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D4.1:

Documentation of advanced smart charging concepts with overview of use-cases scenarios, relevant actors for smart charging concepts and Digital twins architecture.

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Table of Contents

1. Executive Summary

The primary goal of the XL-Connect project is to optimize the charging process from the primary energy supply to the end user, who would charge the vehicle. It focuses on the definition of advanced charging concepts and implications of smart charging as well as Vehicle-to-Everything (V2X) technologies. For that multiple use-cases scenarios are defined in this document to investigate the benefits and feasibility of smart and bidirectional charging. Based on multiple parameters such as location of charging infrastructure, charging topology, different profiles of users, seven use -cases scenarios were defined: 1) Energy community neighbourhood, 2) Residential, 3) Urban Street parking, 4) Highway charging, 5) University campus, 6) Industrial site, 7) Company vehicle fleets. Exploring EVs' driving and charging characteristics is essential for evaluating the impact of different penetration levels of EVs on the current grids. Given that the scenarios are defined in 4 different European countries, the relevant regulations of each country were required to be taken into account.

A multilayered architecture design, that integrates the four main components: EV, charging station, Building/Home and Grid, is defined and then modified by each scenario. Moreover, based on the activities of WP6 "Evaluation of Operational, Social and Economic Impacts" the Key Performance Indicators (KPI) are defined for each scenario and will be adopted in the simulation environment of the digital twin. This digital twin will feature multilevel component models and representative information flow between the agents. The used subcomponents with their corresponding interfaces as well as the software with the necessary tools are also described in this deliverable. In the future they will be used as inputs to other tasks of this work package (e.g. task 4.2 "Subcomponent modelling") as well as to other work packages (e.g. WP5 "Virtual and real demonstrations")

Keywords: V2G, V2B, V2H, Smart Charging, Scenario definition, System Architecture, Advanced charging concepts, Model, Subcomponents, Tool, Data.

2. Introduction

The number of electric vehicles in the EU is projected to reach 30-40 million by 2030, driven by supportive policies and decreasing costs. This surge presents both a challenge in terms of charging infrastructure and an opportunity for Vehicle-to-Grid (V2G) technologies to enhance grid stability. Uncontrolled charging of electric vehicles does not make sense from an economic and grid operation point of view, advanced charging concepts are required. In work package 4, a predictive digital twin of this system of systems is being developed that can be used to analyse advanced charging scenarios and maximize the benefits for all stakeholders in the below defined use cases-scenarios. The activities of task 4.1 include the definition of advanced charging concepts based on the available information from other WPs: 1) Requirements for advanced charging technologies (T1.1), 2) Gaps regarding charging technologies (standards, regulatory frameworks) (T1.2), 3) Interaction between users and new mobility systems (T2.1), 4) Grid topologies and requirements (T2.2) and 5) Definition of demonstrators (T5.1). These activities focus on exploring the potential applications and implications of smart charging and V2X technologies. A smart charging concept is characterized by communication between the vehicle and the charging station. In addition, there should be communication with the grid if V2G is offered. A charging management system should be installed, which intelligently regulates the charging power and can react to future events. The goal is to minimize the grid impact and increase the self-consumption. In addition, load peaks can be reduced. The critical uncertain parameters for the optimization of charging process are arguably vehicle arrival as well as departure times, initial State of Charge (SoC), required power, and price. These parameters were considered on the definition of scenarios.

Task 4.1 ends on M12 of the project and its conclusion is documented on this deliverable 4.1:" Documentation of advanced smart charging concepts with overview of use-cases scenarios, relevant actors for smart charging concepts and Digital twins architecture". The main objectives of this deliverable are:

- Definition of charging scenarios where advanced charging concepts can be applied.
- Definition of KPIs that can be applied to these scenarios.
- Creation of an architecture for the digital twin, which represents the different scenarios.
- Description of subcomponents which are used in the digital twin.

3. Identification of the scenarios

In this work package scenarios are defined for smart charging and V2G applications. In this case scenario refers to a (virtual) location with a specific set of features.

In the appendix you can find a table where multiple charging scenarios are defined. In this table the location, charging topology, user behaviour and other features are defined for each scenario. All features are described and summarized in the following section.

- Charging topology

Alternating current (AC) charging and direct current (DC) charging are the two selections of charging topology. AC charging is already widely used in homes and commercial buildings and AC charging stations are more common nowadays worldwide. While DC charging offers higher charging speeds and higher voltage levels, it also comes with a higher cost, and the numbers will increase in the future perhaps as the demand for high-speed charging increases. Both these two charging topologies will be considered in our different scenarios. Also in the real world, since the cost of building up of AC charging stations is much lower than DC ones, it's necessary for some use cases only considering AC charging stations or have both kind of topologies.

- Charging speed level (based on CHARIN)

There is an overview of power classes of charging stations mentioned in the report from CHARIN. The power class is divided into the following levels: LPC (Low-Power Charging), DC (DC Charging), FC (Fast charging), UFC (Ultra-Fast Charging), HPC (High-Power Charging), and MCS (Megawatt Charging System). In the following table lists the minimum requirements of different level.

Charging speed level	U_{min} (V)	U_{max} (V)	I_{min} (A)	I_{peak} (A)	$I_{derated}$ (A)	Duration (using I_{peak})
LPC	≤ 200	≥ 920	/	< 20	< 20	inf
DC	≤ 200	≥ 920	≤ 1	≥ 20	≥ 20	inf
FC	≤ 200	≥ 920	≤ 1	≥ 125	≥ 94	≥ 30 min
UFC	≤ 200	≥ 920	≤ 5	≥ 250	≥ 188	≥ 20 min
HPC	≤ 200	≥ 920	≤ 5	≥ 500	≥ 375	≥ 10 min
MCS	TBD	TBD	TBD	TBD	TBD	TBD

Table 1 Minimum requirements for different charging speed level. (1)

- Charging technology

V1G (Unidirectional smart charging), V2B/V2H (Vehicle to building/ Vehicle to home), V2G (Vehicle to grid, bi-directional smart charging) are the main technologies involved in the scenarios. V1G allows the EVs to modify the charging rates and time dynamically, which will reduce the cost of charging. EVs can be used to store renewable energy or supply the electric energy to house or buildings when the load is high by implementing V2B/V2H. These kinds of technologies will also help to balance the local grid. In terms of V2G, EVs are more integrated with the grid than the three previously mentioned technologies, allowing for bi-directional energy flow, which supports grid stability and gives prosumers the opportunity to earn some incentives.

- Charging Type

There are four charging types available, which are conductive charging, Inductive charging, dynamic charging, and battery swapping. Most of the scenarios are using conductive charging, since the advantages of maturity, simplicity and low cost.

- Local generation / consumption/ storage

Photovoltaic and waterpower plant are the two main local generation considered by all the scenarios. Energy storage using stationary battery and power to heat are also planned in some of the scenarios.

- User behaviour

User behaviour is divided into three main categories: individual, fleet, and fleet with planned timetable.

- Expected parking time

Expected parking time is also various for different scenarios, we defined three separate features to characterize the parking time. The features are parking time (night/day), average parking hour, variance of charging time. Among them, variance of charging time can be categorized into three levels: 1) Small variance, 2) normal variance, 3) big variance.

- Vehicle type

Vehicle types of the project are mainly passenger cars and light/ heavy duty vehicles.

- Revenue/ Cost saving opportunities

There are in total 7 different revenue/cost saving opportunities listed in the feature table: frequency balancing, peak shaving, arbitrage offers by charging during low-price hours, utilization of locally generated energy (PV plant), reward for providing battery, redispatch, and self- consumption increase.

- Number of vehicles

The number of vehicles depends entirely on the definition of the scenario, for example the number of cars in a home charging scenario would be around 1-3, but in a large parking lot the number of cars can be up to hundreds of vehicles.

- Grid topologies (charging point usually connected to)

Scenarios will select the grid topologies from the following features: AC (OBC) unidirectional, DC (micro-grid) unidirectional and DC (micro-grid) bidirectional.

4. Definition and description of KPI

In this chapter KPIs are grouped from social, environment, economic and technical point of views. As defined in Chapter 3, in total 7 main scenarios will be selected for XL Connect project. The scenarios are defined as following:

1. Energy community neighbourhood
2. Residential
3. Urban street parking
4. Highway charging
5. University campus
6. Industrial site
7. Company vehicle fleets

In the KPI definition table, the number of the scenarios corresponds to the name of the scenarios. Refer to the next chapter for specific scenarios definitions.

Categories	KPI	Definition	Unit	Scenarios						
				1	2	3	4	5	6	7
Social:	Evaluation of cost of electricity bills	Evaluation of price policies	Likert scale	x	x	x		x	x	x
	Customers' satisfaction	Increase in consumers satisfaction with their energy supplier	Likert scale			x	x	x		x
	Consumers' participation	Increase in consumers participation in demand response management programmes	Likert scale			x	x	x		x
	Degree of Landscape Impact	Aestethical measure	Likert scale	x	x					

Environment	Reductions of GHG emissions	Reduction of GHG emissions	tCO2-eq/year	x	x	x		x		x
	Primary Energy Demand and Consumption	Primary energy demand/consumption encompasses all the naturally available energy that is consumed in the supply chain of the used energy carriers	kWh/year	x	x		x	x	x	x
	NER	Lifetime energy supply divided by Total energy invested	[MW]supplied/[MW]invested	x	x	x		x		
Economic	Installation Cost	Capex related to the installation cost of the charging system	$			x		x	x	x
	Grid exstending cost	Cost of investment for exstending the grid	$/year			x				x
	Smart Charging	Opex due to the energy cost	$			x		x		x
	Energy imports	Reduction of energy imports	%	x	x					x

	Energy cost reduction	Reduction of energy cost	%	x	x	x	x	x	x	x
	Maintenance infrastructure	Opex related to the maintenance of the charging infrastructure, both scheduled and unscheduled	$			x		x		x
	OPEX (life cycle cost of energy)	Cost of the usual line of business	$/MWhth	x	x					
	NPV	How much an investment worth through its lifetime, discounted to today's value	$	x	x	x		x	x	x
	ROI	Return on investment	%	x	x	x		x	x	x
	Payback Time	Amount of time it takes to get back the originally investment	Year	x	x	x		x	x	x
	Cost per consumer	Includes both operation and investment expenses	$	x	x	x				
	Total capital cost per kW installed	Initial cost of investment depending on the size	$/kW	x	x	x		x		x
	Revenue in load control	Revenue achieved in	$/day			x		x		

		load control application								
	Revenue in energy trading	Revenue achieved in energy trading application	$/day			x		x		
	Trip cost efficiency	Actual cost for the driver including tolls and charging costs	$/km				x			x
Technical	Peak-load	Curtailment of the peak power by loadshift or load-shedding	% of peak power reduction T6.1	x	x	x		x	x	x
	Share RES	Increase in the share of renewable energy in the generation of electricity	%	x		x		x		x
	Grid Congestion	Grid sustainability to peaks	%			x		x		x
	Accuracy of supply and demand prediction	Increase accuracy of the systems (reduction of the demand and/or supply forecast error)	RMSE(root mean square error)			x		x		
	Flicker	Measure the rapid fluctuation	%			x				x

		in the voltage that cause change in brightness								
	Voltage deviation	Difference between the actual voltage supplied to MV/LV users and the nominal value	%			x		x		x
	Harmonic distortion	Harmonic distortion	%							x
	Frequency Control	Calculated the percentage of time that the average value of fundamental frequency measured over periods goes out of stated ranges	%			x		x		x
	On-site Energy Ratio	Relation between the annual energy supply from local renewable sources and the annual energy demand	%	x	x	x		x	x	x
	Maximum Hourly Surplus-Deficit	Maximum value of how bigger is the hourly local RES supply than the yearly demand	kWh	x	x			x	x	
	Accuracy of supply and	Increase accuracy of the	RM SE(r	x	x					

	demand prediction	systems (reduction of the demand and/or supply forecast error)	oot mean square error) T4.2							
	Battery Degradation rate	Rate at which the battery performance is deteriorating over a year/cycle	% (reduction of Capacity / year) T4.2, T6.2	x	x	x	x	x		
	Degree of self-supply (RES)	Percentage of self-generated energy not injected to the grid	% T4.2, T4.3	x	x		x		x	x
	Degree of self-consumption	Percentage of energy self-consumption compared to total production	% T4.2, T4.3	x	x		x		x	
	Energy efficiency	Improvement of the energy efficiency of electric appliances	%	x	x					

	Storage Energy Losses	Losses because of storage	A·h	x	x			x		
	Driving efficiency	Total travel time	s				x			x

Table 2: KPI Mapping

In the following section important KPIs which will be used or calculated for developing the advanced smart charging concepts are explained.

Social:

- Evaluation of cost of electricity bills: evolution of price policy between the typical context and the incentives proposed, based on surveys.
- Customers' satisfaction: based on surveys and app rating.

Environmental:

- Reductions of GHG emissions: based on the reduction of GHG emission using advancing charging solutions. Impact assessment method: ReCiPe 2016 (H) midpoint.
- Primary Energy Demand (PED) and Consumption: The primary energy consumption of electric energy will be based on prediction based on user behaviour (also BESS and PV will be installed). Also a partition of PED, PED renewable and PED non-renewable, will be proposed. The PED can be calculated based on the composition of the electric energy https://energy-charts.info/charts/power/chart.htm?l=en&c=DE
- NER: Energy supply by the charging station during XL-CONNECT Project (3 years) and also during the infrastructure lifecycle (suggested 10-15 years)

Economic:

- Installation Cost/ Total capital cost per kW installed: cost based on table 4 in deliverable 3.1.
- Smart Charging: operational expenditure (Costs of goods sold) due to the energy cots optimized by an algorithm for smart charging during one year.
- Energy cost reduction: reduction of energy cost using smart charging in percentage respect to the fee proposed by energy suppliers, ask to energy supplier partners for more accurate data.
- Maintenance infrastructure: Consider only ordinary maintenance, ask to infrastructure suppliers for more accurate data.
- Operational expenditures (OPEX - life cycle cost of energy): Operation and maintenance costs of the charging system, including energy costs and grid fees.
- Net present values (NPV): Formula used

$$NPV = \sum_{t=0}^{n} \frac{F_t}{[1+r]^t} - I$$

F = projected revenue of the year according to different grid services proposed

R = discount rate

n = total number of years of revenue in future (project lifetime or infrastructure lifetime)

I = installation costs

- Return on investment (ROI): Formula used

$$ROI = \frac{Ret}{I}$$

Ret = Return

I = Installation Costs

- Payback Time: time period used to cover installation costs, depends on different grid services proposed.
- Cost per consumer: Operation and investment expenses for each consumer.
- Total capital cost per kW installed: Initial investment required to install a power unit (e.g. PV or charging station) per installed kW.
- Revenue in load control / Revenue in energy trading: revenue per day achieved by the demonstrator consider different user behavior. Assumptions on prices of grid services are made upon state of art analysis, e.g., Belmonte et al. 2023 (1).
- Trip cost efficiency: Actual cost for the driver including charging costs and tolls per kilometer.

