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Situationally Aware Innovative Battery Management System for Next Generation Vehicles

InnoBMS - Deliverable report

D1.2 - V2X capabilities, bidirectional interfaces and related critical load scenarios including cloud connectivity

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Project summary

The core objective of InnoBMS is to develop and demonstrate (TRL6) a future-ready best-in-class BMS hard- and software solution that maximizes battery utilization and performance for the user without negatively affecting battery life, even in extreme conditions, whilst continuously maintaining safety. Concretely, the InnoBMS proposal will deliver a 12% higher effective battery pack volumetric density, a 33% longer battery lifetime and a demonstrated lifetime of 15 years. The results will be demonstrated using novel testing methods that give a 36% reduction in the testing time of a BMS. The results will be demonstrated in two use cases, one light commercial vehicle (Fiat Doblo Electric) and one medium-duty van (IVECO eDaily). The key outcomes will enable a cost reduction of 12% and 9.7% for passenger cars and light-duty vehicles, respectively. The core objective will be achieved through five technical objectives. 1) advanced hybrid physical and data-driven models and algorithms to enable a flexible and modular BMS suitable for a wide range of batteries. 2) Software for a fully connected and fully wireless BMS that acts as a communication server inside the vehicle E/E-architecture, the center of connection, on-board diagnostics and decision-taking for all battery-related information. 3) A scalable, fully wireless and self-tested BMS hardware that enables using different battery sizes at different operating voltage levels, and smart sensor integration. 4) Better battery utilization and exploitation using cloud-informed strategies and procedure. 5) A heterogeneous simulation toolchain and automated test methods.

Publishable summary

The core objective of InnoBMS project is to develop and demonstrate (TRL6) a future-ready, best-in-class BMS hardware and software solution that maximizes battery utilization and performance for the user without negatively affecting battery life, even in extreme conditions, while continuously maintaining safety.

InnoBMS leverages on seven work packages, with WP1 identifying and selecting the relevant requirements and specifications for advanced sensors, wireless cell monitoring and balancing (CMBs), BMS components (including edge, software, and hardware), and the potential use with a second-life battery. Additionally, WP1 defines base use cases and targeted test-cases for InnoBMS, to validate the key outcomes for passenger car and light-duty vehicle applications. WP1 establishes relevant usage scenarios for vehicle-to-grid (V2G) applications for both vehicle types. WP1 ensures regular alignment of the subsequent WP outputs and in the final stage, impact assessment and synthesis of project results. WP1 comprises four tasks and this deliverable report D1.2 is a direct output of *Task 1.2: Requirements specification for cloud-supported electric vehicle operation including V2x*, led by BOSCH.

This deliverable report D1.2, presents a detailed analysis for testing and evaluating the demonstrator's functionalities in real-world scenarios. The process begins with defining the base use case of 'Driving an electric passenger vehicle/ an electric LCV during weekdays.' Subsequently, following discussions with OEMs, specific test cases and scenario descriptions for InnoBMS EV, have been identified. Analytical simulations have been conducted to define these use cases. On top of the driving loads, also AC&DC charging and V2x related loads have been identified for the InnoBMS project's test cases. Besides the use case specification, a condensed overview of InnoBMS requirements and their link to use-case phase is also provided.

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Abbreviations & Definitions

Abbreviation	Explanation
AC	Alternating Current
BMS	Battery Management System
C	Charging rate
CH	Charge (direction)
CV	Commercial Vehicle
DC	Direct Current
DCH	Discharge (direction)
DOD	Depth of Discharge
EFC	Equivalent Full Cycles
EHS	Extra High Speed segment of WLTC
eLCV	Electric Light Commercial Vehicle
EOL	End of Life
EV	Electric Vehicle
HS	High Speed segment of WLTC
HW	Hardware
KPI	Key Performance Indicator
LCV	Light Commercial Vehicle
LS	Low Speed segment of WLTC
MS	Medium Speed segment of WLTC
PC	Passenger Car
SOC	State of Charge
SOH	State of Health
SW	Software
UC	Use Case
V2B	Vehicle to Building
V2C	Vehicle to Cloud
V2G	Vehicle to Grid
V2H	Vehicle to Home
V2X	Vehicle to everything
WLTC	Worldwide Harmonized Light Vehicles Test Cycle

1 Introduction

In the evolving landscape of electric mobility, understanding the diverse applications and operational demands of electric passenger cars and light duty commercial vehicles is paramount. This document defines use case scenarios by considering the most relevant applications for these vehicles, aiming to identify future operational scenarios and derive corresponding load cycles.

Electric passenger cars and light duty CVs exhibit distinct usage patterns influenced by their roles, from personal transportation to commercial deliveries. By analysing these patterns, we can develop comprehensive load cycles that encompass not only driving loads but also the impact of various charging methods—both AC and DC—and Vehicle-to-Everything (V2X) related loads.

This holistic approach ensures that we capture the full spectrum of energy demands and interactions these vehicles will encounter. As a result, we can better anticipate the performance, efficiency, and infrastructure requirements necessary to support the widespread adoption and integration of electric vehicles into our daily lives and the broader energy ecosystem.

This introduction sets the stage for a detailed exploration of use case scenarios, highlighting the critical factors that influence electric vehicle operation and the innovative solutions needed to optimize their performance in diverse real-world contexts.

1.1 Definition of the term "use case"

A "use case" refers to a detailed scenario that outlines how an EV is used to achieve specific objectives within a given set of conditions. It describes the interactions between the EV, its user, and the environment to illustrate how the vehicle can be effectively employed in real-world situations.

1.2 Use case derivation process

The derivation of relevant EV use cases involves a collaborative approach, engaging InnoBMS WP1 partners. It starts with a use case questionnaire to get the project team knowledge, followed literature studies. External interviews with courier companies that use eLCV and EV users were conducted to ensure that the use case is comprehensive, addressing real-world needs and challenge.

2 Electric vehicles use cases.

2.1 Classification of vehicles

In the European Union, passenger cars are classified into several segments primarily based on size, with each segment reflecting different car classes from smallest to largest[1]. Based on[2] a breakdown of the segments A through E, and Light Commercial Vehicles (LCVs) is summarized below:

A-Segment (Mini/City Cars)

- Description: These are the smallest cars, often called "city cars" due to their compact size, making them ideal for urban driving and parking.
- Examples: Fiat 500, Hyundai i10, Toyota Aygo.
- Features: Small size, limited cargo space, fuel-efficient, suitable for short trips

B-Segment (Supermini/Subcompact Cars)

- Description: Slightly larger than A-segment cars, B-segment vehicles are also known as superminis in Europe and subcompacts in the US.
- Examples: Renault Clio, Volkswagen Polo, Ford Fiesta.
- Features: More interior space than A-segment, better suited for small families, and still relatively fuel-efficient.

C-Segment (Small Family/Compact Cars)

- Description: These are compact cars, larger than B-segment vehicles, often considered the smallest class suitable for small families.
- Examples: Volkswagen Golf, Honda Civic, Toyota Corolla.
- Features: Balance between size, comfort, and fuel efficiency, with decent cargo space.

D-Segment (Large Family/Mid-size Cars)

- Description: Known as mid-size cars in the US, these vehicles are larger and offer more space and comfort, making them suitable for families.
- Examples: Ford Mondeo, Toyota Camry, Volkswagen Passat.
- Features: Spacious interiors, larger cargo capacity, suitable for longer trips and family use.

E-Segment (Executive/Full-size Cars)

- Description: These are executive cars, larger than D-segment vehicles, often featuring more luxurious amenities and performance enhancements.
- Examples: BMW 5 Series, Mercedes-Benz E-Class, Audi A6.
- Features: High levels of comfort, advanced technology, powerful engines, and higher price points.

Light Commercial Vehicles (LCVs)

- Description: LCVs are vehicles designed for transporting goods rather than passengers, commonly used for commercial purposes.
- Examples: IVECO e-daily, Mercedes-Benz Sprinter, Volkswagen Transporter.
- Features: Variants include vans, pickups, and chassis cab models, offering substantial cargo space and durability for commercial use.

In addition, Fiat Doblo Electric serves as a passenger vehicle, falling under the mini-van segment or MPV (multi-purpose vehicle) category, rather than the traditional car segments such as A, B, C, D, or E. In InnoBMS project, to differentiate between the two demonstrators, we classify the Fiat Doblo Electric under the **passenger vehicle category** and the IVECO e-Daily under the **LCV** category.

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[1] https://alternative-fuels-observatory.ec.europa.eu/general-information/vehicle-types

[2] *"Case No COMP/M.1406 - Hyundai / Kia: Regulation (EEC) No 4064/89 Merger Procedure: Article 6(1)(b) Non-opposition" (PDF). Office for Official Publications of the European Communities. Retrieved 12 July 2021.*

Passenger vehicles

Table 2.1 Overview of the key performance indicators for all electric passenger vehicles segments

Indicator	Unit	Passenger vehicle					
		Lower Class		Middle class		Upper class	
		SoA	2030	SoA	2030	SoA	2030
Energy	kWh	30 – 60	30 – 60	30 – 60	30 – 60	80 – 120	80 – 120
Usable Energy	kWh	95%	95%	95%	95%	95%	95%
Charging power	kW	up to 43	up to 50	up to 160	up to 350	up to 250	Up to 500
C-rate max CH/DC	C	1 – 2	1 – 2	1 – 3	2 – 5	1 – 3	3 – 6
Fast Charging (rate, power)		no	yes	yes	yes	yes	yes
Voltage	V	400	400	400	400	400-800	800
Energy consumption	kWh/100 km	16-20	13-18	18-22	15-20	20-23	16-20
Range	km	250	300	350	450	450	550
Exploitation temperature range	°C	-25 to +55	-25 to +55	-25 to +55	-25 to +55	-25 to +55	-25 to +55
Daily range	km	<70	<70	<70	<70	<70	<70
Cycle life	Charge/Discharge cycles	~1000 – 1500	>2000	~1000 – 1500	>2000	~1000 – 1500	>2000
Lifespan	km	200 000	200 000	200 000	200 000	200 000	200 000
Calendar life	years	8	8	8	8	8	8
Cloud connected	-	no	yes	no	yes	no	yes
V2X	-	no	yes	no	yes	no	yes

Electric Light commercial vehicles (eLCV)

Table 2.2 Overview of the key performance indicators for all electric LCV segments

Indicator	Unit	Light Commercial vehicle	
		SoA	**2030**
Energy	**kWh**	20-100	40-120
Usable Energy	**kWh**	15-80	30-90
Usable SOC window	**%**	80	NA
Charging power	**kW**	<43	<43
C-rate max CH/DC	**C**	3(CH) / 3 (DC)	3.5(CH) / 3.5 (DC)
Fast Charging (rate, power)	**kW**	50	50
Voltage	**V**	400-800	400-1200
Energy consumption	**kWh/100 km**	<60	<50
Range	**km**	~250*	~500
Exploitation temperature range	**°C**	-25 to +55	
Daily range	**km**	<200	<200
Cycle life	**Charge/Discharge cycles**	~1000 – 1500	>2000
Lifespan	**km**	~200 000 – 500 000	~200 000 – 800 000
Calendar life	years	8	8
Cloud connected	**-**	No	Yes
V2X	**-**	Yes	
Battery pack costs	**Euro/kWh**	~200	~85

*depends on battery size and vehicle load.

2.2 Vehicle to Grid (V2G) possible use cases

Vehicle-to-Grid (V2G) technology enables bidirectional energy flow between electric vehicles (EVs) and the power grid. This allows EVs to discharge stored energy back into the grid, providing several potential benefits for grid stability, renewable energy integration, and economic advantages for EV owners. This overview explores possible V2G discharge scenarios, their applications, and the benefits they offer.

Potential V2G Discharge Scenarios:

- **Peak Load Shaving**:
    - **Scenario**: During periods of high electricity demand, EVs can discharge energy back into the grid to help meet the peak load.
    - **Application**: This can be particularly useful during hot summer afternoons when air conditioning use spikes, reducing the need for additional power plants.
- **Renewable Energy Integration**:
    - **Scenario**: EVs can store excess energy generated from renewable sources, such as solar and wind, and discharge it when generation is low or demand is high.
    - **Application**: This helps balance the intermittent nature of renewable energy sources, making the grid more reliable and promoting sustainable energy use.
- **Frequency Regulation:**
    - **Scenario**: EVs can provide fast response energy discharge to help maintain grid frequency within the desired range.
    - **Application**: Grid operators can use aggregated EV batteries to quickly inject or absorb power, stabilizing the grid frequency and preventing blackouts.
- **Emergency Backup Power**:
    - **Scenario**: In the event of a grid outage, EVs can discharge stored energy to power homes or critical infrastructure.
    - **Application**: This provides a reliable backup power source during natural disasters or other emergencies, enhancing energy resilience.
- **Demand Response Programs**:
    - **Scenario**: EV owners can participate in demand response programs, where they discharge energy during high demand periods in exchange for financial incentives.
    - **Application**: This can reduce overall energy costs and help manage grid demand more effectively.

How V2G Can Be Used:

- **Residential Use**:
    - EVs can discharge energy to power homes during peak hours or outages, reducing reliance on the grid and lowering electricity bills.
- **Commercial and Industrial Use**:
    - Businesses with large EV fleets can use V2G technology to provide energy to the grid, reducing operational costs and contributing to grid stability.
- **Utility Partnerships**:
    - Utilities can partner with EV owners to aggregate V2G capabilities, creating a distributed energy resource that can be dispatched as needed.
- **Smart Grid Integration**:
    - V2G technology can be integrated into smart grids, using advanced communication and control systems to optimize energy flow and grid stability.

Benefits of V2G Technology:

- **Economic Benefits**:
  - EV owners can earn money or receive incentives for participating in V2G programs.
  - Reduced electricity costs through peak shaving and participation in demand response programs.
- **Environmental Benefits**:
  - Enhanced integration of renewable energy sources, reducing reliance on fossil fuels.
  - Lower overall carbon footprint by optimizing energy use and reducing the need for peaker plants.
- **Grid Stability and Reliability**:
  - Improved grid frequency regulation and voltage stability.
  - Increased resilience to power outages and emergencies through decentralized energy storage.
- **Technological Advancements**:
  - Promotion of smart grid technologies and advanced energy management systems.
  - Encouragement of innovation in battery technology and energy storage solutions.
- **Social Benefits**:
  - Greater energy security and independence for communities.
  - Increased public awareness and adoption of sustainable energy practices.

Focus on Residential Use of Vehicle-to-Grid (V2G) Technology

The residential application of Vehicle-to-Grid (V2G) technology offers a practical and accessible approach to harnessing the benefits of this innovative energy solution. By concentrating on individual households, key advantages related to battery capacity, cost savings, and simplicity of implementation are highlighted, without the need for extensive coordination with energy providers or utility partners.

