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Connected Electric Vehicle Optimized for Life, Value, Efficiency and Range

CEVOLVER
Connected Electric Vehicle
Optimised for Life, Value,
Efficiency and Range

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CEVOLVER – Deliverable Report

D 1.3: Report on use cases and methodology for developing user centric connected EVs optimized for lifetime, value, efficiency and reach

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Publishable summary

This report D1.3 covers the work carried out in task 1.3 of the CEVOLVER project. This includes the methodological approach for user centric development of electric vehicle (EV) based on a systematic description and application of use cases.

User centric development approach covers both innovative control strategies and rightsizing of components. This approach puts the user needs in the middle in order to identify attractive features for typical usage scenarios for different vehicle types and classes. Apart from experience from previous generations of vehicles big data analysis has been identified as a valuable source of information in describing detailed use cases that in turn serve as a new perspective to support the development of control strategies and decisions regarding system layout and component specifications. In report D2.1 a simulation environment is presented that will be used to implement and analyse the system layout, as well as verify and tune the control strategies to assess the benefit of these strategies. This environment can also be used to evaluate design changes in components and sub-systems that lead to rightsized components.

The focus of this report is to define use cases, which serve as an important step in deriving the control functions according to the System Engineering approach. Use cases are defined as the interaction between the actor, system and the environment to achieve the goals, such as complete a long trip, deliver a set of parcels, complete a commuter trip, etc.. In task 1.3, 14 use cases for 5 usage scenarios are described with the key characteristics. Multiple variations of the use cases have been derived by changing the boundary conditions such as ambient temperature and availability of the charging infrastructure at different power levels. Therefore, boundary conditions are discussed and an updated list (from D2.1) included in the appendix. In the end, two of the representative use cases, namely the long holiday trip and the parcel service daily job, are selected as references, and are further detailed into a list of interactions in the appendix. These use cases serve as important input to realize important features in the CEVOLVER project, such as eco-routing, eco-driving, smart fast charging, advanced thermal management, and assured charging. The detailed defined use cases will be used further to evaluate and assess the solutions developed in the project.

Contents

Table of Figures

List of Tables

Abbreviations

Symbol/Shortname	Description
AC	Alternating Current
CCS	Combined Charging System
C-V2X	Cellular vehicle to everything
DC	Direct Current
DSRC	Dedicated Short Range Communication
E/E	Electric / Electronic
eMBB	Enhanced Mobile Broadband
EV	Electric Vehicle
FKFS	Forschungsinstitut fuer Kraftfahrwesen und Fahrzeugmotoren Stuttgart
GPS	Global Position System
HMI	Human Machine Interface
HVAC	Heating Ventilation Air Conditioning
ITS	Intelligent Transport System
LTE	Long Term Evolution
MMTC	Massive Machine Type Communication
OBC	Onboard Charger
OEM	Original Equipment Manufacturer
SOC	State of Charge
URLLC	Ultra-Reliable-Low-Latency Communication
V2I	Vehicle to Infrastructure
V2N	Vehicle to Network
V2P	Vehicle to Pedestrian
V2V	Vehicle to Vehicle
VCU	Vehicle Control Unit
WLTC	Worldwide Harmonized Light Vehicles Test Cycle
WP	Work Package

1 Introduction

1.1 Objectives

1.1.1 CEVOLVER

The CEVOLVER objectives have been presented in the project's first deliverable D1.1. The project takes a user-centric approach to create battery-electric vehicles that are comfortable and usable for long day trips whilst the installed battery is sized for both affordability and usability. In particular, CEVOLVER tackles the challenge of executing even long trips at reasonable additional trip time with smaller batteries by making improvements to reduce energy consumption by means of user-oriented features such as eco-routing and eco-driving, and the optimization of on-board systems and control strategies targeting on fast charging ability. These features and strategies should benefit from connectivity to support selected functions such as improving range prediction.

In the project it is planned to demonstrate that long-trips are achievable within acceptable time limits even without further increase in battery size that would lead to higher cost, weight and energy consumption. When needed the driver is guided, to fast-charging infrastructure along the route that ensures sufficient charging power is available along the route in order to complete the trip with the acceptable additional time needed for the overall trip. In addition, the vehicle should arrive at a fast charging station in a condition that fast charging is actually possible. This long-trip logic also applies fundamentally to exceptional logistics that may cover significant distance and require interim charging to continue a tour.

1.1.2 Current task and deliverable T1.3 / D1.3

The major objective of Task 1.3 is to develop use cases of EVs following a user centric development approach. To achieve this, the methodology for user-centric development of EVs is introduced in Chapter 2. Following this methodology, the approach and the output of use cases development are shown in Chapter 3. The appendix contains further information about the technological enablers: charging infrastructure and preferences, boundary conditions and 5G mobile network, which are considered for the development and definition of use cases. Additionally, the big data analysis supports the selection of driving profiles of the use cases is described in the appendix.

1.2 Interfaces and interactions within the project

Task 1.3 has strong interactions and interfaces to multiple other work packages in the project. Based on the analysis of the use cases defined in T1.3, stakeholder and system level requirements are defined in T1.4, as well, the functional architectures are built up in a continuous process. The functional architecture will be initially implemented in the simulation environment in Work Package 2 and ultimately be ported the target demonstrators planned in work packages 3, 4 and 5. The use cases together with the boundary conditions serve also as valuable inputs for setting the scope of work package 6, where the test cases are defined and established. For this reason Task 1.3 has also worked on identifying vehicle speed profiles that are realistic with the use cases established in the project.

2 Methodology for user-centric development of electric vehicles

As the conventional approach for the component sizing, OEMs use market research as well as legacy knowledge from the development of conventional vehicles as input to define targets for electric vehicles. Decoupling from the direct interfacing with the end user potentially leads to a potential oversizing of the components, which in turn increases the vehicle price unnecessarily.

In contrast to the conventional approach, the user centric approach for developing EVs is shown in Figure 1. This approach puts the user in the center of the development process in order to develop attractive functions and avoid over-sized components that the user will have to pay for but without clear additional benefits.

