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V2X Scenarios Analysis for Future-Proof Battery Management Systems

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Executive Summary

This paper illustrates how the vehicle-to-everything (V2X) capabilities of an advanced battery management system (BMS) integrating bidirectional energy interfaces and critical load management scenarios could be employed in the daily operation of electric vehicles (EVs). It details the employment of a future-proof BMS V2X, emphasizing enhanced battery utilization, longer lifespan, and improved performance under real-world conditions. Elements include the application of V2X technologies such as vehicle-to-grid (V2G), enabling EVs to contribute to grid stability, renewable energy integration, and household power supply during peak demands or outages. In this paper, comprehensive scenarios for passenger EVs and light commercial vehicles, analyzing energy consumption and charging behaviors across different operational and environmental conditions are provided. This holistic approach aligns with broader sustainability goals by fostering EV adoption and supporting renewable energy grid integration.

Keywords: electric vehicles, consumer behaviour, V2H & V2G, batteries, battery management system

1 Introduction

Vehicle-to-everything (V2X) is a bidirectional charging and/or communication technology that enables vehicles to communicate with various systems, such as other vehicles (V2V), infrastructure (V2I), pedestrians (V2P), and the electrical grid (V2G). Through such integration, road safety, traffic efficiency, and energy management can be enhanced by facilitating real-time data exchange. The growing adoption of electric vehicles (EVs) and the need for coordinated charging of an expanding EV fleet have highlighted the importance of V2X technologies [1, 2, 3, 4, 5, 6].

In an electric vehicle (EV), V2X functions can be integrated into an advanced battery management system (BMS). V2X enables the BMS to communicate with the grid and other infrastructure, allowing for intelligent scheduling of charging and discharging cycles. This coordination ensures that vehicles charge during off-peak hours when electricity is cheaper and discharge during peak demand, benefiting both the grid and the vehicle owner [1, 2, 3, 4, 5, 7, 8]. By managing energy flows more effectively, a V2X-equipped BMS can reduce the depth of discharge cycles, thereby conserving battery life or extending it [9]. At the grid level, EVs can act as distributed energy resources, providing ancillary services such as frequency regulation and load balancing, which are crucial for grid stability, especially for intermittent renewable energy sources. By integrating V2X technology into BMS, EVs become active participants in the energy ecosystem, contributing to a more resilient and efficient power grid [1, 2, 3, 4, 5, 7, 10].

In the evolving landscape of electric mobility, understanding the practical applications and operational demands of EVs is essential, particularly in the transition toward more sustainable transportation systems. This paper will analyze these demands by developing realistic and forward-looking use case scenarios for passenger EV cars and electric light commercial vehicles (eLCVs). These use cases serve as the foundation for defining load cycles that encompass not only typical driving conditions but also the broader energy interactions involved in charging—whether through alternating (AC) or direct current (DC)—and in bidirectional energy exchanges associated with V2X technologies.

The next section, Section 2 will expound on the setup of the use cases. On the other hand, Section 3 will discuss in detail the operation of the considered EVs within the context of the V2X use cases. Lastly, Section 4 will provide a conclusion to this contribution.

2 EV Use Cases

A use case in this context is defined as a comprehensive scenario that illustrates how an EV is utilized to achieve specific objectives within certain environmental and operational constraints. Deriving these use cases in this paper followed a collaborative and iterative process. It began with a structured questionnaire aimed at capturing technical understanding, followed by extensive literature reviews and targeted interviews with stakeholders, including courier companies operating eLCVs and private EV users. This approach ensured that the selected use cases reflect realistic, meaningful challenges and expectations for the next generation of BMS.

In the context of European vehicle taxonomy, EVs are classified into specific segments that reflect their size, design, and intended use. This classification system helps standardize performance expectations and infrastructure planning across the EV market. The European Commission passenger car classification aligns with the traditional internal combustion engine (ICE) vehicle classifications and includes the following segments: (A) city cars, (B) small cars, (C) medium cars, (D) large cars, (E) executive cars, (F) luxury cars, (S) sport coupes, (J) sport utility cars, and (M) multipurpose cars or multipurpose vehicles (MPV) [11].

Two EVs are considered: Fiat e-Doblò and IVECO eDaily. While the Fiat e-Doblò is in the M segment following the classification, it is treated under the passenger vehicle category due to its use case in personal transport. On the other hand, the IVECO eDaily is under the LCV category and represents the more energy-demanding and operationally constrained vehicle segment [1]. The distinction is important, as the differing energy needs, driving patterns, and infrastructure requirements of these vehicle types influence the design and evaluation of battery management strategies, especially for V2X and bidirectional energy flow scenarios.

2.1 Passenger EV Base Use Case

The base use case focuses on operational scenarios for EVs, enabling the development of load cycles that mirror anticipated usage patterns and demands. Key assumptions include the average daily distance traveled by the EVs, as well as battery and energy costs [1]. These factors serve as a basis for modeling and analyzing V2X's feasibility and cost-effectiveness within the European market. By incorporating these elements, the use case serves as a benchmark to evaluate the performance of BMS technologies in everyday urban and suburban driving.

