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Zero Emission flexible vehicle platform with modular powertrains serving the long-haul Freight Eco System

ZEFES - Deliverable report

Deliverable D5.1 – System specification for ZE modular multi-powertrain concepts

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Publishable summary

Within the Green Deal, Europe commits itself to be the first CO2 neutral continent by 2050. To achieve this, a first milestone is defined as an overall CO2 reduction target of 55% by 2030. For the road transport sector, the target is set at 30% less CO2 emissions by 2030, following Regulation (EU) 2019/1242. The regulation requires that manufacturers of heavy-duty vehicles (HDV) deliver more efficient vehicles to achieve a reduction of CO2 emissions for the newly produced fleet of 15% in 2025 and 30% in 2030. This deliverable presents the vehicle and powertrain specifications of the battery-electric vehicles units that apply for the vehicle combinations with a modular multi-powertrain to support the missions in the use case demonstrations. Based on the use cases, the relevant vehicle categories, and the vehicle requirements defined in work package 1, the vehicle and powertrain parameters are defined by the vehicle and trailer manufacturers and tier one suppliers. Three use cases demonstrate three different vehicle combinations with modular multi-powertrains consisting of three battery-electric towing vehicles, two electrified semitrailers and one electrified converter dolly. The vehicle specifications provided by the manufacturers are verified by a simulation-based assessment of its performance and characteristics in terms of the overall range of the vehicle combinations, the energy consumption and energy efficiency, and its ability to serve the use case missions as planned.

The deliverable gives a short overview of the simulation tool IVIsion including the adaptations that are made for simulating the battery-electric modular multi-powertrains. This is followed by a presentation and assessment of the simulation results.

Contents

List of Figures

List of Tables

Abbreviations & Definitions

Abbreviation	Explanation
BEV	Battery Electric Vehicle
EMS	European Modular System
KPI	Key Performance Indicators
PTC	PowerTrain Configuration
SLI	Scandlines
VECTO	Vehicle Energy Consumption calculation TOol
ZE	Zero Emission

1 Introduction

In the ZEFES work package 5 the modular and flexible battery-electric powertrains and their integration in five demonstrators is realized. These demonstrator vehicle combinations consist of five battery-electric towing vehicles, two electrified semitrailers, and one electrified converter dolly.
The work includes the development of a modular battery-electric powertrain concept for long-haul heavy-duty vehicle combinations, which are adaptable to daily demands of mission profiles in terms of range and power, and flexible in terms of integration of batteries and powertrains in different vehicle units. For this powertrain concept a functional safety concept is created.
To realize the vehicle units, specific powertrain components, subsystems, control systems and energy & thermal management systems are adapted and integrated in the prime mover battery-electric powertrains. Development and integration effort are also made to realize the next generation e-trailers serving as range extender integrated in the electric powertrain of the prime mover.

The following list shall clarify the context of deliverable D5.1:

D5.1 - System specification for ZE modular multi-powertrain concepts: In this deliverable the system specification of the battery-electric vehicle combinations with a modular multi-powertrain is verified and evaluated. The upgraded vehicle simulation tool IVIsion is used to verify the final design specifications of each targeted BEV demo.

D5.2 – Functional Safety Concept: The deliverable investigated the functional safety concept for the vehicle combinations with a modular multi-powertrain. The concept of an additional powertrain located in a trailer is described in terms of its application area, its functional behaviour on vehicle level, the powertrain functions and a draft system architecture. Furthermore, the results of the hazard analysis and risk assessment are presented including the derived safety goals and functional safety requirements for the development of the electrified trailers and the application in the ZEFES use cases.

D5.3 - Powertrain components and control systems for next generation battery-electric trucks: Within the deliverable the innovations and system improvements for the battery-electric towing vehicles developed by SCA, VOL and REN are described. This includes results of the proof of concept.

D5.4 - Next generation battery-electric trailers: The deliverable describes the adaptations and improvements of the e-semitrailer and the e-dolly as part of the modular multi-powertrain vehicle combinations. This includes the improvement of the mechanical design for the trailer chassis, based on the existing ZF e-trailer, and the development efforts regarding the powertrain components, controls, and auxiliary systems.

D5.5 - Commissioning, testing and verification connectivity between BEV demonstrators and digital twin tool: The deliverable briefly describes the results of the commissioning and testing of the data interface between the demonstrator vehicles and the digital twin tool developed in work package 4.

D5.6 - Realization and commissioning of all BEV demonstrators: In this deliverable the commissioning and testing of the six battery-electric demonstrator vehicle combinations is presented including the results of short dry run tests. As a result of the work described in this document the vehicle combinations can be handed over to WP7 use cases.

The position of deliverable D5.1 within WP5 and the relation to other deliverables and work packages is shown in Figure 1-1.

