determined with the help of the peak transformer measurement for the reference year.

A first estimate of the maximum load power was obtained by dividing the yearly energy consumption by a constant factor of 1000. The loads were then scaled such that the peak transformer measurement was reproduced, and the resulting load power was assumed to be the peak load power. However, in networks where this scaling resulted in a line loading exceeding 90%, the loads were downscaled to limit them to 90%, where 90% is the DSO specification for steady-state operation. This is because a uniform scaling factor can scale some loads out of proportion. Thus, optimising the scaling factor based on the line loading limit can achieve optimal results. In the absence of transformer measurements, the peak load power was determined based on empirical data, which shows that the maximum load power (in [kW]) can be estimated by dividing the yearly energy consumption (in [kWh]) of each load by a constant factor ranging from 1000 to 5000.

In the Graz and Styria grids, a suitable constant factor was 2000. However, in networks where the maximum line loading exceeded 90%, the constant factor was incrementally adjusted to cap it at 90%. In the Graz LV grid, the constant factor was further tuned to limit the maximum transformer loading to 80%. Transformer measurements were available for the Salzburg and Styria LV grids, though the empirical constant factor approach was also applied for the Styria LV grid. If the constant factor exceeded 5000, the network was excluded from the analyses.

In the low load high infeed scenario, the resulting grid state from the high load no infeed scenario was updated by activating the PV systems and scaling their rated capacities (kWp) to 85% to obtain their effective values. Reasons for not using the full PV module peak power (kWp) are non-optimal orientation, shading, dirt or dust, DC line losses and PV inverter losses. Using 85% of the module peak power is a common practice at Austrian DSOs. Also, the loads were further scaled down to 10% of their peak values in the Styria and Salzburg grids. In the Styria grid, a scenario with 0% load was also analysed while in the Graz grid, only the 0% load scenario was taken into account. The resulting grid states from the “high load no infeed” and “low load high infeed” scenarios were used as the baseline for the integration of the future load and PV scenarios, respectively. That is, the future load scenarios were integrated into the baseline “high load no infeed” grid, while the future PV scenarios were integrated into the baseline “low load high infeed” grid. Hence, future load scenarios were not considered in the “low load high infeed” scenario.

Load flow simulations were then carried out for the reference year to determine the existing worst-case state of the grid. Subsequently, the future PV, EV, and HP forecasts were integrated into the appropriate baseline grid states to evaluate the worst-case state for the respective years (2030 and 2040) with the enhanced feature “Low Voltage load flow calculation” of DIgSILENT PowerFactory. The fleet and private car-sharing charging points were modelled as constant current loads, while all private EVs not participating in car sharing were modelled as low voltage (LV) loads based on the low voltage load model of DIgSILENT PowerFactory. This model considers the impacts of coincidence factors on power consumption and scales the power of the LV loads appropriately. The worst-case coincidence factor of fleet charging, and that of the dedicated charging point for car-sharing EVs, was assumed to be 1, while the coincidence factor of the other charging points was determined with LoadProfileGenerator[168]. The LV voltage load flow simulations were thus carried out to evaluate the future worst-case states of the grids for the "high load no infeed scenario" while simple load flow simulations were done for the "low load high infeed" scenario. A summary of the methodology is shown in Figure 104.

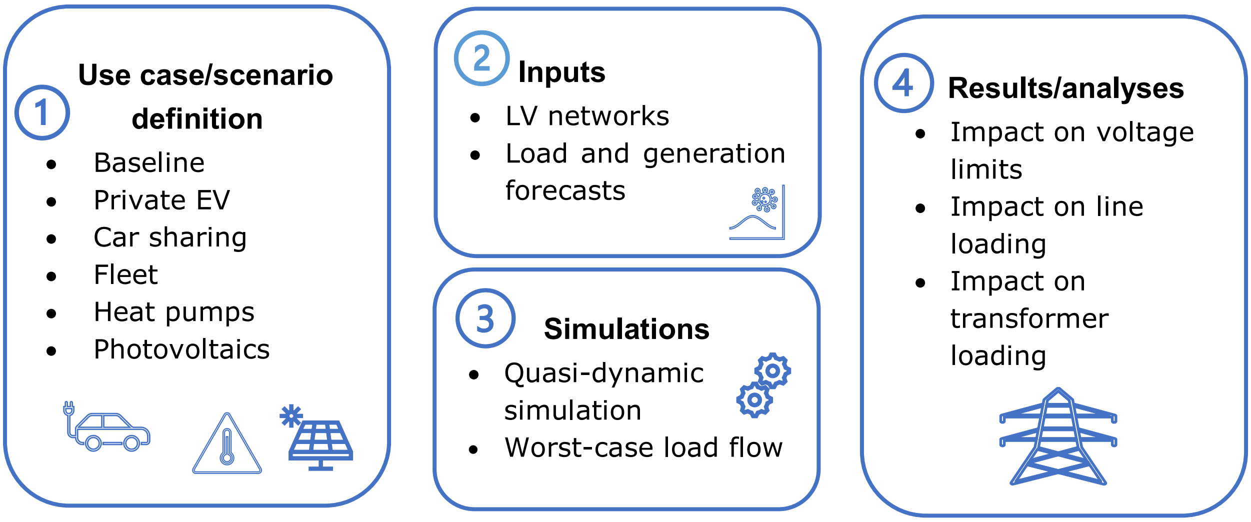


Figure 117 Simulation methodology

8.1.1.4 Uncontrolled vs. market-based (=optimised) EV charging

For the two-week time-series calculation (QDS simulation), EV charging profiles were obtained from the AIT EVPP Tool[169]. These profiles are created with the aim of representing the typical uncontrolled charging behaviour of the average Austrian EV user. These profiles assume that in most cases EV users will plug in their car after they arrive at home (or at work), and consequently, the charging process starts immediately. This will typically result in high simultaneity in car charging in the afternoon and evening hours when most people arrive at home.

In contrast to this, market-based EV charging is modelled in a way that the charging process does not start immediately and is delayed until electricity market prices are optimal in the time frame until the next usage of the car. This will result in even higher simultaneity as market prices are the same for all market participants. From this point of view, optimised charging does not mean optimised for the grid, but it means cost-optimised for the EV user.

As the worst-case power flow calculations were calculated based on the coincidence curve approach, an appropriate coincidence curve had to be elaborated for the market-based EV charging profiles. Figure 105 shows an overview of the coincidence curves for EV charging.

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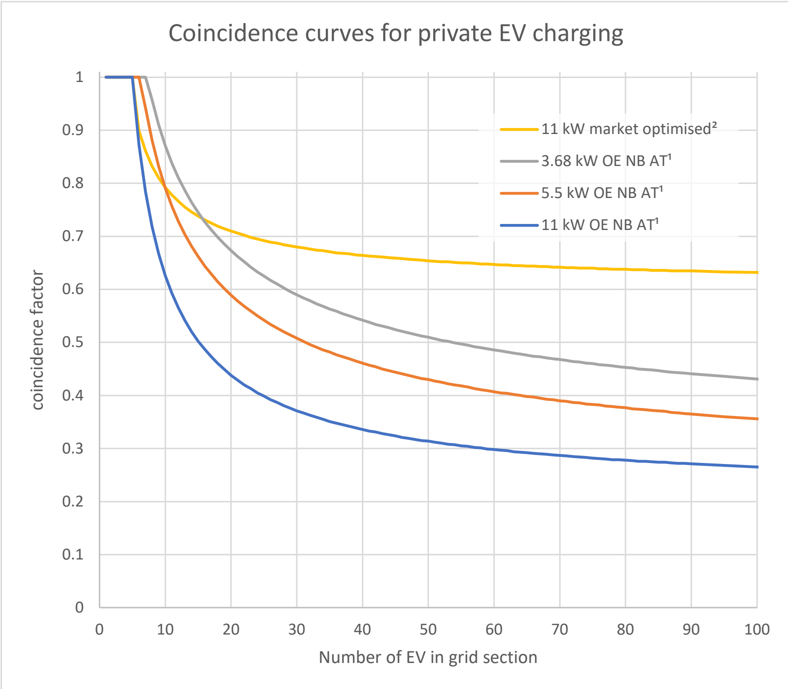
[168] N. Pflugradt, "LoadProfileGenerator," 2020. [Online]. Available: https://www.loadprofilegenerator.de/. [Accessed 2022].

[169] APCS Power Clearing and Settlement AG, "Synthetic Load Profiles," 2023. [Online]. Available: https://www.apcs.at/de/clearing/technisches-clearing/lastprofile. [Accessed 2023]



1 curves from[170]; 2 curves obtained from[171]

Figure 118 Coincidence curves for private EV charging

8.1.2 Results

The extensive calculation of the whole supply area of the DSOs leads to results that contain sensitive/confidential information about the state of the grid of the individual DSOs. Therefore, the results are separated into individual deliverables for each DSO, and only the results of the regionalisation process in section 8.1.2.4 are presented.

8.1.2.1 Stromnetz Graz LV networks calculation results[172]

Stromnetz Graz supplies the capital city Graz and neighbouring areas and therefore operates six primary substations and more than 700 secondary substations. The supply area of around 42 square kilometres, where more than 120.000 customers (metering points) are located, is predominantly urban.

8.1.2.2 Energienetze Steiermark LV networks calculation results[173]

Energienetze Steiermark is the main DSO in the Austrian federal province Styria, which supplies more than 70 primary substations and more than 8000 secondary substations to around half a million customers (metering points). As the capital city of Styria is supplied by a different DSO, the supplied area of more than 10.000 square kilometres is predominantly rural.

8.1.2.3 Salzburg Netz LV networks calculation results[174]

Salzburg Netz is the main DSO in the Austrian federal province Salzburg, which supplies around 30 primary substations and more than 5000 secondary substations to nearly half a million customers

[170] Oesterreichs Energie, „Netzberechnungen Österreich - Auswirkungen von PV und E-Mobilität,“ 2020. [Online]. Available: https://oesterreichsenergie.at/fileadmin/user_upload/Oesterreichs_Energie/Publikationsdatenbank/Studien/2020/2020.11_Studie_NetzberechnungenAT_PVundEV.pdf. [Zugriff am 2023]

[171] M. Rock, „Einfluss von markt- und netzorientieren Ladevorgängen auf die steigende Netzbelastung verursacht durch E-Mobilität,“ Montanuniversität Leoben, Lehrstuhl für Energieverbundtechnik, Masterarbeit, 2024.

[172] Calculation results are confidential and provided by the non-public Deliverable D5.2.SNGrz.

[173] Calculation results confidential and provided by the non-public Deliverable D5.2.ENStmk.

[174] Calculation results are confidential and provided by the non-public Deliverable D5.2.SbgN.

(metering points). As the capital city of Salzburg is supplied by this DSO, the supply area has, in most regions, very rural characteristics, while in the region of Salzburg city, it has urban characteristics.