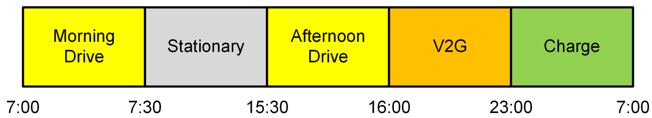

Figure 1: Different phases of the passenger EV use case.

The scenario assumes that the user commutes on a Fiat e-Doblò 22.8 km each way—from home to work in the morning, and back in the evening—totaling approximately 45.6 km per day. Fig. 1 lays out the use case throughout the workday. The vehicle is active during two specific driving phases: 7:00–7:30 for the morning commute, and 15:30–16:00 for the return home. Between these driving periods, the vehicle remains stationary and is typically parked at the workplace, but is not plugged into a charging station.

Upon arrival at home, the passenger EV enters the V2G phase where the vehicle is connected to a public charging station. During this phase, the charger manages charge and discharge based on the grid conditions and the battery SoC. Bidirectional energy flow between the EV and the grid considers factors such as grid stability, energy demand, and renewable energy availability. Excess energy from renewable sources can be stored in the EV battery. The battery can discharge back into the grid when there is demand. During this phase, it is important for the battery SoC not to go beyond the specified SoC limit in case of unplanned trips. From 23:00, the EV battery is recharged in preparation for the next day's driving phase. A specific SoC threshold may be set following off-peak electricity rates to maximize cost savings.

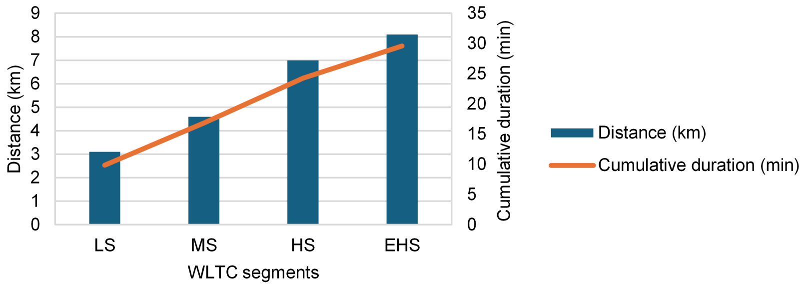

Figure 2: Distribution of WLTC segments for the morning drive phase of the passenger EV use case.

Table 1: Energy consumption of the passenger EV use case by WLTC segments and seasons

Use case	Low speed (LS) (kWh/100 km)	Medium speed (MS) (kWh/100 km)	High speed (HS) (kWh/100 km)	Extra-high speed (EHS) (kWh/100 km)
Summer (UC1)	48.8	45.2	36.9	42.4
Winter (UC2)	62.8	59.7	41.5	45.2

The vehicle is assumed to have a battery capacity of 29 kWh, but only 26 kWh is usable capacity. It goes through various Worldwide Harmonized Light-Duty Vehicles Test Cycle (WLTC) segments for 22.8 km with a maximum speed of 130 km/h during the driving phase to model realistic speed conditions:

1. Low speed (LS): 3.1 km on residential roads (13.6% of 22.8 km)
2. Medium speed (MS): 4.6 km on suburban roads (20.2% of 22.8 km)
3. High speed (HS): 7 km on rural roads with higher speed limits (30.7% of 22.8 km)
4. Extra-high speed (EHS): 8.1 km on occasional highways or expressways (35.5% of 22.8 km)

Fig. 2 shows the typical commute time and distance of the different segments of the cycle. In order to account for the seasons, energy consumption is calculated segment-wise, and ambient temperature is factored in to simulate seasonal variability:

- Summer use case (UC1): 25 °C
- Winter use case (UC2): −10 °C

Energy consumption for the same trip is assumed to be sharply higher for the winter use case compared to the summer one due to heating needs. This can be seen in Table 1, where the energy consumption per 100 km traveled by the Fiat e-Doblò passenger EV is indicated for each WLTC segment and season.

In order to calculate energy consumption for each phase, the following equation was used for each WLTC segment:

$$E_{\mathrm{c}} = d \cdot \frac{E_{\mathrm{cd}}}{100} \tag{1}$$

where E_{c} is the energy consumed (kWh), E_{cd} is the energy consumption per kilometer traveled (kWh/100 km), and d is the distance traveled (km) in the segment. Since the total energy consumed depends on the ambient temperature and vehicle speed, the total $E_{\mathrm{c,total}}$ (kWh) can thus be calculated from the E_{c} for each WLTC segment as their sum:

$$E_{\mathrm{c,total}} = E_{\mathrm{c,LS}} + E_{\mathrm{c,MS}} + E_{\mathrm{c,HS}} + E_{\mathrm{c,EHS}} \tag{2}$$

With regard to the EV battery, the remaining stored energy E_r (kWh) can also be calculated from the total energy consumed:

$$E_\text{r} = E_\text{bat} \cdot \frac{SoC_\text{init}}{100} - E_\text{c} \quad (3)$$

where SoC_init is the initial SoC (%). The trajectories of SoC and consumed energy can be calculated over the distances of both the morning and afternoon driving phases during the summer and winter seasons using Eqs. (1)–(3).