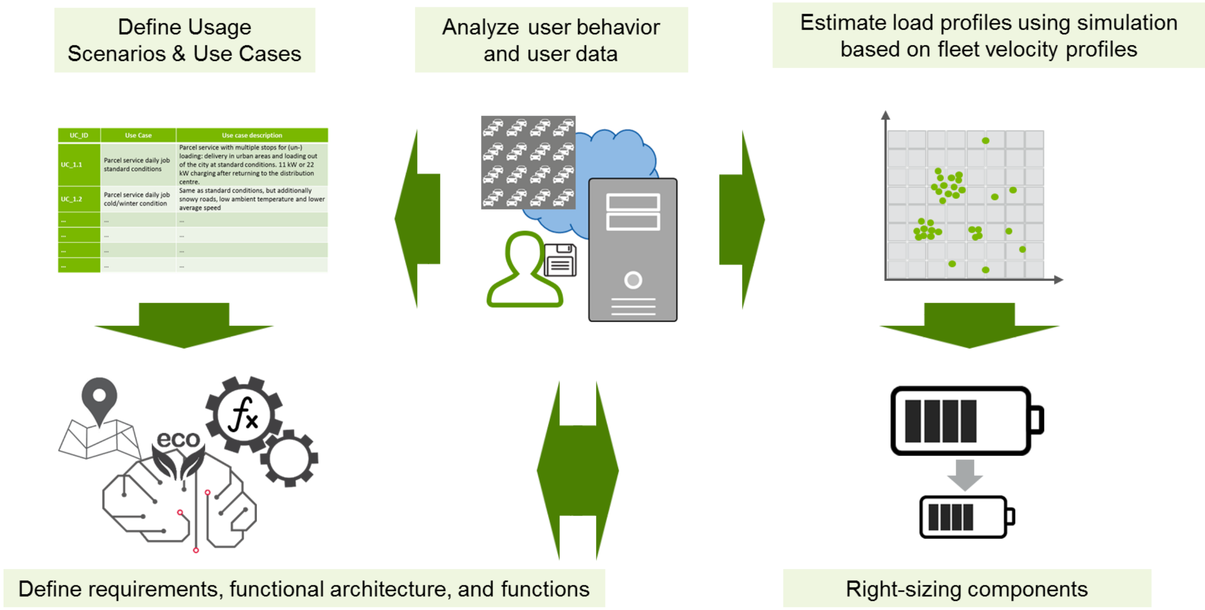

Figure 1 User centric approach for selection and right-sizing of components and optimizing operation of electric vehicles

Typical usage scenarios are supported by analyzing the fleet data from different vehicle classes, e.g. compact class vehicles are often used as short commuter vehicle. Delivery trucks often operate the whole day in urban areas, but need to travel from and back to the delivery center in rural area. The usage scenarios are further broken down into use cases to describe the interaction between user, system, and environment for achieving the goal defined in the usage scenario. In work package 1, the descriptions are intended to be as generic as possible to be brand-independent and to be used by any interested partners, as well as serving as key elements in deriving the functional architecture by looking at the interaction between actor and system and describing a function that will carry out this interaction. The functional architecture (to be shown in WP1.4) interlinks these functions to ensure they have the right inputs to carry out the operation and the outputs are connected correctly to corresponding functions and system boundaries.

Once the functional architecture has been sufficiently developed and accepted as a generic basis, and tested in the simulation environment, it will be adopted by the specific demonstrators in the project as far as possible. These require specific vehicle parameters and use case implementations, ultimately for demonstration in work package 6. This requires more specific data that the project intends to extract from anonymous fleet data to both establish parameter ranges (e. g. both statistical data analysis as well as outliers) for design and testing as well as specific load profiles that serve as the input to the simulation models and test procedures in work package 6.

On the other hand, velocity profiles concluded from the fleet data analysis serves as an important input to derive reference load profiles of the EV components in the simulation environment. This information, together with innovative functions, will support the right-sizing of EV components.

3 Use Case Development

3.1 Approach of developing use cases

Firstly, **usage scenarios** are defined. They describe how different types of vehicles are used by a particular group of users. The assumptions of these usage scenarios are supported by statistical data like average distance, speed and mileage as described above.

In a next step, **use cases** are described within the usage scenarios. A use case is a detailed description of one particular trip or representative part of a trip within a usage scenario. It is not a single manoeuver or a single user interaction. A commonly accepted definition of "use cases" according to the English version of Wikipedia is, "In software and systems engineering, a use case is a list of actions or event steps typically defining the interactions between a role […] and a system to achieve a goal." [1] Since our system of interest, as defined in WP1.1, comprises, to a large extent, of thermal and energy management, the described use cases should especially consist of relevant situations/interactions for energy conversions.

An Example: 30 km city-trip home to work, parcel service daily job or craftsman one-day job, possibly including one or several stops of charging at public charging station per outward and return journey as well as charging at destination. Later on, typical use cases serve to help identify system functions including interactions with user and system context, so that the necessary functions can be described in terms of requirements and architectures.

Varying **boundary conditions** enable the variation of the use cases. This is important, on one hand, for function development to include all the relevant influencing factors; on the other hand, for the subsequent working packages as simulation and testing, to clarify the scope and limits of the simulation and testing capability and for coordinating the resources in an early stage. The list of boundary conditions defined in D2.1 are updated here in chapter 8.2, after the use case definition.

Velocity profiles (velocity vs. time) are also defined for the test cases to serve as an input to the simulation and testing work package. This is either derived by analysing the user preferences, which were collected by the partners supported by big data or based on representative user studies. Automotive standard driving cycles (e.g. WLTC) are selected and tailored for representing different use cases. The approach of selecting the driving cycles is described in chapter 7.3.3.4.

3.2 Overview of usage scenarios and use cases

Since CEVOLVER tackles the challenge to reduce range anxiety for long trips with electric vehicles, use cases covering long distance trips were developed in T1.3. They are integrated in usage scenarios describing the focused application areas of the vehicles selected in CEVOLVER.