8.1.2.4 Comparison of key assumptions for future scenario definition

Figure 106 shows the installed PV power per low voltage line km in the supply area of the three DSOs for the reference year 2020 and the current future projections for 2030 and 2040. According to this diagram, PV density will increase fivefold from 2020 to 2030 and will increase about tenfold from 2020 to 2040. Structural differences between the three DSOs, that supply rural and urban regions seem to have a minor impact on these numbers. This means the installed PV per km low low-voltage line length is nearly the same for rural and urban supply areas.

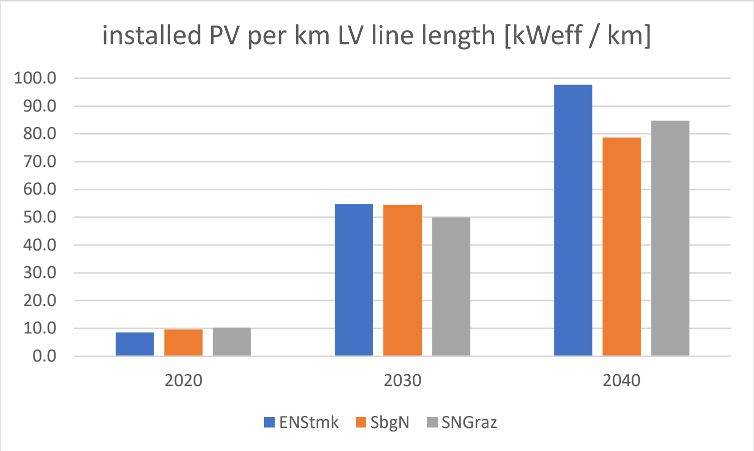


Figure 119 Installed PV power per low voltage line km in the supply area of the three DSOs

Figure 107 shows the future projections of the installed heat pumps (HP) per low-voltage line km in the supply area of the three DSOs. In this diagram, structural differences between rural and urban supply areas are clearly visible – there will be around twice as many HPs per km line length in densely populated areas as in rural areas.

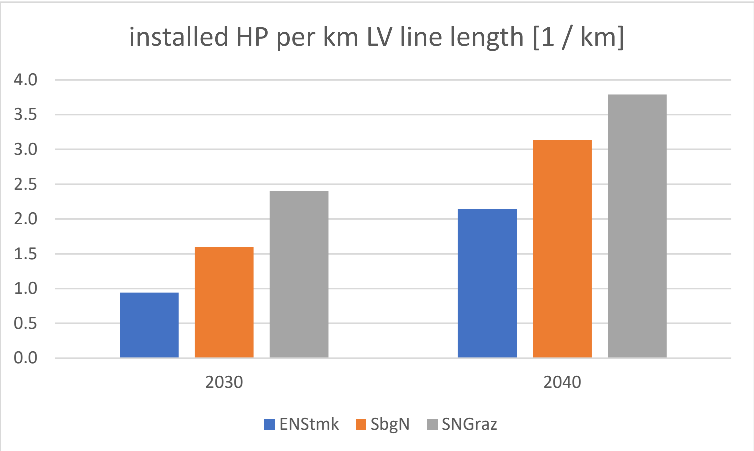


Figure 120 Future projection of installed HPs per low voltage line km in the supply area of the three DSOs

Figure 108 shows the future projections of the installed electric vehicle charging stations (EVCS) for the private EV use case per low voltage line km in the supply area of the three DSOs. In this diagram, structural differences between rural and urban supply areas are clearly visible – there will be more than three times as many EVCSs per km line length in densely populated areas than in rural areas.

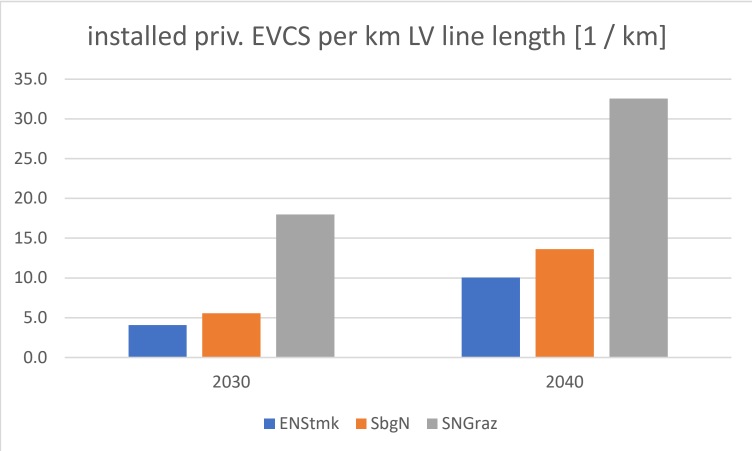


Figure 121 Future projection of installed private EVCSs per low voltage line km in the supply area of the three DSOs

8.1.3 Findings

The type of supplied areas differs significantly between the three DSOs. While Energienetze Steiermark almost exclusively supplies rural regions and Strom Netz Graz almost exclusively supplies urban regions, Salzburg Netz covers a mixture of rural and urban grids, with the focus on rural grids. Consequently, calculation results differ significantly in many aspects, but nevertheless, it was possible to obtain some general valid results.

The concept of car sharing as applied in this study is better suited to urban settings as compared to rural and suburban areas. Following the assumptions made within this analysis for deciding whether car sharing is established or not, the sparse settlement pattern in rural and suburban areas creates the need for every household to own an EV.

Furthermore, it was shown that there is no direct synergy between PV generation and electric mobility demand that would help to reduce peak power situations in LV grids. Timeseries simulations show that neither EV adoption will mitigate peak power feed-ins, nor does PV generation alleviate peak EV charging demands. On the other hand, there are synergies between PV integration and electric mobility integration when it comes to grid reinforcement measures. In cases where PV integration is limited by grid constraints, reinforcement measures not only help enable PV integration but also increase hosting capacity for EV integration, and vice versa.

The time series simulation results of the maximum network voltage are highly comparable with the maximum network voltage results from the worst-case load flow simulation (calculated with maximal / nominal infeed and minimal load). This is because the coincidence factor of PV systems is very high, coupled with the mismatch between EV charging and PV generation. In contrast, the timeseries simulation results of the minimum network voltage differ significantly from the minimum network voltage results from the worst-case load flow simulations (calculated with maximal load and no infeed) because a timeseries simulation of two weeks is by far too short to show realistic worst-case charging combinations. The potential for worst-case scenarios to emerge increases over time, underscoring the limitations of short-term simulations. It is assumed that even time series simulations performed for one year are, in most cases, too short to cover worst-case power flows. Therefore, timeseries simulations are not an appropriate method to obtain results that are useable for electricity grid planning. If results need to be used for grid planning, it must either be ensured that worst-case power flows occur in the simulated period, or worst-case power flows must be done with the help of predefined coincidence factors, as it is the current practice in electricity grid planning.

Furthermore, with optimised EV charging (market price-based charging time shifting), the simultaneity of private EV charging can substantially increase, particularly in areas with a high concentration of EVs, amplifying the adverse effects on the grid. However, its potential implementation may face constraints due to the prevalence of car sharing, which covers a large proportion of mobility needs in urban areas. This is because the extent to which car-sharing charging patterns can be optimised can be hindered by the frequent usage of the EVs, resulting in relatively minor disparities between normal and market price optimised charging. Moreover, while optimal market prices typically coincide with periods of peak PV generation, the output from PV systems may not always be sufficient to meet the elevated load demands, resulting in more network violations compared to normal charging periods.

Car sharing plays a pivotal role in mitigating network operation limit violations within urban environments when compared to scenarios where car sharing is absent. However, the proliferation of car sharing requires proactive city-led initiatives rather than relying solely on natural growth.

Implementing a charge controller, such as throttling EV charging power during peak load periods (5.5 kW charging power in this study), significantly reduces network limit violations in urban supply areas. Conversely, in rural areas where PV integration necessitates network expansion, the scope for savings through applying an EV charging controller as the only measure is limited. If PV integration is also a major driver for grid reinforcement, measurements must be taken at the infeed side and at the consumption side to effectively reduce grid reinforcement.

In summary, future scenarios of EV, HP and PV cannot be seamlessly integrated into most of the LV networks in the next decades without taking additional, cost-intensive grid expansion and retrofitting measures at DSOs. In urban networks with very high load demands and limited potential for PV integration, the projected PV scenarios necessitate minimal grid expansion. However, the problems created by the EVs and HPs persist. Therefore, for the grids to cope with the future PV, EV and HP scenarios, the DSOs can:

- Increase grid capacity in terms of distribution lines and transformer reinforcement to reduce the strain on the existing lines and transformers, respectively. This also requires the construction of new substations.
- Curtail charging power in times of high grid loading (considering the legal framework).
- Provide voltage support to eliminate the voltage issues, which can be achieved through reactive/active power control.
- Control the penetration of PV: This can be done either by curtailment, considering flexibilities e.g., storage or shifting demand to correspond with the periods of peak PV generation (considering the legal framework).
- Provide additional flexibility, such as battery storage at selected points in the distribution grid (considering the legal framework).

It is also important to note that the above measures are inter-dependent in solving the grid issues, and neither is the list exclusive. Thus, an analysis to determine the optimal approach – taking into account technical as well as financial aspects - is necessary.

8.2 Assessment of the impact on RES-E generation of the business models

8.2.1 Modelling and assumptions

The effects of demand-side flexibility and bidirectional storage use of EVs is evaluated on the European electricity market for the time horizon from 2030 to 2040 using the TYNDP2024 “National Trends” scenarios[175]. For this upscaling approach a penetration of 1.6 million EVs in 2030[176] and 5 million EVs in 2040[177] in Austria is assumed. These EVs are divided into six categories to represent the Car2Flex use cases (Figure 109).

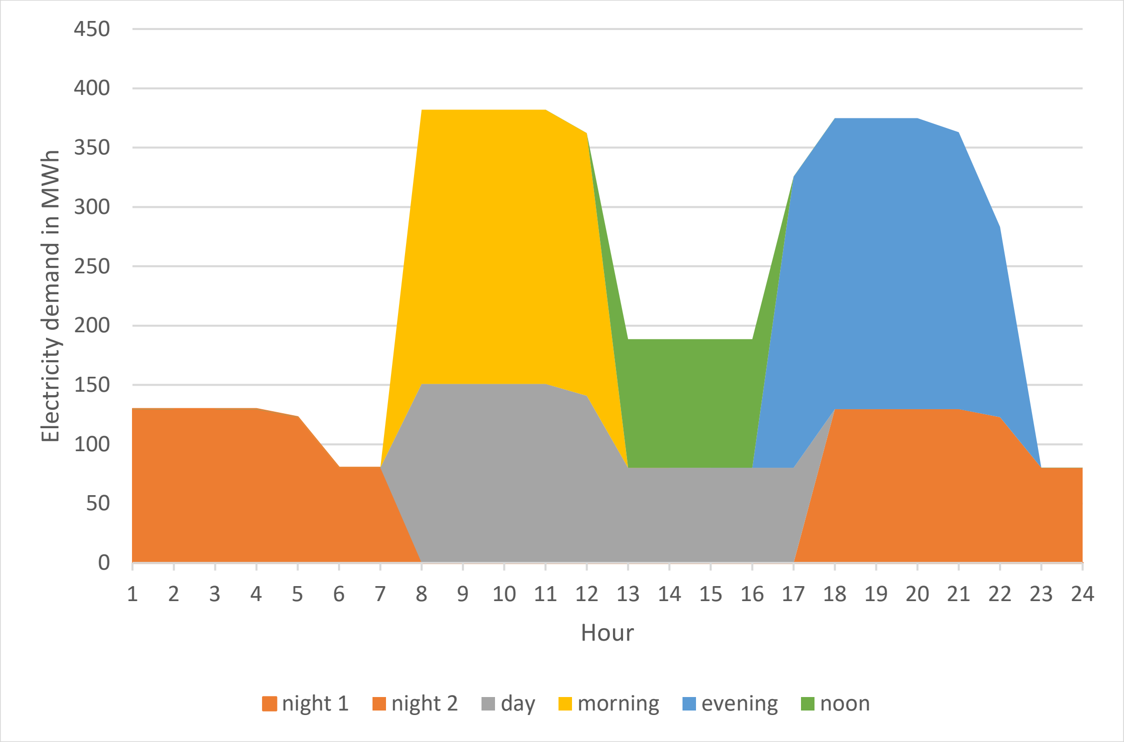


Figure 122 Electric vehicle fleet categories

These colored blocks represent different types of consumption-, and user behavior. These include an electricity demand for this block with an implicit flexibility potential. Several constraints limit the charging power and state-of-charge, and ensure that not end-user limitations occur through insufficient state-of-charge, when the EV is plugged of. Consequently, a demand decrease must be compensated by a demand increase within the plug-in time of an EV. This corresponds to power peaks if flexibility is used.