2.2 eLCV Base Use Case

The base use case regarding eLCVs focuses on operational scenarios which serve as a framework for envisioning future contexts and requirements allowing the derivation of load cycles that would reflect realistic usage patterns and demands. This is important for adapting and future-proofing advanced BMS solutions for eLCV V2X.

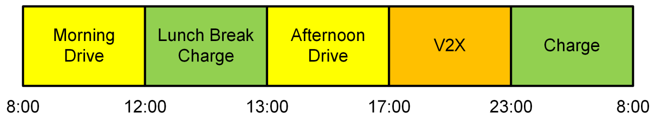

Figure 3: Different phases of the eLCV use case [1].

This use case outlines the daily operation of an IVECO eDaily as an eLCV employed in courier delivery services [1]. The vehicle operates on a standard workday schedule from 8:00–17:00, incorporating a one-hour lunch break. Fig. 3 displays the different phases of the use case for eLCV.

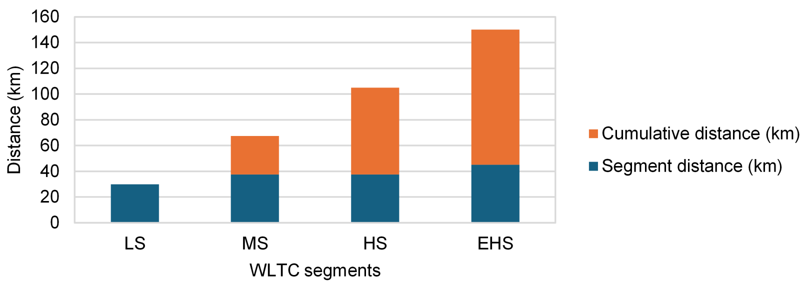

Figure 4: Distribution of WLTC segments for the morning drive phase of the eLCV use case [1].

Assumptions made regarding driving conditions, energy consumption, charging strategies, and SoC management will be expounded on. Key assumptions for the eLCV use case include the vehicle having a battery capacity of 74 kWh, of which 95% (70.3 kWh) is usable. The eLCV carries only half its normal load with working hours from 8:00–17:00 and a one-hour lunch break in the middle. It covers a distance of 150 km in the morning drive phase and the same distance in the afternoon drive phase for a total distance of 300 km daily. The eLCV also goes through various WLTC segments with a maximum speed of 90 km/h during the drive phases:

1. Low speed (LS): 60 km on residential roads (20% of 300 km)
2. Medium speed (MS): 75 km on suburban roads (25% of 300 km)
3. High speed (HS): 75 km on rural roads with higher speed limits (25% of 300 km)
4. Extra-high speed (EHS): 90 km on occasional highways or expressways (30% of 300 km)

Fig. 4 illustrates the distances covered by the different WLTC segments for the morning drive phase. Similar to the previous base use case for a passenger EV, seasonal variability is considered for the eLCV base use case through the season's ambient temperature:

- Summer use case (UC1): 25 °C
- Winter use case (UC2): −10 °C

Table 2 specifies the energy consumed by the eLCV for each WLTC segment depending on the season. Because of the deliveries the vehicle has to do, the eLCV stops eight times, a number based on the survey of courier companies. The distribution of stops is:

Table 2: Energy consumption of the eLCV use case by WLTC segments and seasons

Use case	Low speed (LS) (kWh/100 km)	Medium speed (MS) (kWh/100 km)	High speed (HS) (kWh/100 km)	Extra-high speed (EHS) (kWh/100 km)
Summer (UC1)	22.5	23.5	30	46.8
Winter (UC2)	26.3	27.2	33.8	50.6

- Low speed (LS): Four (4) stops
- Medium speed (MS): Two (2) stops
- High speed (HS): Two (2) stops

The eLCV stops for three minutes per delivery. Similar to the passenger EV, there are morning and afternoon drive phases that incorporate different WLTC segments during the summer and winter seasons. The eLCV starts its courier services by departing from the warehouse at 8:00 with a full charge. For the morning delivery, the vehicle goes through a route of 150 km with stops distributed across urban, suburban, and rural areas. The three-minute delivery stop already accounts for the formal delivery process and the interaction with the recipients.

Eqs. (1)–(3) used for the energy consumed per phase, total energy consumed over all WLTC segments, and the remaining stored energy in the passenger EV battery also hold for this use case for an eLCV.

3 Results and Discussion

3.1 Passenger EV

3.1.1 Morning Drive Phase

Following the discussion in Subsection 2.1, Eqs. (1)–(3) were employed to model and investigate the behavior of the battery SoC and energy consumption of the passenger EV between summer and winter times. Applying Eq. 2 for example, gives a value of 10.2 kWh for the morning drive phase during summer and 13.1 kWh during winter. Fig. 5 traces the evolution of the passenger EV energy consumption throughout the drive.