Key Arguments for Focusing on Residential Use

- **Adequate Battery Capacity for Household Needs**: The smaller battery capacity of most residential EVs is generally sufficient to meet the energy needs of a typical household during peak times or short-term outages. An average EV battery can store enough energy to power a home for several hours, making it a viable solution for peak shaving and backup power.
- **Cost Savings on Electricity Bills**: Homeowners can significantly reduce their electricity bills by using V2G technology to discharge stored energy during peak pricing periods. By discharging during high-rate periods and recharging during off-peak times, homeowners can take advantage of time-of-use pricing to lower their overall energy costs.
- **Simplicity of Implementation**: Residential V2G implementation is straightforward and does not require complex coordination with external entities. Homeowners can independently manage their energy use without needing to negotiate agreements with energy providers, utility partners, or grid operators, streamlining the adoption process.
- **Enhanced Energy Independence**: V2G technology can increase household energy independence, reducing reliance on the grid and enhancing energy security. During outages or grid failures, EVs can provide a reliable backup power source, ensuring continuity of essential services and comfort.
- **Environmental Benefits**: Utilizing V2G technology at the residential level supports the broader integration of renewable energy sources. Homeowners who generate their own renewable energy (e.g., solar panels) can store excess energy in their EVs and discharge it when needed, promoting a cleaner and more sustainable energy ecosystem.
- **Improved Grid Resilience**: While focusing on individual households, the collective impact can contribute to overall grid resilience. Distributed V2G systems at the residential level can provide a buffer during high demand periods, reducing strain on the grid and preventing potential blackouts.

- **Ease of Technology Integration**: Modern smart home systems and V2G-compatible chargers make the integration of V2G technology into residential settings increasingly easy and accessible. Many EV manufacturers and home energy management systems now offer V2G-compatible options, simplifying the technical aspects of setting up and managing V2G systems at home.
- **User Control and Flexibility**: Homeowners have full control over their energy use, allowing for flexible and personalized energy management. V2G technology empowers homeowners to decide when to charge or discharge their EV batteries based on their unique energy needs and preferences, enhancing user autonomy.

Focusing on the residential use of Vehicle-to-Grid (V2G) technology presents a compelling case due to the adequacy of EV battery capacity for household needs, significant cost-saving potential, and the simplicity of implementation without requiring extensive coordination with external entities. Additionally, residential V2G use promotes energy independence, environmental benefits, grid resilience, ease of technology integration, and user control, making it an attractive and practical application of V2G technology for individual homeowners. This focus not only benefits the individual households but also contributes positively to the overall energy system, promoting a more sustainable and resilient future.

2.3 Operational use-case proposal for EVs

2.3.1 Base use case: "Driving an electric passenger vehicle during weekday."

Base use case serves as the foundation to demonstrate the project results under real driving conditions. It provides a comprehensive framework for testing and evaluating the overall demonstrator functionalities in practical, real-world scenarios.

The base use case is centred around future operational scenarios and the subsequent derivation of load cycles tailored for electric passenger vehicles. It provides a framework for envisioning potential future contexts and requirements, allowing to derive specific load cycles that reflect the anticipated usage patterns and demands on electric passenger vehicles.
This approach will help to prove the InnoBms solution viability for implementation not only in the present but also in the future.

The use case operates under the assumption of an average daily distance travelled by electric passenger vehicles in Europe, as well as assumptions regarding battery costs and energy costs. These assumptions provide a basis for modelling and analysing the feasibility and cost-effectiveness of the proposed solution within the European market context. By considering these factors, we aim to evaluate the potential impact of the solution on key metrics such as total cost of ownership, energy consumption, and environmental sustainability.

Use case scenario:

Figure 2.1 Passenger EV - Use case breakdown into different phase

An electric passenger vehicle is utilized personal commute, covering a total distance of 40 to 50 km during a workday. The vehicle operates between 07:00 and 7:30, that represents the commute from the users home to his workplace and from 17:00 to 18:00 , that represents the commute from the users workplace to his home The vehicle starts with an initial state of charge (SOC) of 100%. The driving speed is distributed across urban, rural, and high-speed segments. The use case scenario also includes a Vehicle-to-Everything (V2X) discharge phase and an overnight charging phase between 17:00 and 08:00, which ensures the SOC returns to 100% by the next morning.

- **Driving Phase.**

At 07:30 AM, the worker departs from home and drives 22 kilometers to his workplace.

At 16:30 AM, the worker departs from his workplace and drives 22 kilometers to his home.

- **Stationary phase**

The vehicle is not plugged to the charging station.

- ***V2G Phase.***

While the worker is at home, the passenger-electric vehicle is connected to a public bidirectional charging station. During this phase, the EV is likely to be in a stationary state, with the bidirectional charger managing its charging and discharging activities based on grid conditions and the EV's battery state of charge (SOC).

The bidirectional charging system optimizes energy flow between the EV and the grid, considering factors such as grid stability, energy demand, and renewable energy availability. Excess energy from renewable sources or periods of low demand can be stored in the EV's battery, while the battery can discharge energy back to the grid during peak demand periods or when additional power is required.

The charger ensures that the EV's battery remains within a specified range of the SoC limit required for unplanned trips. This ensures that the EV is always ready to be used for unexpected journeys.

- **Charging phase**

The charger schedules another recharging phase to ensure the EV's battery reaches the target SOC level required for the next working day's commute.

This phase may involve charging the EV's battery to a specific SOC threshold using off-peak electricity rates, maximizing cost savings for the EV owner.

Key Use-Case assumptions:

- Vehicle: Fiat e-Doblo.
- Battery capacity: 29 kWh.
- Usable battery capacity: 26 kWh.
- Use-case initial SOC: 100%.
- Vehicle exploitation hours: 08:00 - 9:00 & 17:00 – 18:00.
- Daily distance covered: 50 km.
- WLTC driving environment distribution over the driving phase:
  - LS (Low Speed): 52.5% of 22km → 11.6 km.
  - MS (Medium Speed): 36% of 22km → 7.9km.
  - HS (High Speed): 7% of 22km → 1.5 km.
  - EHS (Extra-High Speed): 4.5% of 22 km à 1 km.
    Maximum Vehicle speed: 130 km/h
- ambient temperature:
  - Summer Use case (UC1) = 25° C
  - Winter Use case (UC2) = -10° C
- UC1 energy consumption by WLTC segments:
  - LS (Low Speed): 48.8 kWh/100 km
  - MS (Medium Speed): 45.2 kWh/100 km
  - HS (High Speed): 36.9 kWh/100 km
  - EHS (Extra-High Speed): 42.4 kWh/100 km
- UC2 energy consumption by WLTC segments:
  - LS (Low Speed): 62,8 kWh/100 km
  - MS (Medium Speed): 59,7 kWh/100 km
  - HS (High Speed): 41,5 kWh/100 km
  - EHS (Extra-High Speed): 45,2 kWh/100 km

2.3.1.1 *Morning Drive Phase (07:30-9:00).*

At 07:30 AM, the worker departs from home and drives 22 kilometres to the workplace.

During the phase, the vehicle operates in various WLTC driving cycles:

1. **Low-speed cycle**: 3.1 km - Residential areas.
2. **Medium-speed cycle**: 4.6 km - Suburban driving.
3. **High-speed cycle**: 7.0 km - Rural roads with higher speed limits.
4. **Extra-high-speed cycle**: 8.1 km - Occasional highways or expressways

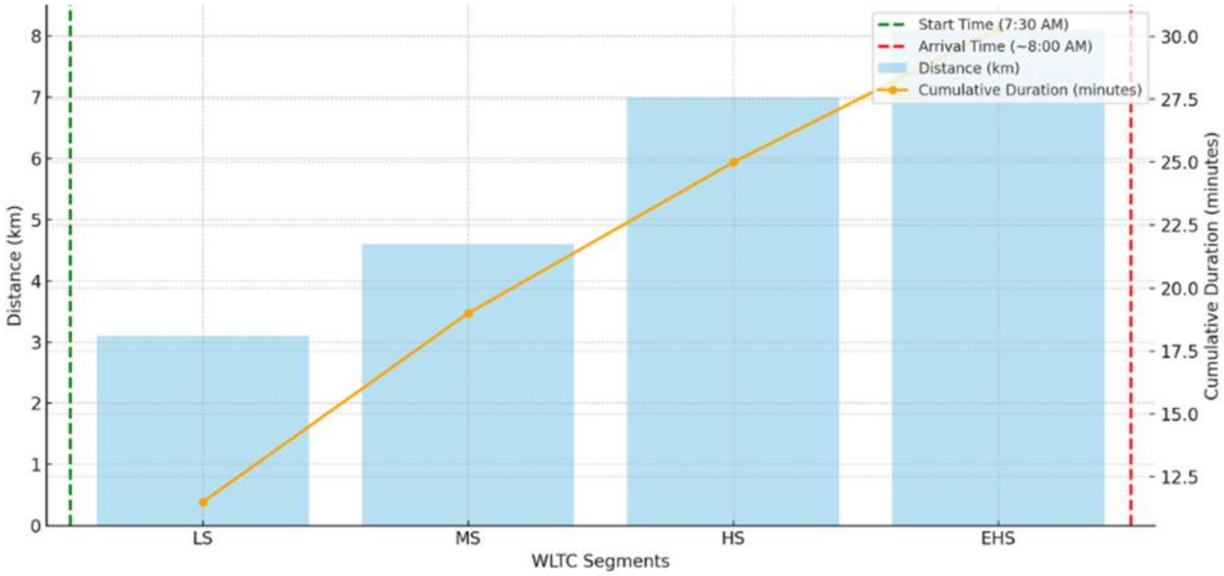

Figure 2.2 Passenger EV - WLTC segments distribution over the Morning Driving Phase

Fig 2.2 illustrates the commute time and distance covered during different segments of the WLTC cycle. The bar chart in sky blue represents the distance (in kilometres) for each segment: Low Speed (LS), Medium Speed (MS), High Speed (HS), and Extra-High Speed (EHS). The orange line chart depicts the duration (in minutes) for each segment. The green dotted line indicates the total commute time window, starting at 07:30 (green dashed line) and concluding at approximately 08:00 (red dashed line). This visual representation helps in understanding the distribution of distance and time across the WLTC segments during a typical commute.

Battery parameters calculation.

1). Total energy consumed during the morning driving phase, was calculated using the formula from below.

$$EnrgC = \frac{\textbf{Distance}\ [\mathrm{km}]\ \times\ \textbf{Energy consumption}\ [\mathrm{kWh/100km}]}{100}$$

The vehicle consumption is influenced by the ambient temperature and vehicle speed, therefore, the total energy consumed is calculated separately for each WLTC cycle segment, therefore the total energy consumption for the driving phase is calculated using the following formula:

$$Consumption\ = LS\ EnrgC +\ MS\ EnrgC + HS\ EnrgC +\ EHS\ EnrgC$$

Remaining energy is calculated with the following formula:

$$Remaining\ energy = \frac{Battery\ capacity \times \text{Initial SOC}}{100} - \ Consumption$$

Summer Use case (UC1) consumption:

- **LS** (Low Speed) energy consumption: 28.8 kWh/100 km

$$UC1\ LS\ EnrgC = \frac{11.6\ [\mathrm{km}] \times\ 48.8\ [\mathrm{kWh/100km}]}{100} = 5.6\ kWh$$

- **MS** (Medium Speed) energy consumption: 26.5 kWh/100 km

$$UC1\ MS\ EnrgC = \frac{7.9\ [\mathrm{km}] \times\ 45.2[\mathrm{kWh/100km}]}{100} = \mathbf{3.5}kWh$$

- **HS** (High Speed) energy consumption: 24.5 kWh/100 km

$$UC1\ HS\ EnrgC = \frac{1.5\ [\mathrm{km}] \times\ 36.9[\mathrm{kWh/100km}]}{100} = 0.55\ kWh$$

- **EHS** (Extra-High Speed) energy consumption: 30.9 kWh/100 km

$$UC1\ EHS\ EnrgC = \frac{1\ [\mathrm{km}] \times 42.4\ [\mathrm{kWh/100km}]}{100} = 0.4\ kWh$$

Total energy consumed during the morning driving phase in summer temperature conditions:

$$\mathbf{UC1} - MDP\ Consumption\ = LS + MS + HS + EHS = 10.05\ kWh$$

Winter Use case (UC2) consumption:

- LS (Low Speed) energy consumption: 42,7 kWh/100 km

$$UC2\ LS\ EnrgC = \frac{11.6\ [\mathrm{km}] \times\ 62.8\ [\mathrm{kWh/100km}]}{100} = 7.2\ kWh$$

- MS (Medium Speed) energy consumption: 33,2 kWh/100 km

$$UC2\ MS\ EnrgC = \frac{7.9\ [\mathrm{km}] \times 59.7\ [\mathrm{kWh/100km}]}{100} = 4.7\ kWh$$

- HS (High Speed) energy consumption: 29,1 kWh/100 km

$$UC2\ HS\ EnrgC = \frac{1.5\ [\mathrm{km}] \times\ 41.5\ [\mathrm{kWh/100km}]}{100} = 0.6\ kWh$$

- EHS (Extra-High Speed) energy consumption: 33,8kWh/100 km

$$UC2\ EHS\ EnrgC = \frac{\mathbf{1}\ [\mathrm{km}] \times\ 45.2\ [\mathrm{kWh/100km}]}{100} = 0.45kWh$$

Total energy consumed during the morning driving phase in winter temperature conditions:

$$\mathbf{UC2}\ -\ MDP\ Consumption\ = LS + MS + HS + EHS = 12.9\ kWh$$

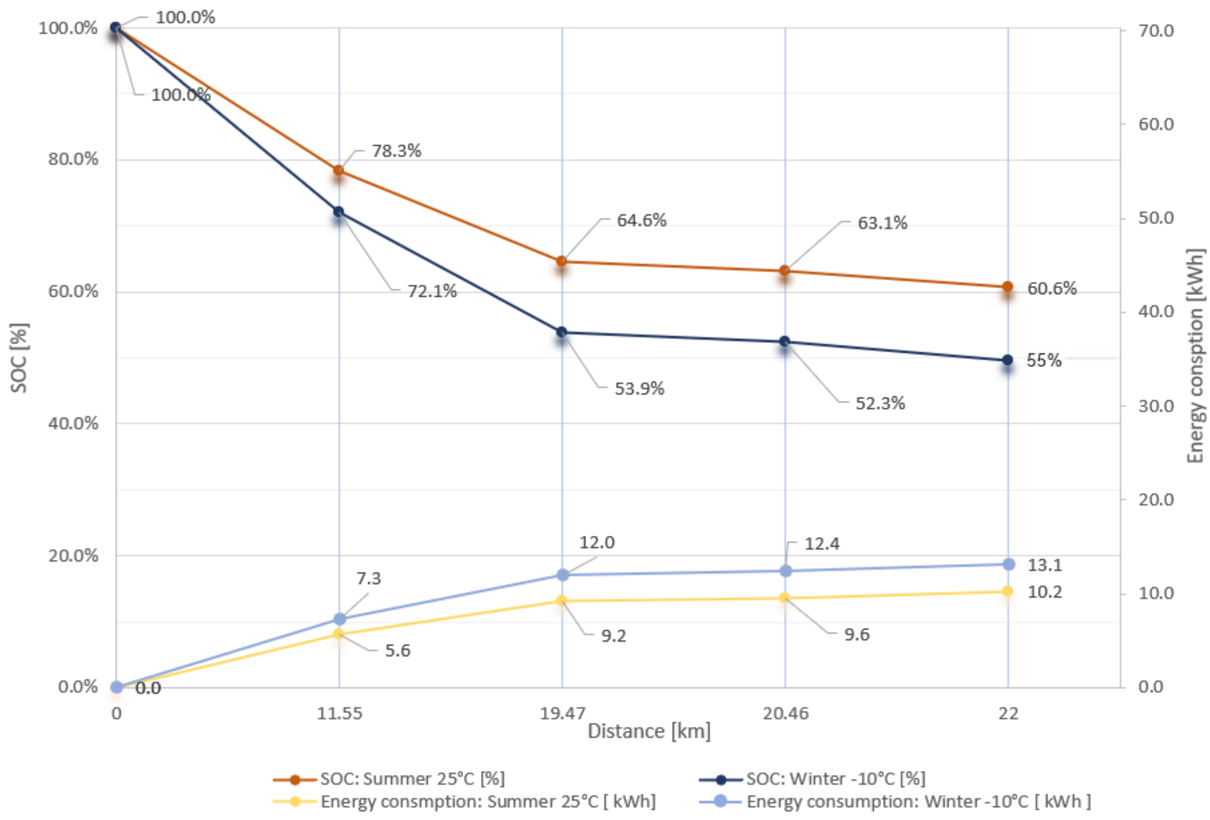

Figure 2.3 Passenger EV - Energy consumption and SOC evolution during the Morning Driving Phase (MDP) in Summer and Winter conditions

UC1 = Sumer Use-case taking in account average ambient temperature in Europe 25° C, UC2 = Winter Use-case taking in account -10° C ambient temperature, MDP = Morning Driving Phase

After the EV user arrives to his workplace, SOC is 76.5% during summertime and 67.9% during wintertime. Within this charge range, we can explore further Vehicle to Grid (V2G) scenarios and use cases.