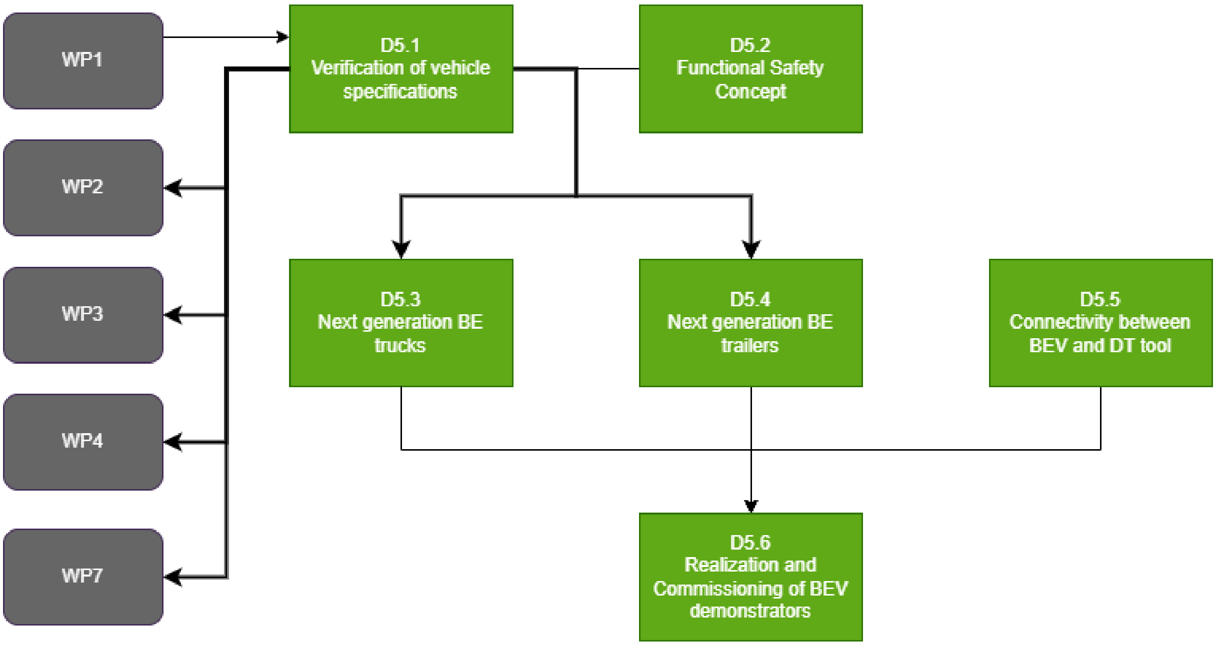

Figure 1-1: Relation of deliverable D5.1 to deliverables of WP5 and other WPs

Chapter 2 of the present document describes the vehicle portfolio that is in the scope of the deliverable. The description includes the vehicle combinations together with a draft version of the logistic missions defined in the use case descriptions of WP1. Based on the resulting vehicle combinations and its different vehicle units the procedure to complete and verify the vehicle specifications that were prepared by the templates developed in task 1.1 of WP1 are presented.
In chapter 3 the verification of vehicle specifications is described in detail. Starting with the main objectives of the verification task and an introduction to the simulation tool IVIsion, the chapter proceeds with a description of the information and parameters that are collected in the vehicle specification documents. The parameters are input to the simulation tool and are completed with the driving cycles and mission profiles that are summarized in the simulation test matrix.
The simulation results per vehicle combination and use case are presented in chapter 4.
Chapter 5 draws conclusions and gives recommendations how to optimize the vehicle specification and the use case planning.
Appendix A presents the vehicle specifications for each vehicle unit used in the simulations.

2 Vehicle portfolio

2.1 Results of WP1

As a result of work package 1 deliverable D1.2 [1] gives an overview of the use cases and the vehicle combinations to be demonstrated in the ZEFES project. To meet the needs and requirements of the shippers, the OEMs of trucks and trailers together with the shippers have developed a proposal for the use of different vehicle concepts. During this process three different use cases were identified where vehicle combinations with modular distributed powertrains are applied.

2.1.1 Use case 7.3.1

Use case 7.3.1 represents an existing transport flow of automotive components operated between Södertälje (S) and Zwolle (NL). The return flow from Zwolle to Södertälje is limited amount of goods. The distance of a one-way trip is about 1325 km. The logistics operator uses a tractor – semitrailer vehicle combination for six months between 05/2025 and 10/2025 (status May 2024). The ZEFES demonstrator vehicle combination will consist of a 4x2 battery-electric tractor, and an electrified semitrailer (e-trailer) that serves as a range extender for the towing vehicle. More details about the vehicles are given in section 3.3.

2.1.2 Use case 7.2.4

Use case 7.2.4 represents an existing daily transport flow of parcels operated by DPD on the Rhine-Alpine corridor between Munich (DE) area and Eindhoven (NL) area. The distance of a one-way trip is about 675 km. DPD operates an EMS1 vehicle combination for six months between 03/2025 and 02/2026 (status May 2024). The ZEFES demonstrator vehicle combination will consist of a 6x2 battery-electric rigid, a standard 2-axle converter dolly, and an electrified semitrailer (e-trailer). More details about the vehicles are given in section 3.3.

2.1.3 Use case 7.2.3

Use case 7.2.3 represents an existing daily transport flow of 45 ft containers with partly hazardous goods operated by Procter & Gamble (P&G) between the P&G factory in Amiens (FR) via the multimodal terminal in Dourges (FR) to the multimodal terminal in Zeebrugge (BE). The distance of the round trip is about 550 km. P&G operates an EMS2 vehicle combination for six months between 09/2025 and 02/2026 (status May 2024). Only the leg of the route between Amiens and Dourges is operated with the EMS2 vehicle combination. At the terminal in Dourges the e-dolly with the second semitrailer is decoupled and stays at the terminal. The tractor with the first semitrailer continues the route to Zeebrugge. On the return trip all vehicles units are combined to the EMS2 vehicle combination at the terminal in Dourges and continue the trip back to Amiens. The ZEFES demonstrator vehicle combination will consist of a 6x2 battery-electric tractor, two standard container semitrailers and an electrified converter dolly (e-dolly). More details about the vehicles are given in section 3.3. It is possible that arbitrary semitrailers are used, as long as they are fulfilling the requirements regarding the coupling of a converter dolly and the turning circles of the EMS2 vehicle combination.