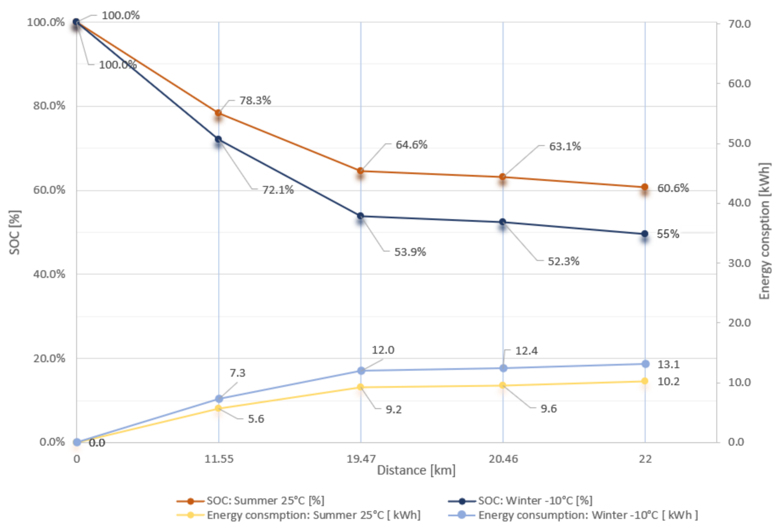

Figure 5: Evolution of battery SoC and energy consumption for the morning drive phase of the passenger EV use case [1].

Upon arrival at the workplace, the SoC of the passenger EV would be 60.6% during summer and 55% during winter. With this much stored energy in the EV, vehicle-to-grid (V2G) scenarios and use cases could be explored. During the following long stationary phase of eight hours, the passenger EV could be connected to a public bidirectional charging station. The charger would then manage charge/discharge of the battery based on the prevailing grid conditions and the battery SoC.

As previously discussed, V2G takes a lot of factors as inputs in order to optimize energy flow between the EV and the grid. For example, V2G considers grid stability, energy demand, available renewable energy, and costs in its optimization process [12, 13]. The idea is to store excess energy, especially those sourced from renewable sources, into the EV battery when demand is low. When demand peaks, energy previously stored in the EV battery can be fed back into the grid to help stabilize the supply. These energy transfers can be viewed as buying and selling energy from the EV owner's perspective. Profit from these transactions can then help offset the sizable investment and costs of acquiring and maintaining an EV.

It is assumed in this paper that V2G functions are performed by the bidirectional charger. Since not all the energy stored can be used for V2G, a ceiling of 8 kWh is set as the only available energy for V2G. This limitation is important to ensure that there is enough stored energy for unplanned trips in the afternoon. The figure is an empirical determination [1].

Table 3: V2G energy consumption after the morning drive phase of the passenger EV use case

Use case	Available capacity before V2G (kWh)	Remaining capacity after V2G (kWh)	New SoC after V2G (%)
Summer (UC1)	15.75	7.75	29.8
Winter (UC2)	12.92	4.92	18.9

Considering that all 8 kWh was discharged from the EV battery during V2G, Table 3 indicates the battery energy capacity and SoC before and after V2G. The resulting SoC levels for both summer and winter use cases, following the morning drive and V2G phases, are 29.8% and 18.9%, respectively. This leaves insufficient energy for unplanned trips in the afternoon. For this reason, V2G functions after the morning drive phase should be discounted for the passenger EV use case. This means that going back to the base use case in Fig. 1, the EV should just remain in a stationary phase without any V2G until after the afternoon drive phase.

3.1.2 Afternoon Drive Phase

Since driving back home approximates the morning route, the distribution of distances and time among the different WLTC segments in Fig. 2 are the same for the afternoon drive phase, but in the other direction. Similar to the morning drive phase, Eqs. (1)–(3) were used to calculate the evolution of SoC and energy consumption for the afternoon drive phase, as shown in Fig. 6. It was previously described in Subsection 3.1.1 that V2G is not possible in between the two drive phases because of the low available energy for driving after V2G. Fig. 6 thus shows that the SoC numbers of the afternoon drive phase start from those at the end of the morning drive phase in Fig. 5.

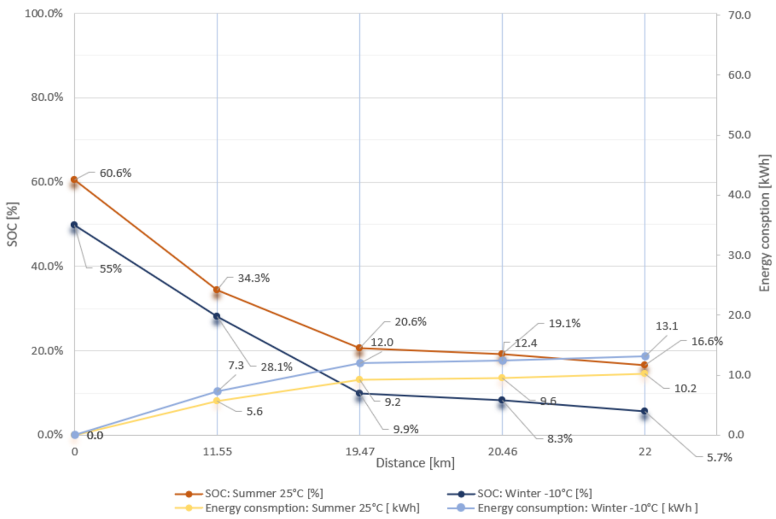

Figure 6: Evolution of battery SoC and energy consumption for the afternoon drive phase of the passenger EV use case [1].