While the worker is at the job site for approximately 8 hours, the passenger-electric vehicle is connected to a public bidirectional charging station. During this phase, the EV is likely to be in a stationary state (resting), with the bidirectional charger managing its charging and discharging activities based on grid conditions and the EV's battery state of charge (SOC).

The bidirectional charging system optimizes energy flow between the EV and the grid, considering factors such as grid stability, energy demand, and available renewable energy. Excess energy from renewable sources or periods of low demand can be stored in the EV's battery, whilst the battery can feed energy back to the grid during peak demand periods or when additional power is required. Owners can benefit from enabling V2G functionalities by getting financial rewards or discounts from utility companies, which can lower their total energy expenses and investment into an electric vehicle.

The charger ensures that the EV's battery remains within a specified range of the SoC limit required for unplanned trips. This ensures that the EV is always ready to be used for unexpected journeys.

Within this timeframe, we can consider that the available power for V2G operations would be at around 8kW. This represents only an empirical evaluation, considering that the vehicle should have enough battery capacity for unplanned trips during the afternoon.

2.3.1.2 V2G energy consumption evaluation during the day

Summer Use case (UC1) V2G energy consumption

Available battery capacity:

$$\text{Available Capacity} = \mathbf{26\ kWh} \times \frac{60.6}{100} = \mathbf{15.75}kWh$$

Remaining Capacity after consuming 8 kWh:

Remaining Capacity=Available Capacity−Energy Consumed

Remaining Capacity=15.75kWh −8 kWh =7.75 kWh

New SOC:

$$\text{New SoC} = \frac{\text{Remaining Capacity}}{\textit{Usable battery capacity}} \times 100$$

$$\text{New SoC} = \frac{7.75\ kWh}{\mathbf{26}\ kWh} \times 100 = 29.8\%$$

Winter Use case (UC2) V2G energy consumption

Available battery capacity:

$$\text{Available Capacity} = \mathbf{26\ kWh} \times \frac{49.7}{100} = \mathbf{12.92}\ kWh$$

Remaining Capacity after consuming 8 kWh:

Remaining Capacity=Available Capacity−Energy Consumed

Remaining Capacity=12.92kWh −8 kWh =4.92 kWh

New SOC:

$$\text{New SoC} = \frac{\text{Remaining Capacity}}{\textit{Usable battery capacity}} \times 100$$

$$\text{New SoC} = \frac{4.92\ kWh}{\mathbf{26}\ kWh} \times 100 = 18.9\%$$

Based on the results from above and considering the final state of charge in wintertime (60.6%) and summertime (49.7%) after the “Morning Drive Phase” during the daytime we should not consider any Vehicle to Grid discharge scenarios because of the low capacity of the battery. If one may consider an additional 8kWh discharge to the grid, the final SoC of the battery would be at 29.8% in summertime and 18.9% in wintertime. This would not leave any room or any additional SoC for unplanned trips.

2.3.1.3 Afternoon Drive Phase (16:30-17:00).

At 16:30 AM, the worker departs from his workplace and drives 22 kilometres to his home.

During the phase, the vehicle operates in various WLTC driving cycles:

1. **Low-speed cycle**: 3.1 km - Residential areas.
2. **Medium-speed cycle**: 4.6 km - Suburban driving.
3. **High-speed cycle**: 7.0 km - Rural roads with higher speed limits.
4. **Extra-high-speed cycle**: 8.1 km - Occasional highways or expressways

For the total energy consumed in the afternoon driving phase the same calculations were used as in the "morning drive phase"

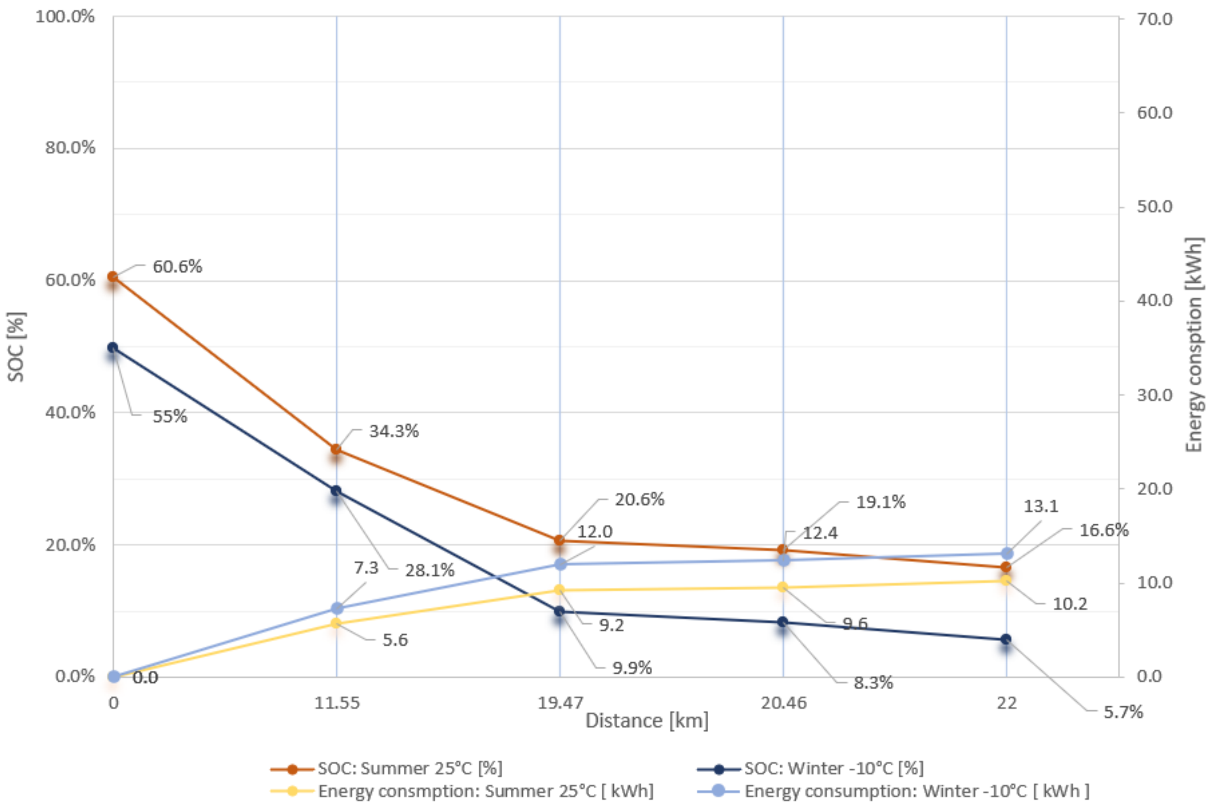

Figure 2.4 Passenger EV - Energy consumption and SOC evolution during the Afternoon Driving Phase (ADP) in Summer and Winter conditions.

Based on the analysis from above, that is being composed by a morning drive phase (MDP) and the afternoon drive phase (ADP), the **final SOC** of the vehicle is: **16.6% during summertime** and **5.7% during wintertime**.

After the user arrives to his home, the vehicle is being parked and plugged into the charger for the next day. This is the scenario where we can also explore Vehicle to Grid (V2G) use cases and examples.

2.3.1.4 Typical Household Energy Consumption

Electricity consumption

Summer:
- Lower heating needs, increased cooling (air conditioning) in some regions.
- Higher electricity usage during midday due to air conditioning and electronic devices.
- **Peak hours: 18:00 - 22:00**.

Winter:
- Higher heating needs.
- Increased electricity usage in the morning and evening when lights and heating are used more intensively.
- **Peak hours: 07:00 - 09:00 and 17:00 - 21:00**.

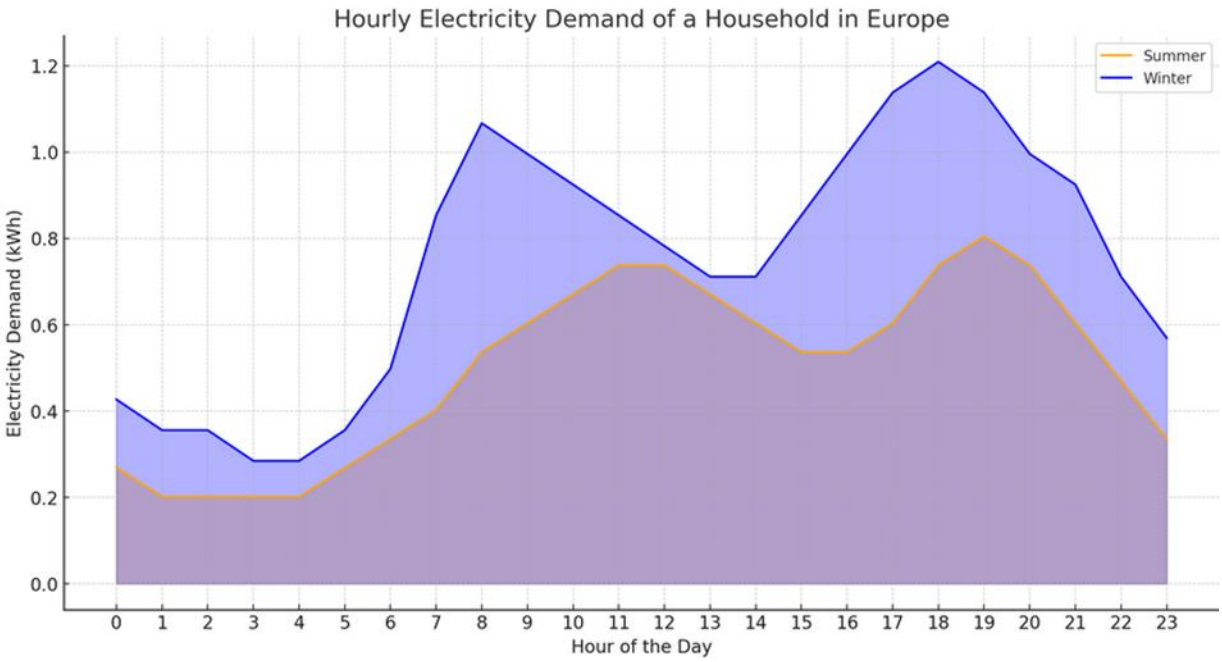

Figure 2.5 Daily Demand average EU household

Hourly Electricity Demand Data (in kWh):

- **Summer**: Average total daily consumption of 12 kWh.
- **Winter**: Average total daily consumption of 18 kWh.

Household energy consumption (17:00-23:00)

In the next section, we will consider V2G discharge scenario for summer and winter between 17:00 and 23:00

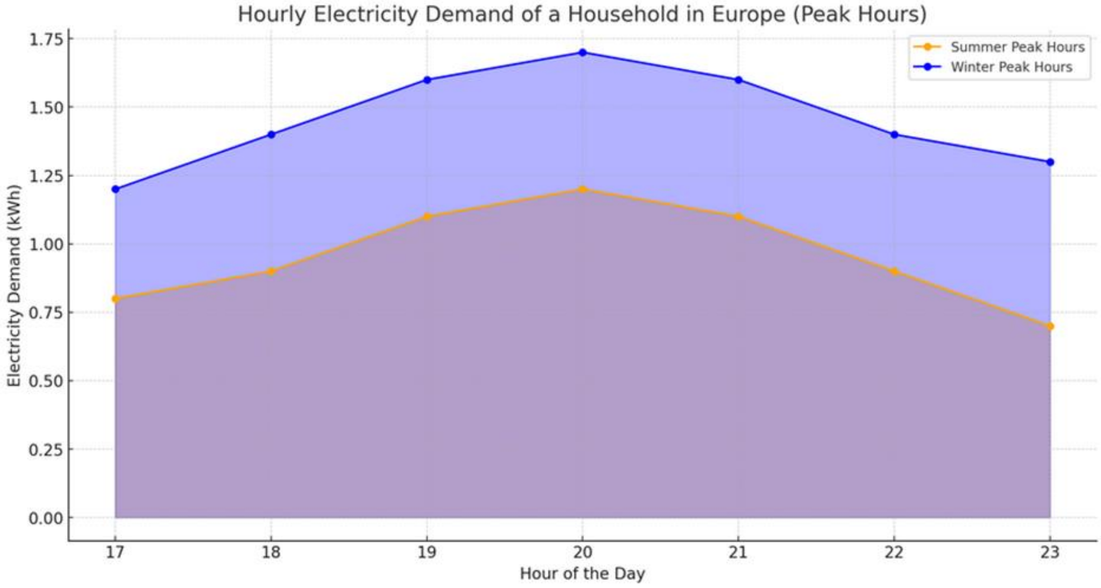

Figure 2.6 Hourly energy demand - average EU household

The graph from Fig 2.6 highlights the following results.

- **Average energy consumption** during peak hours (**summertime**): 0.96kWh
- **Average energy consumption** during peak hours (**wintertime**): **1.46kWh**
- **Total Time Period**: 17:00 to 23:00 is 5 hours.

2.3.1.5 Afternoon charge

In order for the vehicle to be able to discharge, due to the lack of remaining battery capacity, the electric vehicle needs to be charged. The charging time of the vehicle will be considered to be between 16:00 to 17:00 with a charging power of 10 kW, taking into consideration that the usual home charger is able to charge with around 10kW AC.