Technical:

- Peak-load: Percentage of reduction of peak power due to load-shift due to the use of algorithms for V2G charging and BESS charging/discharging usage.

$$PeakLoad = \frac{P_{Unr} - P_{Reg}}{P_{Unr}}$$

P_{Unr} = Peak-Load w/o using advanced algorithms

P_{Reg} = Peak-Load using advanced algorithms

- Share RES: Percentage of increase of RES in the generation of electricity

$$Share\ RES = \frac{P_{RESReg} - P_{RESUnr}}{P_{RESReg}}$$

P_{RESReg} = Load satisfied by RES using advanced charging algorithms

P_{RESUnr} = Load satisfied by RES w/o using advanced charging algorithms

- Grid Congestion: Percentage of grid congestions or grid disruptions resolved by the system.
- Flicker: Short-term voltage fluctuations that can be injected into the electricity grid by charging the vehicle.

- Harmonic distortion: The waveform of the grid can be distorted by frequencies which are integer multiples of the grid frequency. This can be caused by rectifiers (e.g. in EV-Chargers).
- Frequency Control: Hard to get data about this simulation (e.g., frequency range for energy quality).
- On-site Energy Ratio:

$$OnSite\ Energy\ Ratio = 1 - \frac{E_{ReqY} - E_{SupY}}{E_{ReqY}}$$

E_{ReqY} = Energy requested by the system in a year predicted using data on parking occupancy

E_{SupY} = Energy supplied by the RES in a year using data from Italian scenario statistics (e.g., PV irradiance)

- Maximum Hourly Surplus-Deficit:

$$Max\ Hourly\ Surplus\ Deficit = MaxReq_y - MaxSup_{RES}$$

$MaxReq_y$ = Maximum demand of the system in a year with or w/o the algorithm optimization

$MaxSup_{RES}$ = Maximum supplied energy by the RES with or w/o the algorithm

- Accuracy of supply and demand prediction: used the root mean square root error and base prediction of occupancy rate and user behavior for the parking system.

$$RMSE = \sqrt{\frac{1}{n}\sum e_t^2}$$

Forecast error: $e_t = f_t - d_t$

f_t = forecast of supply demand at the time t

d_t = actual demand registered at the time t

n = number of measures

- Battery Degradation rate: reduction of capacity due to the aging of battery pack; using data from literature such as Berzi et al. 2020 (2). Variables such as battery pack temperature can be included in the degradation rate.
- Degree of self-supply (RES): Percentage of used energy which is covered by own production.

$$Self\ Supply = \frac{E_{con} - E_{import}}{E_{con}}$$

E_{import}= Amount of energy imported from the grid
E_{con}= Amount of energy consumed

- Degree of self-consumption: Percentage of energy used form own production

$$Self\ Consumption = \frac{E_{gen} - E_{grid}}{E_{gen}}$$

  E_{gen}= total amount of energy generated by renewable sources
  E_{grid}= Amount of energy fed back into the grid

- Energy efficiency: Improvement of energy efficiency of electric appliances compared to uncontrolled charging.
- Storage Energy Losses: Used battery efficiency related to the type of BESS simulated (e.g., design cell, chemistries) and SOH (aging). Using data from battery suppliers.

5. Scenario Definition

In this chapter the most relevant or common scenarios are highlighted. The selected scenarios will be explained in further detail in the next chapters.

5.1. Home charging

For home charging two scenarios will be addressed: an energy community neighbourhood with several individual houses and a residential building, being a single building with a certain number of apartments.

		HOME	
		Energy community neighbourhood	Residential building
Charging topology	Mandatory	AC	AC
	Optional	DC	DC
Charging speed level (based on CHARIN)	Mandatory	Low power charging (LPC)	Low power charging (LPC)
	Optional		LPC, Normal DC charging, Fast charging (FC)
Charging technology	Mandatory	V1G, V2H, V2G (AC/DC)	V1G, V2H, V2B, V2G(AC/DC)
	Optional	V2B	
Charging type	Mandatory	Conductive charging	Conductive charging
	Optional		
Local generation/ consumption/ storage	Mandatory	Photovoltaic (PV)	
	Optional	Stationary battery, power to heat	Photovoltaic (PV)
User behaviour	Mandatory	Individual	Individual
	Optional		
Expected parking time	Night-time	- Most vehicles are parked - Average parking time: 12h - Small variance	- Most vehicles are parked - Average parking time: 12h - Small variance
	Daytime	- Only a certain percentage are parked - Undetermined time - Dependency on weekdays and weekends	- Only a certain percentage are parked - Undetermined time - Dependency on weekdays and weekends
Vehicle type	Mandatory	Passenger car	Passenger car
	Optional	Vans	
Revenue/ cost saving opportunities	Mandatory	Self-consumption increase	
	Optional	Frequency balancing, peak shaving, arbitrage offers by charging during low-price hours, utilization of locally generated energy (PV)	Arbitrage offers by charging during low-price hours, utilization of locally generated energy (PV), reward for providing battery
Number of vehicles	Mandatory	Between 5-100	1 per parking spot
	Optional		
	Mandatory	AC (OBC) unidirectional	AC (OBC) unidirectional

Grid topologies charging point utilities connected to	**Optional**	DC (micro-grid) unidirectional DC (micro-grid) bidirectional	DC (micro-grid) unidirectional DC (micro-grid) bidirectional

Table 3. Scenario definition summary of home charging.

5.3.1. Energy community neighbourhood

In an energy community of individual homes, each house can exchange energy with the other members of the community to increase the consumption efficiency and reduce costs.

In this scenario, for each individual home the charging scenario is one family with 1-2 electric vehicles which are charged by a conductive AC-Charging station with low to medium charging speed. It can offer V1G, V2G and V2H. Connection to community budlings might be also considered. The houses can be equipped with a PV plant and a stationary battery, that will be used to supply energy to the home, with fixed charges, to charge the self-vehicles. The vehicles are mostly charging during the night. During the day there is a big variance of volume of cars and time of charging. The surplus will be either sent to other houses of the community or to the grid, depending on the overall needs.

The main target of these systems is to increase the self-consumption and reduce power peaks.

The definition of the scenario will need to consider the following specifications:

- Number of homes in the community
- Power installed in each home
- Power needs per home
  - Number of fixed charges
  - Consumption profiles
- Number of electric vehicles per home
- Characteristics and needs of each vehicle
  - Battery capacity
  - Charging/supply curves
    - AC / DC
  - Daily autonomy needs
  - Charging periods
- Characteristics of the stationary batteries
  - Battery capacity
  - Charging/supply characteristics
- Existence of PV plant
  - Total power installed
  - Power generation curves (profiles for each day)
- Existence of community buildings in the neighbourhood
  - Power requirements (fixed charge or daily profile)
- Existence of shared charging points
  - Number of charging points

    - Characteristics (only from home surplus or also from grid)

5.3.2. Residential building

In a residential building the number of apartments is defined, and the maximum charging points in the garage is fixed. Nevertheless, the occupancy of the building may differ from month to month. In this scenario a shared PV plant can be considered for direct consumption of common services like lighting of common areas and a fixed amount for each home/charging spot in case of energy surplus. This amount could be transferred partially between neighbours if someone does not have EV, or some empty apartment during a certain period.

In this scenario the vehicles are mostly charging during the night, and during the day only a certain percentage are parked an undetermined time, which will depend on the type of day (working or weekend/holidays).

Here the main target will be to study arbitrage offers by charging during low-price hours, utilization of locally generated energy (PV), and the reward for providing battery capacity

The definition of the scenario will need to consider the following specifications:

- Number of apartments in the building
- Power installed in each home (in principle the same for each)
- Power needs per home
    - Number of fixed charges
    - Consumption profiles
- Number of vehicles per home
    - 1 parking spot per apartment
- Characteristics and needs of each vehicle
    - Battery capacity
    - Charging curves
        - AC / DC
    - Daily autonomy needs
    - Charging periods
- Characteristics of the stationary batteries
    - Battery capacity
    - Charging/supply characteristics
- Existence of PV plant
    - Total power installed
    - Power generation curves (profiles for each day)
    - Energy consumption of the building
    - Energy quota per neighbour
        - Consider transfers between apartments

5.2. Street parking

For street parking two scenarios will be addressed: an urban street parking considering the public charging stations in the urban area of a smart city and a highway charging during long distance trips.

		Street Parking	
		Urban street parking	Highway charging
Charging topology	Mandatory	AC	DC
	Optional	DC	AC
Charging speed level (based on CHARIN)	Mandatory	Low power charging (LPC)	Fast charging (FC) Ultra-fast charging (UFC) High power charging (HPC)
	Optional	Normal DC charging (DC)	Normal DC charging (DC) Megawatt charging (MCS)
Charging technology	Mandatory	V1G	V1G, V2G (AC/DC)
	Optional	V2G (AC/DC)	
Charging type	Mandatory	Conductive charging	Conductive charging
	Optional	Inductive charging	Inductive charging
Local generation/ consumption/ storage	Mandatory		Photovoltaic
	Optional		Stationary battery
User behaviour	Mandatory	Individual	Individual, fleet based, fleet timetable
	Optional		
Expected parking time	Night-time		Park overnight/ 1hour
	Daytime	2-8 hours (survey information on different countries)	/15-30 mins
Vehicle type	Mandatory	Passenger car	Passenger car, light duty, heavy duty
	Optional		
Revenue/ cost saving opportunities	Mandatory	Frequency balancing, Redispatch	Frequency balancing
	Optional		Utilization of locally generated energy (PV plant), self-consumption increase
Number of vehicles	Mandatory	Between 5-100	20-100
	Optional	over 100	Over 100
Grid topologies charging point utilities connected to	Mandatory	AC (OBC) unidirectional DC (micro-grid) unidirectional	DC (micro-grid) unidirectional
	Optional	DC (micro-grid) bidirectional	AC (OBC) unidirectional DC (micro-grid) bidirectional

Table 4: Scenario definition summary of Street Parking

5.3.1. Urban street parking

Urban street parking is defined as charging the vehicles on-street in urban area, and the parking capacity on each street is defined.

In this scenario, some of the on-street areas are equipped with V2G, DC charging, but some of the areas are not, depending on the infrastructure and foot traffic nearby.

This addresses the issue of temporary parking and charging of EVs in urban areas and provides more flexibility to the grid. The feasibility of different incentives and user feedback will also be analysed. In addition to these, there is also the degradation of the battery to consider.

By building this virtual simulation, we expect to determine the necessity, size, and location of a bi-directional DC/AC street charging station in an urban area based on user satisfaction with price, ease of use, and so on.

The definition of the scenario will need to consider the following specifications:

- Parking capacity on each street
    - Max number of vehicles can be stopped at the same time
    - Frequency of use of street parking
- Existence of on street charging points
    - Number of charging points
    - Characteristics (DC/AC/Uni-/Bi-)
- Location of the urban area
    - Scope of the urban area
- Characteristics and needs of each vehicle
    - Battery capacity
    - Charging/supply curves
        - AC / DC
    - Daily autonomy needs
    - Charging periods
    - Cell aging model
- Grid
    - Day-ahead energy pricing
- User
    - Gender/ age/ location
    - Charing behaviour
    - Satisfaction feedback

5.3.2. Highway charging

Highway charging is defined as the charging of electric vehicles (EVs) during long trips at charging stations located in extended areas, e.g., continental Europe.

Relatively small charging stations will be equipped with fast DC charging and V1G, but large hubs where heavy-duty vehicles can park overnight will also provide slow AC charging and V2G services. These large hubs may further include a PV plant that provides energy to the station locally.

The main target for this scenario is to establish the most favourable trip plan in terms of a cost weighting energy savings, battery degradation and economic costs, by appropriately determining the itinerary, optimal locations for charging, the duration of charging sessions, and the average speeds to be maintained along each segment of the route. Since this target is defined from the driver perspective, it is referred as the *driver target*. (see Figure 1) An additional, optional target for the scenario can be defined from the perspective of the operator of the charging stations (see Figure 2). In this case, the *charging station target* is to establish more convenient prices and availability of the charging points that maximizes the profits for the operator, based on a predicted charging demand.

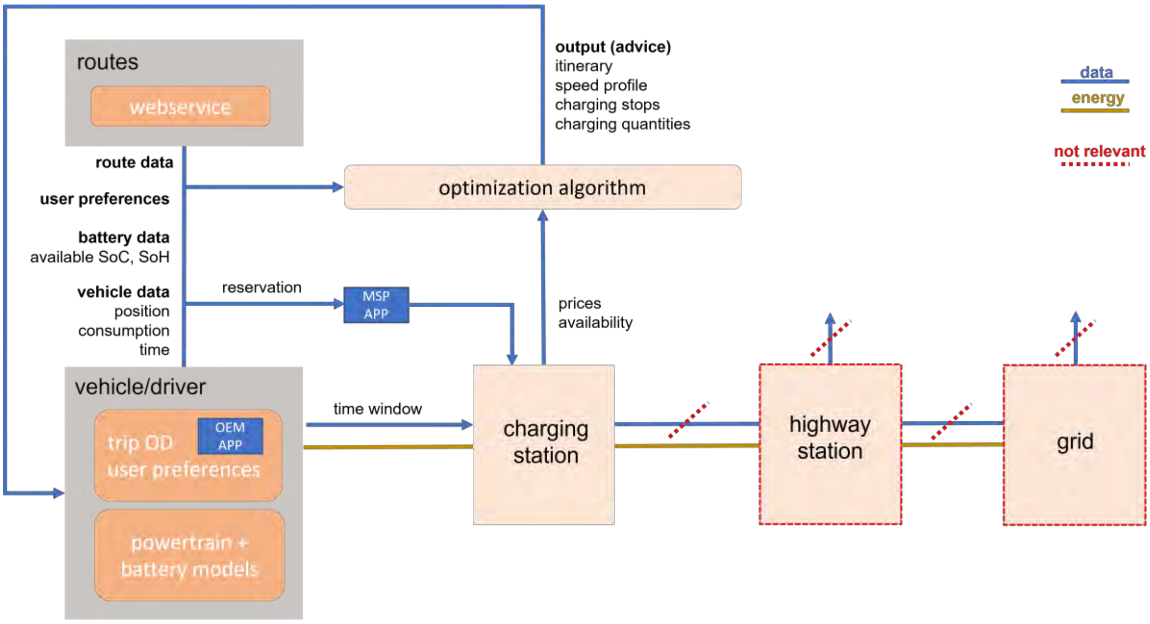

Figure 1 Utilization of the digital twin for the highway charging, from the driver's perspective.