FORD provides a light duty vehicle, which is planned to be used as a delivery vehicle and for commercial trips. Some use cases derived from the usage scenario "commercial traveller" were selected to cover the long distance trips. The use case "craftsman´s one day job 350 km away" describes a trip to a work site 350 km far away from the company, the charging processes along the trip (to and from the site) and during the time the craftsman is working at the site. The passenger cars provided by Bosch and CRF consider different long distance trips fulfilled by both private people (e.g. "700 km holiday trip") and commercial agents.

The investigation of long trips primarily provides assessments regarding the required travel time including the breaks for charging a vehicle. Since a reduction in energy consumption also has a positive effect on the travel time, use cases that support the ability to achieve an appropriate assessment of energy consumption were identified as well. Commuting or short city trips are also taken into account since the light duty vehicles as well as private vehicles are typically used for shorter trips such as for parcel delivery. These use cases are essential to investigate how to reduce the cost as well as energy consumption by selecting the right-sized components, and especially using an optimized control strategy and taking into account connected thermal and energy management.

Following table gives an overview about the usage scenarios and the included use cases selected for CEVOLVER.

Table 1 Overview of Usage Scenarios and Use Cases

Usage Scenario	Use Case ID	Use Case
Parcel delivery service	**UC_1.1**	**Parcel service daily job** standard conditions
	UC_1.2	**Parcel service daily job** cold/winter condition
	UC_1.3	**Parcel service daily job** hot/summer condition
Private & commercial traveller	**UC_2.1**	**Commercial agent** daily customer visit usage
	UC_2.2	**Special Goods Delivery** daily usage w/o intermediate charging
	UC_2.3	**Special Goods Delivery** special usage with intermediate charging
	UC_2.4	**Private visit** of 350 km (distance) away living relatives
	UC_2.5	**Craftsman's one-day job 350 km away** standard conditions, one stop per each 350 km trip
	UC_2.6	**Craftsman's one-day job 350 km away** standard conditions, two stops per each 350 km trip
	UC_2.7	**Craftsman's one-day job 350 km away** with traffic jam at cold condition, two stops per each 350 km trip
	UC_2.8	**Holiday trip (>700 km)**
Short city trip	**UC_3.1**	**Short urban trip(s)** (approx. 5 km)
Short range commuter (approx. 30 km distance)	**UC_4.1**	**home => job => home** (approx. 30 km distance)
Long range commuter (approx. 60 km distance)	**UC_5.1**	**home => job => home** (approx. 60 km distance)

3.2.1 Parcel delivery service

The vehicle´s application area is for parcel delivery. The vehicle is loaded with parcels at least once a day. Most of the time the vehicle is driven in (sub-) urban areas to deliver the parcels. Because of loading and unloading the cargo bay, the vehicle´s weight can vary during the trip and energy input or losses due to frequent opening of the doors must be taken into account.

Table 2 Parcel delivery service: use cases

UC_ID	Use Case	Use case description
UC_1.1	**Parcel service daily job** standard conditions	Parcel service with multiple stops for (un-) loading: delivery in urban areas and loading out of the city at standard conditions. 11 kW or 22 kW charging after returning to the distribution centre.
UC_1.2	**Parcel service daily job** cold/winter condition	Same as standard conditions, but additionally snowy roads, low ambient temperature and lower average speed
UC_1.3	**Parcel service daily job** hot/summer condition	Same as standard conditions, but additionally high ambient temperature and solar radiation

3.2.2 Private & commercial traveler

On weekdays, the vehicle is primarily used as a company car for customer visits. In addition, passenger cars can also be used privately for visiting relatives living further away and holiday trips.

Table 3 Private & commercial traveler: use cases

UC_ID	Use Case	Use case description
UC_2.1	**Commercial agent** daily customer visit usage	Three customer appointments spread out over the day and one fast charging event with (not less than) 50 kW at public charging station
UC_2.2	**Special Goods Delivery** daily usage w/o intermediate charging	Several medium distance delivery jobs spread over the days. Start at a distribution centre with full battery, delivery of goods to three customers and return to distribution centre without intermediate charging. 11 kW or 22 kW charging after returning to the distribution centre.
UC_2.3	**Special Goods Delivery** special usage with intermediate charging	Start at distribution centre with full battery, delivery of goods to four customers, lunch break with 22 kW or 50 kW charging at public charging station, delivery to one customers and return to distribution centre
UC_2.4	**Private visit** of 350 km (distance) away living relatives	One time partial DC fast charging (50 to 150 kW) at public charging station on the trip to target; AC (up to 7 kW) charging at home during the visit.
UC_2.5	**Craftsman's one-day job 350 km away** standard conditions, one stop per each 350 km trip	A craftsman drives 350 km to the construction site and takes at least one break for charging during the journey with 50 to 150 kW at public charging station. While the craftsman is working at the job site, the vehicle can be charged for several hours with 22 kW or 50 kW at public charging station. In the end the craftsman drives back to his company (350 km) with one stop of charging same as the arrival trip.

UC_2.6	**Craftsman's one-day job 350 km away** standard conditions, two stops per each 350 km trip	see UC_2.5: normal conditions, two fast charging stops with 50 to 150 kW at public charging station up to a lower SOC level compared to 1-stop-strategy
UC_2.7	**Craftsman's one-day job 350 km away** with traffic jam at cold condition, two stops per each 350 km trip	see UC_2.5: additionally high traffic volume and low ambient temperature
UC_2.8	**Holiday trip (> 700km)**	e.g. from Stuttgart to Nice: 820 km; (two)/three times fast charging with ≤ 150 kW at public charging station on (or close to) the way with overnighter

3.2.3 Short city trip

The vehicle is used for short trips like shopping or leisure activities.

Table 4 Short city trip: use case

UC_ID	Use Case	Use case description
UC_3.1	**Short urban trip(s)** (approx. 5 km)	Trips to shopping and leisure activities; no charging on the way

3.2.4 Short range commuter (approx. 30 km distance)

The vehicle is used for commuting to and from work.

Table 5 Short range commuter: use case

UC_ID	Use Case	Use case description
UC_4.1	**home => job => home** (approx. 30 km distance)	Regular travel to and from work; optional charging at work; profiles for the weekend are defined separately Charging after arrive home with 2.2 to 22 kW.