This flexibility is optimized in the European Energy model EDisOn[178] to maximize overall socio-economic welfare in the day-ahead electricity market. In the following this model is used to evaluate the KPIs:

- Change in renewable energy share
- Change in greenhouse gas emissions
- V2G discharging power available
- G2V charging power available

[175] https://2024.entsos-tyndp-scenarios.eu/download/
[176] https://oesterreichsenergie.at/publikationen/dossiers-1/elektromobilitaet-photovoltaik-und-netze
[177] FTI-Strategie Mobilität 2040, https://www.bmimi.gv.at/themen/innovation/FTI-Themen/Mobilitaetswende/mobilitaetsstrategie.html
[178] https://doi.org/10.1016/j.ijepes.2024.109992

8.2.2 Crucial periods for flexibility provision

The electricity demand increase through the provided flexibility is shown for 2030 in Figure 110. This evaluates the two KPIs "V2G discharging power available" and "G2V charging power available".

In general flexibility provision tends to shift electricity demand to times with reduced electricity prices and a very high share in renewable energy generation. Hence, flexibility that is available over night, shifts demand to the early morning hours, when solar generation is available. This is especially evident during summer. Following this behaviour fleets that available over noon, lead to drastically increased demand during this time while reducing solar generation curtailment. The third period with a demand increase, at the end of the day tends to shift electricity demand away from the evening demand peak. Due to the model formulations this is the end of the day in this evaluation, but with other configurations it would be even possible to shift this demand again to the first hours of the day with solar generation.

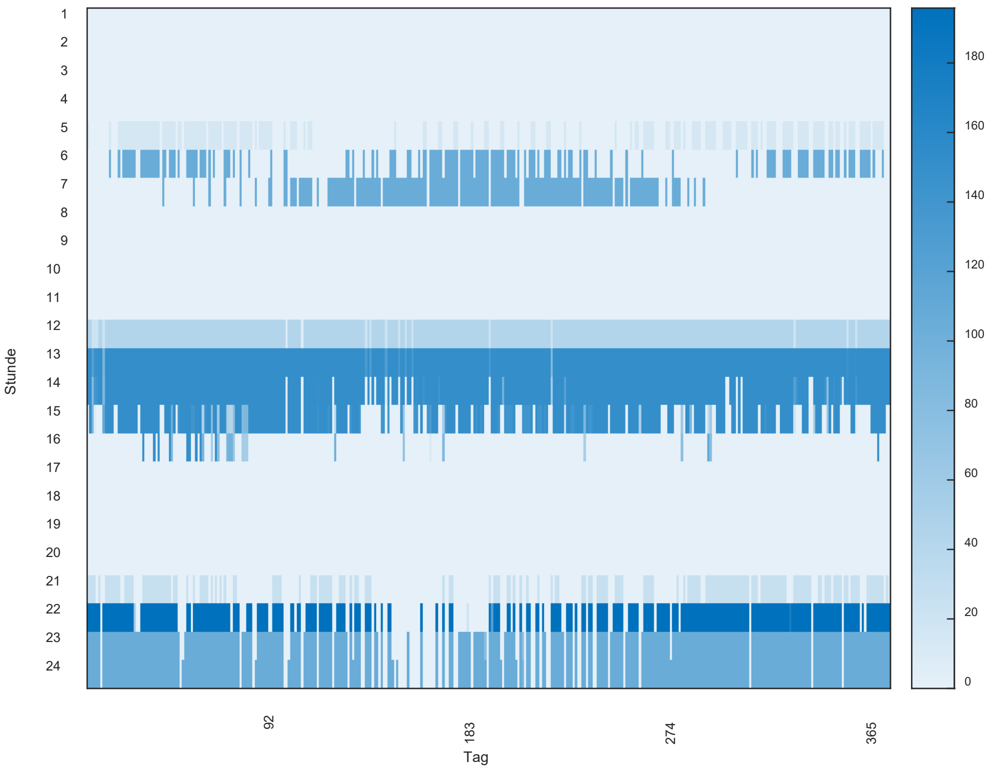


Figure 123 Demand-side flexibility use, 2030

For 2040 (Figure 111) the same three flexibility use patterns are evident. Flexibility use in the morning and during nights is reduced compared to 2030, due to other flexibility options that are already implemented in the electricity market in this scenario. Other flexibility options such as large-scale batteries and intensive hydrogen production and use in Europe tend to reduce electricity price volatility and therefore give a reduced incentive for the EV flexibility use. But these results imply that these huge amount s of battery storages are installed and act market oriented. Using anyway existing EV flexibility instead of investing into batteries can drastically reduce the total cost of the energy transition and reduce environmental impact due to resource utilization.

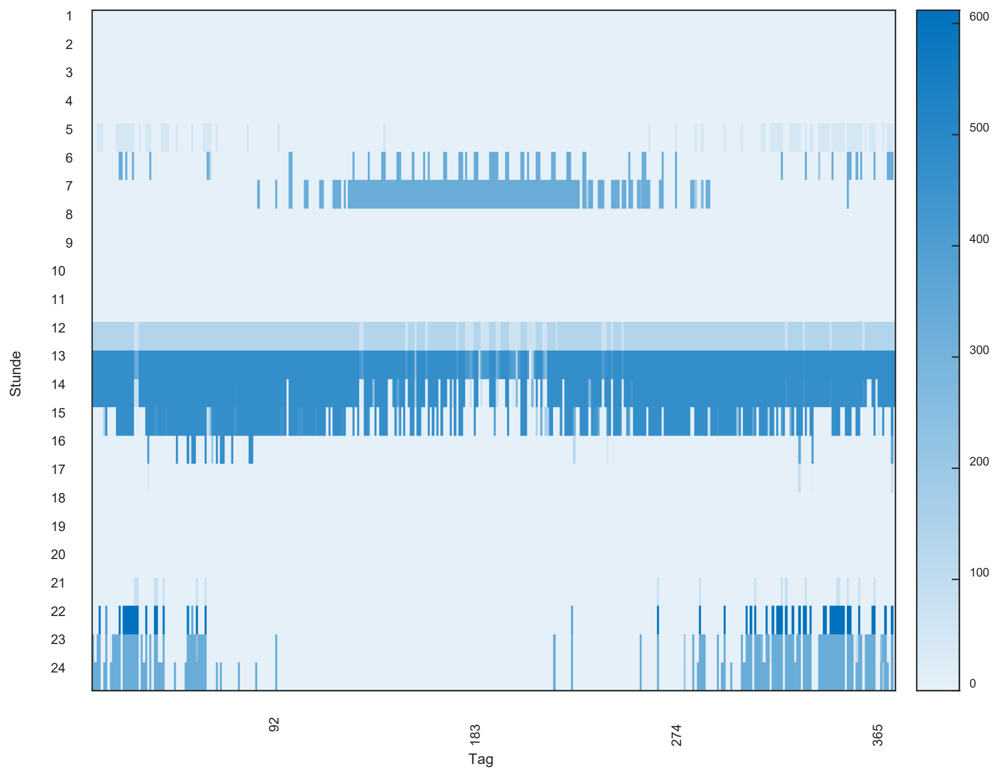


Figure 124 Demand-side flexibility use, 2040

8.2.3 Impact on emissions and renewable energy integration

The impact on CO2 (Figure 112), NO_x, SO_2, NH_3, NMVOC and particulate matter emissions (Figure 113) shows that flexibility has a significant impact on total emissions, even though the calculated scenarios assume 100% net renewable electricity generation in Austria. This evaluates the KPI “Change in greenhouse gas emissions”.

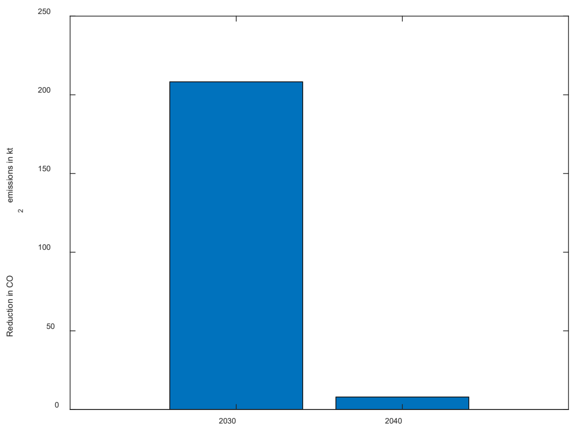


Figure 125 Impact on CO2 emissions

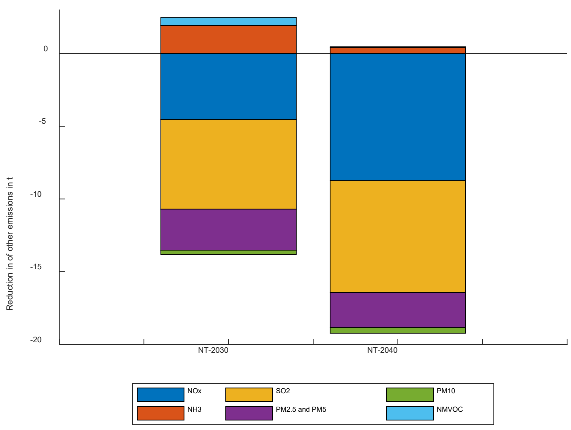


Figure 126 Impact on other types of emissions

Moreover, it is evident that the integration of renewable energies is increasing significantly (Figure 114). This evaluates the KPI “Change in renewable energy share” and demonstrates the avoidance of curtailment of renewable generation through flexibility that can be provided not by producers but by consumers. This has positive effects on the full-load hours of the plants and thus on investment incentives and the efficient use of volatilely generated electricity. This in turn means that fewer generation plants are needed, which reduces, for example, land consumption or the use of resources required for production. This corresponds to a minimum land consumption by PV systems of 7 hectares in 2030 and 22 hectares in 2040. The actual land consumption may be much higher, as the corresponding flexible load for volatile generation must be available.