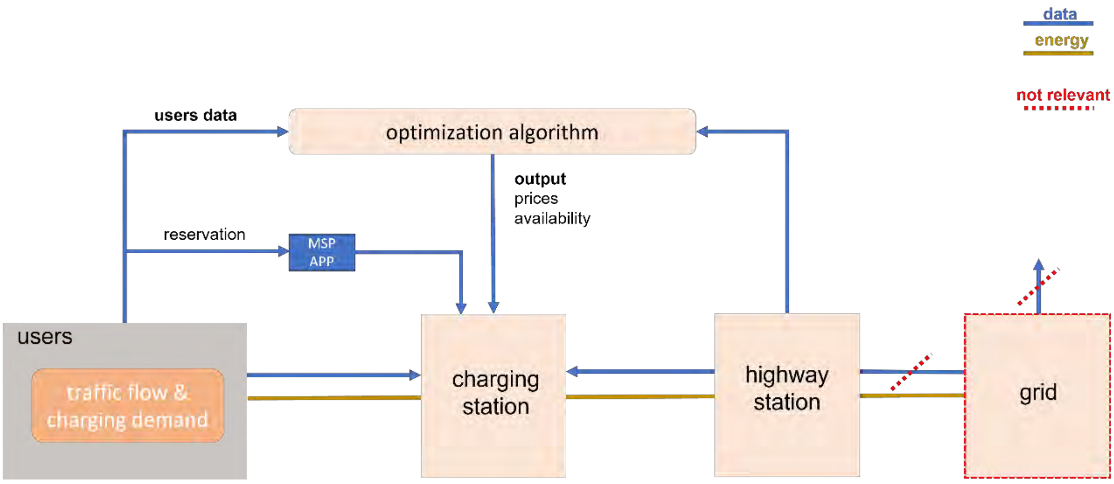

Figure 2 Utilization of the digital twin for the highway charging from the charging station's perspective.

The definition of the scenario will require the following specifications:

- Network infrastructure
  - Identification of existing stations in a well-defined area (e.g., continental Europe)
  - Parking capacity of each station, including information about how many slow (park overnight) and fast (charge & go) charging points
  - V2G availability
  - Location of PV plants

- PV plants
  - Installed capacity
  - Estimate of the power generated for different hours/days of the week
  - Local power consumption of the station (beyond EV charging)
- Vehicles (including heavy-duty vehicles)
  - Characteristics (including powertrain)
  - Battery autonomy/capacity/degradation
  - Battery charging profiles
- Grid
  - Day-ahead energy pricing
- User/Fleet behaviour (charging station perspective)
  - Origins/Destinations
  - Timetable (departure/arrival, dwell times)
  - Number of vehicles
  - Charging demand
- Charging point operators behaviour (driver perspective)
  - Charging availability
  - Prices

5.3. Parking area

For parking area three scenarios will be addressed: university campus, industry site including two separate cases: FEV use case and Neuman use case, and Company vehicle fleets including heavy-duty vehicles equipped with large batteries.

		Parking area		
		University campus	**Industry site**	**Company vehicle fleets**
Charging topology	**Mandatory**	AC	AC	AC, DC
	Optional	DC	DC	
Charging speed level (based on CHARIN)	**Mandatory**	Low power charging (LPC) Normal DC charging (DC)	Low power charging (LPC) Normal DC charging (DC) Fast charging (FC) High power charging (HPC)	Low power charging (LPC) Normal DC charging (DC) Fast charging (FC) High power charging (HPC)
	Optional	Fast charging (FC)		
Charging technology	**Mandatory**	V1G, V2B, V2G(AC/DC)	V1G, V2B	V1G, V2B, V2G(AC/DC)
	Optional		V2G(AC/DC)	
Charging type	**Mandatory**	Conductive charging	Conductive charging	Conductive charging
	Optional	Inductive charging		Inductive charging
Local generation/ consumption/ storage	**Mandatory**	Photovoltaic, Stationary battery	Photovoltaic, Power to heat, Water power plant	Photovoltaic,

	Optional	Power to heat		Stationary battery
User behaviour	Mandatory	Individual	Fleet based	Fleet based
	Optional			Fleet timetable
Expected parking time	Average	2-10 hours	8 hours	8 hours
	Variance	normal	small	small
	Night-time			
	Daytime			
Vehicle type	Mandatory	Passenger car	Passenger car	Passenger car
	Optional			Light duty
Revenue/ cost saving opportunities	Mandatory		Peak shaving, Self-consumption increase	Self-consumption increase
	Optional	Frequency balancing, Peak shaving, Redispatch, Self-consumption increase	Redispatch	Frequency balancing, Peak shaving, Reward for providing battery
Number of vehicles	Mandatory	20-100	Over 100	Over 100
	Optional		20-100	
Grid topologies charging point utilities connected to	Mandatory	AC (OCB) unidirectional, DC (micro-grid) unidirectional, DC (micro-grid) bidirectional	AC (OCB) unidirectional, DC (micro-grid) unidirectional, DC (micro-grid) bidirectional	AC (OCB) unidirectional, DC (micro-grid) unidirectional, DC (micro-grid) bidirectional
	Optional			

Table 5: Parking area

5.3.1. University Campus

The University campus case study is considered because it is part of the real-world demonstration action in XL-Connect and, from a general point of view, it is also representative of a wide class of locations having similar conditions, such as schools, large public or private offices, areas with daily commuting of a large amount of people.

From a general point of view, the University scenario comprehends interesting conditions which suggest their suitability for the implementation of smart or even bidirectional charging logic, due to the variability of the loads. Such conditions are expected to be comparable between different Countries, due to the similarities of university communities worldwide.

In this context, the example will contemplate a campus mainly addicted to office, classroom and administration activities, while other types of campus (e.g., with a predominance of student's apartments and/or heavy laboratories) will be considered later. A few known boundary conditions for typical University Campus therefore are:

- Strong variability expected between working day and weekend.
- Typical presence in the range of 8.00 AM – 7.00 PM hours (2)(Caruso et al., 2017)
    - Most users are present on the campus for a "long" period – 3 to 8 hours, typically, so that energy management opportunities arise.

    - A limited number of visitors (e.g., externals, suppliers etc.) is expected and in this case, it is possible that they present charging needs different from employees and students.
- Strong variability expected during the year, which again suggest to explore the possibilities for energy management optimization (3) (Kolokotsa et al., 2016). At least two conditions can be found:
    - During didactic periods (lectures, exams): the campus is at full operativity, all the employees and the students are commuting from and to the location. This condition is valid for approx. 9-10 Months per year.
    - During reading, holiday, interruption of didactic activities, the campus is mainly hosting employees while the presence of students is approx. 10-20% in comparison with most intense periods.

Amongst these typical characteristics which are expected to be comparable within many campuses, there are some relevant differences which may cause very different energy consumption profiles between sites. The identification of potential differences is necessary to focus the simulation on a specific case study. Variability opportunities are represented by:

- Presence of “heavy duty” laboratories: considering applied research needs, it is possible that certain laboratories will imply a considerable energy consumption, even if only concentrated on experiment period (e.g., testing of turbines, large machines, small-scale production etc.)
- Area in which the campus is inserted.
    - Public areas, with 24-hours open roads, or private house, not accessible during University closures.
    - Urban campus, which are enclosed in cities or even in the historical centre, and peri-urban campus, which are mainly connected through almost-rural roads and highways.
- Number of apartments available: if the campus comprehends apartments and other kind of services for the employees and students (restaurants, sporting areas, students’ accommodation etc.) then commuting will be limited and energy consumption of the whole district/campus is expected to be different in comparison with campus which do not comprehend this kind of services.

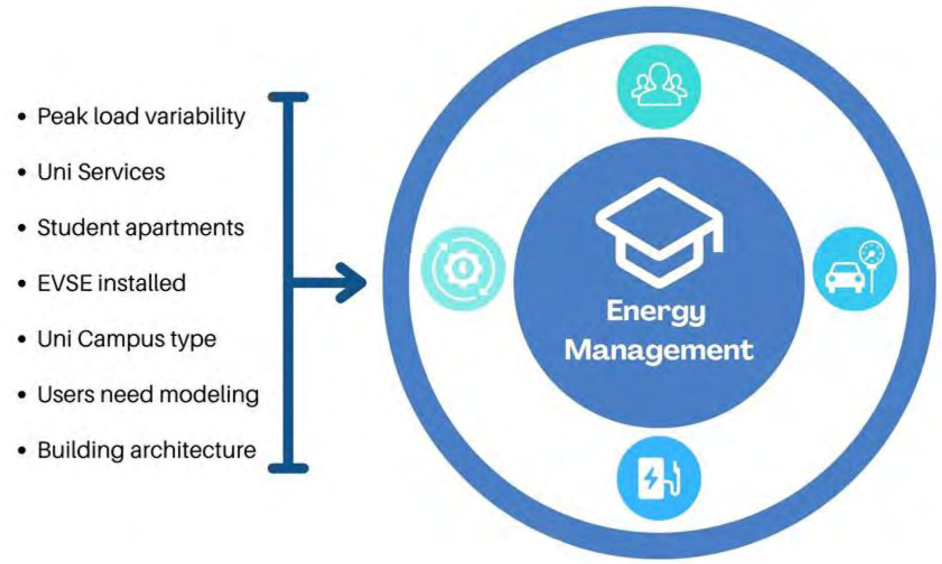

Figure 3 University Campus use case

Therefore, among all the variables that contribute to making university campuses the ideal case study is this one: a typical university campus includes a variety of buildings, parking lots, and services, see Figure 3. Potentially, such sites can be administrated by an energy and/or mobility manager, thus making it an example of “microgrid” or V2B application, especially if PV energy generation is present [(4)](Morales González et al., 2014).

Literature examples (5)(Wu et al., 2020) about University campus application frequently adopt Markov-chain, event based simulation, in order to deal with probabilistic assessments and distribution of data. For this reason, in XL-Connect a similar approach will also be adopted; considering the relevant amount of data needed for such assessment, the input information will come from a blend of primary data and proper hypotheses formulated on different scenarios (6)(Fotouhi et al., 2019).

Data needed will comprehend, mainly:

- Parking lot information
  - Weekday and weekend day volume;
  - arrival/departure time;
  - expected amount of energy needed for departure (e.g., kWh);
  - expected time for parking lot release (e.g., inactive occupation of parking lot);
- Building information
  - expected energy consumption;
  - expected energy production (if any) (e.g., PV, power to heat);
  - expected energy storage (if any) (es. BESS);
- User needs
  - slow-commuting users, with energy management capabilities;
  - fast-commuting users, not available for energy management capabilities;
  - priority needs: which services need to be exploited in a short time;

- Infrastructure
    - installed charging point type and technology;
    - energy storage capabilities (if any);
    - local energy cost and dispatching conditions;

5.3.2. Industrial Site

In the Industrial parking space, the number of charging stations at a parking lot is defined. The occupancy of the charging stations is based on the working shifts of the industrial side.

In this scenario the site is equipped with a PV plant which can be used for direct consumption or for charging the vehicles. The surplus energy can be fed back into the grid. Furthermore, industrial sites have a high energy consumption, with power peaks which can be reduced by peak shaving. Also sector coupling concepts as power to heat can be investigated.

Here the main target will be to study arbitrage offers by charging during low-price hours, utilization of locally generated energy (PV, wind- and Water power plant) and peak shaving.

The definition of the scenario will need to consider the following specifications:

- Power installed on the industrial site
    - Power requirements (fixed charge or daily profile)
- Characteristics and needs of each vehicle
    - Battery capacity
    - Charging/supply curves (provided by CIRCONTROL/IDIADA)
        - AC / DC
    - Daily autonomy needs
    - Charging periods
- Characteristics of the stationary batteries
    - Battery capacity
    - Charging/supply characteristics
- Existence of PV plant
    - Total power installed
    - Power generation curves (profiles for each day)
- Existence of shared charging points
    - Number of charging points
    - Characteristics (only from home surplus or also from grid)

Industrial site scenario can be further separated to FEV industrial site and Neuman use case, which will be described in the following section:

<u>FEV industrial site (lead by FEV):</u>

The Aachen use case of FEV Europe GmbH was considered as part of the real-world demonstration of the project and represents other similar industrial use cases with increasing power demand of EV charging by clean energy sources with important impact on the sustainability and the carbon emissions of the smart grid. FEV offers 26 unidirectional charging stations for their employees on the onsite parking place. The charging stations are operating with a maximum power of 22kW AC. At the moment, the charging is uncontrolled Smart charging of EV can increase the synergy between photovoltaics (PV), and electricity usage, resulting in technological and economic advantages.

In order to achieve FEV's targets to reduce the energy taken from the grid by increasing the self-consumption and provide peak shaving, scalable smart charging algorithms will be developed, which will provide a centralized control. Reliable charging strategies will be designed.

In the scenario FEV wants to analyse the impact of bidirectional smart charging which also takes PV energy, a heat pump and a stationary battery into account. The PV-plant will be installed on the roof of the building at the industrial site. The interaction between gird, PV and EVs will be explored based on the user behaviour. Also, the building consumption as well as the energy required to operate the test benches will be considered in this representative case study of sector coupling. The following figure shows the components that are managed by the charging management system.

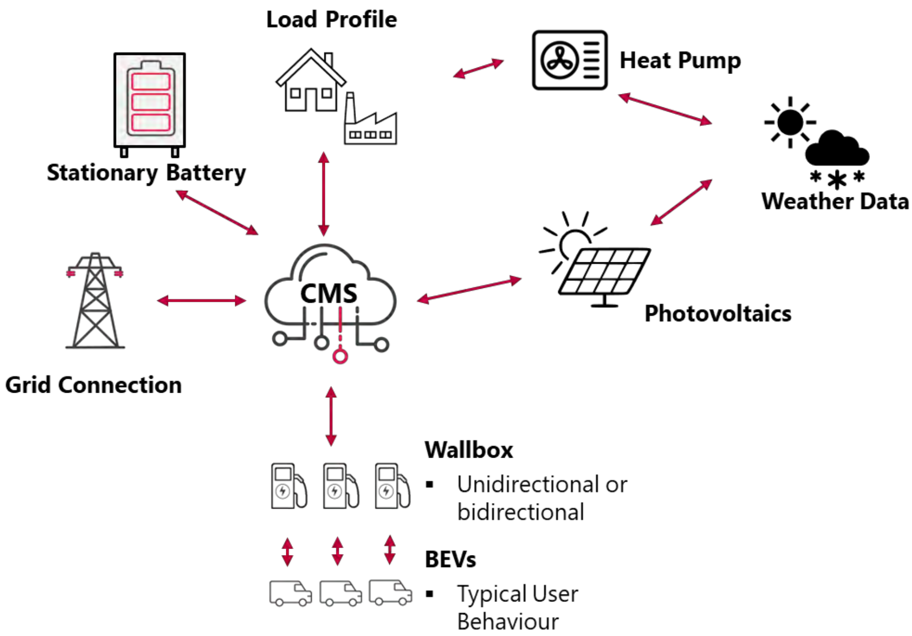

Figure 4: Overview of the charging management system for the FEV industrial case

For the above targets Matlab/Simulink models will be developed to analyse the impact of bidirectional charging stations and a higher EV penetration using historical and public data e.g the parking time of the EVs and the required energy by the building and the EVs. Also, the benefits of V2G will be investigated considering various constraints like grid connection or charging power and user demands.