3.2.5 Long range commuter (approx. 60 km distance)

The vehicle is used for commuting to and from work.

Table 6 Long range commuter: use case

UC_ID	Use Case	Use case description
UC_5.1	**home => job => home** (approx. 60 km distance)	Regular travel to and from work; optional charging at work; Charging with 11 kW or 22 kW at work. Charging after arrive home with 2.2 to 22 kW. profiles for the weekend are defined separately

3.3 Examples of detailed defined use case

The following detailed use cases describe exemplary long trips, which are of particular importance not because they represent daily usage, but rather the seldom drive that is often the reason not to purchase an electric vehicle. Range is too low (especially if the battery needs to be "small" to avoid increasing cost) and charging times are long, even for partial charging due to current C-Rate limitations (this is especially true if the battery is "small" and compact). Demonstrating a viable solution to achieve such a trip without increasing the overall trip time significantly is vital to the success of EVs on the market and thus one of the primary objectives of CEVOLVER.

The first UC presented here only describes a segment of the trip that can then be (in substantial parts) repeated to represent a longer trip.

Assumption:

These particular trips need to account for the energy consumption over all long stretches of road where the average speed is relevant but not the exclusive factor for the energy used. The overall energy for the long trip can be estimated on this basis and confirmed with the numerical simulation tool. Thus, it is possible to estimate the size of battery needed for the long trip (including charging stops), or assess the conditions under which a long trip could be made for a given battery size and available charging interfaces: maximum speed and average speed, as well as the number of stops.

The use case only considers the first travel segment that starts with a fully charged battery and "drives" until the lowest charge level of the battery (comfort zone) is reached before recharging. The following segments can be described quite similarly to this use case, but will most likely not start with a fully charged battery, since achieving a fully charged battery would delay the trip beyond acceptable limits, unless the driver is planning a much longer stop anyway. The battery would thus be charged to a level that is still within the "fast-charge range" for that battery. Thus, this description should be sufficient for understanding most long trips (especially if broken down in segments). For the theoretical description, it is assumed that there is a charging station exactly where it is needed, also assuming no traffic jams or other incidents.

Any other required additional stops will be neglected for the description. However, a break after 2 hours is always recommended and a short charging event (to top-off) can be easily integrated.

A structured detailed list of actions and events for the first segment (to reach the first charging station) are included in the appendix 7.11.

3.3.1 Use case: long trip (e.g. holiday)

Driver and passengers enter the vehicle to start their journey with a preconditioned EV that has a fully charged battery. The vehicle displays the nominal range to show the maximum kilometers (but also subtracting some capacity as an energy reserve). Before leaving, the driver initiates eco-routing and selects a preferred route. Range prediction is continuously updated during the journey. Potential stopping points based on the maximum available kilometers are evaluated for charger availability. This is done by scanning for charging points within an acceptable range window that is virtually located at the maximum number of available kilometers. The maximum number of kilometers may also be influenced by information from the traffic flow. Delays due to traffic jams may shift the search window to find charging spots close to the adjusted maximum available range based on the charge capacity currently available in the vehicle. The driver and passengers are being constantly updated with information about the available range and potential charging stations. The temperature of the battery is also being monitored in case the battery needs to be pre-conditioned for an upcoming fast charge event. The driver can stop any time before reaching the first planned stop if there is a need to stop. Then the driver should plan to use an unscheduled stop to add capacity to battery that would in turn increase the available range. In both cases, planned or unscheduled stop, the driver needs to locate available charging infrastructure, and, as far as possible reserve it just ahead of the estimated time of arrival. This can be calculated by the distance to the charging station by the estimated average speed of the vehicle for the upcoming section of road. It is assumed that assured charging now allows drivers to reserve charging stations within an acceptable time frame and assumes that they are not blocked by the previous EVs or other vehicles just looking for a parking spot. The driver exits that vehicle, attaches the high-power cable and takes a well-deserved break with a nice cup of coffee. Ending the charging event with the designated battery charge level ends the use case for the first segment. See detailed sequence in the appendix chapter 8.1.1.

3.3.2 Use case: parcel service daily job with intermediate charge stop

The use case takes places on a sunny winter day with no wind and low ambient temperature (e.g. -7°C). At first a delivery vehicle is loaded with parcels in a distribution center outside the city area. At trip start, the HV battery is fully charged. Before drive off, the driver gets an overview of the trip for the day, including the optimum route generated by analyzing the parcels to be delivered and optional charging stops in between, considering also the lunch break. If required, the system automatically books the charging station according to the trip planning for the dedicated time slot. The vehicle cabin is pre-conditioned to a temperature, which was set up and stored one day before.

The driver enters and starts the vehicle and drives along the planned trip with the recommended velocity. During the trip, the driver gets reminded about the remaining driving range of the vehicle and the remaining time till the next delivery stop.

The first part of the trip is driven in rural traffic at medium speed and few stops according to the distance from the distribution center to the urban delivery area. When the vehicle arrives the first customer in the urban area, the driver stops, gets off the vehicle and shuts the door. Then, the driver opens the load compartment, picks the first group of parcels, shuts the load compartment and leaves for delivery. After a few minutes, the driver comes back to the vehicle, opens the load compartment and puts back the undelivered parcels. The system gets the delivery status and adjusts the vehicle mass information. The delivery procedure repeats frequently until all parcels are delivered. The system navigates the driver to a public charging station in between, which is booked for the time slot. There, the driver connects the vehicle with the booked charging station and takes a coffee break. After a certain time, the HV battery is charged to the desired SoC and the charging procedure stops automatically. The driver gets an alert, unplugs the charger and continues the trip. The delivery and charging activities take place in turn as planned by the system. A longer time slot for charging is preferably considered during the driver's lunch break, if necessary. The route and charging stops may change due to the dynamic and uncertain change of the vehicle mass.

After all parcels are delivered (or marked undelivered), the driver follows the planned trip back to the distribution center. He arrives at the distribution center, unloads the undelivered parcels and moves the vehicle to the company charging station. The use case ends with the driver starting the charging procedure with a target SoC of 100% and leaves the vehicle.

See detailed sequence in the appendix.