These positive effects are not reflected monetarily by electricity prices around 0 €/MWh in the current electricity market design. Future market mechanisms, such as flexibility markets, can better reflect these benefits.

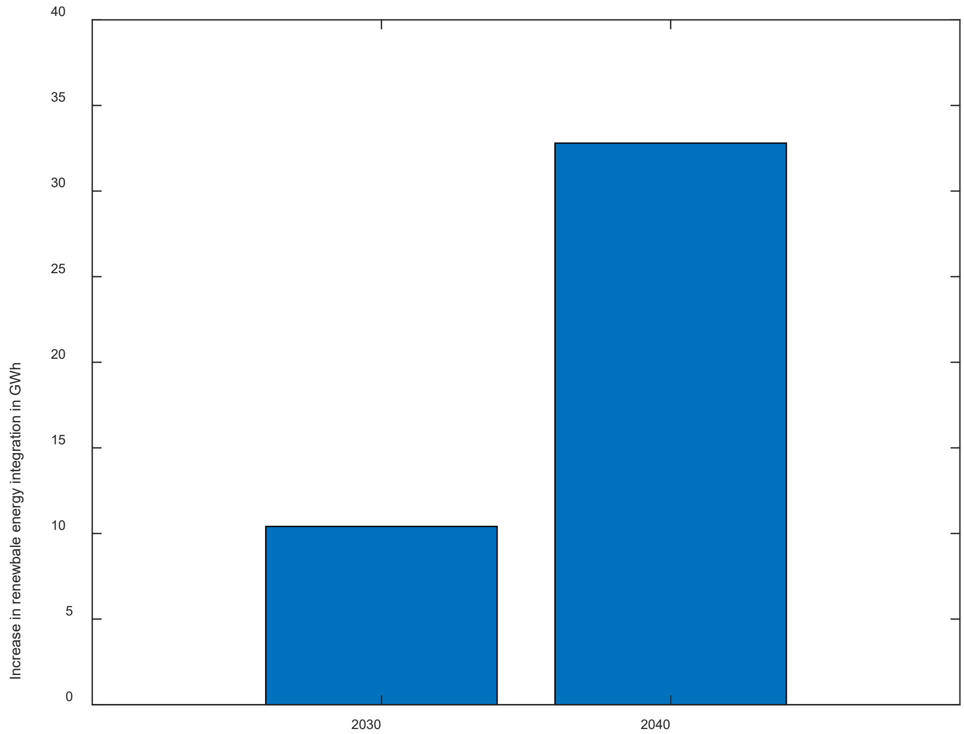


Figure 127 Reduction in renewable energy spillage

8.3 Contribution to Sustainable Development Goals

V2G can play a key role in the decarbonization of the transport and energy sectors by improving the integration of renewable energy into the electricity grid while increasing the flexibility of the energy system. An inter- and transdisciplinary analysis can show the benefits of V2G but also identifies potential barriers that could hinder implementation towards achieving sustainable development goals (SDGs).

8.3.1 General overview of barriers and measures

In the following, each main category of barriers is presented in detail, together with possible measures for overcoming them.

8.3.1.1 Technological barriers and measures

Technological barriers and measures refer to challenges and solutions related to the technical functionality, system integration and technological maturity of a system.

Lack of interoperability and standardization

The most fundamental technical barrier to the widespread adoption of V2G is the lack of interoperability between different components of the system. In practice, EVs, charging stations, and EMS are often developed by different manufacturers, each using their own proprietary protocols and interfaces. This fragmentation results in significant compatibility problems: a vehicle from one manufacturer may not communicate properly with a charging point from another, and the integration into local EMSs or grid operator platforms can be unreliable or impossible. The absence of broadly adopted international standards for communication—such as ISO 15118-20 (which regulates bidirectional communication between EVs and wallboxes), OCPP (Open Charge Point Protocol for infrastructure-backend communication), and IEC 61850 (for grid integration)—leads to a proliferation of incompatible solutions. As a result, the benefits of V2G, which depend on large-scale coordination and aggregation, remain largely unrealized.

<u>**Measures to address interoperability**</u>**:** A unified, open, and enforceable set of technical standards is needed. This includes not only standardizing the physical and digital interfaces (plugs, protocols, APIs) between EVs, charging equipment, and EMS, but also ensuring certification and regulatory alignment at national and international levels. Introducing mandatory compliance with standards such as ISO 15118-20, and harmonizing these standards across all EU member states (and beyond), would reduce fragmentation. Establishing a transparent, third-party certification process for all V2G-relevant devices would provide assurance to manufacturers, service providers, and end-users alike. The development of open-source interface solutions could help bridge existing gaps, facilitating backward compatibility and allowing for faster adoption across the market.

Limited efficiency of current V2G technologies

At present, the efficiency of V2G charging and discharging processes is poor. Existing charging systems are often designed for unidirectional use and adapted only minimally for bidirectional applications. As a result, losses in conversion (AC-DC-AC) and high standby consumption reduce the effective amount of energy that can be exchanged with the grid.

Measures to improve efficiency: Addressing the low efficiency requires investment in research and development of new hardware and software solutions to reduce internal consumption, increasing conversion efficiency, and integrating intelligent algorithms capable of adapting charging and discharging strategies according to the battery SoH. Moreover, the introduction of standardized energy efficiency labels for V2G devices (similar to those used for household appliances) would create market pressure for manufacturers to increase energy efficiency.

Lack of harmonized control logics

The coordination between the various control systems that participate in V2G operations remains poor. These include the EVs onboard EMS, the logic of the local infrastructure system (LIS), and any overarching EMS at building or grid level. Currently, each of these layers use different, sometimes incompatible, control logics and communication standards, resulting in synchronization problems. In the absence of standardized priority hierarchies, conflicting commands from different control systems may lead to suboptimal or unpredictable behavior. Without clear mechanisms for real-time synchronization, charging or discharging cycles may not align with grid conditions, market signals, or the user's own needs.

Measures to foster integration and control: Harmonization and standardization of control protocols involves not only aligning existing standards (such as ISO 15118-20, OCPP, and IEC 61850), but also developing a universally accepted priority scheme that determines which system has authority under various operational scenarios. Centralized middleware solutions could act as coordinators, ensuring that information flows between all components and that actions are consistent.

Grid stability and voltage management in distribution networks

Especially in areas with weaker distribution grid infrastructure, the additional flows of electricity from EVs could lead to voltage excursions beyond permissible limits, compounded by the lack of real-time monitoring data from many transformer stations and substations, which makes it difficult to implement adaptive, grid-friendly feed-in controls.

Measures for enhancing grid integration: Real-time monitoring and data collection infrastructure within distribution networks is needed, by equipping more substations with advanced metering and communications system. This would allow DSOs and TSOs to send dynamic grid load and voltage signals to V2G installations in real time. Extending existing communication protocols (e.g. OCPP, IEC 61850) to support dynamic, grid-responsive charging and discharging is essential. The development of machine learning models, capable of forecasting grid loads and voltage fluctuations, can supplement real-time data in areas where full instrumentation is not yet in place.

Battery degradation and lifecycle concerns

The risk of accelerated battery degradation as a result of frequent charging and discharging cycles in V2G applications can distort V2G implementation. The additional cycling required for V2G can lead to deep discharges and thermal stresses that shorten battery life, reduce usable capacity, and potentially void manufacturer warranties.

Measures for battery health: The implementation of intelligent charging and discharging strategies—based on SoH—can help to avoid deep discharges and unnecessary cycles. Such strategies should be embedded not only in the EV, but also in the infrastructure and central management systems, with clear SoC/SoH limits. Manufacturers need to develop and market battery chemistries specifically optimized for bidirectional charging, with transparent warranty terms. Regulatory frameworks should require the disclosure of battery aging models and mandate minimum standards for cycle stability.

Software complexity and cybersecurity threats

The increasing digitalization and interconnection of V2G systems creates a wider attack surface for cyber threats. Charging stations, vehicles, and back-end platforms are potential targets, particularly as more data is exchanged and more critical functions are managed remotely. Vulnerabilities in communication protocols, insufficient encryption, and lack of clear responsibility for data protection can facilitate unauthorized access or manipulation.

Measures for software security and data protection: A cybersecurity strategy should include mandatory encryption for all communications (aligned with standards such as ISO 27001 and IEC 62443), regular security audits and penetration testing, and the introduction of security certificates for all V2G interfaces. Clear legal assignment of data protection responsibilities—especially in relation to GDPR and critical infrastructure regulations—must be established, with requirements for anonymization, audit-proof logging, and secure data storage. Cybersecurity considerations should be incorporated from the earliest stages of V2G development.

Complexity of data processing

Processing, storing, and analyzing data from millions of EVs in compliance with data protection laws demands advanced IT infrastructure, reliable algorithms, and technical expertise. AI-based solutions are increasingly proposed, but raise additional concerns about transparency, reliability, and the potential for algorithmic bias.

Measures to support data management: The adoption of GDPR-compliant data handling procedures is essential, including encrypted storage, pseudonymization or anonymization, and strict access controls. Ensuring the reliability and security of AI-driven control systems will require decentralized architectures, redundancy mechanisms (e.g. blockchain), and fail-safe protocols. Standardization of data formats and open APIs can support interoperability and lower the barriers to entry for new service providers.

8.3.1.2 Economic barriers and measures

Economic barriers and measures refer to economic barriers and strategies related to costs, market mechanisms and economic viability.

High initial investment costs and uncertain profitability

High upfront investment costs required for V2G-capable infrastructure include the costs of bidirectional charging stations and compatible power electronics, and IT systems. Especially for private users, the financial investment can be a substantial barrier and the potential revenues from providing grid services are uncertain. In addition, there is a notable lack of clarity regarding the actual profitability of V2G operation under current market conditions. Revenues depend on uncertain factors, such as electricity market prices, the frequency of ancillary service calls, and the willingness of DSOs/TSOs to pay for flexibility.

Measures to lower costs and enhance profitability: A combination of direct financial incentives and innovative business models is needed. Public funding schemes, such as grants or low-interest loans for V2G infrastructure, can reduce the initial investment barrier, especially during the early market phase. Tax benefits or subsidies for early adopters could be important. Profitabilty could involve creating new market segments for distributed flexibility and simplifying the participation requirements for small capacity providers. Aggregation platforms—allowing many individual EV owners to pool their capacities and participate collectively in energy markets—can also help to lower the threshold for economic viability.

Insurance products and long-term service contracts can help to mitigate financial risks for investors and operators, providing predictability for revenues and maintenance costs over the lifetime.