At the end of the afternoon drive, the EV battery's SoC would be 16.6% during summer and 5.7% during winter. Upon arrival at home, the EV would be parked and plugged into a charger. It is after the afternoon drive phase that V2G would be feasible and could be exploited.

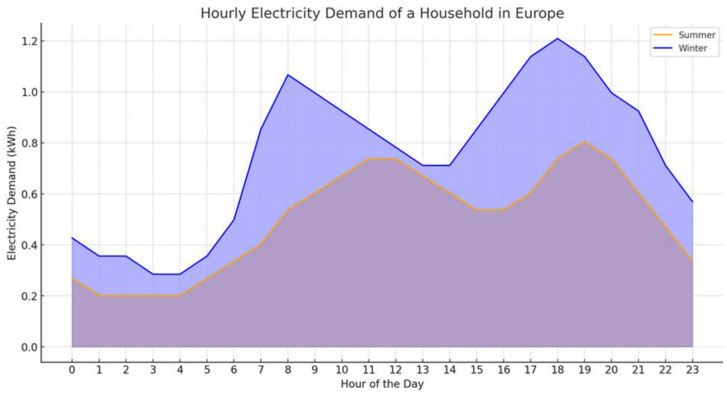

Figure 7: Daily demand of an average European household [1].

3.1.3 V2G Discharge Phase

In order to elucidate V2G examples and use cases, it is necessary to provide some context for the need for V2G. Fig. 7 shows the electricity demand of an average European household during summer and winter. It is evident that electricity demand is significantly lower in summer compared to winter. This is due to lower heating needs. However, there is a need for cooling, so there is higher electricity consumption in the middle of the day because of air conditioning. During summer, demand peaks from 18:00–22:00. During winter, aside from electricity consumption due to heating needs, there is also increased usage for lighting because of shorter days with natural daylight. For this season, demand peaks from 7:00–9:00 and 17:00–21:00. Averaged over the whole day, the total daily consumption during summer is 12 kWh and 18 kWh during winter.

Given the summer and winter time electricity demand peaks, V2G can be set for both seasons between 17:00 and 23:00. Over this six-hour period of peak demand in the day, the average energy consumption is 0.96 kWh during summer and 1.46 kWh during winter.

Table 4: Charge after the afternoon drive phase of the passenger EV use case

Use case	SoC before charge (%)	SoC after charge (%)
Summer (UC1)	16.6	55.06
Winter (UC2)	5.70	44.16

From Fig. 6, it is obvious that the low SoC levels upon arrival at home are not enough for the passenger EV to participate in V2G in any significant manner. To prepare for V2G, the passenger EV must be charged between 16:00–17:00 using a home charger capable of up to 10-kW AC. Table 4 details the change in SoC after the charge, in preparation for V2G.

During V2G from 17:00–23:00, the EV battery can be used to meet the household electricity demand. Fig. 8 displays the electricity demand being met by the energy discharged by the EV battery and the consequent change in battery SoC for both summer and winter times. It shows that the summer household demand can be fully met by the battery through V2G. From a level of 55%, the SoC decreases throughout the period until it reaches 27% at the end to supply the total household demand of 6.7 kWh. During winter, the household demand can also be fully met by the EV battery. The battery goes from an SoC level of 44% down to approximately 5% to supply the total winter demand of 10.2 kWh.

The preceding illustrates that the EV battery can reliably power a household during peak demand hours even during winter when demand is higher. Since the V2G period is only until 23:00, the passenger EV has enough time to get fully charged before the next morning drive phase.

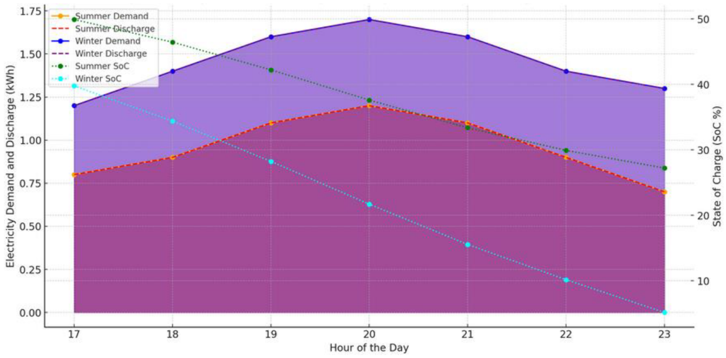

Figure 8: EV battery meeting the electricity demand and its SoC during V2G [1].