Initial SOC:

Winter SOC: 5.7%

Summer SOC: 16.6%

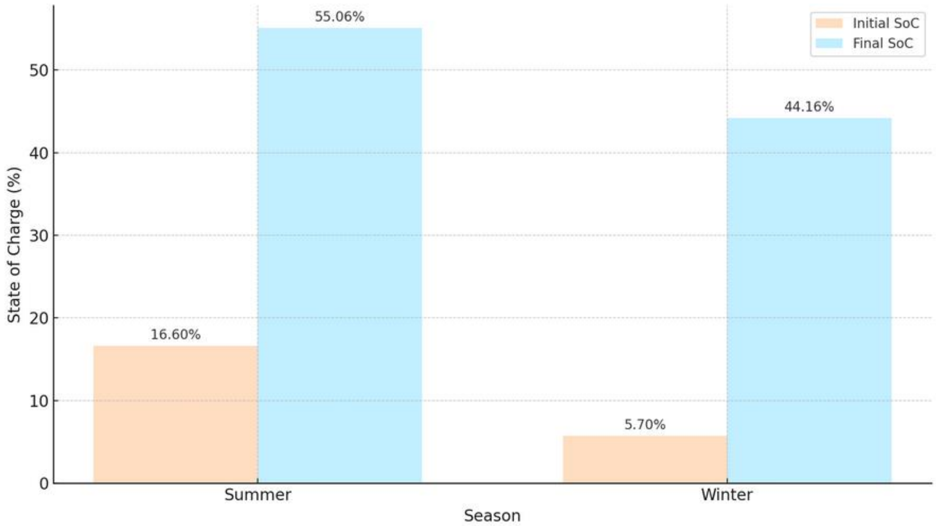

Figure 2.7 Passenger Vehicle - Afternoon charge

2.3.1.6 Vehicle to Grid discharge schedule (17:00-23:00)

Battery discharge based on hourly demand.

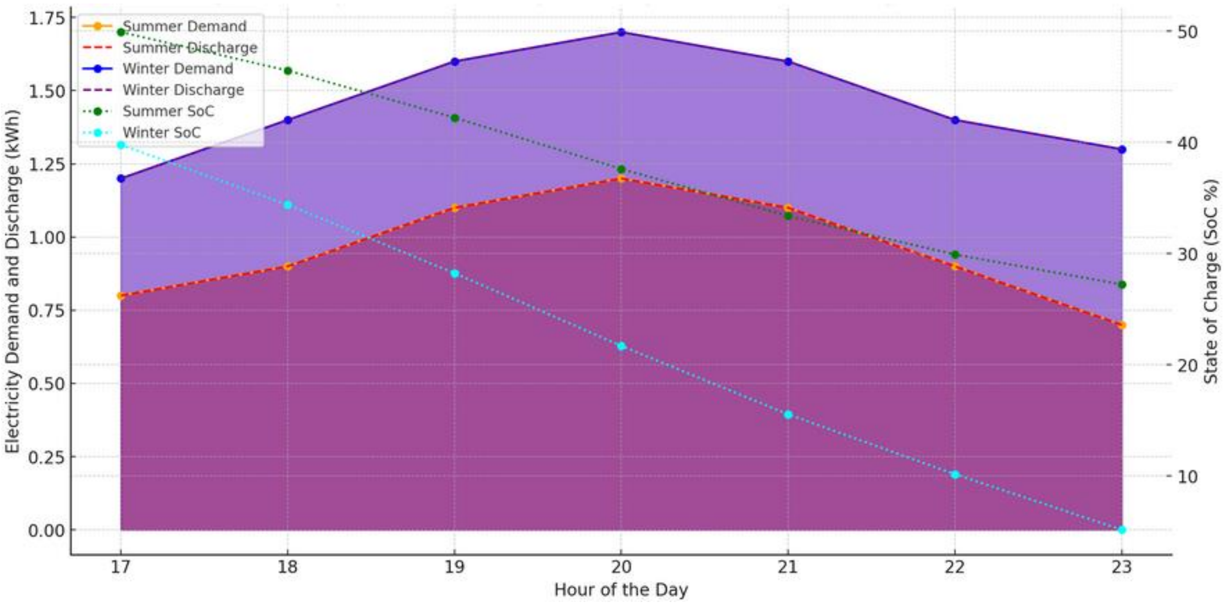

Figure 2.8 Passenger Vehicle - Remaining battery SoC after V2G – winter/summer

The graph above shows the hourly electricity demand of a household, the corresponding discharge from the vehicle battery, and the state of charge (SoC) of the battery for both summer and winter during peak hours (17:00 - 23:00).

Key Observations:

1. **Summer Demand and Discharge**:
   - The household demand is fully met by the battery, as seen in the "Summer Discharge" line closely following the "Summer Demand" line.
   - The initial SoC starts at 55% and gradually decreases as the battery discharges to meet the household demand.
   - By 23:00, the SoC decreases to approximately 27%.
   - Total energy demand: 6.7 kWh
2. **Winter Demand and Discharge**:
   - Similarly, the household demand in winter is fully met by the battery, indicated by the "Winter Discharge" line.
   - The initial SoC starts at 44% and decreases as the battery discharges to meet the higher winter demand.
   - By 23:00, the SoC decreases to approximately 5%.
   - Total energy demand: 10.2 kWh

Summary:

- The vehicle battery effectively meets the household electricity demand during peak hours in both summer and winter.
- In summer, the SoC drops from 55% to around 27%, consuming approximately 26% of the battery capacity.
- In winter, the SoC drops from 44% to around 5%, consuming approximately 39.4% of the battery capacity.

The vehicle battery with V2G technology can reliably power a household during peak hours without fully depleting its charge, though the battery's discharge is more significant in winter due to higher energy demands.

Details over Summer Use case (UC1) for V2G discharge:

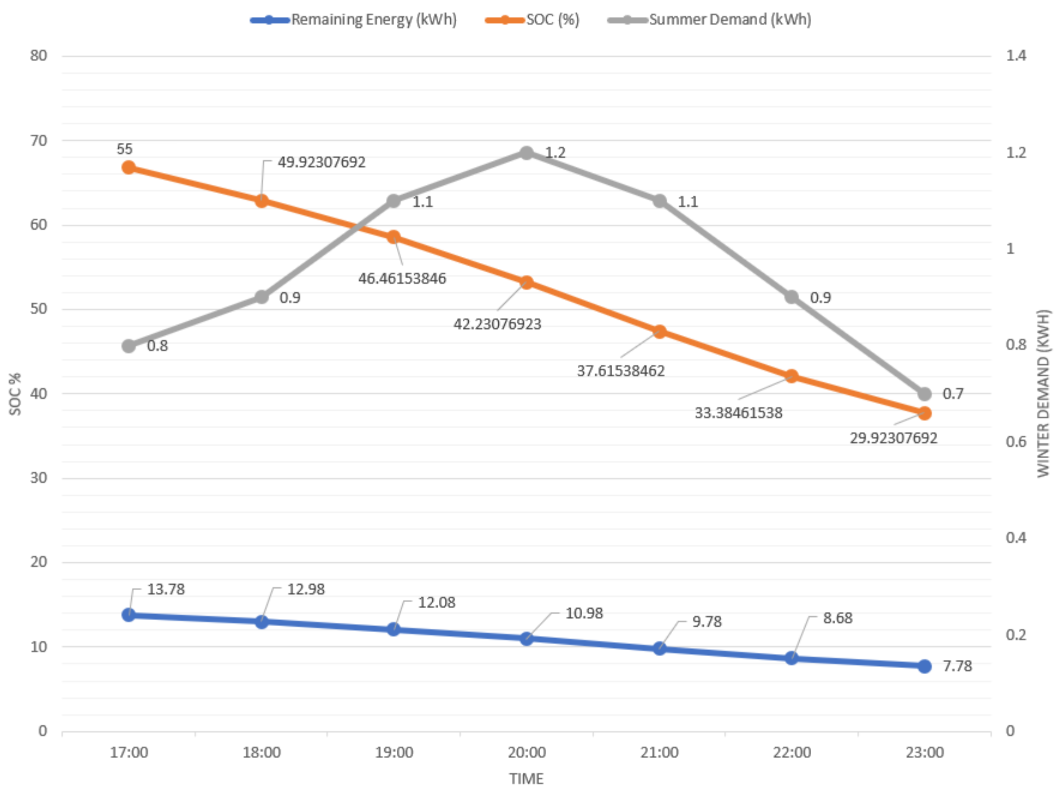

Figure 2.9 Passenger EV - Remaining battery SoC after V2G – summer

Before V2G

- Available Soc: 55%
- Available capacity: 26 kWh

After V2G

- Available Soc:29. 9%
- Available capacity: 7.78 kWh

Details over winter use case (UC2) for V2G discharge:

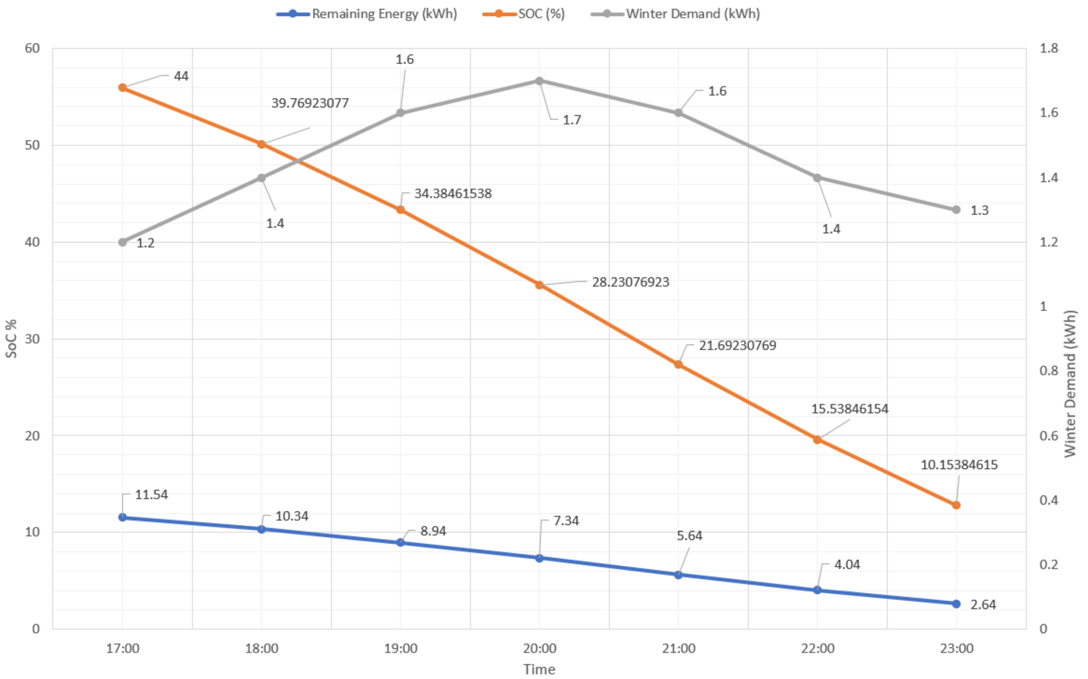

Figure 2.10 Passenger EV - Remaining battery SoC after V2G - winter

Before V2G

- Available Soc: 44. %
- Available capacity: 11.56 kWh

After V2G

- Available Soc: 10.15%
- Available capacity: 2.68 kWh

As a conclusion, based on the figure 2.9 and figure 2.10, that are describing our main use-cases, the vehicle has enough battery capacity to cover the home V2G discharge scenario during afternoon peak demand hours in both summertime and wintertime. After the vehicle is being discharged, the battery has enough time (more than 8 hours) to get a full charge till the next day.

Charging

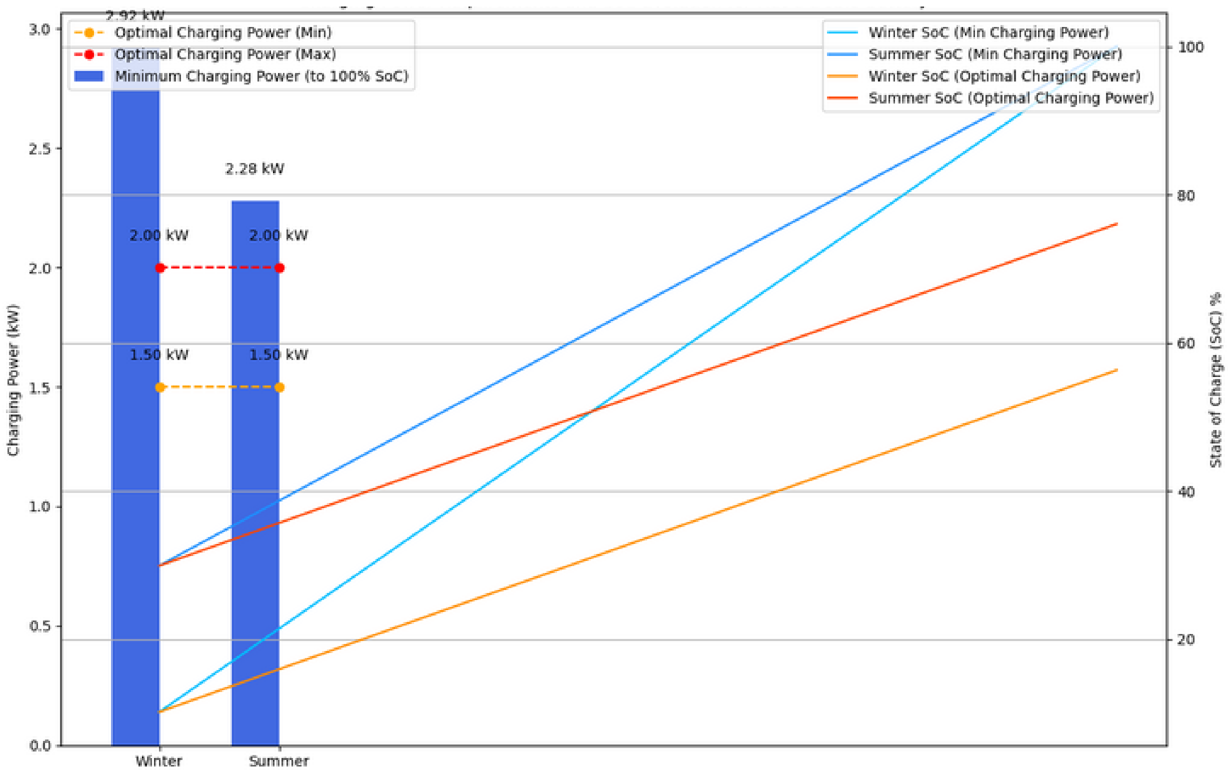

Figure 2.11 Passenger EV - Charging – prolong battery life.

To prolong battery life, the following charging powers are proposed based on seasonal conditions and initial state of charge (SoC):

- **In Winter (-10°C)**: Given the minimum charging power requirement of approximately 2.92 kW starting at an initial SoC of 10.15%, it is recommended to utilize a charging power within the range of 1.5 kW to 2.0 kW. This balances the need for efficient charging with battery longevity considerations.
- **In Summer (+25°C)**: Considering the minimum charging power requirement of approximately 2.28 kW starting at an initial SoC of 29.90%, the recommended charging power range remains 1.5 kW to 2.0 kW. This range effectively supports the balance between charging efficiency and extending battery life.

Implementing these charging power ranges will help optimize the battery lifespan across different environmental conditions and states of charge.

2.3.2 Test-cases and scenario description for InnoBMS EV: "Driving an electric passenger vehicle during weekday."

The base use case, "Driving an electric passenger vehicle during a weekday," serves as a foundational framework for developing specific test cases for the InnoBMS system. These test cases will evaluate the system's performance and its impact on the vehicle's energy management and V2G (Vehicle-to-Grid) capabilities under realistic conditions.

Test Case 1: Morning Commute Energy Consumption and SOC Evaluation
Objective: To evaluate the energy consumption and SOC (State of Charge) during the morning commute.

Description:
- The vehicle departs from home at 07:30 and drives 23 kilometers to the workplace.
- The commute includes various WLTC (Worldwide Harmonized Light Vehicles Test Procedure) driving segments: low-speed, medium-speed, high-speed, and extra-high-speed.