Aggregation and market access barriers

The operation of V2G systems at scale depends on the aggregation of many individual EVs to provide meaningful amounts of flexibility to the grid. Current market rules and technical requirements in most countries create significant obstacles for aggregation. Minimum bid sizes in ancillary service markets may be set at levels that are difficult to reach for individual EV owners or small aggregators. Similarly, the registration, prequalification, and ongoing compliance processes can be complex, time-consuming, and costly. Additionally, technical and administrative barriers, such as the need for standardized interfaces, harmonized metering, and the secure transfer of operational data, often increase transaction costs and deter new market entrants. This leads to a situation in which only large, established players are able to participate, slowing the development of a competitive and dynamic V2G market.

Measures to facilitate aggregation and market participation: Regulatory authorities should adjust the minimum bid sizes and technical requirements for participation in flexibility and ancillary service markets. Lowering thresholds and simplifying registration and prequalification procedures would allow smaller actors and aggregators to enter the market. Standardization of data exchange formats and metering protocols is essential for seamless aggregation, as is the introduction of secure, automated settlement systems for the remuneration of provided services. Pilot projects and regulatory sandboxes can be used to test new market rules in a controlled environment and identify best practices for broader implementation.

Efficiency losses and hidden operating costs

While V2G offers new potential revenues, it also introduces additional operating costs. These include efficiency losses in power conversion, increased wear on charging infrastructure, costs for EMSs, and potential expenses for compliance with evolving standards or cybersecurity requirements, reducing the net benefit from V2G participation. There is also the risk that proprietary solutions or vendor lock-in (where customers become dependent on a single provider's technology) could lead to higher long-term costs and limited flexibility for users.

Measures to reduce operating costs: Regulators and industries should promote transparent reporting of efficiency rates and lifecycle costs for all V2G-capable products. Mandatory product labeling (e.g., efficiency ratings for charging stations) and the publication of total cost of ownership models can help users make informed decisions. Promoting open standards and interoperability can reduce the risk of vendor lock-in, while competitive procurement and purchasing by public institutions or large fleet operators can achieve economies of scale and drive down per-unit costs.

Unclear remuneration models and market signals

There is lack of clear, stable, and predictable remuneration models for the grid services provided by V2G systems. In some cases, existing market mechanisms are not designed to recognize or reward the specific flexibility services that V2G can offer, such as fast frequency response, voltage support, or congestion management at the local grid level. The volatility and complexity of current market signals can deter participation, especially from private users who may be unwilling or unable to constantly monitor price developments or adapt their behavior accordingly. The lack of time-of-use tariffs or dynamic pricing structures in many regions further limits the economic incentives for V2G participation.

Measures to clarify remuneration: The introduction of clear and transparent remuneration models is essential. This could include the creation of flexibility products and services in wholesale and retail electricity markets. Providing standardized, user-friendly tools for revenue forecasting, and automated participation in relevant markets will help users and operators.

Split incentives and risk allocation

The existence of split incentives between different actors in the V2G value chain is a barrier. For example, the costs and risks associated with battery degradation may be borne by EV owners, while the financial benefits of grid services may accrue mainly to aggregators, utilities, or grid operators. Similarly, charging infrastructure may be owned by property managers or third-party service providers who have little incentive to support V2G functionalities.

Measures to align incentives and share risks: Developing fair and transparent business models that allocate costs, risks, and rewards equitably across all involved parties. This can include revenue-sharing agreements between EV owners, aggregators, and infrastructure operators, as well as standardized contracts that clarify responsibilities for maintenance, battery replacement, and liability in the event of malfunctions or losses. Regulators can support this process by requiring clear disclosure of contractual terms and by encouraging the development of insurance products that explicitly cover V2G-related risks.

8.3.1.3 Regulatory barriers and measures

Regulatory barriers and measures include institutional and legal frameworks that can inhibit or promote the adoption or scaling of V2G technology.

Inconsistent or outdated regulatory frameworks

In many countries, current legislation and grid codes were developed for traditional, centralized energy systems, and do not adequately address the requirements of V2G. Gaps exist regarding the legal status of EVs as energy resources, the definition of roles and responsibilities for aggregators and service providers, and the procedures for registering and approving new technologies for grid interaction. The absence of harmonized regulations between countries creates fragmentation and uncertainty for manufacturers, operators, and users. This hampers the development of scalable business models and discourages investment.

Measures to harmonize regulatory frameworks: Governments must review and update existing energy laws, grid codes, and market regulations. The recognition of V2G as a valuable resource for grid flexibility, as well as the definition of clear roles and responsibilities for actors involved, is required. European-level harmonization is essential to prevent market fragmentation and to facilitate the cross-border operation of V2G services.

Unclear liability and insurance provisions

The deployment of V2G technologies raises questions regarding liability, warranties, and insurance. If a EV is used to provide grid services and suffers damage (e.g., battery degradation, malfunction of charging equipment, or cybersecurity incidents), it is often unclear who is responsible—whether it is the EV owner, the aggregator, the charging infrastructure operator, or the DSO. This uncertainty can deter participation, as EV owners and operators may be unwilling to take on undefined risks.

Measures to clarify liability: Developing clear, standardized contractual frameworks is critical to allocate risks and responsibilities in a fair and transparent way. This includes defining the boundaries of warranty coverage for V2G-related use, establishing clear procedures for incident reporting and damage claims, and specifying the obligations of all actors in the value chain. Insurance products tailored specifically to V2G applications should be developed, covering risks such as battery wear, hardware failure, or cyber-attacks. Regulators can support this by providing guidelines for minimum coverage and encouraging the disclosure of insurance and warranty terms at the point of sale. Legal and regulatory frameworks should also make it easier for users in the event of disputes, for example through standardized arbitration mechanisms or support services for consumers.

Complex market entry requirements and prequalification procedures

Participation in electricity markets—especially for the provision of ancillary services or flexibility—often requires compliance with strict technical, financial, and administrative requirements. These prequalification procedures, while originally designed to ensure grid stability and security, can be a significant barrier for new entrants such as V2G aggregators or small-scale operators, e.g., extensive documentation requirements, technical certifications, demonstration of financial stability, and ongoing compliance reporting.

Measures for market entry: Regulatory authorities should review and adapt prequalification and market entry procedures to reflect the characteristics of distributed energy resources, e.g., the creation of simplified requirements for small-scale EV capacities and the use of regulatory sandboxes to test innovative regulatory approaches. Establishing "fast track" approval processes for V2G technologies, as well as providing clear, up-to-date guidance documents for new entrants, would reduce barriers to participation.

Lack of standardization for communication, data, and control

There is a lack of clear, enforceable standards for communication, data exchange, and control in V2G systems. Manufacturers and service providers may be reluctant to invest in the development or adoption of open protocols, leading to further market fragmentation. There are also legal uncertainties regarding the ownership, storage, and processing of operational and personal data generated by V2G systems, especially in light of stringent data protection laws such as the GDPR in Europe.

Measures to promote standardization and data security: Regulators can play a key role by mandating the use of recognized open standards for communication and data exchange (e.g., ISO 15118-20, OCPP, IEC 61850), and by requiring interoperability between devices and systems as a condition for market approval. Establishing clear guidelines for data ownership, use, and protection—including the responsibilities of each actor in the value chain—is essential to safeguard user privacy. Promoting the adoption of best practices for cybersecurity and data management, including certification schemes and regular audits, will strengthen the resilience of V2G systems.

Insufficient regulatory incentives for flexibility and grid support

Existing grid tariffs, remuneration schemes, and incentive programs are often not structured to reward behaviors that support system stability, reduce peak demand, or enable greater integration of renewables.

Measures to establish supportive regulatory incentives: Regulatory reforms could include the introduction of time-of-use tariffs, dynamic grid charges, or direct payments for specific grid services provided by V2G-capable EVs and aggregators. Establishing clear, performance-based criteria for the delivery and remuneration of flexibility services, and integrating V2G into broader energy and climate policy frameworks, will help ensure that the system value of V2G is rewarded.

8.3.1.4 Social barriers and measures

Social barriers and measures refer to societal challenges such as acceptance, participation, trust or social justice as well as to approaches to promoting inclusive and user-oriented solutions.

Limited public understanding of V2G

The generally low level of public awareness and understanding of what V2G is, how it functions, and what benefits and risks it entails is low. The concept of using their EV not only for transportation but also as a flexible energy resource remains abstract. Concerns about battery degradation, technical complexity, or range anxiety may be reasoned through insufficient information, leading to skepticism.

Measures to improve awareness: Targeted information campaigns, public demonstrations, and transparent communication of the facts around V2G are essential to build understanding and trust. Demonstration projects in residential neighborhoods, at public events, or within car-sharing fleets can make the concept more relatable. Educational materials, including simple guides, explanatory videos, and interactive online tools, should be developed and widely distributed. Early engagement of consumers in pilot projects, including opportunities for hands-on experience and feedback, can help fostering positive attitudes towards V2G. Moreover, integrating V2G topics into broader sustainability and climate education initiatives will contribute to long-term awareness and informed decision-making.

User acceptance and willingness to participate

Concerns about the loss of control over one's own EV, fears of unexpected battery depletion, the perceived inconvenience of regular connection to charging points, or the lack of attractive compensation can be deterrent. Many potential users value the autonomy and reliability of their personal mobility and may be reluctant to allow third parties any influence over their EVs charging and discharging patterns. Motivation to participate in V2G programs may be hampered by the perception that personal gains are marginal compared to the required effort or potential risks. Social norms and peer influence can also play a role, especially if V2G participation is not yet common in a given social network.

Measures to foster acceptance and engagement: V2G business models must be designed with the needs and preferences of end users, ensuring that participation is always voluntary, that users retain ultimate control over their EVs availability, and that they can set preferences. Attractive, transparent, and reliable compensation models are important to incentivize participation. Personalized feedback and information on environmental impact, financial earnings, and contribution to grid stability can reinforce motivation and enhance satisfaction. Community-based approaches, such as collective V2G participation within residential complexes, local initiatives, or company fleets, can create a sense of shared purpose and normalize participation. Platforms that allow users to share their experiences, ask questions, and receive support can help lower the threshold for engagement.

Equity, fairness, and access to V2G

Access to V2G-compatible EVs and charging infrastructure is not equally distributed, and there is a risk that the benefits of V2G programs may accrue mainly to more affluent groups, companies, or urban residents, while low-income households or those in rural areas are left behind. The costs of new power infrastructures or providing grid services may be socialized through general network fees, raising questions about the fair distribution of costs and benefits. There is also a risk that V2G participation could, intentionally or unintentionally, reinforce existing social inequalities—either through access barriers, biased incentive structures, or a lack of support for less technically experienced users.

Measures to promote inclusive participation: Policies should be designed to ensure broad and fair access to V2G opportunities. This could involve targeted support or subsidies for low-income households as well as the deployment of public or semi-public charging infrastructure.

Trust in technology, providers, and data security

Users need to be confident that their data and personal information will be handled securely, that the technology will work reliably and predictably, and that providers will fulfill their obligations with respect to maintenance, support, and compensation. Negative experiences—whether through technical failures or perceived misuse of data—can erode trust.