3.4 Further detailing in subsequent work packages

The usage scenarios and use cases described here have been analysed and defined with a brand-independent perspective so that the outcome of task T1.3 is a generic description of relevant use cases for various vehicle segments, not mentioning application-specific features.

In the subsequent WPs (WP3, WP4 and WP5) the list of use cases will be linked (where applicable) to the three different vehicle validators according to their mission profiles (small and large segment passenger cars and delivery vehicle). The clear complementarity of the three validators will help to properly cover the map. In this step, the use case descriptions will be refined by the WP leaders to take care of the application-specific characteristics (for instance in terms of ambient temperature or typical payloads in parcel delivery usage) and the feasibility of the following validation tests (for instance on terms of architectures and components of the different vehicle validators or emulation capability of the clouds).

4 Summary

This report D1.3 covers the work carried out in task 1.3 of the CEVOLVER project. This includes the methodological approach for user centric development of EV based on a systematic description and application of use cases.

The user centric development approach covers both innovative control strategies and rightsizing of components. This approach puts the user in the middle in order to identify attractive features for typical usage scenarios for different vehicle types and classes. Big data analysis has been identified as a valuable source of information in describing detailed use cases that in turn serve as a new perspective to support the development of control strategies and decisions regarding system layout and component specifications. In report D2.1 a simulation environment is presented that will be used to implement and analyse the system layout, as well as verify and tune the control strategies to assess the benefit of these strategies. This environment can also be used to evaluate design changes in components and sub-systems that lead to rightsized components.

The focus of this report is to define use cases, which serve as an important step in deriving the control functions according to the System Engineering approach. Use cases are defined as the interaction between the actor, system and the environment to achieve the goals, such as complete a long trip, deliver a set of parcels, complete a commuter trip, etc.. In task 1.3, 14 use cases for 5 usage scenarios are described with the key characteristics. Multiple variations of the use cases have been derived by changing the boundary conditions such as ambient temperature and availability of the charging infrastructure at different power levels. Therefore, boundary conditions are discussed and an updated list (from D2.1) included in the appendix. In the end, two of the representative use cases, namely the long holiday trip and the parcel service daily job, are selected as references, and are further detailed into a list of interactions in the appendix. These use cases serve as important input to realize important features in the CEVOLVER project, such as eco-routing, eco-driving, smart fast charging, advanced thermal management, and assured charging. The detailed defined use cases will be used further to evaluate and assess the solutions developed in the project.

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Project partners:

#	Partner	Partner Full Name
1	FEV	FEV Europe GmbH
2	BOSCH	Robert Bosch GmbH
3	FORD	Ford-Werke GmbH
5	IFPEN	IFP Energies Nouvelles
6	RWTH	Rheinisch-Westfaelische Technische Hochschule Aachen
7	VUB	Vrije Universiteit Brussel
8	UNR	Uniresearch BV
9	I2M	I2M Unternehmensentwicklung GmbH
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7 Appendix

The appendix contains supporting information and results that would otherwise overload the main text of the report and distract from essential aspects of the report. It includes more detailed descriptions of the use-cases, complete update list of the boundary conditions, and the technology enablers for the eco-functions such as 5G mobile network, charging infrastructure, and an explanation of big data analysis for deriving representative velocity profiles for the use cases.

7.1 Examples of structured detailed list for use cases

7.1.1 Use case: holiday trip

Actor	System	Context/Environment
Driver and passengers enter vehicle to start journey		
	EV starts journey (with family) and fully charged battery	
	Range shows maximum kilo-meters (but subtracting some capacity as an energy reserve)	
Initialize eco-routing and select preferred route (operator)		
	Range prediction updated regularly throughout the drive	
	Stopping point at max kilometres after journey begin evaluated for charger availability.	
	Scan for charging points of interest some designated km before stopping point and buffer km after the point.	
		inform on traffic jams
	Range prediction continues to assess the ability to reach the first target (realistically)	
	The first stopping point (and buffer km range) is shifted accordingly and assessed for the availability of charging stations.	
	Inform driver/operator about the availability of charging stations	
	Monitor temperature of the battery for fast charging suitability	
	Initiate battery pre-cooling/-heating measures sufficient km before charging station	
	Range prediction continues to updated (more frequently) regularly throughout the drive	

Actor	System	Context/Environment
		Information on available charging stations along route of interest
	Assess and Inform driver/operator about the availability of charging stations	
Driver chooses charging station suitable to achieve trip plan		
	Reserve charging station (if assured charging is possible) at the selected charging station some minute (> buffer km left) before reaching the charging station	
		Arrive at (hopefully unblocked) charging station with SoC just before reaching the reserve energy (with tolerance +/- X.Y% corresponding to approximately "comfortable" km)
	Check battery temperature for target range for pre-cooling/-heating.	
Position vehicle for fast charge event		
Exit vehicle to attach high-power cable to EV		
Connect high-power cable (operating > 50 kW) to the EV		
	Start charging process with > 50 kW charging power (considering SoC swing that protects the battery life) approximating XX kWh -> just above 2C	
Take a well-deserved break and monitor the charging process (with a hand-held device)		
	(charging should take approximately 20 minutes (plus/minus)	
		Five (or 10 minutes) minutes before charging ends, user (driver) gets a message about charge level, and any information about approaching vehicles that may be requesting to charge.

Actor	System	Context/Environment
User (driver) can decide if more break is needed (another cup of coffee) which may add a little more SoC beyond the target 80% or continue the journey		
		Charging process is ended either when driver is ready to leave (generally with at least 80% charge) or 100% has been reached.
		Driver receives a message to please disconnect charging cable
Cable is disconnected and stored properly (at the charging station)		
Driver continues on with the next segment of the trip starting with at least sufficient SoC (note that SoC could be lower if the last travel segment of long trip is less than swing achieves for this example)		

7.1.2 Use case: parcel service daily job with intermediate charge stop

Actor	System	Context/Environment
		Ambient condition is a sunny winter morning with no wind, and an ambient temperature of e.g. -7 °C.
	The HV battery is fully charged	
		The delivery vehicle is loaded with parcels.
	The vehicle cabin is pre-conditioned to a temperature which was set up and stored from one day before. Components are also conditioned to desired temperature	
The driver enters and starts the vehicle.		
	The system generates the overview of the trip for the day, including the optimum route generated by analysing the parcels to be delivered, and the optional charging stops (if necessary) in between, considering also the lunch break.	Optimization criteria may consider: over all energy consumption trip time HV battery state of health
	If required, the system automatically books the charging station which was planned for the trip for the dedicated time slot	
		The charging stations sends back the confirmation for the booking
	The system displays: calculated route including proposed charging stop(s), estimated charging time estimated trip end time	
Driver confirms or changes proposed route and environment settings according to his preferences and initiates new trip calculation		
	The system re-triggers the route planning if necessary	
The driver drives along the planned trip, with the recommended velocity.		