Parameters:
- Distance: 22 kilometers
- WLTC Segments:
  - Low-speed (3.1 km)
  - Medium-speed (4.6 km)
  - High-speed (7.0 km)
  - Extra-high-speed (8.1 km)
- Initial SOC: 100%
- Ambient Temperature: Summer (25°C) and Winter (-10°C)

Metrics:
- Energy consumption for each WLTC segment
- Total energy consumption during the morning commute
- Remaining SOC upon arrival at the workplace

Expected Results:
In Summer (+25°C):
- Energy consumption for each WLTC segment
  - Low-speed (3.1 km) →-45,85 kWh/100km
  - Medium-speed (4.6 km) →-44,36 kWh/100km
  - High-speed (7.0 km) → 40,91 kWh/100km
  - Extra-high-speed (8.1 km) → 45,88 kWh/100km
- Total energy consumption during the morning commute
  - Total energy consumption is 10,13kWh during the morning commute
- Remaining SOC upon arrival at the workplace
  - After the morning commute, remaining SOC is 55,18 % starting at an initial SoC of 100,00%

In Winter (-10°C):
- Energy consumption for each WLTC segment
  - Low-speed (3.1 km) →-59,93 kWh/100km
  - Medium-speed (4.6 km) →50,88 kWh/100km3
  - High-speed (7.0 km) → 45,54 kWh/100km
  - Extra-high-speed (8.1 km) → 48,78 kWh/100km
- Total energy consumption during the morning commute
  - Total energy consumption is 11,43kWh during the morning commute
- Remaining SOC upon arrival at the workplace
  - After the morning commute, remaining SOC is 49,2 % starting at an initial SoC of 100,00%

Regarding the energy consumption in summer (+25°C) and winter (-10°C) in the existing LCV vehicle with the battery capacity 29 kWh, the vehicle consumes half of the battery capacity nearly. In winter, energy consumption is higher than the consumption in summer due to battery heaters.
In the InnoBMS project, a 60kWh battery pack is considered to be used for achieving 12% gravimetric energy density increasing target. The battery's chemistry is NMC 811, which will help extend the vehicle's range with the capacity increasing from 29 kWh to 60 kWh. In this way, the range will be expected to be two times compared to an existing e-vehicle.

Test Case 2: V2G Energy Consumption Evaluation During the Day

The TOFAS e-Doblo will not be considered for grid energy injection due to its absence of Vehicle-to-Grid (V2G) capability, which is essential for bi-directional energy flow and integration into the power grid.

Test Case 3: Afternoon Commute Energy Consumption and SOC Evaluation
Objective: To evaluate the energy consumption and SOC during the afternoon commute.
Description:

- The vehicle departs from the workplace at 16:30 and drives 22 kilometers home.
- The commute includes various WLTC driving segments: low-speed, medium-speed, high-speed, and extra-high-speed.

Parameters:

- Distance: 22 kilometers
- WLTC Segments:
  - Low-speed (3.1 km)
  - Medium-speed (4.6 km)
  - High-speed (7.0 km)
  - Extra-high-speed (8.1 km)
- Initial SOC: SOC after V2G operations (from Test Case 2)

Metrics:

- Energy consumption for each WLTC segment
- Total energy consumption during the afternoon commute
- Remaining SOC upon arrival at home

Expected Results:
In Summer (+25°C):

- Energy consumption for each WLTC segment
  - Nearly same with morning commute
- Total energy consumption during the morning commute
  - Total energy consumption is 10,16 kWh during the afternoon commute
- Remaining SOC upon arrival at the workplace
  - After the morning commute, remaining SOC is 7,75% starting at an initial SoC of 55.18%

In Winter (-10°C):

- Energy consumption for each WLTC segment
  - Nearly same with morning commute
- Total energy consumption during the morning commute
  - Total energy consumption is 11,46 kWh during the afternoon commute
- Remaining SOC upon arrival at the workplace
  - After the morning commute, remaining SOC is 11,93% starting at an initial SoC of 65,00%

In summer (25°C), the vehicle can go back home without charging before home. On the other hand, in winter (-10°C), the vehicle should be recharged before the afternoon commute at least 15-20% SoC to arrive home. In InnoBMS project, it is expected not to recharged before afternoon journey in winter and summer thanks to capacity increase.

Test Case 4: Evening V2G Discharge Scenario
The current vehicle setup does not support V2G.

Test Case 5: Overnight Charging Scenario
Objective: To ensure the vehicle's battery fully recharges overnight in preparation for the next day's use.
Description:

- The vehicle is connected to a charging station from 23:00 to 07:00.
- The charger schedules recharging to maximize cost savings and ensure a full SOC by morning.

Parameters:

- Initial SOC: SOC after evening V2G discharge (from Test Case 4)
- Charging duration: 8 hours
- Charging rate: Based on off-peak electricity rates.

Metrics:

- Final SOC by 07:00 : 100%

Expected Results:
In an existing vehicle, the battery can be charged with 3 phase AC charger with the power 22 kWh. During an 8 hour charging period, up to 80% SoC, the battery will be charged with 20,5 kWh power at constant current. After 80% SoC, the battery will be charged at constant voltage with lower current. In the morning, the battery is expected to be charged fully.

2.3.3 Base use-case: "Driving an electric LCV during weekday."

The base use case focuses on future operational scenarios and the subsequent derivation of load cycles tailored for light commercial electric vehicles (electric LCV). It provides a framework for envisioning potential future contexts and requirements, allowing us to derive specific load cycles that reflect the anticipated usage patterns and demands on electric LCV. By demonstrating the adaptability and foresight of our solution in addressing future needs, this approach will help to prove InnoBMS solution viability for implementation not only in the present but also in the future.

This use case scenario describes the daily operation of an electric light commercial vehicle (eLCV) used for courier delivery services. The vehicle operates on a typical workday schedule from 08:00 to 17:00, including a one-hour lunch break. The scenario includes specific assumptions regarding driving conditions, energy consumption, charging strategies, and state of charge (SOC) management.

Figure 2.12 presents an overview over the "Driving an electric LCV during weekday" base use-case.

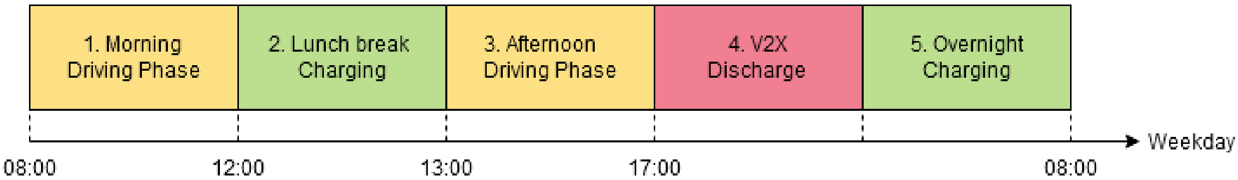

Figure 2.12 eLCV – Use case breakdown into different phases

Key use-case assumptions:

- vehicle: IVECO eDaily;
- vehicle payload: half load;
- Vehicle weight 2517 kg (vehicle target road load model F0:218.5 [N]; F1=0 [N/(km/h)]; F2=0.0849 [(N/(km/h)^2])
- battery capacity: 74 kWh;
- usable battery capacity: 70.3 kWh (95% SOC);
- Use case simplification: Usable battery capacity (70,3 kWh) = 100% SOC
- use-case initial SOC: 100%;
- working hours: 08:00 - 17:00 (8 hours of driving, 1-hour lunch break);
- daily distance covered: 300 km (morning driving: 150 km, afternoon driving: 150 km);
- eLCV UP time KPI: 100% (the vehicle shall be available during the driving phase period);
- WLTC driving environment distribution over the driving phase:
  - LS (Low Speed): 20% of 300 km → 60 km;
  - MS (Medium Speed): 25% of 300 km → 75 km;
  - HS (High Speed): 25% of 300 km → 75 km;
  - EHS (Extra-High Speed): 30% of 300 km → 90 km;
  - Max 90 km/h;
- ambient temperature:
  - Summer Use case (UC1) = 25° C;
  - Winter Use case (UC2) = -10° C;
- UC1 energy consumption by WLTC segments:
  - LS (Low Speed): 20.13 kWh/100 km;
  - MS (Medium Speed): 23.69 kWh/100 km;
  - HS (High Speed): 29.51 kWh/100 km;
  - EHS (Extra-High Speed): 41.68 kWh/100 km;

- UC2 energy consumption by WLTC segments:
    - LS (Low Speed): 23.95 kWh/100 km;
    - MS (Medium Speed): 27.39 kWh/100 km;
    - HS (High Speed): 33.31 kWh/100 km;
    - EHS (Extra-High Speed): 45.48 kWh/100 km
- stops per driving phase: 8 stops; - it is based on the survey with courier companies.
    - Stops distribution:
        - 4 stops during LS,
        - 2 stops during MS,
        - 2 stops during HS.
- stop duration: 3 minutes/stop.

The use case assumptions provide a framework for understanding the operational dynamics of the eLCV in a courier delivery setting. By clearly stating these assumptions, we ensure that the scenario is realistic and applicable to real-world conditions, helping to identify potential challenges and optimize the vehicle's performance throughout the workday.

2.3.3.1 Morning Driving Phase (MDP)

The courier departs from the warehouse at 08:00, with a fully charged EV battery. The morning delivery route includes 150 km, with stops that are spread across urban, suburban, and rural areas. Each delivery stop takes approximately 3 minutes, accounting for potential interactions with the recipients and the need for delivery confirmations.

During the MDP phase, the vehicle operates in various WLTC driving cycles:

1. Low-speed cycle: 30 km - Residential areas.
2. Medium-speed cycle: 37.5 km - Suburban driving.
3. High-speed cycle: 37.5 km - Rural roads with higher speed limits.
5. Extra-high-speed cycle: 45 km - Occasional highways or expressways.

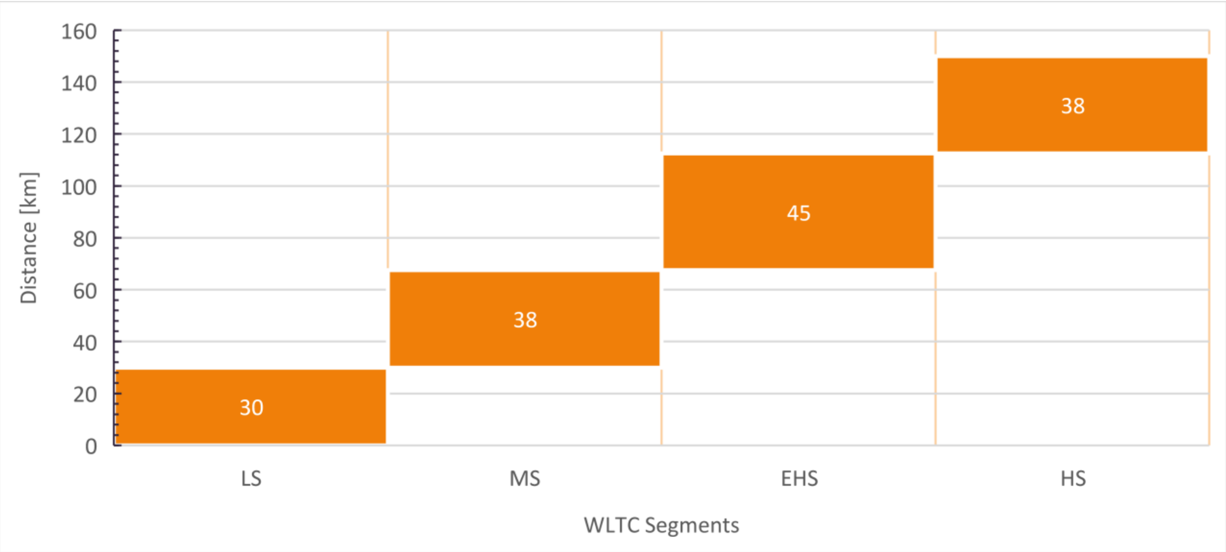

Figure 2.13 eLCV - WLTC segments distribution over the Morning Driving Phase

LS – WLTC low speed segment, MS - WLTC medium speed segment, EHS – WLTC extra high segment, HS – WLTC high speed segment.

Figure 2.13 present an overview over the WLTC segments distribution over the Morning Driving Phase. First segment of 30 km distance is driven in residential area and could be mapped to a LS WLTC cycle with an average speed of 18.9 km/h. The second segment of 37.5 km distance is driven in suburban area and could be mapped to MS WLTC cycle. After that the courier drive 37.5 km distance on highway. This segment could be mapped to an EHS WLTC cycle. The final segment of 45 km is driven in rural area that could be mapped to HS WLTC cycle.

Battery parameters calculation:

Total energy consumed during the morning driving phase.

$$EnrgC = \frac{\mathbf{Distance}\ [\mathrm{km}] \times \mathbf{Energy\ consumption}\ [\mathrm{kWh/100km}]}{100}$$

The vehicle consumption is influenced by the ambient temperature and vehicle speed, therefore the total energy consumed is calculated separately for each WLTC cycle segment, therefore the total energy consumption for the driving phase is calculated using the following formula:

$$Consumption = LS\ EnrgC + \boldsymbol{MS}\ EnrgC + HS\ EnrgC + EHS\ EnrgC$$

Remaining energy is calculated with the following formula:

$$Remaining\ energy = \frac{Battery\ capacity \times \mathrm{Initial\ SOC}}{100} - Consumption$$

Summer Use case (UC1) consumption:

- LS (Low Speed) energy consumption: 20.13 kWh/100 km

$$UC1\ LS\ EnrgC = \frac{\mathbf{30}\ [\mathrm{km}] \times \mathbf{20.13}[\mathrm{kWh/100km}]}{100} = 6.04\ kWh$$

- MS (Medium Speed) energy consumption: 23.69 kWh/100 km

$$UC1\ MS\ EnrgC = \frac{\mathbf{37.5}\ [\mathrm{km}] \times \mathbf{23.69}[\mathrm{kWh/100km}]}{100} = 8.88\ kWh$$

- HS (High Speed) energy consumption: 29.51 kWh/100 km

$$UC1\ HS\ \boldsymbol{EnrgC} = \frac{\mathbf{37.5}\ [\mathrm{km}] \times \mathbf{29.51}[\mathrm{kWh/100km}]}{100} = 11.07\ kWh$$

- EHS (Extra-High Speed) energy consumption: 41.68 kWh/100 km

$$UC1\ EHS\ EnrgC = \frac{\mathbf{45}\ [\mathrm{km}] \times \mathbf{41.68}\ [\mathrm{kWh/100km}]}{100} = 18.76\ kWh$$

Total energy consumed during the morning driving phase in summer temperature conditions:

$$UC1\ MDP\ \boldsymbol{Consumption} = 6.04 + 8.88 + 11.07 + 18.76 = 44.75\ kWh$$

Winter Use case (UC2) consumption:

- LS (Low Speed) energy consumption: 23.95 kWh/100 km

$$UC2\ LS\ EnrgC = \frac{\mathbf{30}\ [\mathrm{km}] \times \mathbf{23.95}[\mathrm{kWh/100km}]}{100} = 7.19\ kWh$$

- MS (Medium Speed) energy consumption: 27.39 kWh/100 km

$$UC2\ MS\ EnrgC = \frac{\mathbf{37.5}\ [\mathrm{km}] \times \mathbf{27.39}[\mathrm{kWh/100km}]}{100} = 10.27\ kWh$$