2.2 Focus of WP5 – Taks 5.1

The simulation-based verification of vehicle specifications focuses on the vehicle combinations that will be demonstrated in the use cases described in section 2.1. Therefore, simulations are conducted for the vehicle combinations with modular distributed battery-electric powertrains presented in Table 2-1.

Table 2-1: Vehicle combinations simulated to verify the vehicle and powertrain specification

Type of vehicle combination	**Prime mover**	**1st trailer**	**2nd trailer**	**3rd trailer**
Tractor – semitrailer 	4x2 BEV tractor	e-semitrailer	-	-
EMS1 	6x2 BEV truck	Standard dolly	e-semitrailer	-
EMS2 	6x2 BEV tractor	Standard semitrailer	e-dolly	Standard semitrailer

To parameterize the vehicle and component models of the simulation tool, general vehicle parameters including powertrain requirements based on gross and cargo weight, vehicle speed and acceleration capabilities as well as specific requirements on powertrain components and auxiliaries are collected. As a result of work package 1 deliverable D1.1 [2] presented a template that combines the main vehicle and powertrain requirements and needs. The information and parameters that are collected in these templates are input to the work packages 2, 3, 4, 5, 6 and 8.
The vehicle and powertrain parameters cannot completely be provided by the OEMs due to confidentiality reasons. Therefore, the templates are reduced to the mandatory parameters of the spreadsheet “vehicle parameters”. The parameters are aligned between FHG and the OEMs in an iterative process. First, the general information like axle configuration, tare weight and wheelbase are provided by the OEMs to define the type of vehicle. In a second step the missing parameters are added by FHG based on the existing vehicle and component models. In a final alignment the OEMs adjust the given parameters where necessary to guarantee that the specifications represent the real vehicles.
For the simulation of the vehicle combinations applied in the use case missions corresponding mission profiles are provided by TNO.
The main focus of task 5.1 is to verify the vehicle specifications with respect to the use case missions and the objectives of the ZEFES project. By simulating the vehicle combinations, the following details of the use case mission planning are confirmed:

- Energy consumption of vehicle units
- Trip time
- Charging time
- Range extension by the e-trailer considering its operational strategy, route topology etc.

Furthermore, the effect of operational strategies, operating and environmental conditions are analyzed:

- Dimensioning of powertrain components
- ambient temperature, solar radiation, …
- Operational strategy of the battery-electric powertrain (e.g. recuperation, DoD of the battery)
- Operational strategy of the auxiliaries (e.g. air conditioning)
- payload, distribution of axle loads

3 Verification of vehicle specifications

3.1 Objectives

The simulations enable a first assessment of the battery-electric vehicles and its innovations in terms of the powertrain-related Key Performance Indicators (KPI)

- KPI 1: energy consumption in [kWh/km] and its corresponding percentage energy consumption reduction compared to the baseline vehicle combination (to compare different vehicle configurations carrying the same payload)
    - equation absolute numbers: $\frac{absolute\ energy\ consumptioin\ [kWh]}{distance\ [km]}$
    - equation relative numbers: $\frac{energy\ consumption\ baseline\ vehicle\ \left[\frac{kWh}{km}\right] - energy\ consumption\ ZEFES\ vehicle\ \left[\frac{kWh}{km}\right]}{energy\ consumption\ baseline\ vehicle\ \left[\frac{kWh}{km}\right]} * 100\%$
- KPI 2: energy efficiency in [(t-km)/kWh] and its corresponding percentage energy efficiency gain compared to the baseline vehicle combination
    - equations absolute numbers: $\frac{payload\ [t] * distance\ [km]}{absolute\ energy\ consumption\ [kWh]}$
    - equation relative numbers: $\frac{fuel\ efficiency\ ZEFES\ vehcile\ \left[\frac{t*km}{kWh}\right] - fuel\ efficiency\ baseline\ vehicle\ \left[\frac{t*km}{kWh}\right]}{fuel\ efficiency\ baseline\ vehicle\ \left[\frac{t*km}{kWh}\right]} * 100\%$
- KPI 5: average speed in [km/h] as a relevant value for appropriate comparison of fuel consumption on a specific cycle
    - equation absolute numbers: $\frac{distance\ of\ cycle\ [km]}{time\ to\ complete\ cycle\ [h]}$

During the ZEFES project a measurement campaign for collection of reference data of conventional vehicles with an ICE is planned. Since this reference data is not available yet, the simulation-based verification uses baseline vehicles in terms of the abovementioned vehicle combinations (see chapter 2) that contain a standard semitrailer or dolly instead of an e-trailer.
Beyond that the simulations verify the mission planning of the use cases in terms of the separation in several legs, required charging stops and charging time.