Actor	System	Context/Environment
	During the trip, the driver gets reminded about the remaining driving range of the vehicle and the remaining time till the next delivery stop.	
	Continuous monitoring and re-calculation of vehicle speed profile. The system calculates a new speed profile based on updated and new information provided from the vehicle or cloud services.	
Driver deviates from the calculated route.		
	Re-trigger route calculation (from system) Predicted energy consumption is different from estimated. Regularly update Server reconnect	
		The first part of the trip is driven in rural traffic at medium speed and few stops according to the distance from the distribution centre to the urban delivery area
When the vehicle arrives the first customer in the urban area, the driver stops and gets off the vehicle, and shut the door. He opens the load compartment and picks the first group of parcels. He shuts the load compartment and left for delivery.		
After a few minutes, the driver comes back to the vehicle, opens the container, put back the undelivered parcels.		
	The system gets the delivery status, adjusts the vehicle mass information, and re-triggers the route calculation	
The delivery procedure repeats frequently until all parcels are delivered.		
	The system navigates the driver to a public charging station in between, which is booked for the time slot.	

Actor	System	Context/Environment
	The system preconditions the components to a desired temperature before reaching the charging station.	
The driver arrives the charging station.		
The driver charges the vehicle with the booked charging station and takes a coffee break.		
	After a certain time, the HV battery is charged to the desired SoC and the charging procedure stops automatically.	
The driver gets an alert, unplugs the charger and continues the trip.		
	The delivery and charging activities take place in turn as planned by the system.	
	A longer time slot for charging is preferably considered during the driver's lunch break, if necessary.	
After all parcels are delivered (or marked undelivered), the driver follows the planned trip back to the distribution centre.		
He arrives at the distribution centre, unloads the undelivered parcels and moves the vehicle to the company charging station.		
	The use case ends with the driver starting the charging procedure with target SoC of 100% and leaves the vehicle.	

7.2 Boundary Condition

7.2.1 Overview

As mentioned, a use case description lists the actions and events of interactions between an actor and the system to achieve a goal. Variations of generalized use case can be derived when considering the boundary conditions as presented in the deliverable D2.1. E.g. a long trip use case would generally be started by describing the list of actions and events under ambient conditions. Once this use case description has been agreed upon and is complete and accepted, then it is advantageous to consider how the use case would change if there were variations in the context or surrounding environment.

One typical example that has been considered in this work is variations in temperature. How would the use case possibly vary for changes in temperature, especially the boundaries that also make up the corner cases: The low-temperature case (maybe even as far down as the extreme boundary temperature) and for the high-temperature case. If an additional function (e.g. some aspect of thermal management) arises from considering these extremes, then it would be added to the functional architecture. Under the "normal" ambient conditions this function may be "inactive" and only operational under the extreme conditions.

7.2.2 Updated boundary conditions

Boundary conditions reported in D2.1 are included here with updated values (e.g. min. temperatures) and wording (charging station AC / DC) and additions (extra load) that better represent under which conditions the user could be expected to interact with the system.

Table 7: Boundary Conditions Range for the Use Cases

boundary condition	**Min**	**Max**	**unit**	**start**	**cycle**	**end**
Ambient temperature	-7	40	°C	x	x	x
Battery SOC	0	100	%	x		x
Battery temperature	-7	max	°C	x		
Cabin temperature (actual)	-7	80	°C	x		
Charging station AC (power level)	3.6	22	kW	x	x	X
Charging station DC (power level)	10	150	kW	x	x	X
Connection to services / server	Disconnected	Connected	-	x	x	
Data transfer rate	2G	5G	-	x	x	x
Extra load	0	1000	kg	x	x	
GPS	not used in this phase		-	x		x
Road gradient	-35	35	%	x	x	x
Rolling resistance coefficient (f_R)	0.005	0.015	-	x	x	x
Solar radiation	0	1200	W/m²	x	x	x
Subject. desired cabin temperature	acc. To DIN 1946-3		-	x	x	
Thermal storage SOC	0	100	%	x		x
Traffic volume	free flowing	congested	-	x	x	
Wind	0	100	km/h	x	x	x

7.3 Technology Enablers

7.3.1 Charging infrastructure

Sufficient charging public or semi-public infrastructure available at the right spot and at the right time is a key element for the success of recharging the batteries in a timely manner during the journey.

Table 8 presents an overview of charging infrastructures, which are most commonly available in Europe. It also highlights the availability degree by means of colour coding. An 'X' denotes the most common type for per location category both for AC and DC.

Table 8 Overview of the most commonly available charging infrastructure in Europe[1].