3.1.4 Charging Phase

The eight-hour charging phase starts from 23:00 until 7:00 the next day. In order to prolong battery life, the following charging strategies are proposed based on seasonal conditions and SoC:

- Summer (UC1): Considering the SoC level of 29.9% at the end of the V2G phase, a minimum charging power of 2.28 kW is needed to reach a full charge by the end of the charging phase. However, to balance charging efficiency and extending EV battery life, a charging power of 1.5–2 kW is recommended.
- Winter (UC2): To reach a full charge by the end of the charging phase from an SoC of 10.15%, charging power needs to be at least 2.92 kW. However, for the same reasons as in the charging strategy for summer time, a charging power of 1.5–2 kW is also recommended.

3.2 eLCV

3.2.1 Morning Drive Phase

As previously described in Subsection 2.2, Eqs. (1)–(3) apply even to the eLCV use case. Using Eq. 2, a value of 47.9 kWh of total energy consumed can be found for summer time and a value of 53.5 kWh for winter time. Consistent with the assumptions and the other use case, the eLCV consumes more energy during winter, highlighting the effect of the colder temperature necessitating additional energy for heating. Fig. 9 shows the evolution of the eLCV energy consumption throughout the morning drive phase. Looking at the consequent change in SoC, the low SoC of 23.8% means that the vehicle has to do more charging stops or adjustments to the route planning to accommodate the increased use of energy.

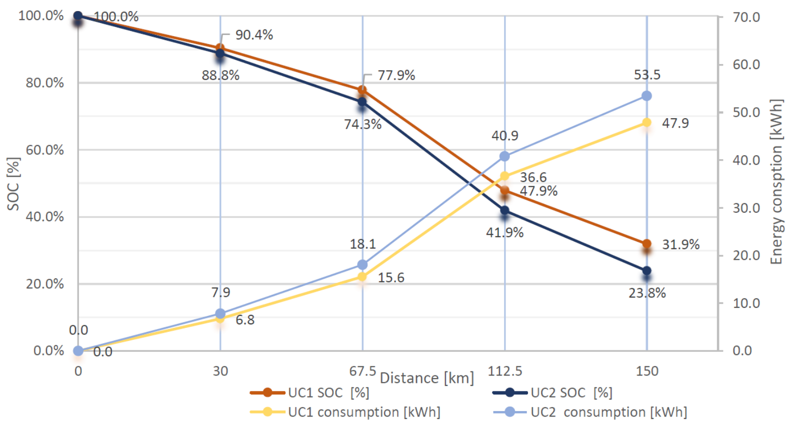

Figure 9: Evolution of battery SoC and energy consumption for the morning drive phase of the eLCV use case [1].

3.2.2 Lunch Break Charge

The courier completes the morning drive phase at 12:00 and would have covered a distance of 150 km. For the lunch break, the eLCV goes to a charging station to recharge. The SoC at the start of the lunch break charge is the SoC at the end of the morning drive phase. In order for the courier to cover the 150-km afternoon drive phase, recharging should reach a minimum required SoC that would still leave 10% SoC at the end of the day.

Since the afternoon drive phase covers the same distance of 150 km and WLTC segments as the morning drive, the eLCV battery must store an amount of energy equal to that consumed during the morning drive phase. This means that the afternoon drive phase needs a charge of 68.1% during summer and 76.2% during winter. Taking into account the required additional 10% SoC allowance, the minimum required SoC has to reach 78.1% and 86.2% during summer and winter times, respectively.

Table 5: Charging scenarios for the lunch break charge of the eLCV use case

Charging scenario	AC charging power (kW)	DC charging power (kW)
Workplace charging	3.7–22	—
Public charging	7	—
	22	—
Fast charging	—	50
	—	80

Because of the relatively high charge needed within the one-hour lunch break, it is important to appraise the options with regard to charging. The choice will significantly affect the speed of charging and consequently, the delivery operation and efficiency. Table 5 details the possibilities for charging the eLCV during the lunch break. It is not possible to do workplace charging given that the vehicle is en route to do deliveries, so discussions can focus on public and fast charging.

The slow 7-kW charge will not reach the required SoC levels within the allotted time for the lunch break. The same is true for 22-kW charging. However, the time at which the requirements are reached is much earlier. During summer, the SoC of 78.1% is reached at 13:28, while an SoC of 86.2% is attained at 13:59 for winter. The option of extending the lunch break will not be acceptable because uptime is a crucial metric for the industry.

For DC charging, combinations of fast DC charge up to 80% SoC, either 50-kW or 80-kW, and AC charging from there up to full charge. Using a combination of DC and AC charging as a charging strategy can ensure that required SoCs are reached within an hour. During summer, there is no need to perform additional AC charging once 80% charge is reached using DC charging. Employing a combination charging strategy will assure that the original working schedule with a one-hour lunch break is respected. A combination charging strategy of DC and AC charging is thus the proper solution for the lunch break charge.