Measures to build trust: Clear communication, transparent terms of service, and accessible support channels are crucial for building trust. Providers should proactively inform users about privacy protections, data management practices, and their rights with respect to data access and correction. Certification schemes for V2G equipment and visible quality guarantees can enhance user trust. Independent third-party audits and regular publication of reliability will further increase transparency.

Community engagement

The successful scaling of V2G depends not just on individual decision-making, but also on the existence of supportive social infrastructure and opportunities for collective action. In some contexts, the lack of early adopters and first-movers and limited social networks may slow technology diffusion.

Measures to strengthen social infrastructure: Investing in social infrastructure—such as local energy agencies, community energy advisors, or peer-to-peer support networks—can foster V2G adoption. Facilitating knowledge exchange, showcasing success stories, and providing regular opportunities for dialogue and feedback will foster participation. Public recognition of pioneers, awards for innovative community initiatives, and partnerships between public authorities, industry, and civil society can all contribute to building momentum and recognizing that the social dimensions of V2G development are not overlooked.

8.3.1.5 Ecological barriers and measures

Ecological barriers and measures concern environmental aspects such as resource use, emissions or life cycle impacts of a technology as well as strategies to minimize ecological impacts.

Resource extraction and material criticality

The production of lithium-ion batteries requires significant quantities of raw materials such as lithium, cobalt, nickel, etc. Mining and processing these resources can have severe local and global environmental impacts. Moreover, the geopolitical concentration of resource extraction—often in regions with weak environmental regulations or labor standards—raises issues of environmental justice and increases the vulnerability of supply chains to disruption.

Measures to address resource consumption: Advancing battery technology toward chemistries that require less critical or more abundant materials can reduce ecological pressures and supply risks. Implementing environmental and social standards for resource extraction is essential. Certification schemes for sustainably sourced materials, mandatory due diligence for supply chains, and transparent reporting of material origin can help ensure higher standards and promote responsible sourcing. Promoting the use of recycled materials in battery manufacturing can reduce the need for primary extraction. Setting targets for minimum recycled content, supporting the development of advanced recycling processes, and creating closed-loop supply chains are important steps.

Environmental footprint of manufacturing

The entire manufacturing process for EVs, batteries, and charging infrastructure is associated with significant environmental impacts. Energy-intensive production methods and the use of chemicals and solvents contribute to air and water pollution and resource consumption.

Measures to reduce manufacturing footprint: Improving the energy efficiency of manufacturing processes, increasing the use of renewable energy in factories, and implementing circular economy principles can substantially reduce the ecological footprint. Policies that require or incentivize the use of renewable electricity and low-carbon technologies in production should be expanded and enforced. Additionally, environmental product declarations and transparent lifecycle assessments should be required for all V2G-relevant equipment.

End-of-life management, recycling, and second life

Without proper recycling infrastructure and processes, large volumes of waste batteries could pose risks of toxic pollution, fire hazards, and resource loss. Recycling rates for EV batteries remain relatively low, and many used batteries are exported to countries lacking stringent environmental controls. The design of batteries and devices often makes disassembly and recycling difficult and hazardous materials insufficiently labeled.

Measures for sustainable end-of-life management: Developing robust collection and recycling systems for batteries is essential. This includes investing in recycling facilities, improving logistics for the safe collection and transport of used batteries, and setting clear legal responsibilities for manufacturers, distributors, and users. Encouraging eco-design principles—such as modular construction, clear labeling of materials, and the avoidance of hazardous substances—can facilitate more efficient recycling and reduce environmental footprints. Furthermore, supporting the development of second-life applications for stationary storage can extend their service life. Policymakers should set ambitious targets for recycling rates, minimum recycled content, and the phase-out of non-recyclable materials.

Environmental impacts during operation

The environmental benefits of EVs and V2G systems depend on the context of operation. If the electricity used to charge EVs primarily comes from fossil fuels, the overall reduction in greenhouse gas emissions may be limited. The additional cycling of batteries inherent in V2G operations may increase energy losses, slightly reduce battery efficiency, and potentially accelerate battery wear—all of which can impact the net ecological benefit.

Measures to maximize operational sustainability: Efforts must be made to ensure that the electricity used for charging and grid services is sourced predominantly from renewable energy. This can be achieved through the integration of smart charging strategies, the use of guarantees of origin for green electricity, and direct coupling with on-site renewable energy systems (e.g., rooftop PV). Providing transparent information to users about the CO_2 intensity of their electricity supply, as well as personalized feedback on the ecological impacts of their participation in V2G, can support more sustainable user behavior and choices.

8.3.2 Contribution to Sustainable Development

The following section outlines how V2G can contribute to the SDGs.

8.3.2.1 Transdisciplinary criteria development

The following criteria were established and applied to the comparative assessment of V2G use cases:

Criterion	Description	Type
CO_2 emission reduction (tCO_2)	The actual or potential greenhouse gas savings achieved through the use of V2G, such as by avoiding fossil peak-load power plants and optimizing the use of renewable energy.	Quantitative
Volume of grid services (MWh)	The amount of system services provided by V2G fleets, such as frequency control and voltage regulation.	Quantitative
Available flexibility (MW)	The total available power provided by the charging and discharging capacity of V2G-capable electric vehicles to support grid stability.	Quantitative
Economic performance (€)	Total revenue generated for participants, savings in network investment needs, operational cost savings, and total cost metrics.	Quantitative
Adoption and participation rate (%)	The proportion of eligible EVs, charging points, and users actively participating in V2G programs, measured as a percentage of the total available capacity and the number of potential participants.	Quantitative
Environmental impacts (PEF)	Life cycle impact assessment, including raw material extraction, production, operation, and end-of-life management, based on a Life Cycle Assessment (LCA) and the European product environmental footprint (PEF) assessment.	Quantitative
Battery lifetime extension (%)	The percentage increase in the lifetime of V2G-capable EV batteries compared to conventional operation, and the proportion of batteries that are reused or repurposed (second life phase).	Quantitative
Interoperability and standardization (e.g. score 1-5)	The degree of compatibility between different V2G technologies and systems, such as EVs, charging infrastructure, and IT systems, based on recognized standards.	Qualitative
User acceptance (e.g. score 1-5)	User satisfaction and acceptance regarding participation in the V2G program, including perceived ease of participation, comfort, and transparency of data security.	Qualitative
Regulatory clarity (Score 1-5)	The clarity and transparency of regulatory requirements affecting V2G technologies, including the predictability and adaptability of legal frameworks to future developments.	Qualitative
Equity and accessibility (e.g. score 1-5)	How accessible V2G technologies are for different social groups, including the distribution of benefits and costs and the risk of exclusion, based on targeted support for disadvantaged groups.	Qualitative
Data security and trust (e.g. score 1-5)	Assessment of cybersecurity, data management practices, and transparency of responsibilities related to data security and privacy.	Qualitative

8.3.2.2 V2G contribution to the SDGs

The inter-and transdisciplinary assessment linked the effects of V2G to the following most relevant SDGs, as illustrated in Figure 115**.**

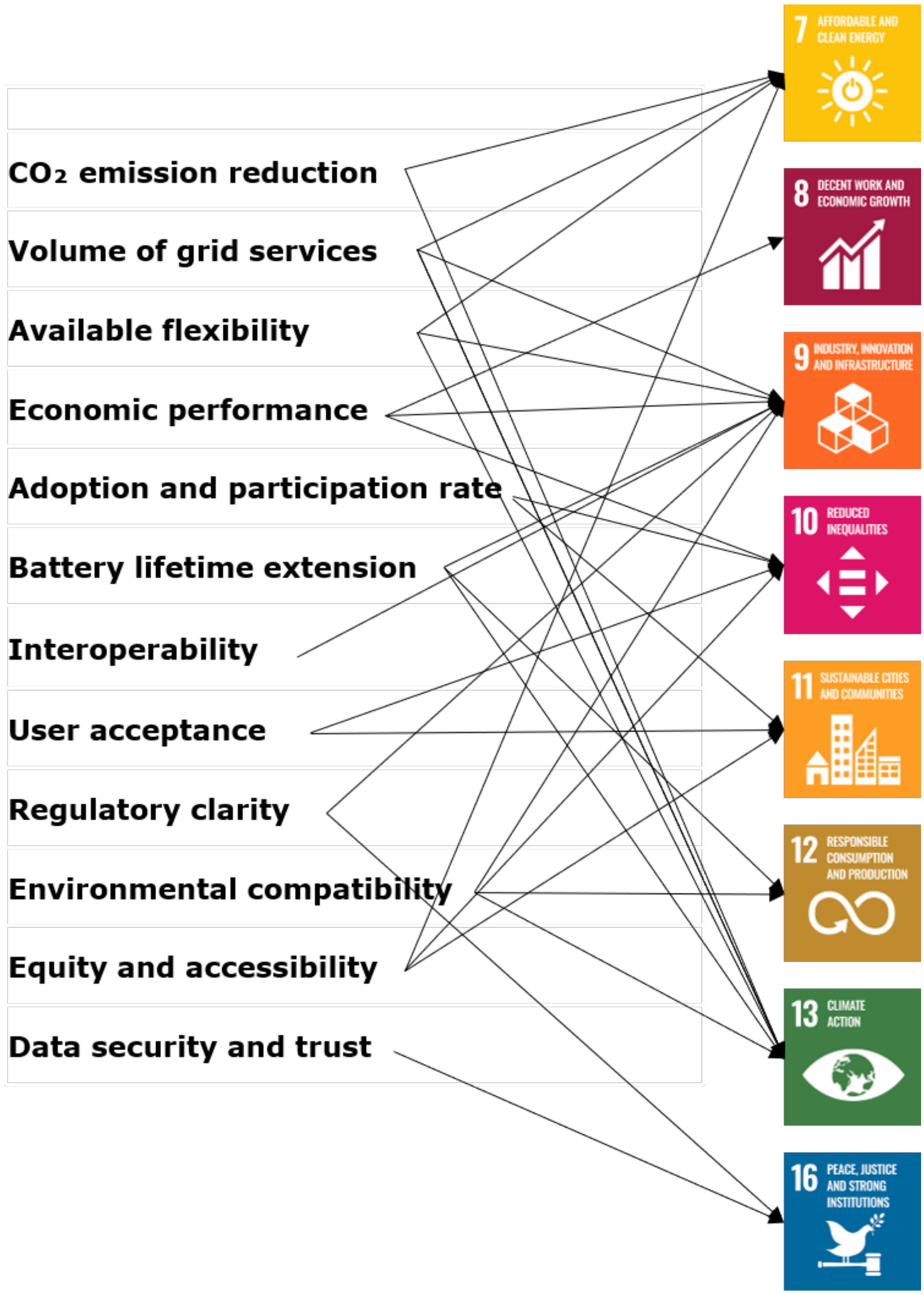


Figure 128: Sustainability criteria and link to the SDGs

- **CO_2 emission reduction – SDG 13: C**limate Action, SDG 7: Affordable and Clean Energy:
  - ➢ CO_2 emission reduction is a direct contribution to SDG 13 (Climate Action) by helping reduce greenhouse gas emissions, primarily through optimizing the use of renewable energy and avoiding fossil-based peak-load power plants. This also supports SDG 7 (Affordable and Clean Energy) by enabling cleaner energy use.
- **Volume of grid services – SDG 7: Affordable and Clean Energy, SDG 9: Industry, Innovation, and Infrastructure, SDG 13: Climate Action:**
  - ➢ The volume of grid services provided by V2G fleets contributes significantly to SDG 7 (Affordable and Clean Energy) by enhancing grid stability and enabling a higher share of renewable energy integration. It fosters the development of advanced grid technologies, promoting SDG 9 (Industry, Innovation, and Infrastructure). Additionally, supporting grid

stability and reducing reliance on fossil fuel-based power plants directly supports SDG 13 (Climate Action) by lowering emissions from the energy sector.