To sum up, the main contributions of the industrial scenario are:

- Consider multiple load profiles for the charging management
- Satisfy EV user demands while providing V2G service

- Develop EV smart charging schemes and assess their impacts in improving the synergy between PV and EVs at industrial site.

Neuman use case (led by Virtual Vehicle):

The company Neuman Aluminium, located in Austria, produces aluminum parts and has an overall energy demand of ~111,000 MWh/year. Neuman Aluminium has employed three small hydroelectric power plants with an overall size of 0.95 MWp and a PV system of size 1.1 MWp. Currently, these power plants produce ~4,100 MWh/year. For the virtual use case an expansion of the renewable energy production is assumed where additional PV systems (up to 4 MWp) and two wind turbines (overall 10 MWp) will be employed. Therefore, we analyze three scenarios that present different states of the renewable expansion at Neuman Aluminium. A schematic overview of the Neuman Aluminium use case is shown by Table 6.

	Status Quo	Scenario 1	Scenario 2	Scenario 3
Hydroelectric power plant	0.95 MWp	0.95 MWp	0.95 MWp	0.95 MWp
Photovoltaic system	1.1 MWp	1.3 MWp	4 MWp	4 MWp
Wind power station	-	-	-	10 MWp

Table 6: Neumann power overview

To analyze these scenarios, a four-step approach is applied.

1) The energy production and consumption data of Neuman Aluminium will be assessed.
2) The periods and amount of surplus of energy production for the different scenarios will be determined.
3) A vehicle-to-building concept for a parking area with 300 vehicles for self-consumption optimization or peak shaving is discussed and conceptualized. The parking situation at Neuman Aluminium will be analysed in order to determine the available energy storage capacity during the day, considering the different work shifts and fluctuations in the state of charge of the vehicles. Here, it is also important to show under which conditions employees would agree to (temporarily) discharge their vehicles. This is investigated by using a survey data that were collected during the project and contain answers from all over Europe.
4) A battery storage is simulated as an alternative storage solution to the vehicle-to-building concept.

For the analysis, the software tools RStudio and Matlab are used for data analysis and electric modelling.

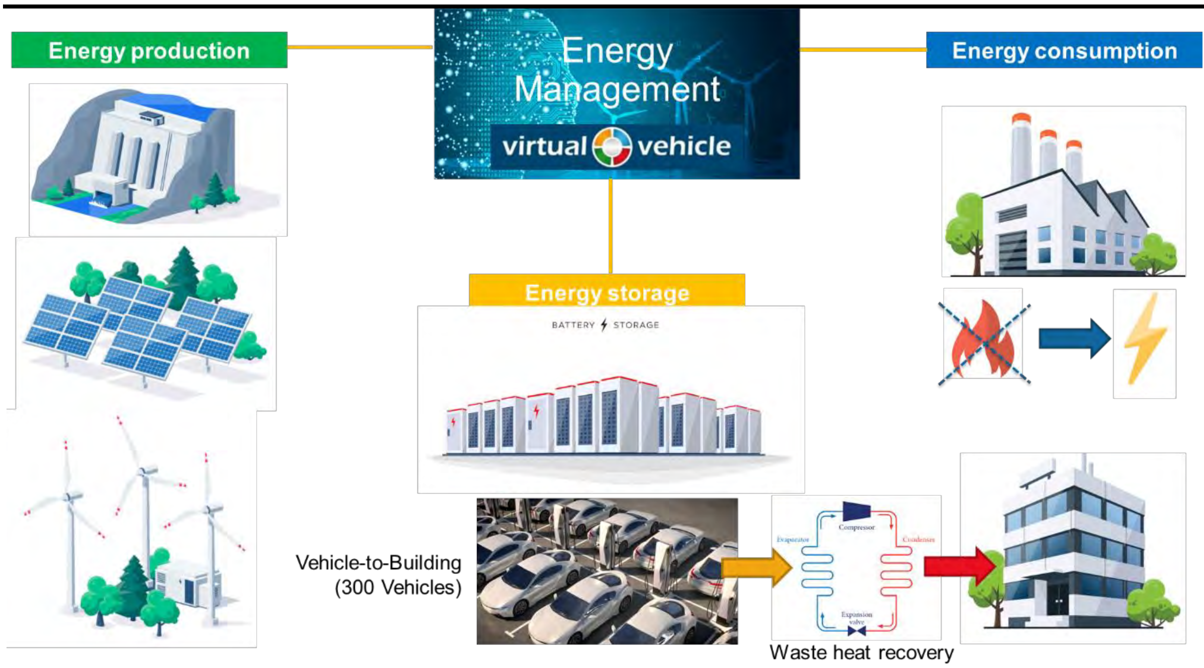

Figure 5: Schematic of the Neuman use case

With the help of the simulation setup the different scenarios will be investigated and the following research questions shall be clarified:

1) From which energy surplus on does a battery storage pay off and how large does it have to be?
2) From what range of price volatility (spot market) does a battery storage pay off and how large does it have to be?
3) Can a parking lot with 300 cars (electric vehicles) and a vehicle-to-building concept be an alternative solution to a battery storage?
4) What is the optimal solution for future investments (further increase of PV production or battery storage)?
5) Is an integration of an emergency power solution feasible (island-capable battery solution with base load 1 MW)?

5.3.3. Company vehicle fleets

The company vehicle fleets case study is considered because it is part of the real-world demonstration action in XL-Connect and, from a general point of view, it is also representative of a wide class of locations having similar conditions.

Company vehicle fleets scenario comprehends interesting conditions which suggest their suitability for the implementation of smart or even bidirectional charging logic, due to the variability of the loads and the availability of many storage batteries located into EVs. Furthermore, the company vehicle fleets scenario comprehend heavy duty vehicles that are equipped with high sized battery storages; they could be used for additional energy source as to storage surplus energy or to feeding back it to the grid in order to substain it in case of high-energy demand periods. Such conditions are expected to be comparable between different countries, due to the similarities of company vehicle fleets worldwide.

In this context, the example will contemplate a parking near the factory equipped with and ESS which is linked to the main grid and PV power plant generation that allowed isolated mode of the microgrid.

A few known boundary conditions for typical company vehicle fleets therefore are:

- Strong variability expected between working and weekend days.
- Typical presence in the range of 7.00 AM – 6.00 PM hours
    - Most vehicles are present on the parking for a “long” period – 6 to 8 hours, typically, so that energy management using V2G opportunities arise.
    - Number of vehicles that need to be recharged as they will need to be used on the current day or the next.
- Little variability expected during the year, which otherwise suggest to explore the possibilities for energy management optimization, in particular between the vehicles that will be used in the current day and the others that don’t need energy immediately. At least two conditions can be found:
    - During main part of the year: the parking is at full operativity, all the employees and the vehicles are operative commuting from and to the location. This condition is verified approximately for 10-11 Months per year.
    - During holiday periods (August, December…) the parking is mainly hosting fewer employees;10-20% in comparison with most intense periods.

Amongst these typical characteristics, which are expected to be comparable within many vehicles fleet, there aren’t some relevant differences which couldn’t cause very different energy consumption profiles between sites. Otherwise, the identification of potential differences is necessary to focus the simulation on a specific case study; for example, one important variable is the number of the vehicles in the fleet and the path that they’ll travel that lead to different energy consumption, but the typical characteristics will be unchanged.

In the company vehicle fleets scenario the number of charging stations at a parking lot is defined and the occupancy of the charging stations is based on the working shifts of the factory.

In this scenario the site is equipped with an PV plant which can be used for direct consumption or for charging the vehicles and it’s also expected an ESS which can be used for energy storage; it allows to switch the (industrial) plant from the external AC grid to a locally supplied AC grid, isolate the microgrid from the main grid realising the “island mode operation”. On the other hand ESS will ensure grid support functions as to reduce the grid load, like peak shaving or load levelling, during high energy consumption periods.

The surplus energy given by PV plants can be feed back into the grid and it can use to charge internal battery of ESS during low-demand hours. Furthermore, the industry side have a high energy consumption, with power peaks, which can be reduced by peak shaving. It's also possible to implement load levelling that allowed to flat the load curve during the day; that allowed to reduce main grid load during peak hours, and the main grid will be less stressed. Both strategies are based on the energy storage into battery's ESS during low-price hours and, in case of high energy consumption during the high-price hours, the energy stored will be redispatched to avoid grid overload or economical revenue. That system allowed to size the PV solar plant related to ESS storage size, that will ensure a certain time of stand-alone mode operation, and the bidirectional flow of energy through micro and main grid allows to feed surplus energy at other chargers located externally respect to the micro grid.

Here the main target will be to realise a "stand-alone" microgrid which'll be able to operate disconnected from the main grid and ensure the recharge of the vehicle fleet; it'll be possible due to PV plants, that provide energy directly used for the EVs charge or for recharge the ESS, and in case of relevant load ESS will provide the remaining amount of energy.

The V2G chargers, that'll be installed in the microgrid, contributes to the grid stability feeding energy during high-demand hours to reduce the amount of energy given from the grid and reducing main grid energy demand. Another important function of V2G chargers is that they must be able to manage the transition during micro grid re-connection, aligning frequency and voltage to main grid's values.

The definition of the scenario will need to consider the following specifications:

- Network infrastructure
    - Parking capacity, including information about how many slow (park overnight) and fast (charge & go) charging points.
    - V2G availability.
    - Location of PV plants.
- Power installed on the industrial site.
    - Power requirements (fixed charge or daily profile)
- Characteristics and needs of each vehicle
    - Battery capacity/autonomy/degradation
    - Charging/supply curves (battery charging profiles)
        - AC / DC
    - Daily autonomy needs
    - Charging periods
- Characteristics of the stationary batteries ESS
    - Battery capacity
    - Charging/supply characteristics
- Existence of PV plant
    - Total power installed
    - Estimate of the power generated for different hours/days of the week
    - Local power consumption of the station (beyond EV charging)
- Existence of shared charging points
    - Number of charging points
    - Characteristics (only from home surplus or also from grid)

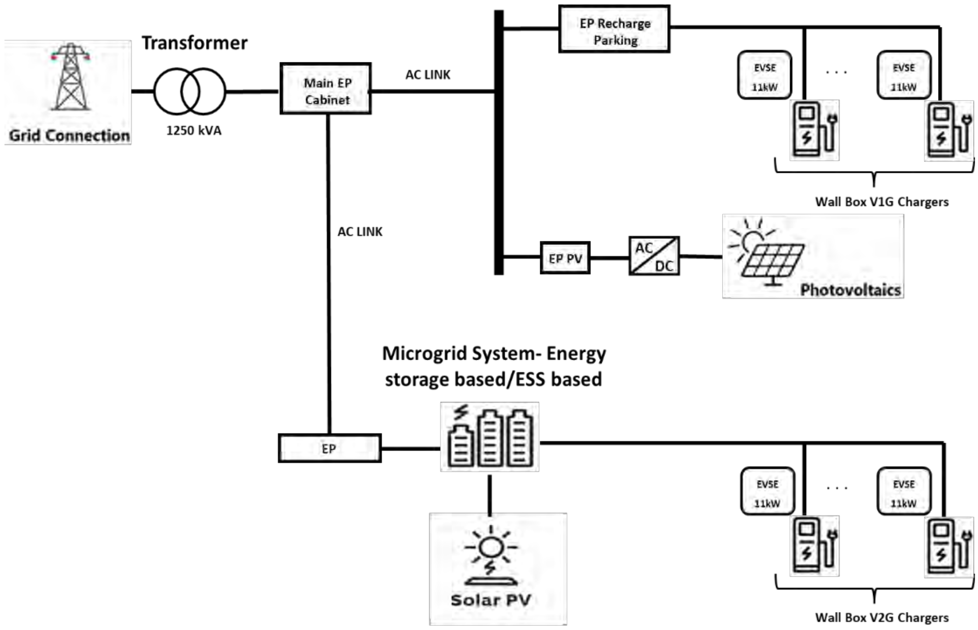

Figure 6: Scheme of AC microgrid with company vehicle fleets

6. Digital twin architecture diagram

The architecture diagram in Figure 7 shows the different actors and platforms as well their possible interactions. For each of the following use cases parts of this diagram will be used.

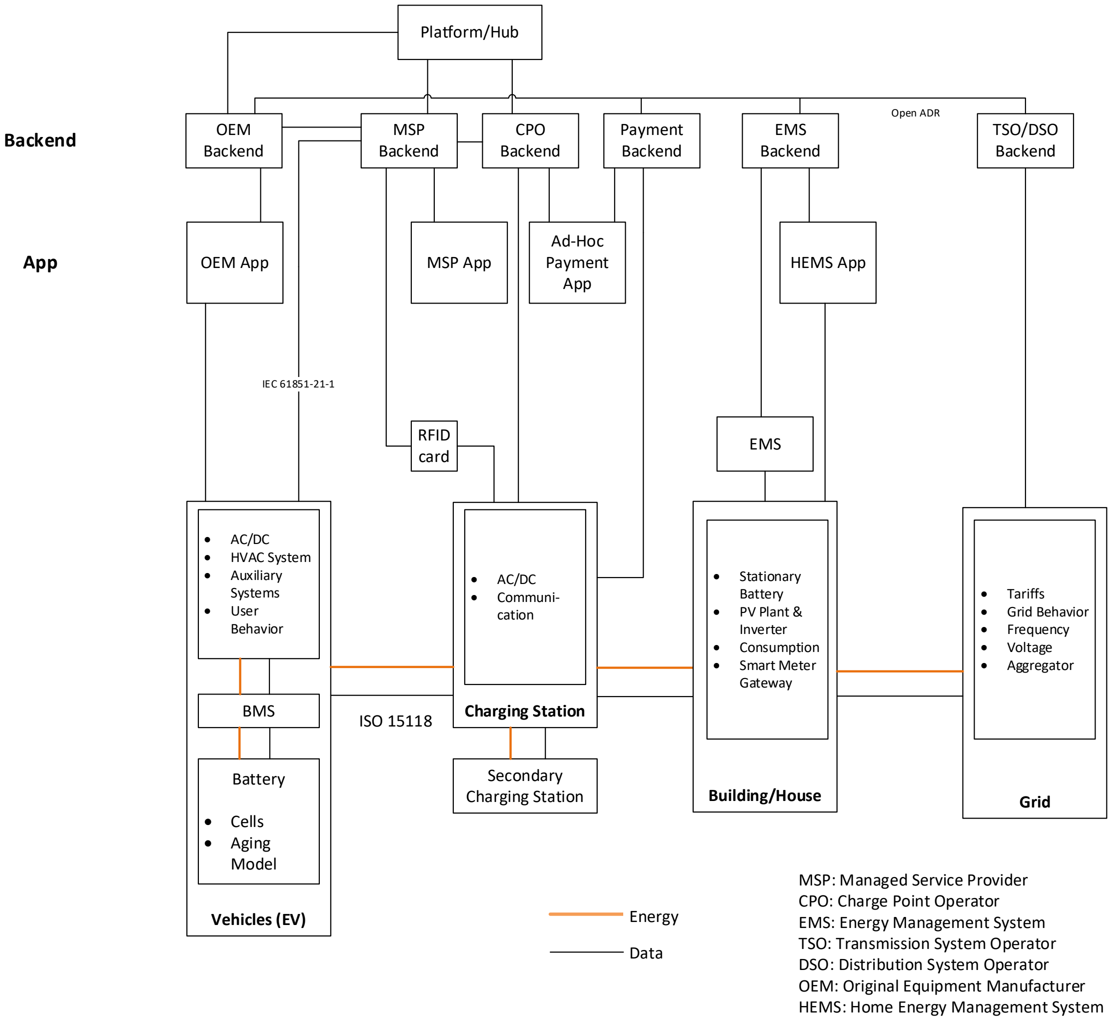

Figure 7: General digital twin architecture.(8)(9)

6.1. Home charging

For home charging you need information about the local consumption and production and a charging management system which communicates to the vehicle via the ISO 15118.