- HS (High Speed) energy consumption:33.31 kWh/100 km

$$UC2\ HS\ EnrgC = \frac{\mathbf{37.5}\ [\mathrm{km}] \times \mathbf{33.31}[\mathrm{kWh/100km}]}{100} = 12.49\ kWh$$

- EHS (Extra-High Speed) energy consumption: 45.48 kWh/100 km

$$UC2\ EHS\ EnrgC = \frac{\mathbf{45}\ [\mathrm{km}] \times 45.48\ [\mathrm{kWh/100km}]}{100} = 20.47 kWh$$

Total energy consumed during the morning driving phase in winter temperature conditions:

$$UC2\ MDP\ Consumption = 7.19 + 10.27 + 12.49 + 20.47 = 50.42\ kWh$$

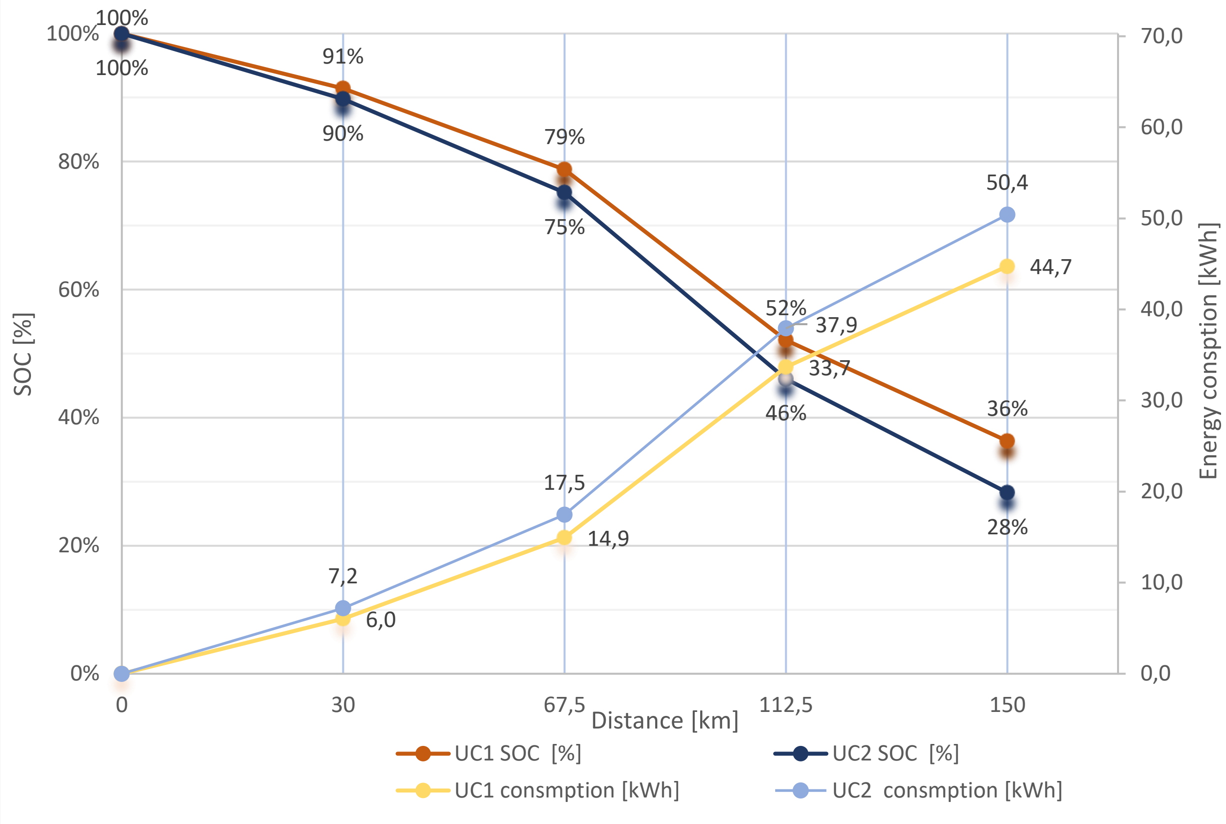

Figure 2.14 eLCV - Energy consumption and SOC evolution during the Morning Driving Phase (MDP) in Summer and Winter conditions

UC1 = Sumer Use-case taking in account average ambient temperature in Europe 25° C, UC2 = Winter Use-case taking in account -10° C ambient temperature, MDP = Morning Driving Phase.

As can be seen in Fig. 2.14, the energy consumption is higher in winter with 5.7 kWh, highlighting the impact of colder temperatures on battery performance and the additional energy required for heating the vehicle. The lower SOC in winter suggests that the eLCV effective range is reduced, which could necessitate more frequent charging stops or adjustments to route planning to accommodate the increased energy usage.

2.3.3.2 Lunch break Charging

The Courier complete the morning driving phase at 12:00, covering 150 km distance, and is going to the charging location for the lunch break and recharging phase.

The vehicle starts the lunch break with an initial state of charge (SOC) after the MDP. A minimum required SOC after the lunch break is defined to ensure that the vehicle can cover 150 km in the afternoon with at least 10% SOC remaining at the end of the workday.

Key lunch break assumptions:

- Initial SOC at lunch break
  - UC1: 36 % (22.4kWh)
  - UC2: 28% (16.7kWh)
- SOC Needed for afternoon driving
  - UC1: 64% (47.8 kWh)
  - UC2: 72% (53.5 kWh)
- Minimum required SOC after lunch break
  - UC1 : 74% (54.8 kWh)
  - UC2 : 82% (60.5 kWh)
- Minimum SOC limit at end of day: 10% (7 kWh)
- DC charging within the supported SOC range of 10% to 80%.
- Charging time: 1 hour (12:00 - 13:00)

During the 1-hour lunch break, the courier has several options for recharging its battery. The choice of charging strategy can significantly affect the amount of energy replenished during this period, impacting the vehicle's operational efficiency for the remainder of the day.

Table 2.3 eLCV possible charging scenarios during the lunch break

Charging Scenario	Charging Power AC [kW]	Charging Power DC [kW]
Workplace charging	3.7-22	-
Public Charging	7	-
	22	-
Fast Charging	-	50 (between 10-80 % SOC)
	-	80 (between 10-80% SOC)

Table 2.3 presents the available option for charging the eLCV battery during the lunch break: workplace charging, public charging, and fast charging. Given that public and fast charging scenarios are more likely in a courier delivery context, our research will focus primarily on these options under both summer and winter conditions.

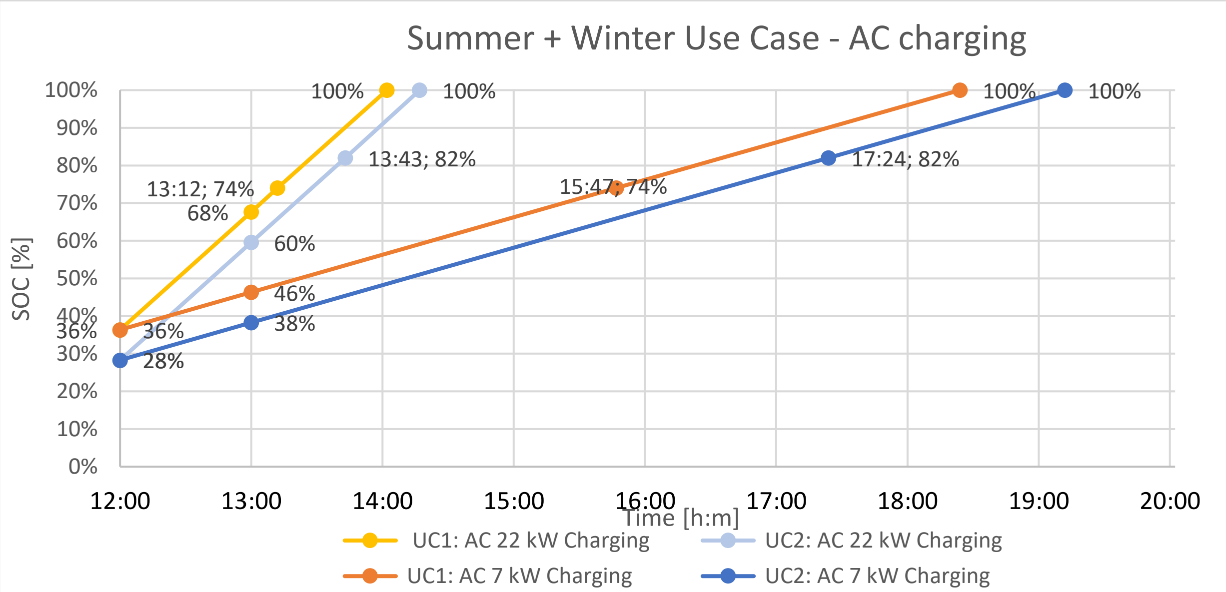

Figure 2.15 eLCV - AC charging scenario during lunch break for summer and winter use-case

UC1 = Sumer Use-case taking in account average ambient temperature in Europe 25° C, UC2 = Winter Use-case taking in account -10° C ambient temperature

Figure 2.15 present an overview over the AC charging scenario taking in account fastest (22kW) and lowest (7kW) charging power available at a public charging station.

The charging strategy that involves the lowest charging power (7kW) it is far below expected SOC. After one hour lunch break the SOC reaches 46 % and the expected SOC is reached 3 hours later, at 15:47 for summer use case conditions. For winter use case conditions, the SOC reaches 38% and the expected SOC is reached 4 hours later, at 17:24.

The charging strategy with public 22 kW AC charging does not meet the minimum required SOC of 74% in summer and 82% in winter after the lunch break. After one hour, the SOC reaches 68% in summer conditions and 60% in winter conditions. The expected SOC is reached at 13:12 (12 minutes later) for summer conditions and at 13:43 (43 minutes later) for winter conditions. To meet the required SOC, adjustments need to be made to the charging strategy or afternoon driving phase:

Solution: adjust the charging time & working schedule.

If the lunch break can be extended beyond one hour, the vehicle can achieve the required SOC. Additional charging time needed is 12 minutes during summer conditions and 43 minutes during winter conditions. Therefore, the lunch break can be extended to one hour and 12 minutes, respectively to one hour and 43 minutes. Another option can be to include an additional or multiple charging phases which can be completed when the courier must deliver multiple packages in a residential area.

The working schedule will be adjusted, between 08:00 and 17:12 during summer and between 08:00 and 17:43 during winter.

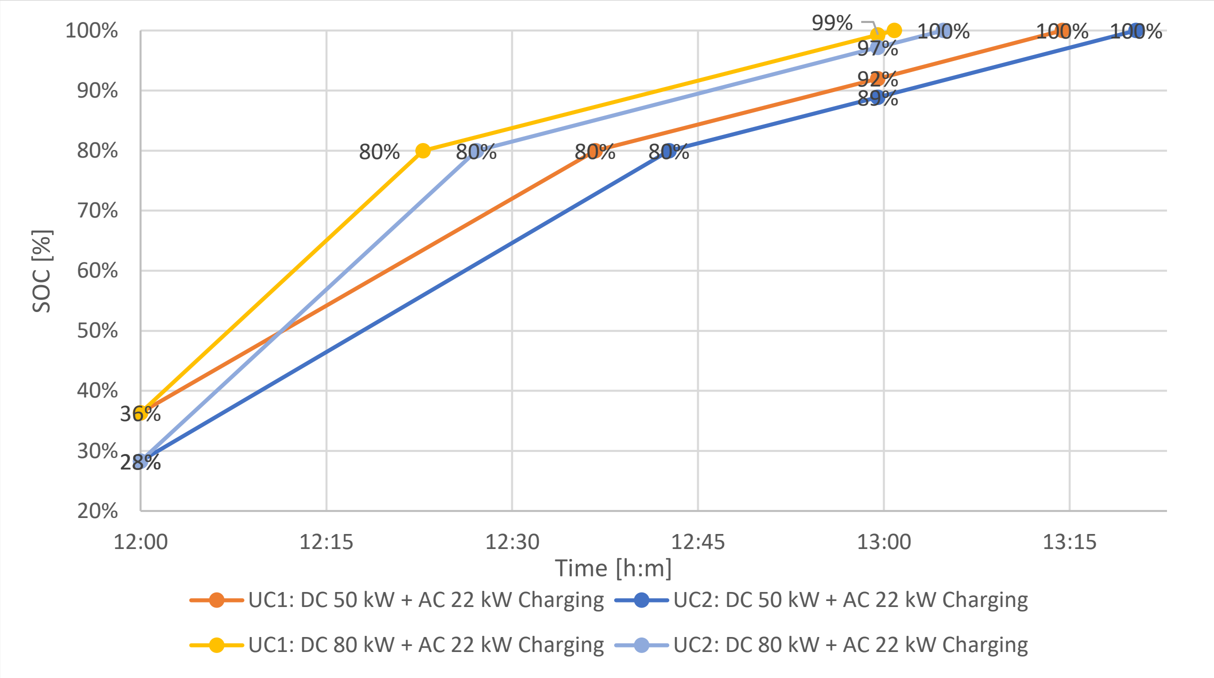

Figure 2.16 eLCV - DC charging scenario for summer use-case (UC1)

UC1 = Sumer Use-case taking in account average ambient temperature in Europe 25° C, UC2 = Winter Use-case taking in account -10° C ambient temperature

Figure 2.16 present the lunch break charging scenario during summer and winter ambient temperature conditions for electric light commercial vehicle (eLCV) with public DC 50kW and 80 kW charging.

By utilizing a combination of DC charging up to 80% SOC and AC charging for the remaining SOC range, the eLCV can ensure a minimum SOC after the lunch break, meeting the operational requirements for the afternoon driving phase. Proper charging management is essential to maintain a minimum SOC of 10% at the end of the workday for continued operations.

Table 2.4 eLCV charging strategy accepting table

Ambient temperature conditions	Charging Strategy	Initial SOC at Lunch Break	Target SOC	SOC after lunch break charging	Meets requirement
Summer 25° C	AC 7 kW Charging (1 hour)	36%	74%	46%	No
	AC 22 kW Charging (1 hour)			68%	No
	AC 22 kW Charging (1 hour 12 minutes)			74%	Yes
	DC 50/80 kW up to 80%			80%	Yes
	DC 80 kW + AC 22 kW (1 hour)			99%	Yes
	DC 50 kW + AC 22 kW (1 hour)			92%	Yes
Winter -10° C	AC 7 kW Charging (1 hour)	28%	82%	38%	No
	AC 22 kW Charging (1 hour)			60%	No
	AC 22 kW Charging (1 hour 43 minutes)			82%	Yes
	DC 50/80 kW up to 80%			80%	No
	DC 80 kW + AC 22 kW (1 hour)			97%	Yes
	DC 50 kW + AC 22 kW (1 hour)			89%	Yes

As it can be seen in table 2.10.2 the charging strategies that are fulfilling the minimum required SOC after lunch break are the strategies that involves DC charging (between 10%-80% SOC) and AC charging (between 80%-100%). In summer conditions, DC charging up 80% will be enough to meet the minimum SOC required for afternoon driving phase, yet for winter conditions this charging strategy it will not meet the requirements.

Extending the lunch time with 12 minutes in summer and 43 minutes in winter is not an acceptable solution, since the vehicle up time is an important KPI for the currier companies.

As the lunch break is during the off peak period, the proper charging strategies to be applied are the ones that involve DC up to 80% and AC charging between 80% and 100%.