	AC, type 2, mode 3						DC, CCS or CHAdeMO				
	Slow Charge				Semi-Fast Charge	Fast Charge	Slow Charge	Semi-fast charge	Fast Charge	Super-Fast Charge	Ultra-Fast Charge
	1-phase 10 A, 2.2 kW	1-phase 16 A, 3.6 kW	1-phase 32 A 7 kW	3-phase 16 A 11 kW	3-phase 32 A 22 kW	3-phase 64 A 44 kW	10 kW	20 kW	50 kW	150 kW	350 kW
Home		X					X				
Work				X					X		
Public				X					X		

Legend: green = common, yellow = sometimes available, red = rarely available, black = non-existent. 'X' denotes most commonly available at a certain location category

Where there is a general trend of battery sizes increasing, and with that the power level of charging stations, the type of charging (AC or DC, power level, connector type) installed within the vehicle is different per vehicle manufacturer and vehicle model. This is subjected also to evolution of the market with respect to the technology (for example an evolution to reduce AC charging capacity to limit the size of the OBC and switch towards DC charging for the full range of power levels, from slow charging up to super-fast charging). It is important to understand that the available type of charging infrastructure will impact the driving use case defined in chapter 3. As the goal here is to define generic use cases, charging as a component of the use cases will be defined irrespective of the type of charger (AC or DC, connector type) and purely based on power level. This approach is suited for the objectives of CEVOLVER, e.g. right sizing of components and optimized thermal and energy management, which are relatively independent of the type of power transfer (AC/DC and connector). It is however important to understand that types of power transfers in the vehicle and charger mutually limit each other by their common minimum of phases and minimum of current per phase. So will a single phase plug from the vehicle side only have the single phase power of the three phase charging station available, which might be lower than the single phase power at the vehicle side, and vice versa. Within WP3-WP5 these power levels will have to be linked to the specific charging technology of the vehicle.

From Table 8 we can identify four categories of power level: slow charging at 11 kW, semi-fast charging at 20 kW, fast charging at 50 kW, super-fast charging at 150 kW, ultra-fast Charging at 350 kW. It is important to note that with the rise of smart charging, these power levels only indicate the upper power level and

[1] It is useful to note that a charging point with power levels below or equal to 22kW are referred to as "normal power recharging" and the above 22kW as "high power recharging" without further distinction by the DIRECTIVE 2014/94/EU on the deployment of alternative fuels infrastructure, and consequently reported in this way by the European Alternative Fuel Observatory [2], [3].

power could be reduced. Until now, the analyses carried out in CEVOLVER cannot justify more charging power than 150 kW (current work here will be presented at the upcoming TRA 2020 conference in Helsinki). Under ideal conditions more power will certainly lead to shorter charging time, but on the other hand limited by de-rating (reduced power) as soon as the condition of the battery does not allow the high power (temperature levels of cells or pack exceed acceptable limits).

Charging an EV at home is commonly done with either a mode 2, 10 A, 2.2 kW connection to a regular household or a low power home charger of 3.6 kW. Higher powers are possible but most households can be limited to single phase charging because of the single phase connection to the distribution grid, which is strongly dependent on the country and distribution grid. These types of chargers are hardly installed for public charging anymore because of the long charging times. Public chargers tend to be more 3-phase chargers of either 11 kW or 22 kW. The advantage of the 22 kW charger is that it can supply all other AC chargers specified in Table 8 (single phase 10 A, single phase 16 A, single phase 32 A, 3-phase 16A) and do semi-fast charger if the vehicle is capable of it. Typically, 11 kW chargers are the result of splitting the rated power over two connector on the same charging station. The disadvantage is the cost of the charger and the difficulty to connect to the grid (because of the power level and 3-phase connection) for potentially a very infrequent use (because not many vehicles allow it).

3-phase 64 A chargers exist but are generally not deployed because very few vehicles allow charging at 64 A AC at this point. For the DC chargers, 50 kW and to a lower degree 150 kW charging network do exist across Europe. Low power DC charging is gradually being introduced in the market at this point ultra-fast chargers exist but are very complex and niche and are considered outside of the scope of CEVOLVER. The charging infrastructure deployed at work can be a combination of different types of chargers, depending on the nature work site and its specific mobility needs and grid constraints (office building, plant, etc.).

Based on the above analysis and the overview in Table 8, the following use scenarios for charging are proposed, and are mapped into the use cases defined in Chapter 3.

Table 9: Typical Charging Scenarios

Place	Power Level	Rationale
Home	2.2 kW - 3.6 kW	Represents the most basic household plug if there is no specific charging infrastructure available. Power level depends on the current limit (10 A to 16 A).
Home	7 kW	Represents the home charging case if there is charging infrastructure for EVs present. The power level of 7 kW is chosen because it provides more flexibility (faster charge time, flexibility on the power level In case of smart charging) than the 3.6 kW charger, is the most restrictive compared to the 3-phase charging (meaning also 3-phase systems can plug in and charge through one phase). This use case also includes lower power DC-charging, which has similar power levels.
Public	7 kW	Represents public slow charging. Lower power levels on public charging infrastructure are not very commonly installed anymore. Can also be serviced by 3-phase 32 A chargers through 1 phase or DC charger.
Public	22 kW	Represents public semi-fast charging.
Public	50 kW	Represents fast charging on public domain.
Public	150 kW	Represents super-fast charging on public domain.

Place	Power Level	Rationale
Work	11 kW	Represents the slow charging case at work. Though the work site might provide outliers in terms of what infrastructure is possible and desired by the company (from slow to ultra-fast charge), 11 kW chargers have the flexibility to service different types of vehicles, and provide sufficient power for long duration charging during working days.
Work	22 kW	Represents the semi fast charging case at work, since faster options are necessary for short term visitors. A 22 kW charger with power split could provide an interesting tradeoff solution. It has the flexibility to service different types of vehicles, as it can serve both single and 3-phase charging capable vehicles from very low to higher power levels (3.6 kW up to 22 kW).

7.3.2 User preference of charging

A literature review on users' charging preferences in terms for charging durations, times, and transferred energy is done. This review is used as reference and plausibility check for detailing the charging activities within the use cases. Even though the studies in the literature review are mainly focusing on the commuter EVs for city trip, which do not cover the detailed defined use cases in chapter 3.3, the information is yet helpful for further detailing the use case in the follow up work packages.

In [4], an analysis of the key criteria for purchasing an EV is conducted. It appears naturally that home charging is the most important piece of infrastructure, work charging is the second main place for EV charging. Public charging stations appear to be the least frequently used locations but are still important. They contribute to assured charging [5].