3.2 Simulation tool IVIsion

Figure 3-1 shows the IVIsion toolchain from measurement to optimization of vehicles. IVIsion contains the four main tools IVImap, IVInet, IVIdrive and IVIplot.
For mapping of vehicle system data IVImap provides several functions to

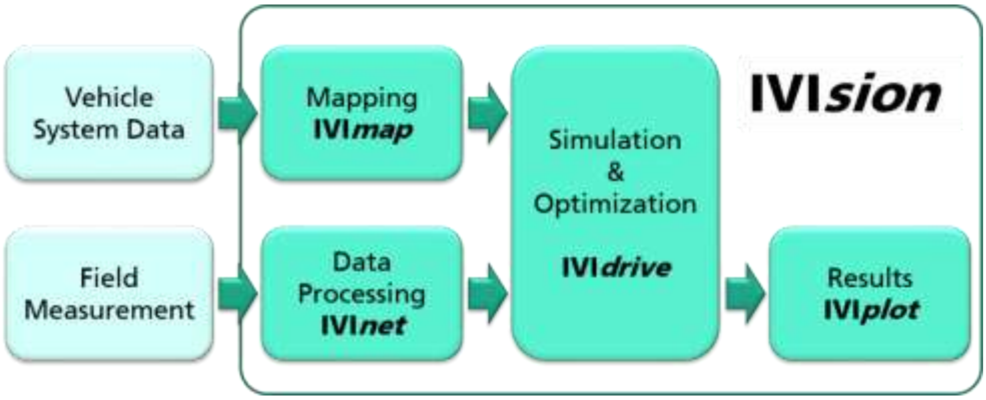

Figure 3-1: IVIsion toolchain

- read, scale and edit image-based maps,
- use a large variety of implemented maps of typical powertrain components,
- adapt the implemented maps to the exact values of the respective application.

For processing measurement data IVInet provides algorithms to automatically process large amounts of data from long-term measurements for simulations (GPS data, CAN data, load, …). The core part for simulation and optimization tasks is implemented in IVIdrive. For the definition of the vehicle concept, it includes

- numerous pre-configured drivetrain configurations,
- component management strategies,
- basic model parameters and characteristic maps,
- simple and fast dimensioning calculations,
- simple settings of the model,
- functions for fast and easy concept comparison.

The given model structure can be optimized and/or enhanced with more details by using more complex sub-models, e.g. LV systems, HVAC, or pneumatic systems. The use of real component-related maps of various suppliers increases the model accuracy and provides the basis for the investigation of energy management strategies and the comparison and optimization of operating strategies.
The overall vehicle simulation is configured via a graphical user interface (see Figure 3-2).

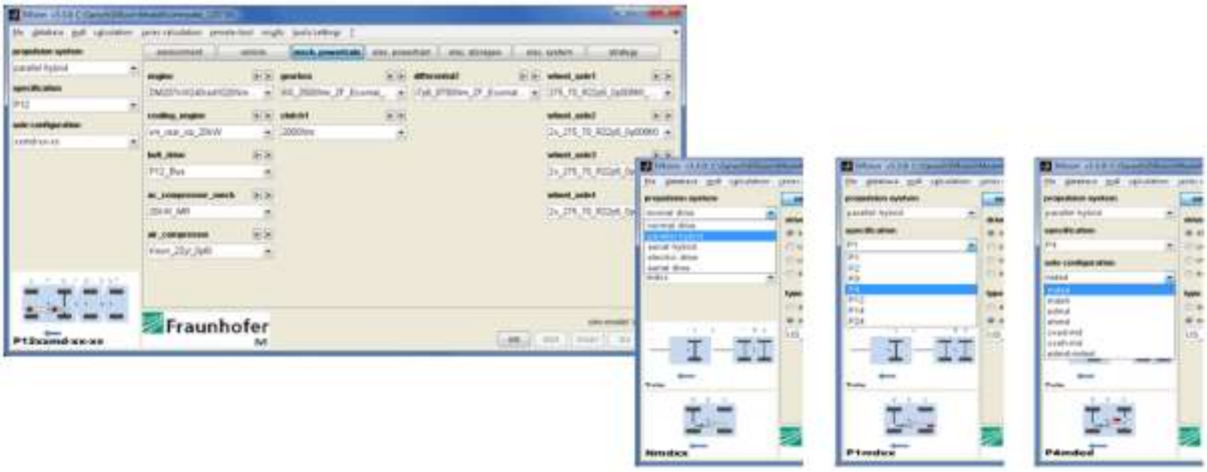

Figure 3-2: IVIdrive graphical user interface (left), selection of basic vehicle configuration (right)

Via the user interface more than 100 pre-set vehicle and powertrain configurations can be selected (see Figure 3-3), including vehicles up to four segments and 11 axles with map-based models of combustion engine, fuel cells, batteries, electric motors and gear boxes or power electronics based on characteristic curves.

Thus, IVIdrive is applicable for the calculation of driving performance, fuel consumption or CO2 emissions, the optimization of the complete vehicle energy balance, the dimensioning of components and the overall system optimization. Furthermore, it is used for testing of operational energy management strategies with pre-configured algorithms which are adaptive regarding performance of powertrain. This includes self-learning SOC control of electric energy storages and intelligent auxiliary management.