- **Available flexibility – SDG 7: Affordable and Clean Energy, SDG 9: Industry, Innovation, and Infrastructure, SDG 13: Climate Action**
  - ➢ Available flexibility provided by V2G, which supports grid stability through the charging and discharging capacity of EVs, contributes to SDG 7 (Affordable and Clean Energy) by facilitating the integration of intermittent renewable energy sources. It also enhances SDG 9 (Industry, Innovation, and Infrastructure) by driving innovation in energy infrastructure and systems. Furthermore, it supports SDG 13 (Climate Action) by reducing reliance on fossil-based backup power and enabling cleaner energy management.
- **Economic performance – SDG 8: Decent Work and Economic Growth, SDG 9: Industry, Innovation, and Infrastructure, SDG 10: Reduced Inequalities**
  - ➢ Economic performance from V2G, which includes revenue generation and operational savings, contributes to SDG 8 (Decent Work and Economic Growth) by fostering new business models, jobs, and economic opportunities in the clean energy sector. It also promotes SDG 9 (Industry, Innovation, and Infrastructure) by driving innovation in the energy and mobility sectors. If designed inclusively, it can help reduce economic disparities, contributing to SDG 10 (Reduced Inequalities), as disadvantaged groups can benefit from more affordable, clean energy and flexible pricing models.
- **Adoption and participation rate – SDG 10: Reduced Inequalities, SDG 11: Sustainable Cities and Communities.**
  - ➢ The adoption and participation rate of V2G programs is critical for ensuring broad access to the technology. This contributes to SDG 10 (Reduced Inequalities) by ensuring equitable access to V2G benefits for all social groups, including low-income households. A high participation rate in urban areas supports SDG 11 (Sustainable Cities and Communities) by improving the sustainability and resilience of urban energy systems.
- **Battery lifetime extension – SDG 12: Responsible Consumption and Production, SDG 13: Climate Action, SDG 9: Industry, Innovation, and Infrastructure.**
  - ➢ The battery lifetime extension resulting from V2G contributes to SDG 12 (Responsible Consumption and Production) by reducing the need for new battery production, thus lowering material consumption and waste. It also supports SDG 13 (Climate Action) by reducing the environmental impact of battery production and disposal. Furthermore, innovation in battery longevity aligns with SDG 9 (Industry, Innovation, and Infrastructure) by promoting the development of more sustainable technologies and business models in the energy and transport sectors.
- **Interoperability and standardization– SDG 9: Industry, Innovation, and Infrastructure.**
  - ➢ Interoperability and standardization are essential for the success of V2G, ensuring compatibility across technologies and infrastructure. This supports SDG 9 (Industry, Innovation, and Infrastructure) by enabling efficient, scalable solutions.
- **User acceptance– SDG 11: Sustainable Cities and Communities, SDG 10: Reduced Inequalities.**
  - ➢ User acceptance of V2G is key to its success. High acceptance rates contribute to SDG 11 (Sustainable Cities and Communities) by ensuring that urban populations use sustainable technologies. By ensuring accessibility for a diverse range of users, V2G can also help reduce inequality, aligning with SDG 10 (Reduced Inequalities).
- **Regulatory clarity – SDG 16: Peace, Justice, and Strong Institutions, SDG 9: Industry, Innovation, and Infrastructure**
  - ➢ Regulatory clarity is essential for the success of V2G technologies. Clear regulations contribute to SDG 16 (Peace, Justice, and Strong Institutions) by ensuring stable and transparent governance in the energy sector.

- **Environmental compatibility – SDG 12: Responsible Consumption and Production, SDG 13: Climate Action, SDG 9: Industry, Innovation, and Infrastructure.**
  - ➢ Environmental compatibility evaluates the entire lifecycle impact of V2G systems, contributing directly to SDG 12 (Responsible Consumption and Production) by promoting sustainable material use and recycling. It also supports SDG 13 (Climate Action) by reducing CO_2 emissions through the optimization of energy use. It fosters SDG 9 (Industry, Innovation, and Infrastructure) by encouraging the development of environmentally friendly technologies and infrastructures.
- **Equity and accessibility – SDG 10: Reduced Inequalities, SDG 7: Affordable and Clean Energy, SDG 11: Sustainable Cities and Communities.**
  - ➢ Equity and accessibility of V2G technologies ensure that all social groups can benefit from these advancements. This supports SDG 10 (Reduced Inequalities) by ensuring that V2G does not disproportionately benefit affluent groups, but is accessible to disadvantaged people as well. Moreover, it contributes to SDG 7 (Affordable and Clean Energy) by making clean energy accessible to everyone and to SDG 11 (Sustainable Cities and Communities) by promoting inclusive, sustainable urban energy systems**.**
- **Data security and trust – SDG 16: Peace, Justice, and Strong Institutions**
  - ➢ Data security and trust are critical to user adoption of V2G systems. Ensuring secure data handling and transparency in data use contributes to SDG 16 (Peace, Justice, and Strong Institutions) by promoting fair data management practices.

8.3.2.3 Interdependencies and goal conflicts

For a holistic assessment, it is essential to examine potential trade-offs between the different dimensions of sustainability. Figure 116 illustrates systemic interdependencies related to social and ecological sustainability, which serve as the basis for discussing relevant goal conflicts.

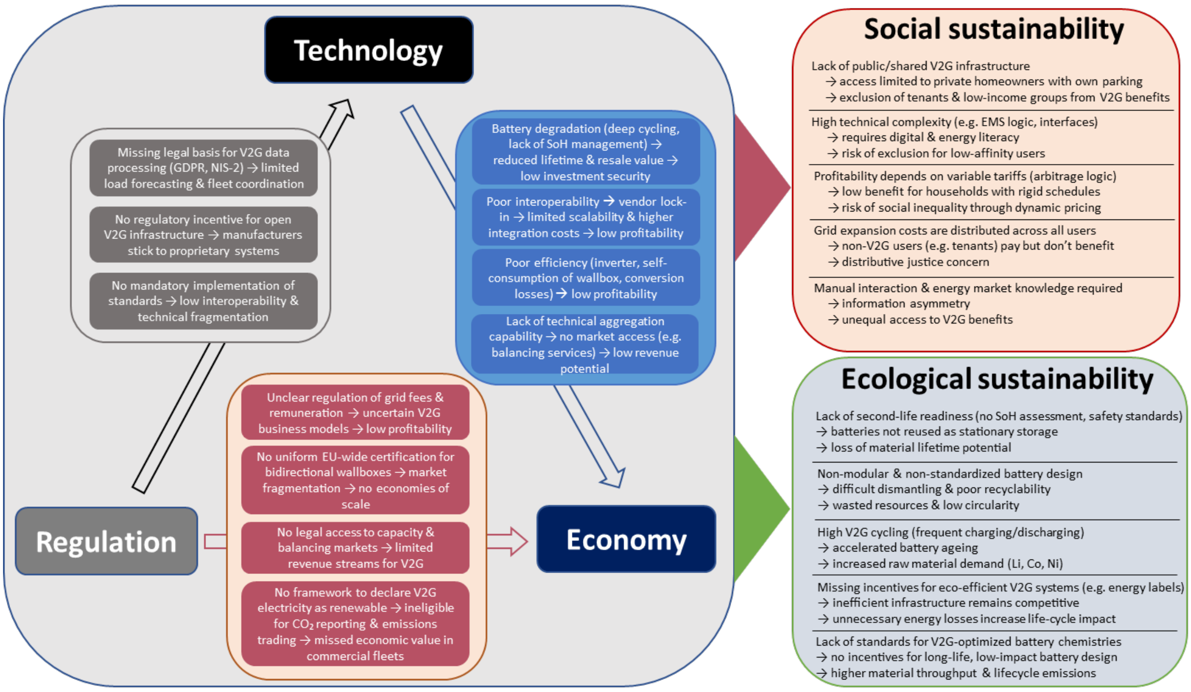


Figure 129: Systemic interdependencies of barriers

The most significant goal conflicts to sustainable development are:

Economic efficiency vs. environmental sustainability: Frequent V2G charging/discharging cycles may lead to increased battery degradation and greater resource consumption. Additionally, financial incentives may encourage prioritization of short-term economic benefits over long-term environmental protection through neglected SoH.

> Measures: 1) Implement advanced systems that balance economic returns with SoH, minimizing unnecessary cycling, 2) promote the development and adoption of sustainable battery chemistries that reduce environmental impact, alongside robust recycling and second-life strategies, and 3) integrate ecological performance indicators (e.g., carbon intensity, resource efficiency) into V2G remuneration and incentive models.

Technology vs. regulation: The lack of a legal framework for V2G data processing hinders technological progress and limits the integration of open systems. On the other hand, over-regulation could restrict technological flexibility and slow down innovation.

> Measures: 1) Develop clear, consistent regulations that promote technological innovation while ensuring data privacy and security, and 2) implement regulatory sandboxes where new V2G technologies can be tested in a controlled environment to ensure both compliance with regulations and innovation.

Technology vs. social equity: The high technical complexity of V2G systems, which require digital skills, limits access for low-income households or those with less digital literacy, hindering social inclusion.

> Measures: 1) Design user-friendly, intuitive interfaces that make V2G systems accessible to all, 2) implement subsidies or incentives that lower the entry barriers for low-income households, and 3) promote educational initiatives and training programs to enhance digital literacy and empower users to effectively engage with V2G technologies.

Regulation vs. social equity: Stricter regulatory requirements for V2G infrastructure integration may lead to higher costs, negatively affecting low-income households, making access to the technology difficult.

> Measures: 1) Develop cost-effective regulations that ensure V2G infrastructure is installed in affordable housing without raising financial barriers, and 2) promote PPP initiatives to provide affordable V2G solutions for low-income households.

Technology vs. ecology: Technological advancements (e.g., increased battery capacity and faster charging/discharging cycles) may lead to faster battery degradation, shortening battery lifespans and increasing material consumption.

> Measures: 1) Promote research and development of longer-lasting and recyclable battery materials, 2) encourage the use of second-life applications for batteries to extend their lifespan and reduce waste, and 3) establish robust standards and incentives for battery recycling, ensuring that resources are reused and waste is minimized.

Social equity vs. ecology: Higher costs associated with sustainable V2G technologies (e.g., long-lasting batteries) may make them less accessible to low-income groups, leading to social inequality, as wealthier individuals are the primary beneficiaries, conflicting with ecological goals that aim to reduce resource consumption.