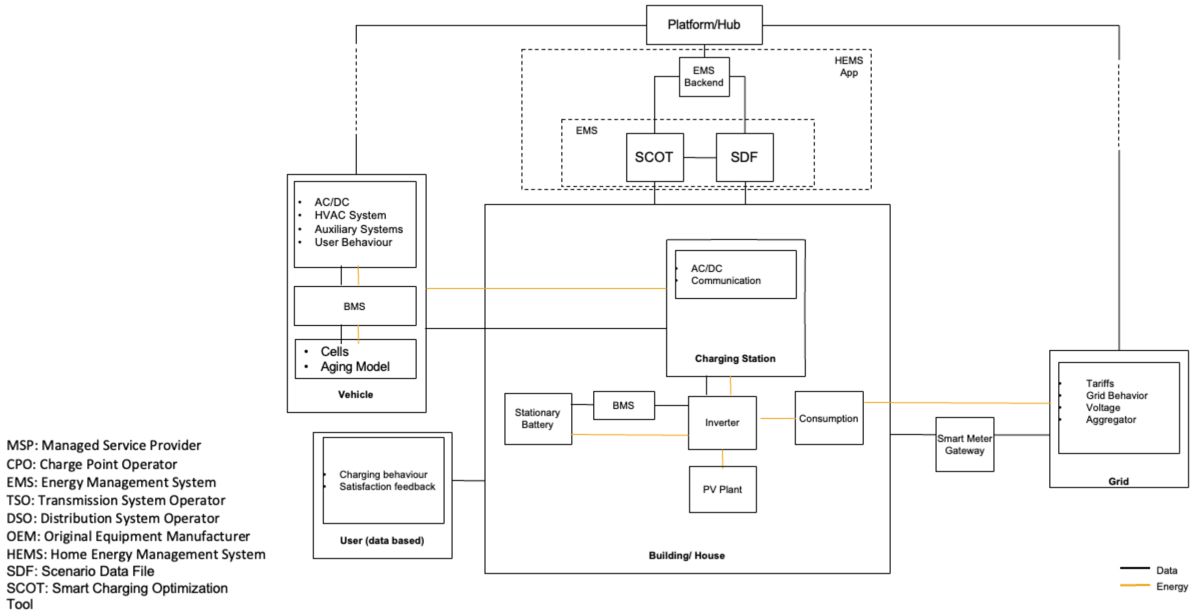

Figure 8: Architecture of Home Charging(8)

6.2. Street parking

For street parking, a public charging aggregator need to communicate with the backend to transfer payment information, charging request. User requirement and feedbackswill be given by the user model.

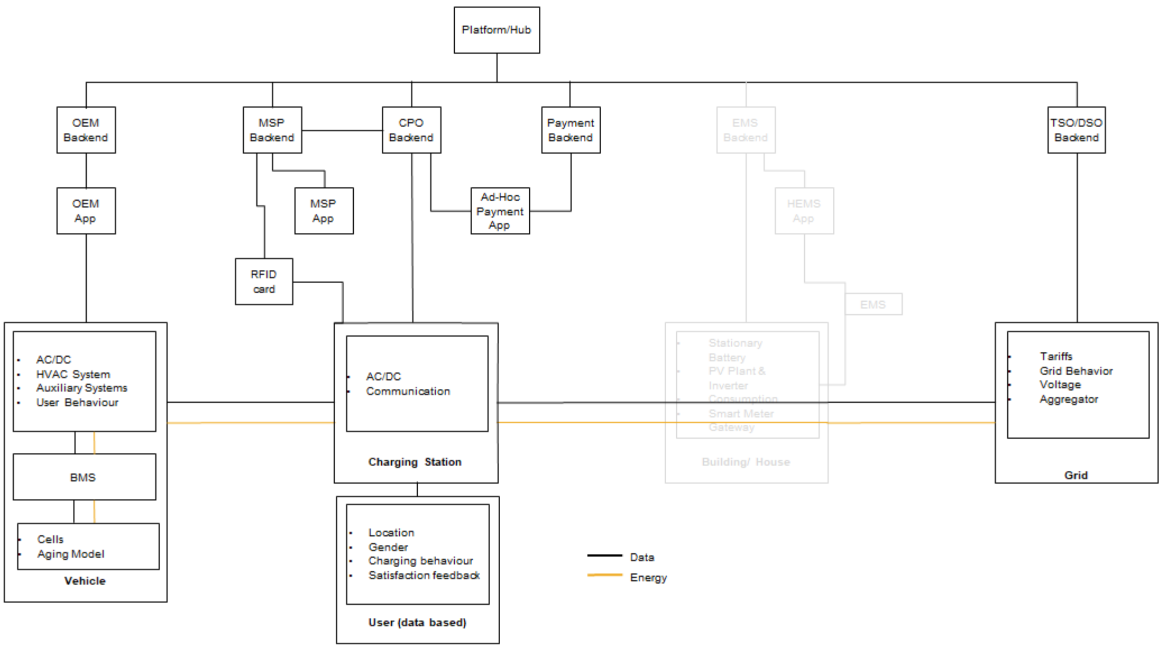

Figure 9: Architecture of Street Parking

6.3. Parking area

For a parking area there needs to be an information exchange between the charging point and the grid. Also, communication to the backend is necessary to exchange payment information.

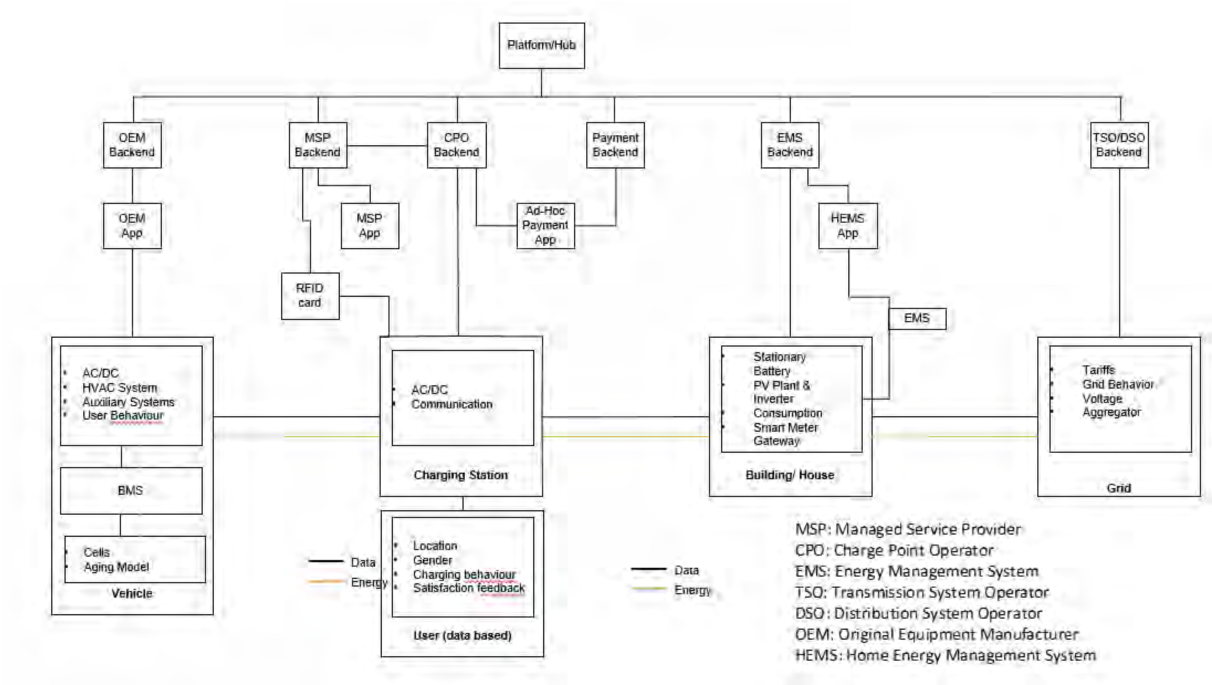

Figure 10: Architecture of Industrial Site.

7. Regulations

The regulations can differ for each country and selected scenario. Because of that the table below summarizes the regulations of Belgium, Germany, Italy and Portugal, which need to be referred to when setting up the scenario.

7.1. Summary of regulations of Belgium, Germany, Italy and Portugal

Name	Description	Applies in Country	Relevant aspects
Flemish Decree on Exemption	The operator of the charging point has the option to build a private distribution network, manage and maintain it without any public service obligations towards the customers.	Belgium	In this case, the operator does not require an additional supply license. However, if the private network extends into the public domain, the operator must obtain permission from the DSO.
Walloon Electricity Decree	An exemption from a supply license is granted for the supply of electricity to users of public charging points, provided that the connection of the charging point itself is covered by a supply license.	Belgium	Classifies charging via charging points as a service rather than a direct supply of electricity. By doing so, charging stations are considered exempt from the ban on private distribution grids and therefore do not require a supply license.
CWaPE advice of January 29, 2021	A challenge on the Walloon Decree arises when the operator of the charging point is also the supplier of self-generated electricity. The Walloon energy regulator proposed that operators in this scenario should also be explicitly exempted	Belgium	

	from the obligation to hold a supply license.		
Feed in Tariff	The money you get if you feed in surplus PV-Energy into the grid	Germany	Current price is ~7c/kWh
Double-Taxation	You must pay taxes for purchasing and selling electric energy	Germany	Results in lower profits
Grid-serving use in accordance with § 14a EnGW	By participating in Section 14a EnWG, operators of control systems are to receive relief via the grid usage fees.	Germany	The subscriber can choose between two modules for the grid fee reduction. Module 1 provides for an annual grid fee reduction (approx. €110-190/a) and a so-called grid operator-specific stability premium. Alternatively, the subscriber can choose Module 2, which provides for a reduction in the energy price (ct/kWh). This is set at 60% nationwide for consumption without load profile measurement by controllable consumption devices.
Concession fees - § 48 EnWG	As defined in Section 48 EnWG, the concession fee (KA) is payable to energy supply companies, which are obliged to pay a KA to municipalities for the use of public infrastructure for the laying and operation of	Germany	The concession fee is part of the electricity price that the consumer, and therefore also a charging point operator (e.g. employer or owner of a single-family home), has to pay.

	lines for the direct supply of end consumers.		
Exemption from electricity Tax StromStG / StromStV	Electricity from a renewable energy system up to 2 MW that is withdrawn by the operator of the system for self-consumption (Section 9 (1) no. 1 StromStG) or for electricity generation (Section 9 (1) no. 2 StromStG) is exempt from electricity tax.	Germany	
Tax exemption for charging (§3 Nr.46 German Income Tax Act (EstG))	Tax exemption (no non-cash benefit) for charging electricity obtained from the employer or from a company car at a home charging point.	Germany	provides a privilege in favor of electromobility, which is intended as an incentive for the market ramp-up phase.
Metering Point Operation Act (MsbG)	In order to enable participation in the German energy market, quarter-hourly billing by means of a smart metering system in accordance with TEF7 is required as meter reading	Germany	Governs installation and operation of smart meters and how measured values are to be communicated within the energy sector. It contains sector-specific data protection rules for the energy sector including electric mobility
ARERA Resolution 352/2021/R/EEL	Procurement and remuneration schemes for local flexibility services.	Italy	Ensure technological neutrality
ARERA Resolution 541/2020/R/EEL	Facilitate the EVs charging at private charging station at night and during holydays.	Italy	Additional availability of up to 6 kW of capacity (from their current 2-4.5 kW)

ARERA Resolution ARG/elt 242/10	Volumetric network tariff (€/kWh) to support the installation of public charging points.	Italy	This tariff was confirmed until the 31st of December 2023
ERSE Regulation on Electric Mobility (854/2019)	Defines rules for the relationship between players in the electric mobility sector, for measuring, reading, and providing charging and consumption data, for regulated tariffs and for the provisioning of information.	Portugal	DSOs are responsible for supplying, installing, maintaining, and reading measurement equipment at the border with the electricity sector and for providing consumption data.
ERSE Regulation on Electric Energy Self Consumption (815/2023)	Regulates the integration of storage devices in self-consumption systems. It applies on the assumption of autonomous connection of devices to the network and is common to static storage devices and bidirectional charging points for EVs.	Portugal	Refers to pilot projects the compatibility between the sharing of energy in self-consumption and its use for charging EVs, in the event that the respective charging points are integrated in the electric mobility network.

Table 7: Regulations of Belgium, Germany, Italy and Portugal

8. Description of Submodels

After the scenario is defined the required submodels should be named and described. The following aspects of information about the model should be defined in detail:

- Does the component in the system architecture needs subcomponents in the simulation (e.g. Electric vehicle has: Charge controller, Battery, BMS…)
- Define the exact models that are needed for the scenario groups with detailed describtion
- Responsible partner

In the following Table 7 all the models and sub-components are listed with their responsible partners.