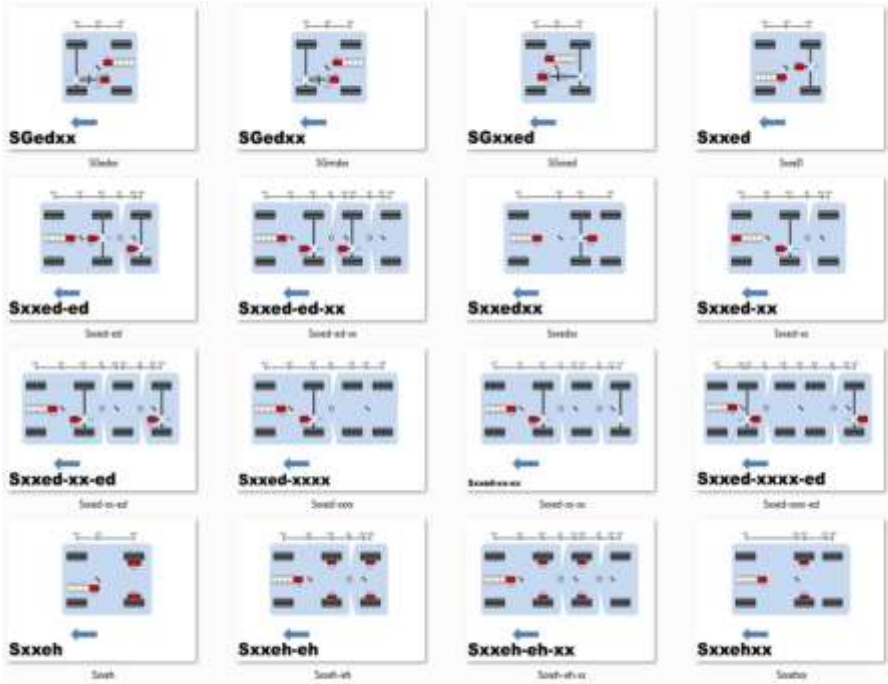

Figure 3-3: Selection of vehicle models and powertrain configurations implemented in IVIsion

3.3 Vehicle and powertrain specifications

The specifications are given in Appendix A – Vehicle and powertrain specifications of battery-electric vehicles. The parameters are divided into seven categories that contain different topics.

Topic	Parameter
Use Case	Sub Task ID
	vehicle combinations
	vehicle type
	licence plate number

Figure 3-4: Parameter category - use case information

Topic	Parameter
General vehicle information	vehicle brand
	axle configuration
	tare weight
	gross vehicle weight
	Frontal area
	Drag coefficient
	Wheelbase axle 1 – axle 2
	Wheelbase axle 2 – axle 3
	Center of gravitiy from axle 1
	horizontal distance of kingpin/coupling from axle 1
	Permissible axle loads (front)
	Permissible axle loads (rear)
	Power brake choper
Tyre information of vehicle	Front Tyre type / size
	Rear Tyre type / size

Figure 3-5: parameter category - vehicle characteristics and dimensions

Topic	Parameter
AC Charging Requirements	AC charging standards
	AC connector
	On Board Charger(OBC): power (efficent)
	OBC HV system: input voltage, output voltage
	OBC efficiency
	number of AC inlets (charging ports)
	position of AC inlets (charging ports)
DC Charging Requirements (CCS)	DC charging standards
	DC connector
	DC charging voltage level
	DC charging power
	number of DC inlets (charging ports)
	position of DC inlets (charging ports)
DC Charging Requirements (MCS)	DC charging standards
	DC connector
	DC charging voltage level
	DC charging power
	number of DC inlets (charging ports)
	position of DC inlets (charging ports)
Hydrogen Fueling Requirements	Fueling pressure (350bar / 700 bar / both)
	Fuel Receptacle Type
	Fueling protocol
	Location of fueling on vehicle (left / right / both)
	Nozzle Type
	Developments during demonstration - do you anticipate changing nozzle or protocol during the demonstration if advances allow, eg HF Nozzle?
	Hydrogen Purity requirement.

Figure 3-6: parameter category - charging/fuelling information

Topic	Parameter
HV battery	Cell chemestry
	Cell type
	Number of cells per row
	Number of cell rows
	Cell capacity
	Battery installed energy capacity
	Operating temperature range for cont. discharge current
	Operating temperature range for cont. charge current
	Operating temperature range for max. discharge current
	Operating temperature range for max. charge current
	Optimum operating temperature range
	Cont. charge current
	Max. charge current
	Max. time for max charge current
	Cont. discharging current
	Max. discharge current
	Max. time for max discharge current
	Ohmic resistance of cell dependent on temperature
	Max. state of charge
	Min. state of charge
	Cooling system (air/liquid)
	Mounting position (battery center of gravity from axle1)
	Battery weight
	DC/DC converter (of battery) applicable
	DC/DC converter (of battery) max. charging current on battery side
	DC/DC converter (of battery) max. discharging current on battery side
	DC/DC converter (of battery) average efficiency

Figure 3-7: parameter category - HV battery characteristics

Topic	Parameter
Fuel cell	fuel cell type
	Mass of max stored hydrogen
	DC/DC efficiency
	Max. power
	number of fuel cell stacks
	Energy consumption of auxiliaries depending on power of stacks
	Fuel Cell efficiency