2.3.3.3 Afternoon Driving Phase (ADP)

The afternoon delivery route includes 150 km, with stops that are spread across urban, suburban, and rural areas. Each delivery stop takes approximately 3 minutes, accounting for potential interactions with the recipients and the need for delivery confirmations.

During the phase, the vehicle operates in various WLTC driving cycles:

1. Low-speed cycle: 30 km - Residential areas.
2. Medium-speed cycle: 37.5 km - Suburban driving.
3. High-speed cycle: 37.5 km - Rural roads with higher speed limits.
5. Extra-high-speed cycle: 45 km - Occasional highways or expressways.

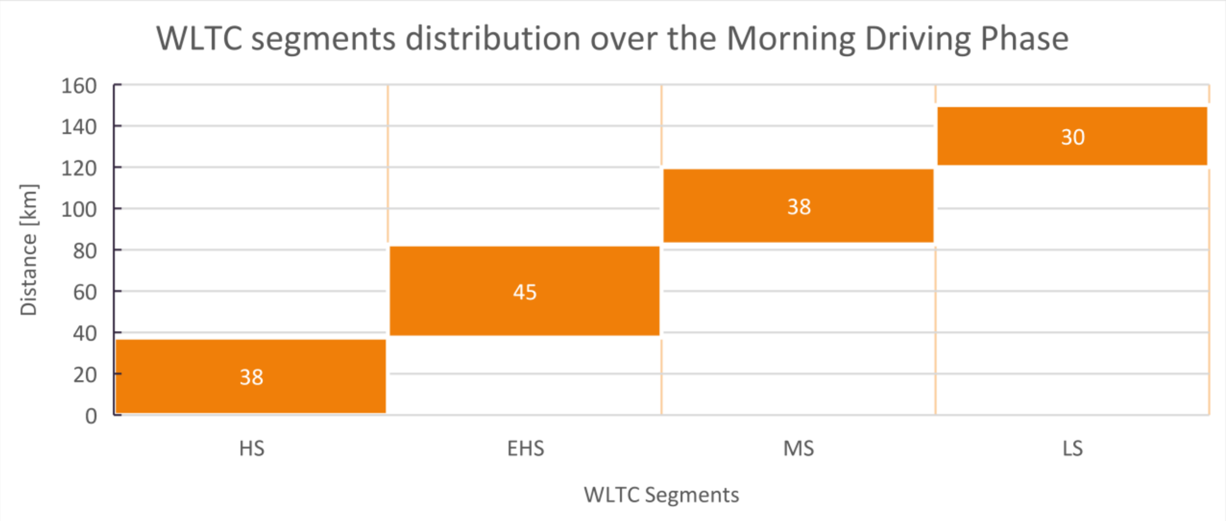

Figure 2.17 eLCV - WLTC segments distribution over the Afternoon Driving Phase

LS – WLTC low speed segment, MS - WLTC medium speed segment, EHS – WLTC extra high segment, HS – WLTC high speed segment.

Figure 2.17 present an overview over the WLTC segments distribution over the Afternoon Driving Phase. First segment of 37.5 km distance is driven in rural area and could be mapped to a HS WLTC cyclE, the second segment of 45 km distance is driven on highway and could be mapped to EHS WLTC cycle. After that the courier drive 37.5 km distance in suburban area, followed by the last segment of 30 km that could be mapped to LS WLTC cycle.

The courier departs from the charging station at 13:00, with a charged eLCV battery as described in table 2.5.

Table 2.5 Lunch break initial eLCV SOC for different charging strategies and ambient temperatures

UseCase ID	Ambient Temperature	Charging strategy	Initial SOC at afternoon driving phase
UC1.**1**	25° C ambient temperature	DC 50 kW + AC 22 kW	92%
UC1.**2**		DC 80 kW + AC 22 kW	99%
UC2.**1**	-10° C ambient temperature	DC 50 kW + AC 22 kW	89%
UC2.**2**		DC 80 kW + AC 22 kW	97%

As is presented in table 2.5, there are different initial SOC's for the afternoon driving, due to the different charging strategies applied. The difference on the ambient temperature conditions comes from different initial SOC at the start of the charging phase.

The use case definition includes DC charging strategies only, since AC charging strategies does not meet the minimum required SOC after one hour lunch break.

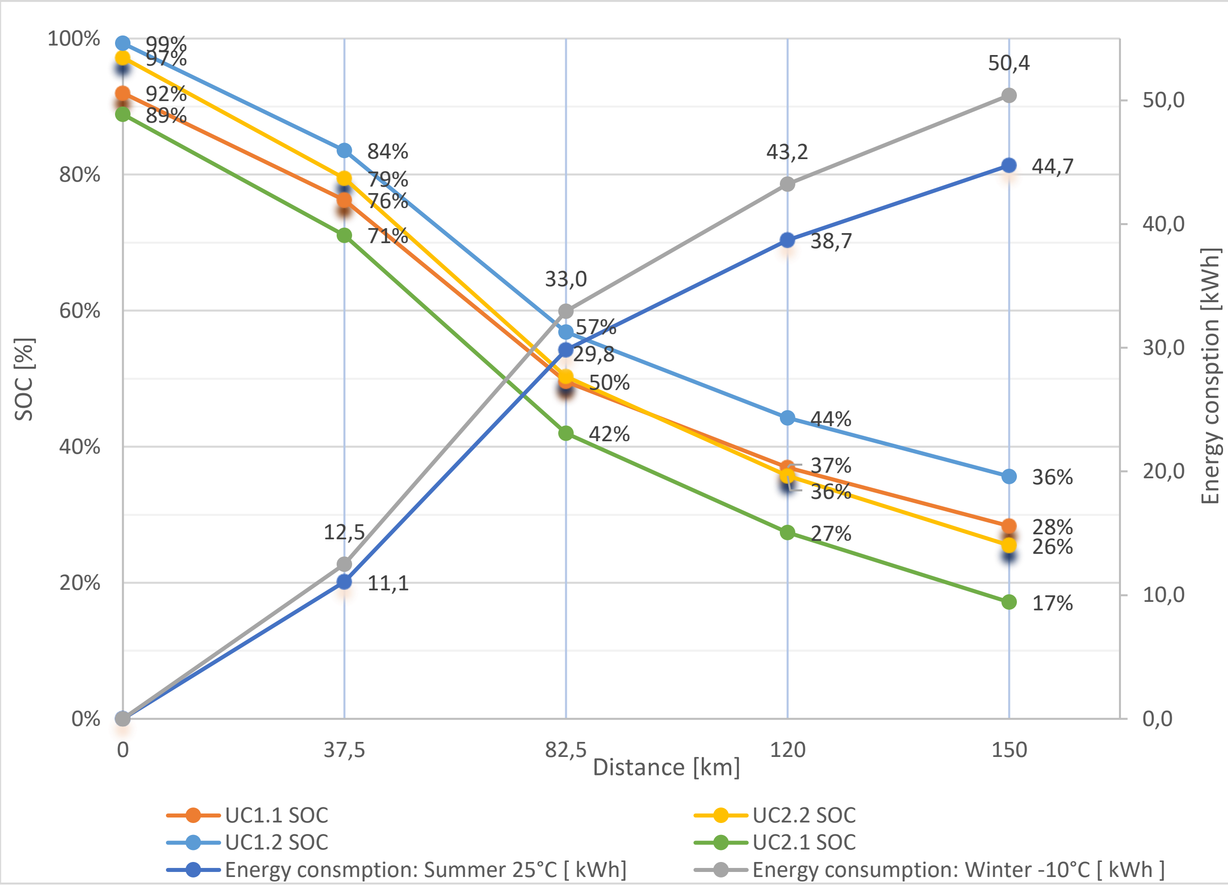

Figure 2.18 eLCV - Energy consumption and SOC evolution during the Afternoon Driving Phase (ADP) in Summer and Winter conditions.

UC1.1 = 25° C ambient temperature and DC 50 kW + AC 22 kW charging during lunch break, UC1.2 = 25° C ambient temperature and DC 80 kW + AC 22 kW charging during lunch break, UC2.1= -10° C ambient temperature and DC 50 kW + AC 22 kW charging during lunch break, UC2.2= -10° C ambient temperature and DC 80 kW + AC 22 kW charging during lunch break

As can be seen in Fig. 2.18, the SOC evolution during the afternoon driving phase is influenced by the ambient temperature conditions, having a higher SOC decrease during winter compared with summer conditions. The SOC at the end of the driving phase being influenced by the consumption in different ambient temperature conditions and the initial SOC value.

Lowest SOC value, 17%, is encountered at the end of UC2.1, which include two driving phases in winter conditions, and one hour charging at 50 kW DC + 22 kW AC.

Highest SOC value, 36%, is encountered at the end of UC1.2, which include two driving phases in summer conditions, and one hour charging at 80 kW DC + 22 kW AC.

2.3.3.4 V2X Discharge & Charging

The Courier complete the morning driving phase at 17:00, covering 150 km distance, and is going to the warehouse to park the eLCV overnight. During this time the eLCV is plugged-in to the warehouse charging *station with bidirectional functionalities installed*.

V2X functionalities allow electric vehicles to power home or building appliances, providing a backup energy source during outages or peak electricity pricing periods. A smart energy management can lead to significant cost savings for homeowners by reducing reliance on the grid during these expensive peak times. Moreover, the ability to use stored vehicle energy for home or building appliances enhances energy resilience and supports the integration of renewable energy by balancing supply and demand. Financially, this can lower household or building energy bills and provide potential income through grid services incentives. Nonetheless the EV owner will be able to decide the SoC limits within such V2X functionalities can operate.

Key V2x assumptions:

- Initial SOC at V2X phase
  - UC1.1: 28% (15.7 kWh)
  - UC1.2: 36% (21.1 kWh)
  - UC2.1: 17% (7.7 kWh)
  - UC2.2: 26% (13.4 kWh)
- SOC Needed at the end of the V2X phase: 100%
- Minimum SOC threshold for V2X: 20%
- V2X phase duration: 13 hours (17:00 - 08:00)
- EU Off peak period: 17:00-18:00 and 00:00-06:00;
- EU Peak period 18:00-00:00 (6 hours) and 06:00-08:00 (2 hours).
- Warehouse energy consumption per year :1 925 818 kWh/year -507 715 kWh/year
- Warehouse energy consumption per day: 5 276 kWh/day -1 391 kWh/day
- Medium value of warehouse energy consumption per day: 3 333 kWh/day
- Use case simplification:
  - medium value of warehouse energy consumption per day is considered for use case;
  - warehouse energy consumption is constant during the day;
  - Electrical power for warehouse taking in account medium consumption: 139 kW.

There are several V2X strategies presented in chapter 2.2, yet the most suitable V2X strategy for InnoBMS eLCV is Peak Load Shaving.

The **peak load shaving** V2X strategy includes charging during off-peak hours and discharging during peak periods, with a constraint that the vehicle cannot be discharged during the second peak period (06:00-08:00) to ensure it starts the day with a 100% SOC.

Including the restriction on V2X discharging during the 06:00 - 08:00 peak period, we ensure the scenario is realistic and applicable to real-world conditions. This approach helps to identify potential challenges and optimize the vehicle's performance throughout the workday, while aligning with the needs of the use case

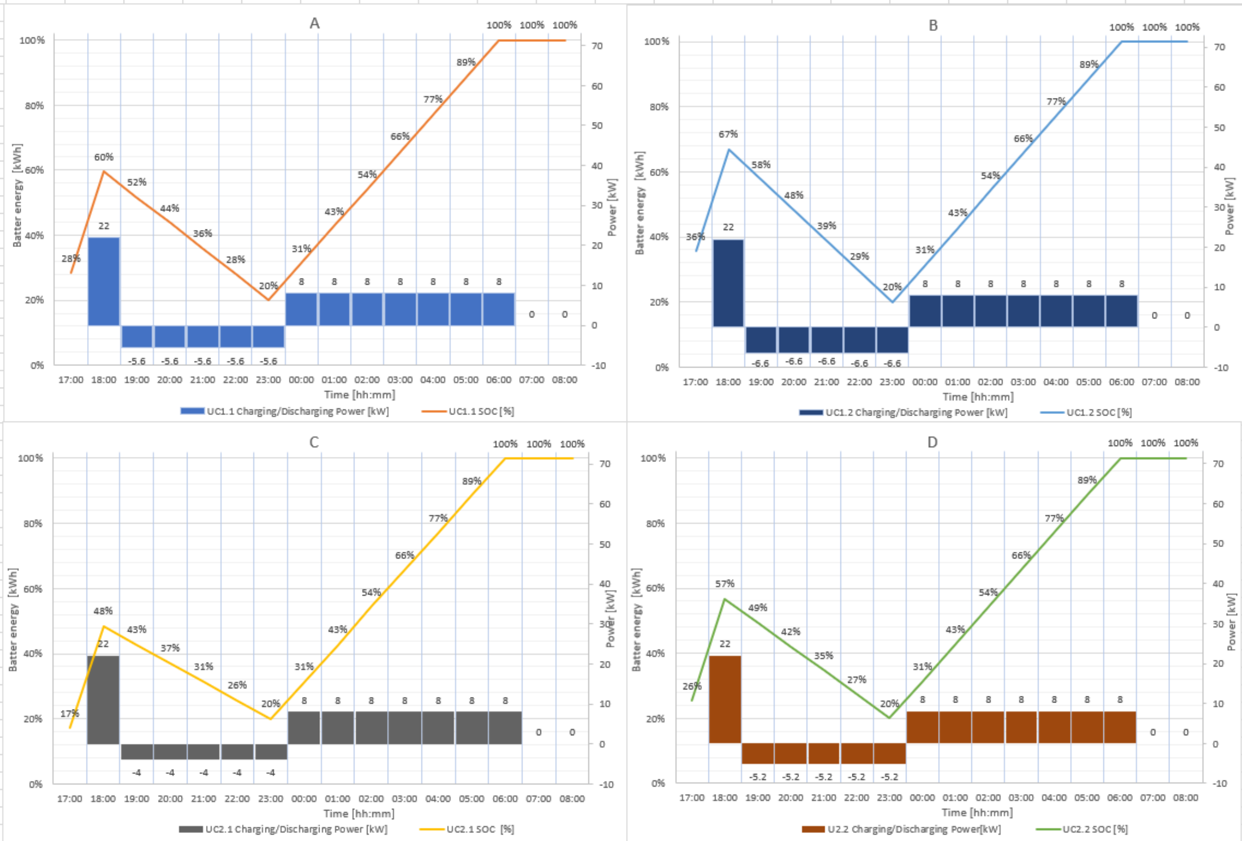

Figure 2.19 eLCV operation simulation outputs during the V2X Discharge & Charging phase.

(A) UC1.1 = 25° C ambient temperature and DC 50 kW + AC 22 kW charging during lunch break, (B) UC1.2 = 25° C ambient temperature and DC 80 kW + AC 22 kW charging during lunch break, (C) UC2.1= -10° C ambient temperature and DC 50 kW + AC 22 kW charging during lunch break, (D) UC2.2= -10° C ambient temperature and DC 80 kW + AC 22 kW charging during lunch break

Fig 2.19 present the eLCV operation simulation during the night period in for different scenarios differentiated by the ambient temperature and charging strategy during the lunch break. For all for scenarios it is applied the same V2x to grid strategy, including one hour charging between 17:00 and 18:00, followed by a discharge period of five hours during the night peak period, and in the end the battery is fully charged during the off-peak period.