In [6] and [7], two studies of the charging preference have been conducted respectively in Ireland and UK/US in 2015-2016 with 22 kWh and 24 kWh battery vehicles. In these studies, the standard charging is mostly used in the evening, with a mean duration of 130 minutes [4] and a mean charging interruption occurrence is less than 1. As for fast charging, events take place between 11:00 to 18:00, once or twice, for short stop period. The mean duration varies between 20 to 30 minutes, depending on the considered country. Typical, the mean average energy transferred is 8.3 to 9.2 kWh, values respectively given in [6] and [7]. It should be noted that there are significant improvements of battery capacity and charging power in the past few years after the studies have been taken place. However, despite of those improvements, actual user habits regarding duration for fast charging remain close to what is describe here.

In [5], a survey of EV user done in Germany gives the acceptable charging scenario to contribute to the fast charging station location in case of detour. Results show an ideal acceptable detour for fast charging of 0.5 km, ideally located at a walking distance of 50 meters from the point of interest (shopping or place to eat) in metropolitan regions and less than 2 km in rural or highway areas. Users mostly use standard charging points at departure and arrival locations, and fast charging stations at interim stops.

CEVOLVER project will consider these studies outcome (less than 2 km detour and less than 30 min charging duration) in the connected features eco-routing and assured charging for the charging stop planning along the trip.

7.3.3 5G mobile network

7.3.3.1 *5G introduction*

5G network technology is expected to be a key enabler for many future technologies. Compared to 4G, 5G offers increased data exchange volumes with reduced latency and supports a large number of connections. In reality, these advantages will not be available all in one. 5G offers a network that is divided in slices with each slice fulfilling a specific objective.

- Enhanced Mobile Broadband (eMBB) or handsets enable the exchange of high volumes of data, such as Ultra High Definition video streaming.
- Ultra-Reliable-Low-Latency Communications (URLLC) includes industrial applications and autonomous vehicles.
- Massive Machine Type Communications (MMTC) is the enabler for smart cities and smart homes via the so-called Internet-of-Things.

The 5G frequencies can differ worldwide. In Europe 5G will use the existing LTE band (600 MHz to 6GHz) and additionally the millimetre wave bands (24-86 GHz). The transfer rates in the LTE band are similar to 4G, however the transfer rates in the millimetre wave band are significantly higher with speeds up to 20 Gigabits per second [8].

7.3.3.2 *5G for the automotive industry*

C-V2X offers two complementary modes of communication. The direct mode operates in the ITS band independent from the cellular network to support short range V2V, V2I and V2P communication. The network mode operates in the traditional mobile broadband network to offer long range V2N communication. [9]

Today, manufacturers are ramping up quickly the installation of 4G LTE modems in their vehicles for communication with the cloud. Some manufacturers are offering also V2X communication based on the Dedicated Short Range Communication (DSRC) technology. DSRC is using the 802.11p technology and allows among others V2V and V2I communication. Opposed to this technology, 5G offers also a direct connection between participants in the traffic via the PC5 “Sidelink”. It does not need a connection to the network or a SIM card.

The automotive industry sees 5G in the first place as a breakthrough technology for autonomous vehicles. Automated driving requires the communication of large amounts of data at a low latency. Electric vehicles are sometimes linked with automated vehicles since the two areas complement each other so well. In a first step towards automation, the low latency slice in the 5G network (URLLC) might offer opportunities to improve safety critical decisions on-board. There are however also other opportunistic use cases for 5G. The potential benefit for the CEVOLVER functions will be addressed in the next paragraph.

7.3.3.3 *5G use cases in CEVOLVER*

The CEVOLVER project targets the development of features such as ECO-routing, ECO-driving, drive range prediction, smart fast charging and assured charging. As part of this project, the potential of using fleet data to enhance the range prediction function is also analysed. For most of the functions and for most of the thinkable use cases, the currently available communication technologies (3G, 4G) satisfy the communication requirements. The fleet statistics range predictor defines the most stringent requirements with regard to V2X communication capabilities. It is expected that this function will benefit from the currently available 4G network. The potential of 5G to exchange high volumes of data, might in the future lead even to an additional benefit for this function, primarily due to the higher bandwidth of the 5G network. The goal of this function is to provide range prediction based on the feedback from the actual energy consumption obtained from vehicles in the fields. Each vehicle sends information on a regular basis to the cloud. Within the cloud, the fleet range predictor classifies the energy consumption values according to its dependencies, which also have been sent over from the vehicle. The resulting statistics allow an update of the remaining electric range of a vehicle at a specific point in time and depending on the geographical area (road segment or wider area). In order to create valid statistics, the function requires a regular input from a very large amount of vehicles. Next to that, the use of more input signals allows to refine the classification even further. Finally, an increased exchange rate allows better real-time capability, for example, when weather conditions change. High volumes and rates of data exchange require higher capabilities from the communication network up to the point where 5G could open the door for additional accuracy benefits.

There are also specific cases where the local network is highly charged, like typically on New Year's eve, or there is limited network availability, like in so-called "city canyons". For these cases, the amount of data easily exceeds the network capability resulting in higher latencies. Consequently, some of the CEVOLVER functions will not be able to deliver their targeted benefit. One example is when the re-routing information from ECO-routing reaches the HMI after a crossing where the driver should have turned off. Another example is when the battery pre-conditioning before a fast charging event starts later than optimal. The increased capacity of the 5G network, especially the eMBB slice, promises a significant improvement for these special cases even without over design to meet the need of peak performance.

7.3.4 Big Data analysis as basis for the definition of the use cases

For each use case of the different usage scenarios presented in the previous chapter, the project partners will translate the use case descriptions in a quantified velocity profile with proper boundary conditions. In the following application work packages (WP3, WP4 and WP5), for the different validators, they will be customised for the control development and tuning activities and the following WP6 experimental validation phase.

In order to define realistic use cases and corresponding speed profiles, in-house data derived from fleet tests is taken into consideration by the partners. Since this confidential data cannot be shared with the public, it was decided to look for public available speed profiles that are representative for the corresponding use cases. For that purpose, information from fleet tests about occurring ranges for average speed, top speed, vehicle acceleration and frequency and duration of stops was analyzed and compared with common driving cycles.

As a result, the different sections of the WLTC were determined as suitable to approximate the speed profiles of both a transporter and passenger car in the relevant use cases as described above. In contrast, the FKFS cycles show strong acceleration events, which are exceeding the capability of delivery vans, at least at high payload.