Figure 3-8: parameter category - fuel cell characteristics

Topic	Parameter
E-drive	electric machine type
	Max. cont. torque
	Max. peak torque
	Max. cont. power, mech
	Max. peak power, mech
	Max. efficiency
	Torque over speed
	Average mech. Efficiency from E-drive output to wheel
	E-machine configuration (center, wheel)
	Number of gears
	Ratio E-machine to wheel

Figure 3-9: parameter category - characteristics of the electric powertrain

Topic	Parameter
Auxiliaries	Vehicle electrics (24 V), rated power
	cabin air conditioning (AC), rated power
	cabin heating, rated power
	Chiller (compressor + fan + pump) for battery cooling, rated power
	Cooling fan + pumps for high temperature circuit (EMG + power electronics), rated power
	fan + pumps for FC cooling circuit, rated power
	Steering pump, rated power
	Air compressor for brake, rated power
	DC / DC for LV (24V / 12V), rated power
	DC / DC HV (between fuel cell and battery), rated power
	Brake chopper, rated power
	additional HV consumers (e.g. cooling of cargo), rated power

Figure 3-10: parameter category - rated power of the auxiliaries

In the tables in Appendix A the generic values are marked in yellow. The values marked in green are provided by the vehicle manufacturers.

3.4 Mission profiles

The vehicles are simulated with two types of driving profiles. The VECTO ("Vehicle Energy Consumption calculation TOol") provides a long-haul mission profile in terms of a target speed cycle over distance and a generic driver model. To gain reference driving cycles for each vehicle combination, they are simulated as a standard combination with a battery-electric towing vehicle but without e-trailers on the VECTO long-haul cycle (see Figure 3-11). The resulting driving cycle is used as target driving cycle for the vehicle combinations with the modular multi-powertrains. Thus, the driving performance of the reference vehicle combination is reproduced by the vehicle combinations with modular multi-powertrain and KPI5 (average speed in [km/h]) is similar between the vehicle combinations.
The driving cycle is simulated in a loop until the HV battery of the towing vehicle reached its minimum state of charge.

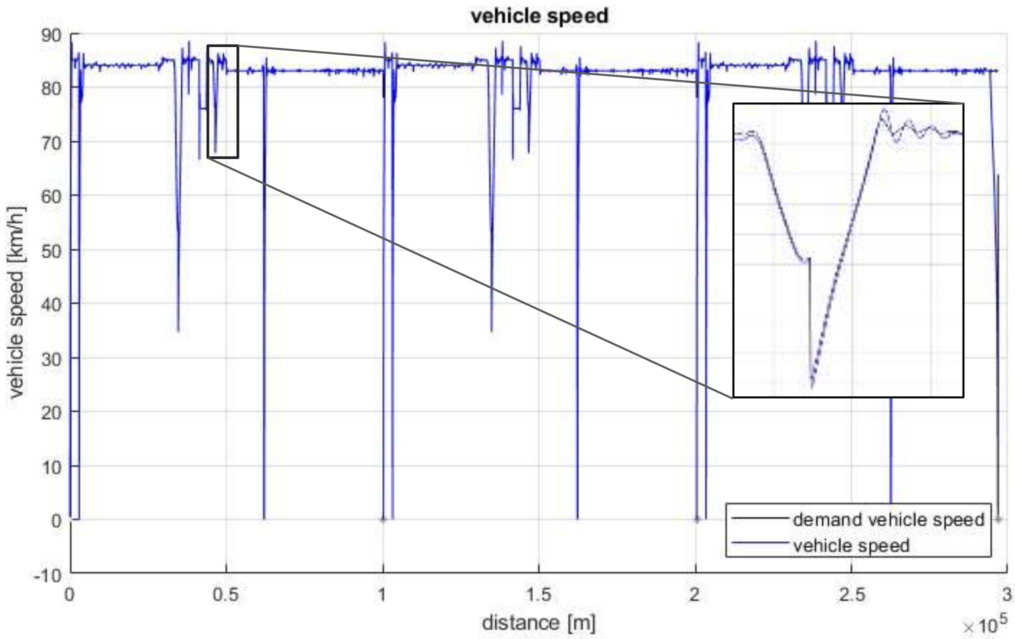

Figure 3-11: Speed profile of the tractor - semitrailer vehicle combination with a standard semitrailer simulated on the VECTO long-haul mission profile

Additionally, the mission profiled of the real ZEFES use cases are applied. Since the measurement campaign with reference vehicles is conducted in a later stage of the project, real world driving profiles of the specific use cases are not available for the simulations. Therefore, synthetic driving profiles using the following input information are generated by TNO:

- filtered elevation and slope profiles based on SRTM (Shuttle Radar Topography Mission) data,
- speed limits based on open street map (limited at 85 km/h),
- simple driver model including
    - fixed acceleration at 0.5 m/s2 if slower than speed limit,
    - fixed deceleration at -1 m/s2 if faster than speed limit)

3.4.1 Use case 7.3.1

During the outward trip the vehicle combination is fully loaded with a gross vehicle weight (GVW) of 44 tonnes. During the return trip the vehicle combination is partially loaded with a GVW of 25 tonnes.
The route is shown in Figure 3-12 and contains the legs presented in Table 3-1.