Models	Components	Sub- Components	Responsible partners
EV model	Battery	BMS	RIC
		Cells	AIT
		Aging model	AIT, ABEE, EUT
	On-board charger	OBC	RIC
	HVAC System		AIT and ABEE
	Communication (Vehicle to CS)		FEV
Charging point model	PEs (Charging station)		FEV, UNIFI, ABB
	Communication (CS to Vehicle)		FEV
	Stationary battery	BMS	RIC
		Cells	AIT
		Aging model	AIT, ABEE, EUT
Building/House	Load profile		FEV, VIV
	RES	PV	FEV
Grid	Grid Usage Region / Area	Connection points and their energy production /	MYC

		consumption behaviour	
		Communication Chargers and Grid	EUT
User behaviour	User behaviour	Sperate scenarios relative behaviours models	IFPEN, VIV, RWTH, RIC
	Fleet operators' behaviour		IFPEN, VIV (interview)

Table 7: Sub-model responsibility overview

EV model

For the investigation of the defined scenarios a comprehensive EV model will be setup consisting of several subcomponent models to simulate the EV behaviour and the occurring effects for smart charging. Figure 11 shows the basic structure of an EV model build up in the simulation environment Dymola. The physics orientated EV model considers all driving resistances of the vehicle, an electro-thermal battery model as well as an Heating, Ventilation and Air Conditioning (HVAC) system model (cf. Figure 12) enabling preheating and the investigation of various driving cycles under different ambient temperature conditions. The several subcomponent models are interconnected via mechanical and electrical connectors and interfaces as well as a bus system.

This deliverable (D4.1) provides an overview of the subcomponent models to be used in the EV model. The detailed technical description occurs in D4.2 (for the subcomponent models) and in D4.3 (for the control strategies implemented).

Chapter 9 below deals with a description of the Dymola software used.

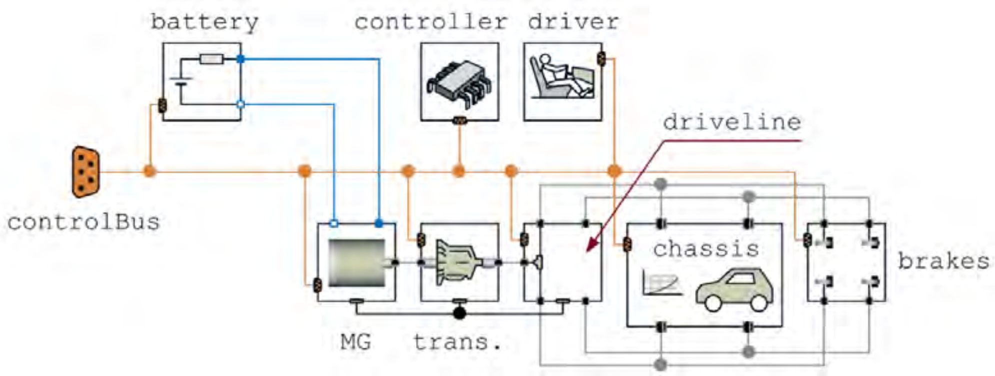

Figure 11: Principle of a 1D physics orientated EV model in Dymola

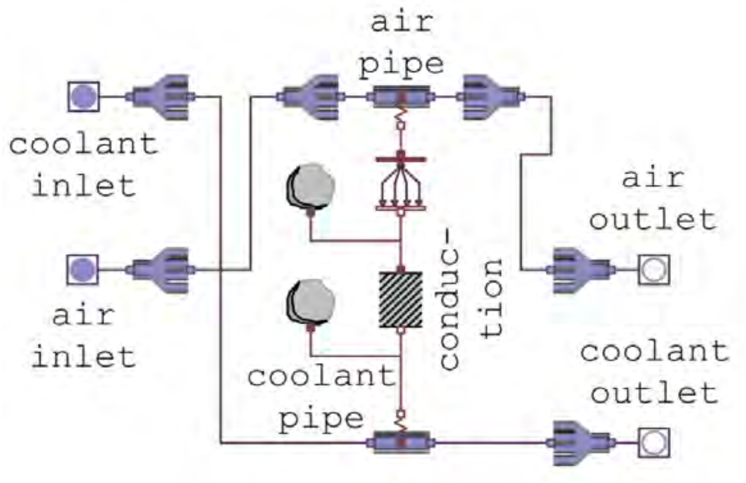

Figure 12: Partial (sub) model of an HVAC system in Dymola

Battery/cell model

The basic concept of the battery model which will be used is depicted in Figure 13. The model can be structured in three modules:

- Electric model (V),
- Thermal model (T),
- Parameter adaption block (P).

The electric model (V) is used to map the dynamic material characteristics from the battery to an electric equivalent circuit. Either single battery cells or entire battery stacks, consisting of a serial and parallel connection of single cells can be considered.

The thermal model (T) is used to consider thermal aspects during operation. The electric losses generate a heat flow to be processed in this model.

The parameter adaption block (P) calculates the electric, thermal and aging dependencies of the internal battery parameters. The values thus obtained will be forwarded for configuring the electric battery cell model.

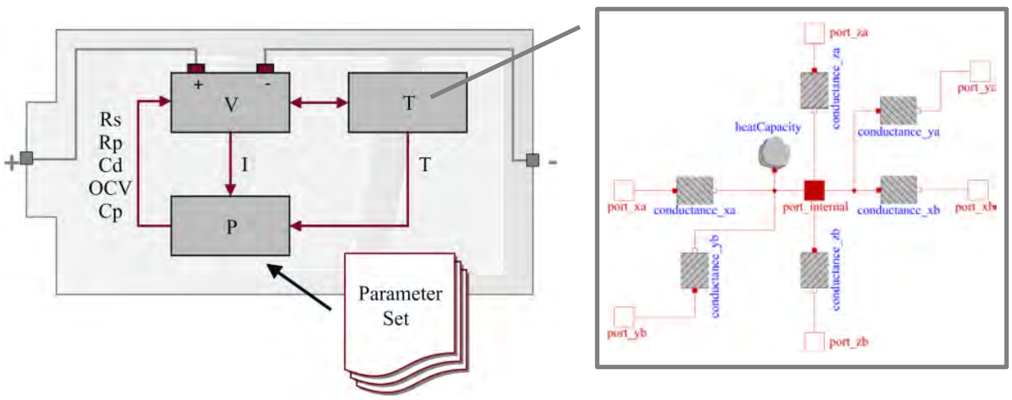

Figure 13: Basic modular concept of the battery model (left) and thermal model of a prismatic cell in Dymola (right)

The aging dependencies calculated in the parameter adaption block (P) are considering irreversible aging effects such as fade of the cell capacity and increase of the internal resistance (the underlying aging model considers two kinds of aging effects: cyclic aging and calendaric aging).

The detailed technical description of the concept of the 1D electro-thermal battery cell model in Dymola (including the aging and the thermal cell modelling, cf. Figure 13, right) occurs in D4.2.

BMS Model

The BMS model used in the digital twin will be based on that developed in the HIFI-ELEMENTS project. The model is based on Matlab Simulink. Its purpose is to manage the charging and discharging events accordingly and to provide the prediction of SOC and the true current within the pack. The inputs are the actual battery current and voltage and the ambient temperature. The outputs are the predicted SOC from the BMS (based on real BMS operation), the true current when adjusted for sensor bias, the calculated current limit of the battery pack and the measured pack power.

OBC Model

The OBC model used in the digital twin will be based on Simulink and will provide an estimation of the losses induced during the power conversion within the OBC. It will take inputs of Operating mode (charging/discharging), charge/generation current demand, battery voltage and AC grid RMS voltage. Using available test data within RIC, efficiency maps will be generated, allowing the model to output the charging/discharging losses and the AC grid / battery current draw.

Charging point model:

The MATLAB Simulink model of the charging point is simulating the communication and the energy transfer between the charging station and the EV. The communication is based on the ISO-15118-20 and transfers information about e.g. the power, current and voltage demand and request of the EV and the charging station. Also, the energy constraints are communicated.

The energy transfer is modelled in Simscape which takes the frequency, voltage and currents into account.

The charging point model is a main component in all the defined above scenarios.

Building/house model:

In the scope of XL connect project, the building or house models are divided into groups: Industrial buildings and Office buildings which will be explained by the following sections:

<u>Industrial building: VIV</u>

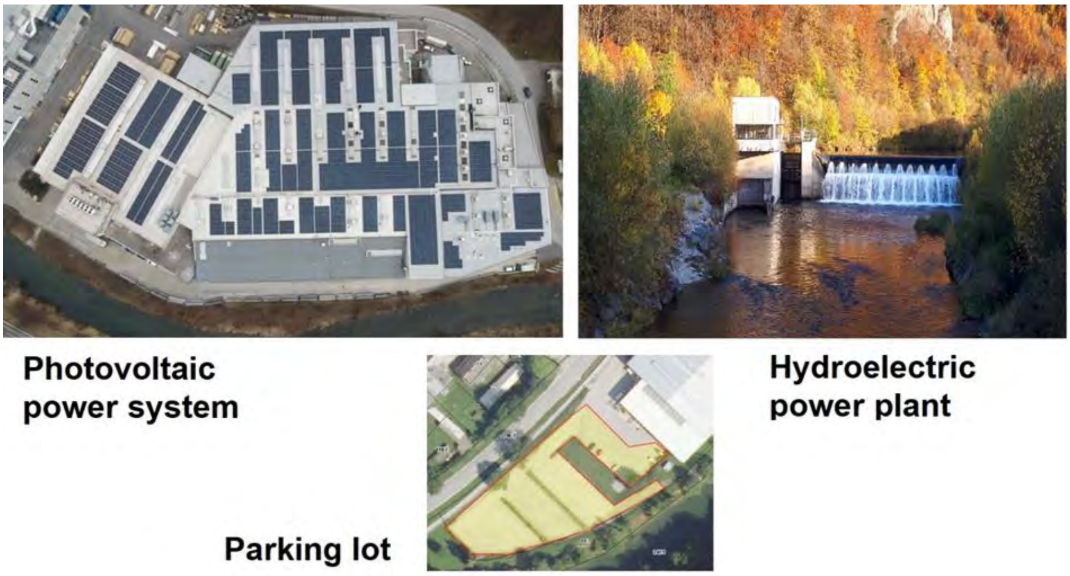

Figure 14 Neuman Aluminium - PV system, Hydro power plant and one of several parking lots

In this virtual use case, the expansion of renewable energy power plants (see Figure 14) in combination with different storage possibilities including a vehicle-to-building concept to optimize the on-site energy management are investigated. The goal is to analyse the overall energy consumption of the company as well as the impacts of increasing renewable energy sources and their associated financial benefits.

In general, the company Neuman Aluminium, located in Lower Austria, produces aluminium parts and has an overall yearly energy demand of ~110,000 MWh according to their energy intensive production processes. Overall, the energy demand in 2022/23 of this use case can be divided in ~36% electricity demand and ~64% natural gas demand. According to this high energy demand, Neuman has employed two hydroelectric power plants with an overall size of 0.95 MWp and a photovoltaic (PV) system of size 100 kWp which was expanded to 1.1 MWp in June 2023. Currently, these power plants 4,100 MWh/year. As the production covers only 7.7% to 10% of the needed energy, Neuman wants to increase their renewable energy production by employing additional PV systems (up to 4 MWp). In addition, the virtual use case has an additional scenario where two wind turbines (overall 10 MWp) are employed. Therefore, three future scenarios for the virtual use case are elaborated:

	Status Quo	Scenario 1	Scenario 2	Scenario 3

Hydroelectric power plant	0.95 MWp	0.95 MWp	0.95 MWp	0.95 MWp
Photovoltaic system	1.1 MWp	1.3 MWp	4 MWp	4 MWp
Wind power station	-	-	-	10 MWp

Table 8 Scenario Overview - Neuman Aluminium Use Case

Office building: FEV

The Office building model from FEV will be based on a load profile which was measured at the FEV building in the last year. It consists of the energy consumption of multiple office buildings including everyday office operations to more energy-intensive processes. The model also factors in energy consumption of a data center and energy required for heating.

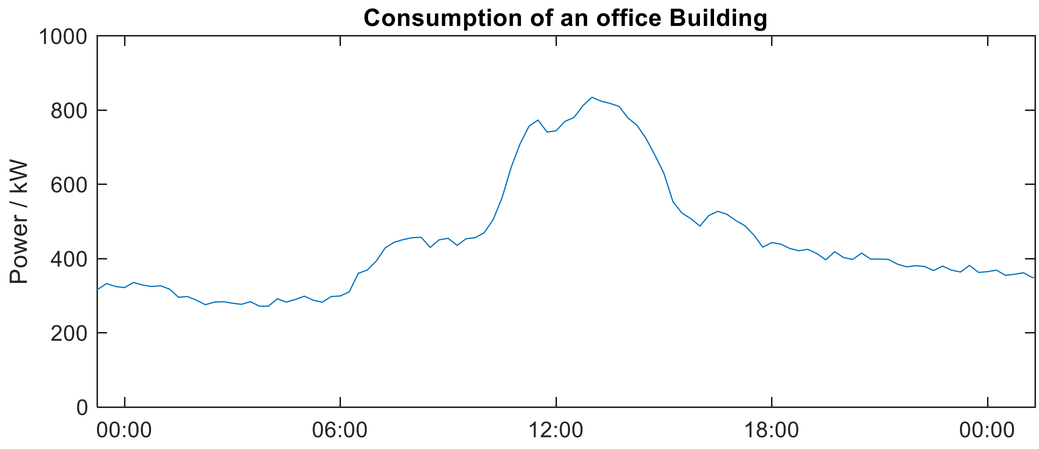

Figure 15: Consumption of an office Building

Figure 15 shows that the consumption of the office building is the highest during noon, when most employees are in the office. Outside the office hours the base load is recognisable. From 6:00 a.m. when the first employees arrive the load increases.

Grid model:

MYC has developed the Future Grid Usage (FUGU) modelling tool for generating and assessing possible scenarios of EV/DER evolution.