Between 17:00 and 18:00 the vehicle is charged using maximum power available to maximize the benefits of charging during the off-peak period and discharge during peak period.

Between 16:00 and 23:00 the vehicle is discharged at a power level that ensures the battery State of Charge (SOC) reaches 20% at the end of the phase. It can be seen that the maximum discharge power of 6.6 kW is present in scenario (B) summer use case and DC 80 kW + AC 22 kW during lunch break and lowest discharge power of 4kW is in scenario (C) winter use case and DC 50 kW + AC 22 kW during lunch break.

If we consider the power needed by the warehouse of 139 kW, we can conclude that warehouse needs to draw energy from 35 (scenario C) or 21 (scenario B) eLCV to avoid using any energy from the grid during peak period.

Starting from 23:00 until 06:00 the vehicle is fully charged, using a constant power of 8 kW. The charging power represent the minimum power to achieve 100% SOC at 06:00.

The vehicle is not discharged between 06:00 and 08:00 to ensure it starts the morning driving phase with a 100% SOC.

Renewable Energy Integration V2X strategy for charging electric light commercial vehicles (eLCVs) can be challenging due to several factors. Setting up a renewable energy system (like solar panels and wind turbine) involves high initial investment costs.

Solar panels only generate electricity during the day, therefore they do not match the charging needs of an eLCV. A potential solution is to implement large-scale battery storage that help to store excess renewable energy and provide it when needed.

Similarly, wind power is dependent on wind speeds, which can be unpredictable and vary throughout the day and seasons.

Frequency Regulation V2X strategy can be implemented to use the eLCV battery for the frequency regulation services, providing rapid response to fluctuation in grid frequency.

The main issue with this strategy is that frequent charging and discharging for frequency regulation can accelerate battery degradation and reduce its lifespan.

The strategy generates revenue for the building owner by providing ancillary grid services, yet the economic benefits of providing frequency regulation services must outweigh the costs of additional battery degradation, infrastructure investment.

Emergency Backup Power V2X strategy uses eLCV as emergency power source during grid outages to power the warehouse. The strategy avoids downtime and potential losses from business interruption, resulting in cost savings.

For eLCV use case scenario it is assumed one hour power outage, in most critical scenario, between 17:00 and 18:00, where eLCV encounters lowest SOC 17% in UC2.1 conditions. If a minimum emergency SOC is considered at10%, then the available energy for discharge will be 4.9kWh.

Taking in account the medium energy consumption of a warehouse, it is needed to draw the energy from around28 eLCV to power-up an warehouse for one hour.

2.3.4 Test-cases and scenario description for InnoBMS EV: "Driving an electric LCV during weekday."

Key use-case assumptions	Iveco E-Daily
Vehicle	IVECO eDaily
Vehicle payload	half load
Battery capacity	74 kWh
Usable battery capacity	70.3 kWh (95% SOC)
Fast charge capability	50kW & 80 kW.
Fast charge limitations	Fast charge allowed between 10%-80% SOC
Maximum AC charging	22 kW
Maximum V2x discharging	10 kW
Maximum vehicle speed	90 km/h
25°C ambient temperature energy consumption by WLTC segments	Low Speed: 20.13 kWh/100 km Medium Speed: 23.69 kWh/100 km High Speed: 29.51 kWh/100 km Extra-High Speed-max 90 km/h: 41.68 kWh/100km
-10°C ambient temperature energy consumption by WLTC segments	Low Speed: 23.95 kWh/100 km Medium Speed: 27.39 kWh/100 km High Speed: 33.31 kWh/100 km Extra-High Speed - max 90 km/h: 45.48 kWh/100km

3 Integration of cloud functionalities within EV's

The integration of cloud functionalities within EVs is ready to significantly enhance the value and performance of key components and subsystems. By leveraging cloud-based services and connectivity, EVs can achieve superior efficiency, improved user experiences, and advanced energy management capabilities. This section explores the specific cloud functionalities that contribute added value to crucial EV components and subsystems, demonstrating how these innovations drive the evolution of modern electric transportation.

Central to this advancement is V2C connectivity, which allows EVs to exchange data with cloud servers. V2C facilitates a range of applications from navigation and traffic management to remote diagnostics and predictive maintenance. This connectivity ensures that vehicles are not only smarter and more efficient but also better integrated into the broader energy ecosystem, including smart grids and renewable energy sources.

Outline of how V2C connectivity can be integrated to optimize EV usage:

- Data exchange over:
  - grid conditions: V2C enables the vehicle to receive close to real-time data on grid conditions, such as demand peaks, frequency, renewable energy availability, and energy prices. This information can be used to adjust the V2X discharge strategy dynamically to support grid stability and maximize economic benefits. Possible V2X discharge algorithms:
    - Load balancing: advanced algorithms running in the cloud can optimize the discharge across multiple vehicles to balance the load on the grid, ensuring the use preferences and vehicle's primary use.
    - Cost optimization: the cloud can optimize the discharge strategy to take advantage of lower energy prices or higher incentives during peak demand periods.
    - Energy trading: the vehicle can participate in energy trading markets, selling excess energy back to the grid when prices are high and buying energy when prices are low.
  - vehicle status: the vehicle can send real-time updates about its SOC, battery health, and current usage patterns to the cloud. This helps in making informed decisions about when and how much energy to charge or discharge to maximize the battery lifetime and economic benefits.
- Predictive analytics over:
  - energy demand forecasting: using historical data and predictive analytics, V2C can forecast future energy demand and advise the vehicle on optimal charge and discharge times to support grid stability and efficiency.
  - weather and renewable energy integration: predictive models can integrate weather forecasts to predict the availability of renewable energy sources (like solar and wind) and adjust the V2X strategy accordingly.
  - user behavior analysis: by analyzing historical driving patterns and user behavior, V2C can predict the optimal times for energy discharge without compromising the vehicle's primary use.
  - energy consumption prediction: V2C uses predictive analytics to forecast energy consumption based on driving patterns, route profiles, and real-time environmental conditions. This helps in better managing the vehicle's SOC.

- Remote monitoring and control:
  - Personalized settings: users can set preferences for V2X discharge, such as minimum SOC thresholds and preferred discharge times or strategies, via a cloud-based interface. This ensures that the vehicle's discharge strategy aligns with the owner's needs and lifestyle.
  - Notification and alerts: V2C can send notifications and alerts to the user regarding V2X activities, providing transparency and control over the discharge process.
  - User preferences synchronization: synchronization of user preferences across multiple vehicles or drivers, including seat settings, climate control, and preferred driving modes.
  - Automated decision-making: cloud-based algorithms can automate the decision-making process for V2X discharge, optimizing the balance between driving needs and grid support.
  - Vehicle health monitoring: continuous monitoring of vehicle health and performance data allows for early detection of potential issues. This can trigger maintenance alerts or even remotely diagnose and address minor issues.
  - Driver behavior monitoring: analysis of driver behavior can help improve driving efficiency and safety by providing feedback and recommendations.

4 2nd life use

Second-life applications of EV batteries present a promising future solution for sustainable energy storage and resource optimization. Per definition: once a EV battery degrade to about 70-80% of their initial capacity, it may no longer be usable for transport applications, but it might be still usable in less demanding energy storage applications.

A significant second life application is in stationary energy storage or buffer systems, where these batteries can be used to store and provide excess energy generated from renewable sources. Such systems would help balance energy supply and demand, ensuring a more stable and reliable grid. Therefore, a second-life application not only extend the overall lifetime of a battery it will also support the integration of renewable energy into the grid.

Additionally, second-life EV batteries can be considered for residential energy storage solutions, allowing homeowners to store energy during off-peak periods or from their own renewable energy installations. This enhances energy independence, provides backup power during outages, and can lead to significant cost savings and energy demand from the grid.

Repurposing EV batteries will reduce the environmental impacts associated with battery disposal. By delaying recycling processes, the environmental footprint of battery production is reduced, promoting a more circular economy. Overall, second-life applications of EV batteries are a crucial step towards a more sustainable energy future.

5 Results & Discussion

5.1 Results

Besides the use case specification, that can be found in the chapters 2 and 3, in the following a condensed overview of InnoBMS requirements and their link to use-case phase and V2C integration.

Table 5.1 Use case derived Requirements

Use-case phase	Requirement owner	Requirements
Driving Phase	EV	InnoBMS shall include advance thermal management functionality.
		InnoBMS shall provide accurate battery parameters.
Charging phase	EV	InnoBMS shall support fast charge functionality.
		InnoBMS shall implement predictive models to forecast future trips and their energy requirements, optimizing charging strategy.
V2X Phase	EV	InnoBMS shall supports bidirectional energy flow, allowing it to both charge from and discharge to the grid.
		InnoBMS shall ensure safe and efficient energy transfer, monitor battery health, and manage charging/discharging cycles.
		InnoBMS shall provide remaining useful life of the battery to adjust the V2G strategies.
		InnoBMS shall allow user to set preferences for V2G participation, such as SOC levels, V2G timing, consumable power for V2G functionality.
	Home / building	Charging unit with bidirectional functionality shall be installed, to supports both charging the EV and drawing power from the EV to supply the home/building or grid.
		Smart meters shall be installed to monitor energy flow, usage, and pricing, enabling dynamic response to grid signals.
		An energy management system shall be installed to optimize energy use within the home/building, balancing between the EV, grid, and home/building energy needs.
	Electrical Grid	Grid infrastructure shall integrate V2G services into the energy market, allowing EV owner to use different V2G strategies.
		Grid owner shall develop incentive for EV owners to participate in V2G, such as financial rewards, reduced energy tariffs, or V2G-capable equipment.
		Grid infrastructure shall facilitate real-time data exchange between EV's, charging station and grid management system.
All	V2C	The V2C shall synchronize data efficiently between the vehicle and the cloud to provide up-to-date information.
		The V2C shall provide high bandwidth capabilities to handle large volumes of data from telematics and sensors.
		The V2C shall provide scalable storage solutions to support growing data volumes generated by EVs.
		The V2C shall analyse EV behaviour to monitor and improve efficiency and safety.
		The V2C shall provide high processing power to support complex analytics and machine learning for EVs.
		The V2C shall provide personalized services to support customized user profiles, preferences, and settings synchronization.
		The V2C shall connect with grid management systems to support V2G and other V2X applications.
		The V2C shall provide connectivity with energy trading platforms to allow vehicles to participate in energy markets.
		The V2C shall be able to perform remote software and firmware updates to enhance performance and add new features.

Based on the use case scenario, the following bidirectional interfaces have been identified to enable V2G functionality.

Table 5.2 Bidirectional interfaces V2G

Interface	Interface flow (bidirectional)
Voltage limit	EV to charger
Electric current limit	EV to charger
SOC	EV to charger
Charging status	EV to charger
Charging/discharging rates	EV to charger
Battery capacity	EV to charger
Demand-response signals	Charger to Grid
Frequency-response signals	Charger to Grid
V2G participation	Charger to Grid
Energy prices	Charger to Grid

5.2 Contribution to project (linked) Objectives

This deliverable contributes to all of the InnoBMS objectives as it sets up the initial input for requirement processes and the test case scenario that will be used to demonstrate the InnoBMS project results.

5.3 Contribution to major project exploitable result

This deliverable is in-line with the required project targets by exploring the technical basis and respecting actual trends in the EU - as input for the following work packages and exploitations.

6 Conclusion

Analyzing the driving phases for both passenger vehicles and electric light commercial vehicles reveals that ambient temperature is a significant factor influencing electric vehicle consumption. Cold temperatures, particularly in winter, increase energy consumption due to the need to heat both the vehicle and the battery, leading to a reduced vehicle range. Therefore, improving thermal management could greatly impact vehicle consumption and extend vehicle range.

Analyzing the charging phases for both passenger vehicles and electric light commercial vehicles reveals distinct needs based on usage patterns.

Passenger Vehicles require one charging phase overnight due to the reduced daily distance traveled. Overnight charging with a slow, optimal power strategy ensures the vehicle reaches 100% SOC by morning.

Electric light commercial vehicle used for Courier Delivery require two charging phases: lunch break charging and overnight charging. Due to the limited time available and the high energy needed for the second driving phase, a fast-charging strategy is necessary for the lunch break charging phase. Similar to passenger vehicles, electric light commercial vehicles also benefit from a slow, optimal power charging strategy overnight to achieve 100% SOC by morning.

In conclusion, a fast charging strategy is essential for electric light commercial vehicles to meet the demands of their daily operations, whereas for passenger vehicles, fast charging is optional and depends on the daily distance covered.

Vehicle-to-Everything (V2X) applications offer a variety of energy-related benefits, enhancing efficiency and sustainability. Key among these is Vehicle-to-Grid (V2G) technology and Vehicle-to-Home (V2H), which allows EVs to feed stored energy back into the grid during peak demand periods, stabilizing the grid and supporting renewable energy sources or act as a stationary battery for home appliances. This helps to keep a balance between supply and demand, reducing the need for additional power generation.

By optimizing energy flow between EVs and the grid, V2X applications can significantly lower overall energy costs for EV owners, who can earn financial benefits from their contributions. Bidirectional energy exchange will enhance grid resilience, stability and reliability. Moreover, by integrating renewable energy sources, such as solar or wind, with V2X-enabled EVs, excess energy can be stored in vehicle batteries during low-demand periods and later used or fed back into the grid when demand is high. This promotes the efficient use of clean energy and reduces reliance on non-renewable resources. Overall, V2X applications play a crucial role in creating a more efficient and sustainable energy system.

Integrating V2C connectivity into EVs represents a significant step forward in creating intelligent, efficient, and user-friendly vehicles. By harnessing the power of cloud computing and real-time data exchange, V2C transforms the way EVs operate, interact with their environment, and deliver value to their users. This integration supports efficient navigation, personalized user experiences, and proactive vehicle maintenance, leading to improved vehicle performance and safety.

Moreover, V2C connectivity optimizes V2X discharge and charging strategies, enhancing the efficiency, flexibility, and responsiveness of EV energy management. By leveraging real-time data and predictive analytics, V2C ensures that vehicles can support grid stability, reduce energy costs, and maximize the use of renewable energy. As the technology continues to evolve, V2C will play a crucial role in driving the adoption and success of electric vehicles worldwide, paving the way for a sustainable and connected future.

7 Risks and interconnections

7.1 Risks/problems encountered.

Because the use cases outline the general boundary conditions for the following work packages no specific risks have been identified.

7.2 Interconnections with other deliverables

Based on the results of this WP, the requirements will be followed through the WP2 and WP5.
WP2: Advanced Functionalities, Simulation and Testing Methods
WP5: Testing, validation and demonstration with which interactions exist are completed.

8 Deviations from Annex 1

No deviations.

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Project partners:

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2	TOFAS	TOFAS Turk Otomobil Fabrikasi Anonim Sirketi
3	BOSCH	Robert Bosch GmbH
4	AVL	AVL List GmbH
5	AVL-SFR	AVL Software and Functions Gmbh
6	IDIADA	Idiada Automotive Technology SA
7	CID	Fundacion Cidetec
8	UL	Univerza v Ljubljani
9	THIL	Tajfun Hil Društvo sa Ograničenom Odgovornošću za Istraživanje, Proizvodnju, Rgovinu i Usluge Novi Sad
10	UNR	Uniresearch BV
11	FMF	FPT Motorenforschung AG
12	PTE	Potenza Technology Limited

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