3.2.3 Afternoon Drive Phase

The afternoon drive phase covers the same WLTC segments of 150 km with stops spread across urban, suburban, and rural areas, but in the other direction. Table 6 provides the initial SoCs of the afternoon drive depending on the combination charging strategy used, whether it is 50-kW DC and 22-kW AC or 80-kW DC and 22-kW AC, for the two seasons of summer and winter considered. No pure AC charging strategy was included because of its insufficiency to reach required SoCs within the lunch break charge.

Table 6: Initial SoCs of the different charging strategies of the afternoon drive phase of the eLCV use case

Use case	ID	Charging strategy (kW)	Initial SoC (%)
Summer (UC1)	UC1.1	50-kW DC + 22-kW AC	90.4%
	UC1.2	80-kW DC + 22-kW AC	98.3%
Winter (UC2)	UC2.1	50-kW DC + 22-kW AC	86.8%
	UC2.2	80-kW DC + 22-kW AC	95.6%

Fig. 10 illustrates the evolution of the battery SoC and the energy consumed of the eLCV for the different charging strategies during summer and winter times. The influence of the ambient temperature through

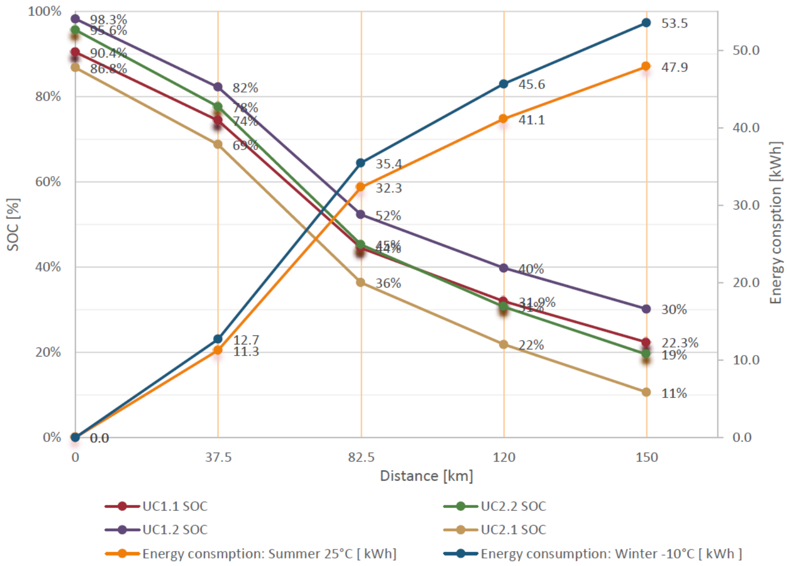

Figure 10: Evolution of battery SoC and energy consumption for the afternoon drive phase of the eLCV use case [1].

the season can again be seen in the figure. It also follows that the lowest charge of 11% after the afternoon drive occurs during winter for the charging strategy with lower power rating (50-kW DC + 22-kW AC). On the other hand, the highest SoC results from the charging strategy with higher power rating (80-kW DC + 22-kW AC) during summer, when there is no need for heating.

3.2.4 V2X Discharge and Charging Phase

The eLCV is expected to be back at the warehouse at 17:00 after covering 150 km in the afternoon drive phase. The vehicle would be at the warehouse overnight until the next morning drive phase. It is assumed that the eLCV will be plugged into the warehouse charging station with bidirectional functionalities. A smart energy management system using V2X can lead to significant cost savings for EV owners, if not additional income through grid services incentives. However, EV owners should be able to define SoC limits within which V2X can operate.

At the end of the V2X phase, the SoC needs to be 100% in preparation for the next drive phase. A minimum SoC of 20% can be set as a threshold for V2X, which begins at 17:00 and ends at 8:00 the next day. There is thus 13 hours available for this phase. Two peak periods are considered. The first goes from 18:00–0:00 (six hours) and the second is from 6:00–8:00 (two hours). Considering the energy consumption of the warehouse, a range of 1,391–5,276 kWh/day is considered. To simplify the use case, the warehouse consumption is assumed constant throughout the day and the mean consumption of 3,333 kWh/day that gives a power consumption of 139 kW is used. Peak load shaving, which includes charging during off-peak hours and discharging during peak hours is the most suitable strategy for the eLCV use case. There should be a restriction for the vehicle not to be discharged during the second peak, nevertheless. This is to ensure that the eLCV starts the next drive phase at full charge.

Fig. 11 presents the charge and discharge scenarios of the eLCV for V2X. All scenarios have an hour of charging from 17:00–18:00, followed by a discharge of five hours during the first electricity demand peak. By the end of the off-peak period, the battery is fully charged. During the discharge period from 16:00–23:00, the eLCV is discharged ensuring that the vehicle has 20% SoC at the end of the period.

Scenario B (80-kW DC + 22-kW AC during summer) in Fig. 11 has the largest discharge power of 5.8 kW, while scenario C (50-kW DC + 22-kW AC during winter) has the lowest at 3.1 kW. This supports the chosen lunch break charging strategy. Given the discharge power of scenario B, at least 24 eLCVs are needed to meet the 139 kW power consumption of the warehouse. This number would be 45 eLCVs for scenario C. The range of minimum number of eLCVs needed to cover the total warehouse consumption is then 24–45.