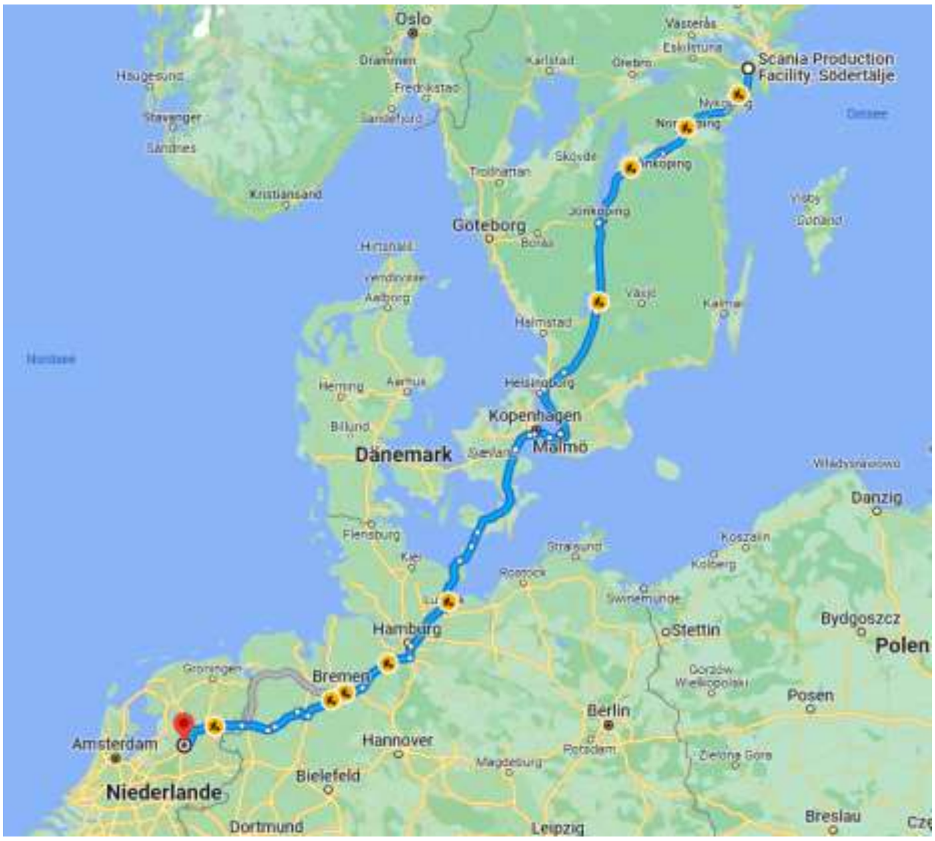

Figure 3-12: UC7.3.1 - route map (source: Google Maps, ©2023 Google, GeoBasis-DE/BKG (©2009)

Table 3-1: Use case 7.3.1 - legs of outward and return trip

Leg	Start	End	Distance	Remarks
1	Scania Production Facility Södertälje, 15148 Södertälje, Sweden	Jönköping, Sweden	300 km	CCS charging at starting point
2	Jönköping, Sweden	Copenhagen, Denmark	288 km	CCS charging at starting point
3	Copenhagen, Denmark	Hamburg (Stillhorn), Germany	297 km	CCS charging at starting point
4	Hamburg (Stillhorn), Germany	Scania Production Zwolle, 8041 AL Zwolle, The Netherlands	331 km	MCS charging at starting point
5	Scania Production Zwolle, 8041 AL Zwolle, The Netherlands	Hamburg (Stillhorn), Germany	331 km	CCS charging at starting point
6	Hamburg (Stillhorn), Germany	Copenhagen, Denmark	297 km	MCS charging at starting point
7	Copenhagen, Denmark	Jönköping, Sweden	288 km	CCS charging at starting point
8	Jönköping, Sweden	Scania Production Facility Södertälje, 15148 Södertälje, Sweden	300 km	CCS charging at starting point

3.4.2 Use case 7.2.4

The route is shown in Figure 3-13 and contains the legs presented in Table 3-2.