It is based on following data model:

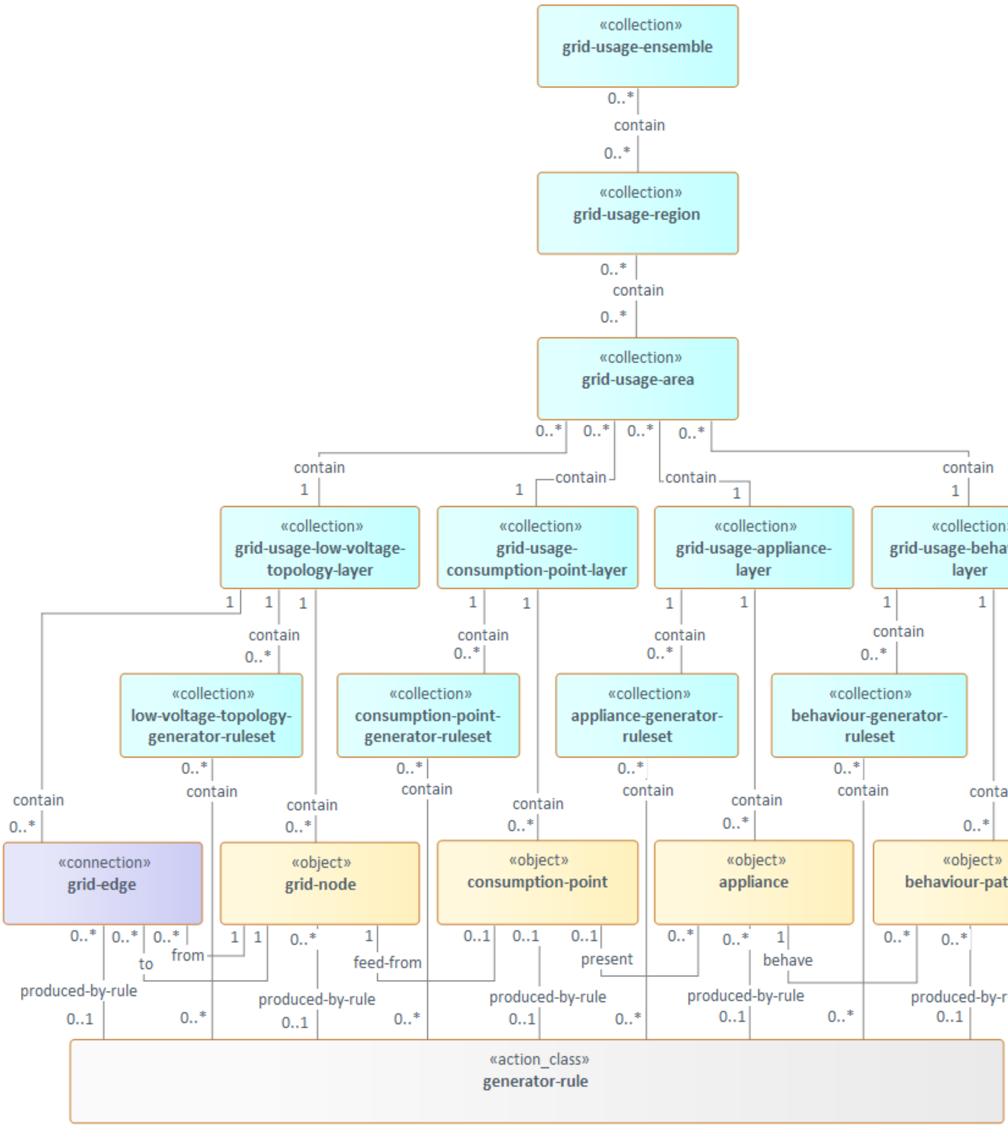

Figure 16: Grid model

Result of the modelling is **grid-usage-ensemble**. It is collection of possible alternative scenarios of future grid usage of given **grid-usage-region**. Alternative scenarios can differ by amount of EVs connected to grid, usage patterns of EV charging etc. Alternative scenarios can be compared to identify key parameters and inflection points in EV/DER penetration evolution. Each grid-usage-region is composed from one or more **grid-usage-areas.** Grid-usage-area is typically modelling area fed by one secondary substation and representing small village, village part or area in city. Each grid-usage-area is composed of four layers (see chapter 3) – **grid-usage-low-voltage-topology-layer**, **grid-usage-consumption-point-layer**, **grid-usage-appliance-layer**, **grid-usage-behaviour-layer**. Layers are consisting of respective interconnected objects **grid-node**, **grid-edge**, **consumption-point**, **appliance**, **behaviour pattern**. Those objects are generated and connected by rules (**generator-rule**). Each object is connected to rule by which it was generated. Rules are organized in respective rulesets: **low-voltage-generator-ruleset**, **consumption-point-generator-ruleset**, **appliance-ruleset**, **behaviour-generator-ruleset**.

FUGU model will allow to simulate EV and DER evolution on modelled consumption points / secondary substations / collection of interconnected secondary substations. Model is constructed using generating rulesets which are adding new types of consumption points, new appliances, and new appliance usage patterns. Rulesets are constructed to generate valid and realistic results.

Communication Chargers and Grid:

In the case of battery chargers, the communication is performed via Modbus protocol over RS485 or RS422, and Ethernet (depending on compatibility).

Open Charge Point Protocol (OCPP): is an application protocol, a language that allows communication between a compatible charging point and any control system. The goal of OCPP is to enable a truly interoperable electric vehicle charging infrastructure. Unlike proprietary communication protocols, OCPP is open and is not associated with any additional costs or licenses, making it easy to adopt. Adopted by many charge point providers and control system providers, OCPP compliance is becoming a "must have" standard.

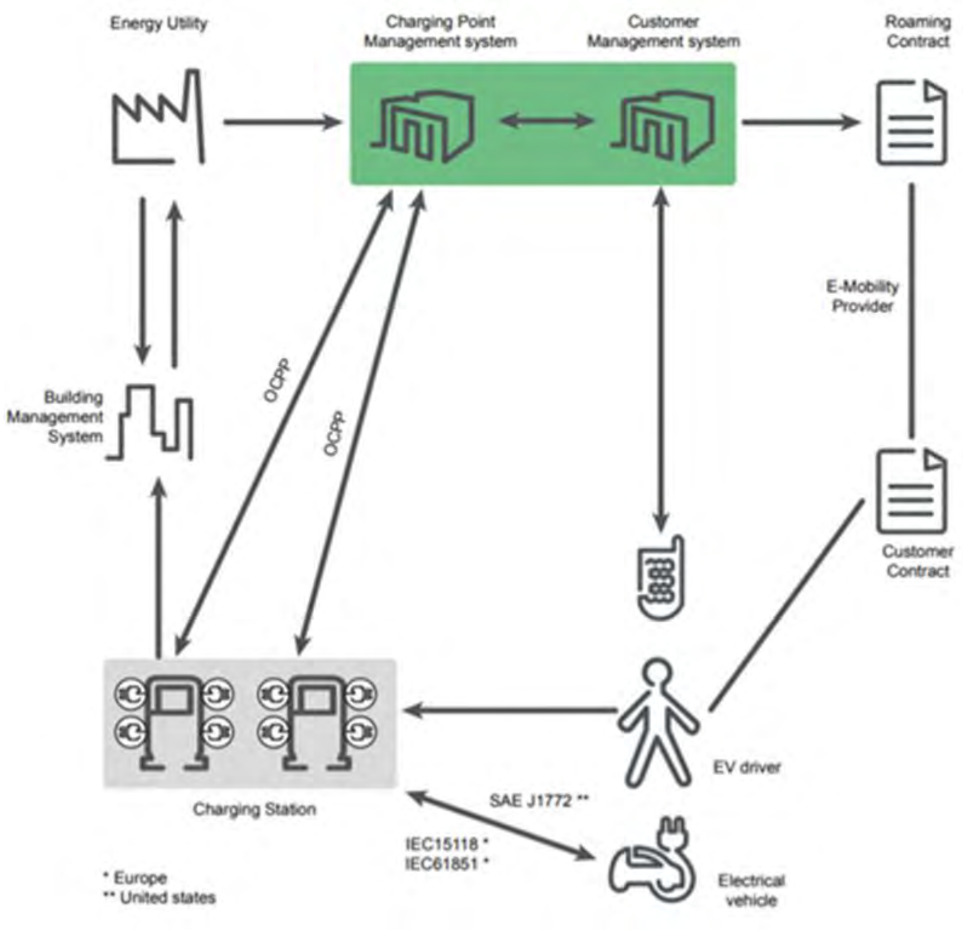

Figure 17 Open Charge Point Protocol Implementation Guide (SCHNEIDER)

Charge control: Charge control involves the management and control of the amount of energy supplied to electric vehicles during charging. There can be different levels of control, from unrestricted loading to loading with specific limitations. Some aspects of load control include:

Charging power: Allows you to adjust the charging speed by limiting the amount of power supplied. This can be useful to avoid overloading the electrical infrastructure or to optimize charging during times of high demand

Charging Prioritization: Allows you to prioritize certain electric vehicles, such as commercial fleets or emergency vehicles, to ensure fast and efficient charging when necessary.

Charging Scheduling: Allows users to schedule charging at specific times, taking advantage of the cheapest electricity rates or when there is more capacity on the electrical grid.

Grid Integration: Enables two-way communication between electric vehicles and the power grid, enabling more efficient balancing of energy charging and discharging, and facilitating the integration of renewable energy sources and storage into the grid.

These aspects of initialization, transactions and charging control are essential to ensure a safe, efficient and convenient charging infrastructure for electric vehicles.

Developing an integration between Modbus and MQTT involves establishing bidirectional communication between devices using the Modbus protocol and an MQTT server.

The validation proposal consists of installing a device, it may be an element for EV charging or a hybrid inverter, in the Manresa laboratories and verifying that the communication protocols work properly, checking that correctly execute initialization, transaction, and load control.

It is expected to be able to verify that the software is capable of issuing the described notifications and, in the event of an error, displaying the signal indicating the problem and performing the respective diagnosis. The latter with the idea that it makes it easier for the user to carry out the necessary operations to correct the problem.

Figure 18 Example of Hybrid Inverter connected to EV charger

User behaviour model:

Statistical models for user behaviors will be generated by IFPEN based on real-world data and parameters related to EV charging behavior. This calibration will ensure that the models align with actual charging patterns and preferences.

For the home parking scenarios, information about population, preferences and habits (daily routines, work hours, overnight stays) of specific areas, namely the metropolis of Paris and Lyon, will be used to generate charging schedule decisions on well-defined time windows (e.g., a week).

The same data will be used for generating models for the urban street parking scenario, further relying on MATSim (Multi-Agent Transport Simulation), a software simulating the dynamic decision-making processes of individual agents on a given area. MATSim, primarily designed for simulating travel behavior, includes indeed modules for representing agents, plans, and events. The obtained simulation results will be processed by analyzing agents' activities to determine visits to public charging stations. Therefore, probabilities of stops at stations based on agents' home or workplace charging availability, battery levels at departure, willingness to wait, will be established, allowing for the generation of the charging demand based on time and location. For the highway charging scenario, department-level Origin/Destination pairs will be used rather than MATSim, potentially with more recent data than currently available (2011).

User behavior model for parking area at Neuman Aluminium:

The user behavior for the Neuman Aluminium use case is analysed by doing a survey to find out under which conditions EV owners would agree to provide their battery as a temporary storage possibility for the company. As in the Neuman Aluminium use case a parking lot with EVs is compared to a local storage it is important to know under which general conditions this type of alternative storage possibility could work.

Application example for the use cases

With the example depicted in Figure 19 the influence of V2G on the aging of a battery system can be investigated (the application example can be adapted individually for each use case described in the subchapters 8.1 - 8.3). A battery stack is attached to a cell thermal model with variable outside temperature (temperature cycle over a certain time). From the battery a driving current of a vehicle and a current from a stationary V2G application is withdrawn.

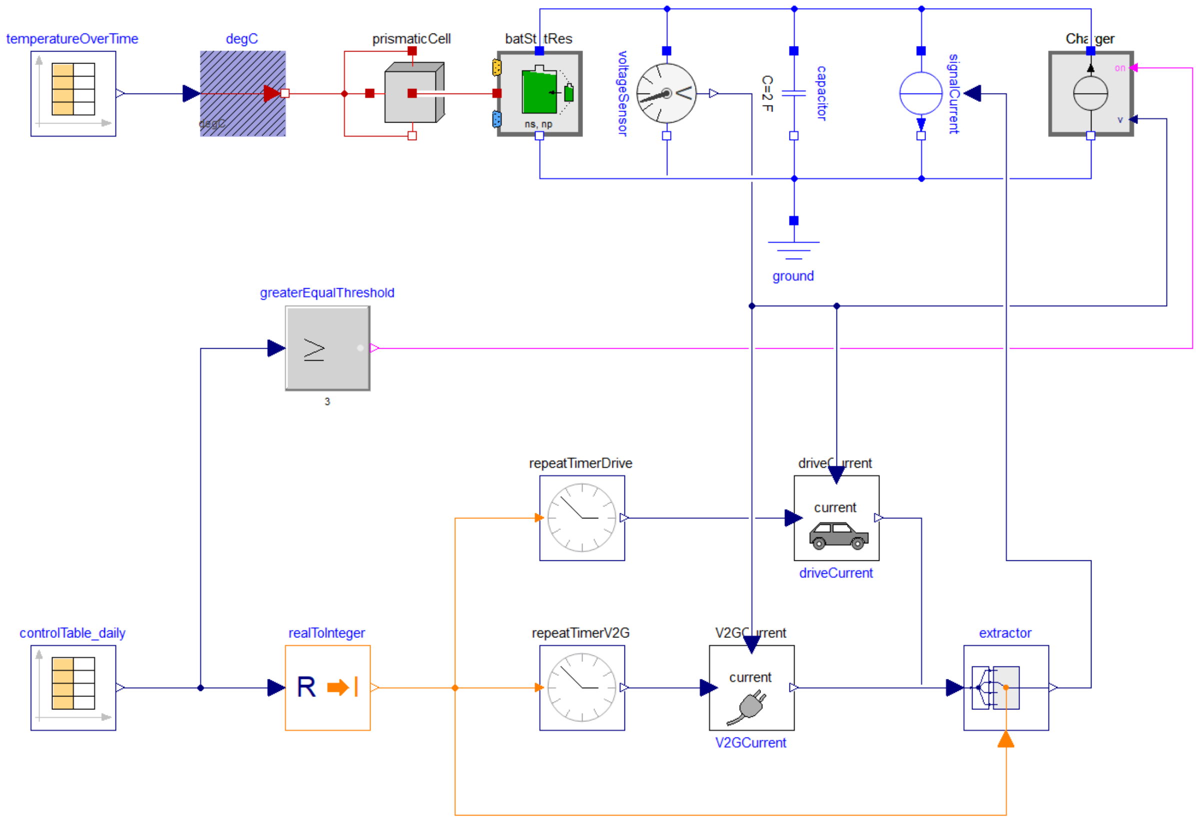

Figure 19: Parameter adaption block and aging block in Dymola (right

In the controlTable_daily the current status of the system is given. Either the battery is charged (controlled charging), or the vehicle is driving or V2G mode is activated (depending on the use case). A simple vehicle model provides the driving power and current, respectively. During controlled charging the charger charges the battery first with a maximum current and after the maximum voltage is reached with decreasing current. In the model V2GCurrent, the V2G functionality can be disabled to demonstrate the influence of V2G on the aging of the battery. Due to an increased load current drawn from the battery the cycling of the battery is higher than without V2G. Hence, (each use case dependent) cycle-aging has an individual impact on the battery, and the battery capacity decreases correspondingly.