From 23:00–6:00, the vehicle is charged with a constant power of 8 kW. This is the minimum charging power needed to achieve full charge by 6:00. As discussed earlier, the vehicle should not be allowed to discharge again during the second demand peak between 6:00 and 8:00 to ensure the vehicle starts the

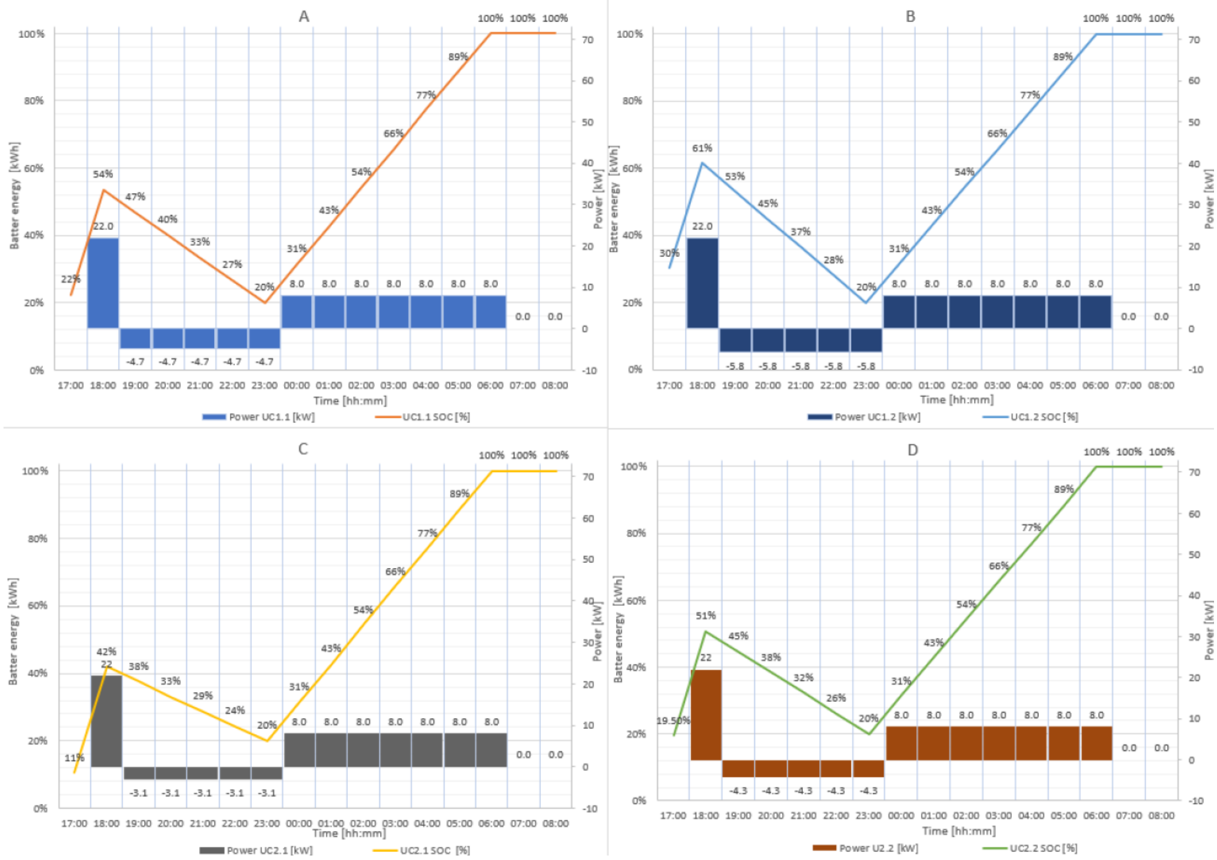

Figure 11: V2X charge and discharge phase of the eLCV use case [1].

morning drive phase with a full charge.

4 Conclusion

The analysis of driving and charging phases for both passenger EVs and eLCVs highlights the significant impact of ambient temperature on energy consumption, particularly in colder climates where additional heating demands reduce vehicle range. Improved thermal management can therefore enhance efficiency and extend range.

Charging patterns differ based on usage: passenger EVs typically require one overnight charging session using a slow, optimal power strategy to reach full charge by morning, while eLCVs used for courier delivery need two charging phases—one fast charge during a short lunch break and another overnight slow charge. Fast charging is essential for eLCVs to sustain their daily operations, whereas it remains optional for passenger EVs depending on daily travel.

Additionally, V2X technologies, such as V2G and V2H, allow EVs to supply stored energy back to the grid or home systems during peak demand, supporting grid stability and renewable energy integration. These bidirectional energy flows offer financial benefits to EV owners, improve grid resilience, and promote the efficient use of clean energy, ultimately contributing to a more sustainable energy ecosystem.

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Presenter Biography

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