> Measures: 1) Introduce progressive pricing models for V2G systems, where wealthier individuals subsidize the costs for low-income households, 2) prioritize cost-effective technologies that reduce

both environmental impact and cost barriers for low-income communities, and 3) establish cross-sector funding from public, private, and non-profit sectors to make V2G technologies affordable for all.

Regulation vs. technology: Lack of uniform regulations for V2G systems leads to proprietary technologies that hinder interoperability. On the other hand, too strict regulations may suppress innovation.

Measures: 1) Create flexible regulations that promote interoperability while allowing innovation in technology development, and 2) develop international interoperability standards that ensure different V2G systems can work together and reducing fragmentation.

Economic efficiency vs. social equity: V2G systems promise revenues through the use of variable tariffs and flexible charging and discharging processes. However, households with limited flexibility - for example due to childcare obligations (e.g. children), shift work or a lack of alternatives to EV use - can only take advantage of these economic benefits to a limited extent. As a result, there is a risk that lower-income or structurally disadvantaged households in particular will be excluded from the potential benefits of V2G systems, which can exacerbate social inequalities.

Measures: 1) Introduce equitable tariff structures where less flexible households can also benefit through basic payments or targeted subsidies, 2) establishment of neighborhood-based or cooperatively organized V2G infrastructures in which the usage costs and flexibility requirements are borne collectively, and 3) development of V2G programs that take individual mobility needs into account and create alternatives (e.g. multimodal mobility offers) for non-flexible households.

Technology vs. economy: Investment costs for advanced V2G technologies may create barriers to entry for smaller players, while larger players benefit from economies of scale, increasing market concentration and reducing competition.

Measures: 1) Provide financial incentives or subsidies for smaller players to encourage innovation and market participation, and 2) develop shared infrastructure models where smaller players can share costs.

Ecology vs. economy: Developing eco-friendly V2G systems (e.g., through the use of sustainable materials) may increase production costs, leading to higher market prices, which may affect the economic viability of these technologies.

Measures: 1) Research and develop eco-friendly materials, and 2) provide long-term investment incentives (e.g., tax credits, subsidies) to offset higher initial costs and make eco-friendly technologies economically competitive.

9 Conclusion

Interoperability has largely related to the implementation of standards/protocols between electric vehicles charging hardware, the electric vehicles themselves and various back-end systems. The most common issues surround the implementation of different versions of communication protocols like OCPP and ISO 15118-20.

The standard ISO 15118-20, which was published in 2022, defines communication between electric vehicles and charging infrastructure as well as standardizes and enables bidirectional charging and discharging, in addition to many other features. In the Car2Flex project, a prototype charging station was developed, tested and installed by Fronius International GmbH. It communicates with electric vehicles through Powerline Communication technology. The developed charging station supports the ISO 15118-20 communication protocol. However, the charging process is only possible if the used standard is supported by both the charging station and the electric vehicle. Due to the current lack of support for ISO 15118-20 amongst vehicle manufacturers, communication between the charging stations and electric vehicles in the Car2Flex project takes place via ISO 15118-2, which is supported by both the charging station and the electric vehicles. The problem of implementing the ISO 15118-20 standard therefore lies with vehicle manufacturers and must be solved there. To our understanding, the main difficulty lies in the implementation of the TLS 1.3 encryption standard required by ISO 15118-20.

The key standard for communications between the charging station and the charge point management system is OCPP, which is an open-source protocol for communication. Between the charging station from Fronius and the charge point management system from Reisenbauer, OCPP 1.6 is used as the communication protocol. Since OCPP 1.6 does not support the discharge of electric vehicles, MQTT is used instead as an internally defined workaround solution. This is a Car2Flex project-specific solution and is therefore not scalable.

As there are a large number of stakeholders with different interests, development, implementation and roll-out of the ISO 15118-20 standard has been relatively challenging. Currently most solutions of bidirectional charging and discharging are based on CHAdeMO. ISO 15118-20 was recently released, which means that in principle no car manufacturer has directly adapted electric vehicles to ISO 15118-20. It will still take time until this standard is integrated into electric vehicles. On one hand, it is recommended that all vehicle manufacturers take proactive actions to implement ISO 15118-20 as standard for vehicles. On the other hand, incentive policies are needed to encourage vehicle manufacturers to fulfill the V2G interoperability requirements. It would also be helpful to develop a regularly updated list of electric vehicles to check which manufacturers are actively implementing ISO 15118-20 to allow bidirectional power flow in their car models. Besides, while the communication standard ISO 15118-20 exists, variations in its implementation across different car manufacturers introduce challenges during individual vehicle charging. Addressing these issues necessitates rigorous testing within the overall system to ensure seamless and consistent performance.

Similar as for the electric vehicle manufacturers, there are differences in implementation of the communication protocol between charging station manufacturers. This must also be countered by intensive testing in the overall system and corresponding mutual adaptation. Until now, neither OCPP 1.6 nor OCPP 2.0.1 supports the bidirectional charging and discharging. Only the standard OCPP 2.1, which is not yet available, will make the bidirectional charging and discharging possible. It is recommended to implement OCPP 2.1 as the common communication protocol between the charging stations and the charging station management systems as soon as it is available. Implementing OCPP 2.1 by all the charge point management systems and charging stations will be the future solution.

In conclusion, OCPP 2.1 and ISO 15118-20 are two essential standards in the electric vehicle charging ecosystem. Each of them serves a distinct but interconnected purpose. Both versions of OCPP 2.1 and ISO 15118-20 support V2G functions. OCPP shall also work in a compatible way together with different versions of ISO 15118-20. Compatibility allows different components in the electric vehicles charging ecosystem to work together seamlessly. Standardization is crucial for creating a unified and secure charging infrastructure that can be implemented internationally. This is the only way to ensure the interoperability of charging electric vehicles and will create a user-friendly and globally connected charging network that will ultimately encourage the widespread adoption of electric vehicles.

The stakeholder results demonstrate a preference for bidirectional over unidirectional charging among both the participating individual EV owners and REC members, though cost sensitivity re-mains one of the major barriers. The private EV users indicated the strongest acceptance at acquisition costs below €4,000, with warranties of at least eight years, while REC members were much more flexible, accepting up to €5,000 and shorter warranties. In both groups, higher minimum charge levels (30–50%) were preferred despite lower ratings, reflecting a trade-off between battery availability and perceived security. Climate-friendly and cost-optimized charging options were most favored, while grid-optimized variants, though well-rated, were less frequently chosen. Acceptable charging times clustered below 9–11 hours for private EV users and below 8–10 hours for REC members. Overall, the findings reveal strong environmental values, high technological confidence, and openness to innovation among respondents, but also underscore the importance of lowering costs, providing warranty incentives, and communicating clear user benefits to foster widespread V2G adoption.

Survey and interview results highlight that private EV users and company fleet or car sharing operators show strong interest in bidirectional charging, though their perspectives differ. Among private users, willingness to pay is pronounced, with bidirectional capability valued at more than €3,000 in comparison to conventional charging. The main motivations are reduced electricity costs through dynamic tariffs and the provision of backup power during blackouts, while uncertainty about costs, technical maturity, and compatibility remains a barrier. Monitoring data further confirm that most users rely on private or semi-private charging at moderate power levels (7–11 kW) and pursue deliberate charging strategies that align with electricity prices and household routines. Fleet and car sharing operators report limited prior experience with bidirectional charging but see controlled charging as beneficial for optimizing PV self-consumption and managing load peaks. Bidirectional charging is acknowledged as promising for future business models, yet installation complexity, interoperability challenges, and unclear regulatory conditions (e.g., double grid fees, guarantees of origin) are significant obstacles. Operators emphasize the need for plug-and-play solutions, standardized communication, and reliable system integration with booking platforms and energy management systems.

Using the European energy system model EDisOn, the study evaluates the system-level impacts of EV flexibility in Austria under the TYNDP2024 "National Trends" scenarios for 2030 and 2040. Assuming 1.6 million EVs in 2030 and 5 million in 2040, the modeling shows that bidirectional flexibility can significantly enhance renewable energy integration and reduce greenhouse gas emissions. Flexibility shifts demand into periods of high renewable availability, particularly midday solar peaks, thereby reducing curtailment, improving full-load hours of renewable plants, and lowering the need for additional generation capacity. By 2040, the relative contribution of EV flexibility declines somewhat due to the availability of other flexibility options such as large-scale batteries and hydrogen production. Nonetheless, the use of existing EV batteries remains highly cost-efficient compared to new infrastructure investments and provides substantial environmental benefits by reducing land use for additional PV installations. These advantages are currently undervalued in the market, underscoring the necessity of flexibility markets to appropriately reward EV-based flexibility services.

The assessment of sustainability contributions demonstrates that bidirectional charging has clear added value across social, economic, and environmental dimensions. Socially, it strengthens user empowerment by increasing control over energy use, enhancing energy autonomy, and improving resilience during outages. Economically, it enables cost savings for households, creates new business opportunities for fleet and car sharing operators, and supports more efficient use of renewable generation assets. Environmentally, it reduces greenhouse gas emissions, lowers curtailment of renewables, and decreases land and resource demand by optimizing existing capacity.

Overall, the deliverable shows that bidirectional charging is both technically feasible and socially desirable, provided that regulatory, technical, and economic barriers are addressed. Clear compensation schemes, interoperability standards, and cost-effective infrastructure will be key to realizing the full sustainability potential of the Car2Flex use cases

The widespread introduction of bidirectional charging, particularly vehicle-to-grid (V2G) and vehicle-to-home (V2H) applications, faces a range of technical, regulatory, and economic barriers.

Throughout the entire project period up to the present, no electric vehicles in Austria are available with certified V2G capability. Moreover, no EV on the market has fully implemented the ISO 15118-20 standard, which defines the communication framework for advanced bidirectional charging. Instead, some manufacturers rely on ISO 15118-2 combined with proprietary communication protocols, such as the VW ID series working with the E3DC "Hauskraftwerk" system. While such proprietary solutions enable early functionality, they restrict interoperability and can place the end customer at a disadvantage, locking them into specific hardware and service ecosystems.

For feeding energy back into the public grid, compliance with country-specific "grid codes" is required. These codes, based on the EU Regulation 2016/631, differ significantly between countries. This results in high implementation effort for equipment manufacturers, as each market demands tailored certification and testing.

Another hurdle is battery degradation. Bidirectional charging introduces additional charge–discharge cycles, potentially accelerating battery wear. Uncertainty over warranty terms adds further hesitation, as vehicle owners are unclear whether V2X-related degradation will be covered.

From an economic standpoint, Europe currently lacks comprehensive incentives to promote bidirectional charging. In many cases, double taxation applies to stored energy: one tax on charging and another on discharging. This can occur even when energy is fed back to the grid for system support functions, such as LFSM-U (Limited Frequency Sensitive Mode – Underfrequency), without providing a tangible benefit to the vehicle owner.

In summary, the combination of missing standard-compliant vehicles, fragmented regulations, technical risks to battery health, and unfavorable economic frameworks makes the implementation of bidirectional charging in Europe a complex challenge that requires further coordinated action between manufacturers, policymakers, and grid operators.

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