8.1. Home charging

For the home charging scenarios, the following submodels are necessary:

- Battery model of EV
    - Specifications and charging/supply curves
    - State Of Charge
- Stationary Battery model
    - Specifications and charging/supply curves
    - State Of Charge
- PV plant
    - Specifications of installed power and performance
    - Real power curves
    - Solar radiation data (required when PV data is not available)
- Parking data
    - Real and/or simulated data: occupancy periods
- House consumption
    - Definition of fixed charges and consumption profiles
        - Collected from real pilot sites through smart meters
        - Simulated
- Scenario Data File (SDF) generator
    - File compiling the information of all the previous submodels

All these submodels will provide the required data for the Smart Charging Optimization Tool (SCOT), which can be considered as well as a subcomponent of the Digital Twin.

8.2. Street parking

For the Street parking scenarios, the following submodels are necessary:

- Battery model of EV
    - Specifications and charging/supply curves
    - State Of Charge
    - State of health
- PV plant
    - Specifications of installed power and performance
    - Real power curves
    - Solar radiation data (required when PV data is not available)

- Parking data
  - Real and/or simulated data: occupancy periods
  - Parking locations
- User behaviour model
  - Satisfaction of the users (Survey or app)
  - Feedback to incentives
  - The model can predict the user departure time based on the historical data
- Charging point model
- Scenario Data File (SDF) generator
  - File compiling the information of all the previous submodels

8.3. Parking area

8.3.1. Neuman usecase and FEV industrial

The following list will be suitable for FEV industrial and Neuman Aluminium Use Case

For the parking area scenario on the industrial site the following submodels and data are necessary:

- Model of EV battery and stationary battery
  - Specifications and charging/supply curves
  - State Of Charge
- Model of charging station
  - Energy transfer and communication to the EV
- PV plant
  - Specifications of installed power and performance
  - Real power curves
  - Solar radiation data (required when PV data is not available)
- Parking data
  - Real and/or simulated data: occupancy periods
  - Parking locations
  - Energy demand
  - Number of parking slots
- Consumption of industrial site
  - Load profile and heatdemand of the site
- User behaviour model
  - Satisfaction of the users (Survey)
- Scenario Data File (SDF) generator
  - File compiling the information of all the previous submodels

8.3.2. University Campus

For the parking area scenario on the university campus the following sub-models and data are necessary:

- Model of EV battery and stationary
  - Specifications and charging/supply curves
  - State Of Charge
- Model of charging station
  - Energy transfer and communication to the EV
- PV plant
  - Specifications of installed power and performances
  - Power curves
  - Solar radiation data (required when PV data is not available)
- Parking data
  - Real and/or simulated data: occupancy periods
  - Parking locations
  - Numbers of parking slots
  - Charging point model
- User behaviour model
  - Satisfaction of the users (Survey or app)
  - Feedback to incentives
  - Prevision based on historical data
- Aggregator
  - Communication between different parking sites
  - Optimization algorithms based on cost/energy targets
  - Incentives based on user behaviour models and occupancy periods
- Scenario Data File (SDF) generator
  - File compiling the information of all the previous submodels

8.3.3. Company fleet

For the company vehicles fleet scenario on the industrial site the following submodels and data are necessary:

- Model of EV battery and stationary battery
  - Specifications and charging/supply curves
  - State Of Charge
- Model of charging station
  - Energy transfer and communication to the EV
  - Charging point model
- PV plant
  - Specifications of installed power and performance
  - PV energy curves
  - Solar radiation data (required when PV data is not available)
- Parking data
  - Real and/or simulated data: occupancy periods
  - Parking locations
  - The model can predict the user departure time based on the historical data
  - Energy demand

    - Number of parking slots
- Consumption of industrial site
    - Loadprofile of the site
- User behaviour model
    - Satisfaction of the users
    - Prevision based on historical data
    - Scenario simulation
- Scenario Data File (SDF) generator
    - File compiling the information of all the previous submodels

9. Software, Tools and Data

In this chapter the required tools, software and data are described. The following information is included:

- Software/Platform (Release/version that is used for all the tools).
- Required data for model setting up.
- Generated data
- Data provider and detailed data variables
- Data format

As refer to chapter 5 The scenarios are defined as following:

1. Energy community neighbourhood
2. Residential
3. Urban street parking
4. Highway charging
5. University campus
6. Industrial site
7. Company vehicle fleets

To summarize all those information for all scenarios included in XL Connect project, two general tables are listed below. In the software and data collection table, the number of the scenarios corresponds to the name of the scenarios.

Submodel	Software / tool	Required data	Generated data	Scenarios						
				1	2	3	4	5	6	7
EV battery model	- Matlab - Simulink - Dymola	- Grid data - Inverter data - EV data - Home consumption data	- Charging / supply curves	x	x	x	x	x	x	x
Stationary battery model	- Matlab - Simulink - Dymola	- Grid data - Inverter data - EV data	- Charging / supply curves	x	x			x	x	x

		- Home consumption data								
PV plant	- Matlab - Simulink	- Installed power - Solar irradiation	- Generated energy curves	x	x		x	x	x	x
Heat pump	- Matlab - Simulink	-Heat consumption	-							
Communication	- Matlab - Simulink					x			x	
Parking data			- Parking occupancy schedule	x	x	x	x	x	x	x
House/ building consumption				x	x				x	
SDF generator	- Python	- User behavior profiles - Charging requirements	- Scenario definition specifications	x	x		x	x		
SCOT	- C - Python	SDF	- Optimized scenario characteristics	x	x					

Table 9: Software tools and data for scenarios

Data	Variables	Provided by	Expected format	Scenarios

Grid data	Time, V, I, f, P	Partner (EREDES)	CSV/JSON	1	2	3	4	5	6	7
Inverter data	V, I, Pmax	Partner (IDIADA, CIRCONTROL)	CSV/JSON	x	x	x		x		x
EV data	C, Q, V, I, P	Partner (IDIADA, CIRCONTROL)	CSV/JSON	x	x	x	x	x		x
Charging / supply curves	Time, V, I	Partner (AIT, EUT, RIC)	CSV/JSON	x	x	x	x	x		
Home consumption data	Time, P, V		CSV/JSON	x	x					
Solar irradiation	Time, I	External	CSV/JSON	x	x			x	x	x
PV energy curve	Time, E	Partner	CSV/JSON	x	x		x	x	x	x
Parking occupancy	Time, location	Partner	CSV			x	x	x	x	x
SDF	All previous	Partner (EUT)	JSON				x			

Table 10: Data provided.

10. Conclusions

This section summarizes the work performed in Task 4.1 of the XL Connect project and further outlines the different sections of the deliverable. Work package 4 of the XL Connect project is focusing on the development of a predictive digital twin of system of systems that supports the development of advanced and optimal charging and control strategies and further maximizes the benefits for all stakeholders. The second objective is the development of the control strategies itself and assessing its impact in different EV penetration scenarios as well as weighing options for fast charging against pervasive low power charging. For this purpose, D4.1 has described the framework of the digital twin models, outlining the architecture for different scenarios.

D4.1 has been built upon prior deliverables that were deliverable as part of the XL-Connect project. In D1.1. a first glimpse at the use-cases for smart charging has been given. These have been considered for the definition of the advanced charging concepts for the digital twin. Further the regulatory framework that needs to be considered within the scenarios is based on the information provided in D2.1. One focus of Work package 2 is the user behaviour and the evolution of e-mobility. Therefore, the deliverables D2.1 and D2.2 have been considered for the general scenarios as well as the user models specifically. Since the scenarios for the digital twin models are also tightly coupled with the virtual and real-world demonstrators in work package 5, the scenarios and the corresponding architecture has been aligned with the definition of the demonstrators that is provided in D5.1.

Based on the described input and the work conducted in Task 4.1 this document firstly defines relevant scenarios. The key questions for defining the scenarios were, where is charging of electric vehicles happening now, and where will it happen in the future, what demonstrations are planned within the scope of the overall project and what scenarios were agreed upon in the Grant Agreement (GA) already. For each scenario defined, relevant KPIs have been identified. Detailed descriptions of the scenarios are given in chapter 5 as text and chapter 6 by providing an architecture, showing the involved subcomponents. The relevant regulations have been pointed out in chapter 7. The sub-models used to represent the subcomponents from the scenario architectures have been shown in chapter 8 before describing the tools and data that will be used in the modelling process in Task 4.2 in chapter 9.

In general, this document serves as an overview as well as a guideline for the development of models and control strategies for relevant scenarios with regards to smart and bidirectional charging.

A risk associated with this deliverable is related to the development process conducted within work package 4. During the development of detailed models and control strategies throughout upcoming years, there might be the need for adjustments. These could be caused I.e. by updates with regards to the regulatory frameworks or standardization, new business models, or unexpected changes in user behaviour. In order to mitigate this risk, while using this document as a guideline throughout the development process, the content should be reflected critically, if new information come to light, that might affect its content.

11. References

(1) CharIN DC CCS Power Classes V7.0, accessed in March 2023.

(2) M. Caruso, P. Livreri, R. Miceli, F. Viola, and M. Martino, “Ev charging station at university campus,” in 2017 IEEE International Telecommunications Energy Conference (INTELEC), Broadbeach, QLD, 2017, pp. 615–623.

(3) D. Kolokotsa et al., “Development of a web-based energy management system for University Campuses: The CAMP-IT platform,” Energy and Buildings, vol. 123, pp. 119–135, 2016, doi: 10.1016/j.enbuild.2016.04.038.

(4) R. Morales Gonzalez, T. A. J. van Goch, M. F. Aslam, A. Blanch, and P. F. Ribeiro, “Microgrid design considerations for a smart-energy university campus,” in IEEE PES Innovative Smart Grid Technologies, Europe, Istanbul, 2014, pp. 1–6.

(5) Y. Wu, J. Zhang, A. Ravey, D. Chrenko, and A. Miraoui, “Real-time energy management of photovoltaic-assisted electric vehicle charging station by markov decision process,” Journal of Power Sources, vol. 476, p. 228504, 2020, doi: 10.1016/j.jpowsour.2020.228504.

(6) Z. Fotouhi, M. R. Hashemi, H. Narimani, and I. S. Bayram, “A General Model for EV Drivers’ Charging Behavior,” IEEE Trans. Veh. Technol., vol. 68, no. 8, pp. 7368–7382, 2019, doi: 10.1109/TVT.2019.2923260.

(7) H. Elmqvist, S. Mattsson, and M. Otter, “Object-Oriented and Hybrid Modeling in Modelica,” Journal Européen des systèmes automatisés, vol. 35, pp. 395–404, 2001.

(8) https://sysarc.ffe.de/, accessed in March 2023.

(9) https://www.charin.global/technology/customer-journey/, accessed in March 2023.

12. Abbreviations and Definitions

AC	Alternating Current
BESS	Battery Energy Storage System
BMS	Battery Management System
CharIN	Charging Interface Initiative e. V.
CO2	Carbon dioxide
CS	Charging Station
CSV	Comma-Separated Values
DC	Direct Current
DER	Distributed Energy Resources
ESS	Electrical Storage System
EV	Electric Vehicle
FC	Fast Charging
FMU	Functional Mock-up Unit
FUGU	Future Grid Usage
GHG	Green-House Gas
HPC	High Power Charging
HVAC	Heating, Ventilation, and Air Conditioning
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
LPC	Low Power Charging
LV	Low Voltage
MATSim	Multi-Agent Transport Simulation
MCS	Megawatt Charging System
MV	Medium Voltage
MW	Megawatt
MWh	Megawatt hours
MWp	Megawatt peak
NPV	Net Present Value
OBC	On-Board Charger
OPEX	Operating Expenses
PE	Power Electronics
PED	Primary Energy Demand
PV	Photovoltaic
RES	Renewable Energy Sources
RMSE	Root-Mean-Square Error
ROI	Return on Invest
SCOT	Smart Charging Optimization Tool

SDF	Scenario Data File
SOC	State of Charge
SOH	State of Health
V1G	Smart Charging
V2B	Vehicle to Building
V2G	Vehicle to Grid
V2H	Vehicle to Home

13. List of Figures and Tables

14. Appendix

Scenario:
In this work package we will define **scenarios** for smart charging and V2G applications. In this case scenario refers to a **(virtual) location** with a specific set of **features.**

Features of Digital Twins

			Charging Topology		Charging speed level (based on CHARIN)						Charging Technology				Charging Type				Local generation / consumption/ storage				User behavior			Expected Parking time			Vehicle type		Revenue/ Cost saving oppurtunities							Number of vehicles					Grid topologies charging point usually connected to		
x: Mandatory o: Optional Partner in red: the primary resiponsible partner			AC	DC	LPC	DC	FC	UFC	HPC	MCS	V1G	V2H	V2B	V2G (AC/DC)	Conductive charging	Inductive charging	Dynamic Charging	Battery Swapping	Photovoltaic	Stationary battery	Power to heat	Water power plant	individual	fleet based	fleet timetable	Parking time (night/day)	Average	Variance	passanger car	light duty vehicle	Frequency balancing	Peak shaving	Arbitrage offers by charging during low-price hours	Utilization of locally generated energy (PV plant)	Reward for providing battery	Redispatch	self- consumption increase	1	1-5	5-20	20-100	100-inf	AC (OBC) unidirectional	DC (micro-grid) unidirectional	DC (micro-grid) bidirectional
Senarios		Responsible			Low power charging	Normal dc charging	Fast charging	ultra fast charging	high power charging	mega watt charging																	in Hours	1: Small variance 2: normal variance 3: big variance																	
Homecharging	Energy community neighborhood	EUT,RWTH	x	o	x						x	x	o	x	x				x	o	o		x			-night most of vehicles are parked - day some vehicles are present, some are not present	Strongly depends on the individual user behavior. During night the vehicle would usually park for ~12 hours, but during the day it varies. Also varies between work days and weekend	- night: 1 - day: 2	x		o	o	o	o			x			x	x		x	o	o
Homecharging	Residential	EUT,RWTH	x	o	x	o	o				o	o	o	o	x								x						x				o	o	o			x					x	o	o
Street parking	Urban street parking	RWTH, FEV, IFPEN	x	o	x	o					x			o	x	o							x				2~8 (survey info. based on different cities)		x		x					x							x	x	x	o
Street parking	Highway charging	IFPEN, RWTH	o	x		o	x	x	x	o	x			x	x				x	o			x	x	x	<1 hour during the day & park overnight	between 30 mins and 2 hours	3	x	x (heavy duty vehicles/coaches)	x			o			o				x	o	o	x	o
Parking area	University Campus	UNIFI, ABB, E-REDES, RWTH.	x	o	x	x	o				x		x	x	x	o			x	x	o		x				2-10	2	x		o	o				o	o				x		x	x	x
Parking area	Industrial Site	FEV, VIV, ABEE, E-REDES, RIC, RWTH, UNIFI,	x	o	x	x	x		x		x		x	o	x				x		x	x		x			8	1	x			x				o	x				o	x	x	x	x
Parking area	Company vehicle fleets	ABB	x	x	x	x	x		x		x		x	x	x	o			x	o				x	o	day	8	1	x	o	o	o			o		x					x	x	x	x