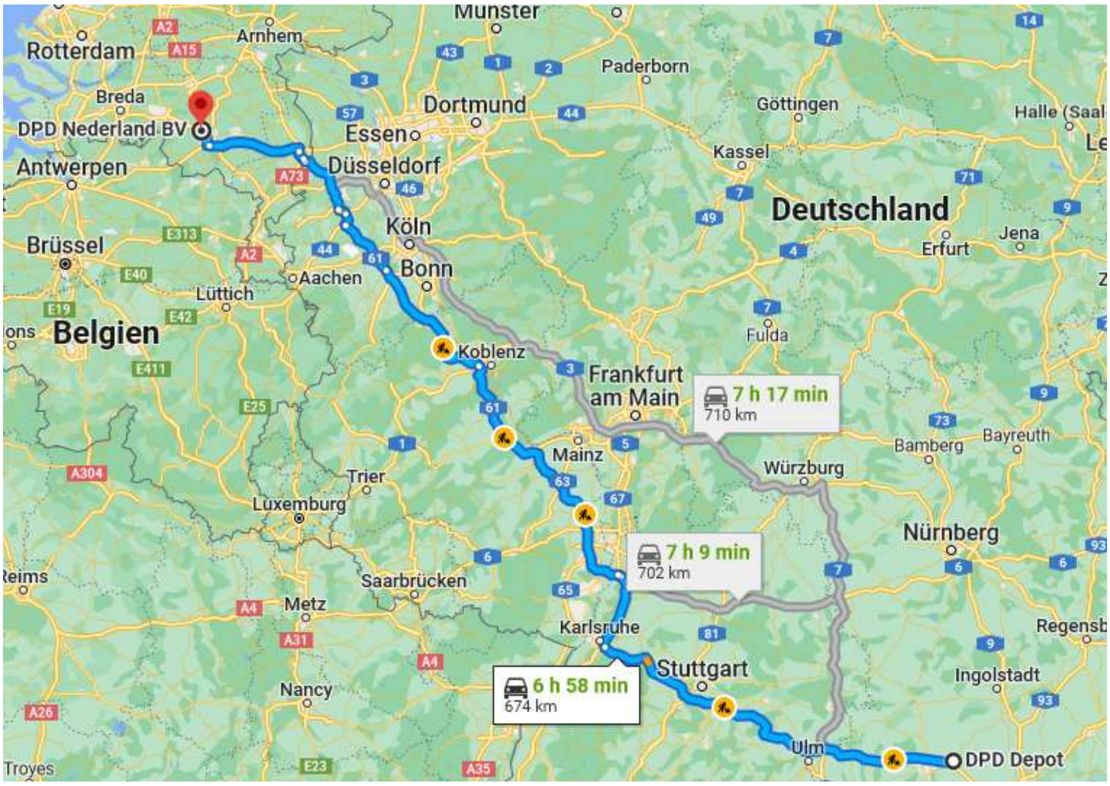

Figure 3-13: UC7.2.4 - route map (source: Google Maps, ©2023 Google, GeoBasis-DE/BKG (©2009)

Table 3-2: Use case 7.2.4 - legs of outward and return trip

Leg	Start	End	Distance	Remarks
1	Neuss, Germany	DPD NL, 1410 HA Oirschot, The Netherlands	120 km	CCS charging at starting point
2	DPD NL, 1410 HA Oirschot, The Netherlands	Neuss, Germany	120 km	
3	Neuss, Germany	Wertheim, Germany	304 km	CCS charging at starting point
4	Wertheim, Germany	DPD DE, 86551 Aichach, Germany	290 km	CCS charging at starting point
5	DPD DE, 86551 Aichach, Germany	Wertheim, Germany	290 km	CCS charging at starting point
6	Wertheim, Germany	Neuss, Germany	304 km	CCS charging at starting point

3.4.3 Use case 7.2.3

The route is shown in Figure 3-14 and contains the legs presented in Table 3-3.

Figure 3-14: UC7.2.3 - route map (source: Google Maps, ©2024 Google, GeoBasis-DE/BKG (©2009)

Table 3-3: Use case 7.2.3 - legs of outward and return trip

Leg	Start	End	Distance	Remarks
1	Procter & Gamble Amiens (FR), 80080 Amiens, France	LDCT Lille Dourges Terminal Conteneur, 62119 Dourges, France	123 km	CCS charging at starting point
2	LDCT Lille Dourges Terminal Conteneur, 62119 Dourges, France	CLdN Ports Zeebrugge Nv, 8380 Brugge, Belgium	115 km	
3	CLdN Ports Zeebrugge Nv, 8380 Brugge, Belgium	LDCT Lille Dourges Terminal Conteneur, 62119 Dourges, France	115 km	CCS charging at starting point
4	LDCT Lille Dourges Terminal Conteneur, 62119 Dourges, France	Procter & Gamble Amiens (FR), 80080 Amiens, France	123 km	

3.5 Simulation test matrix

To assess the influence of the modular multi-powertrain concept in terms of the KPIs presented in section 3.1, the vehicle combinations with an e-trailer or e-dolly are compared with the vehicle combinations with a battery-electric towing vehicle only (base vehicle combination). Since there are two battery capacities possible to be installed in the e-trailer and both are applied in the use cases, they are both compared to the base vehicle combination. In case of the e-dolly only one battery capacity is used in the simulations.
The vehicle combinations are first simulated with the VECTO long-haul cycle. In a second step the simulations are conducted with the real-world driving cycle of the respective use cases (see Table 3-4 and Table 3-5).
Furthermore, the simulations are varied in terms of payload (empty/full).

Table 3-4:Driving cycles used for the simulations of vehicle combinations including an e-trailer with different installed battery capacity

		Installed battery capacity of e-trailer		
		None (standard trailer)	210 kWh	315 kWh
Vehicle combination	Tractor – semitrailer	VECTO long haul	VECTO long haul	VECTO long haul
		Use Case 7.3.1	Use Case 7.3.1	Use Case 7.3.1
	EMS1	VECTO long haul	VECTO long haul	VECTO long haul
		Use Case 7.2.4	Use Case 7.2.4	Use Case 7.2.4
		Use Case 7.2.3	Use Case 7.2.3	Use Case 7.2.3

Table 3-5: Driving cycles used for the simulations of vehicle combinations including an e-dolly with different installed battery capacity

		Installed battery capacity of e-dolly	
		None (standard trailer)	73,5 kWh
Vehicle combination	EMS2	VECTO long haul	VECTO long haul
		Use Case 7.2.3	Use Case 7.2.3

3.5.1 Operational strategy of the e-trailer

The operational strategy of the e-trailer is modelled with the parameters presented in Table 3-6. The secondary powertrain represents the powertrain of the e-trailer or the e-dolly.
The power of the secondary powertrain depends on the calculated tractive force in the joint between the e-trailer and the towing vehicle. It is further limited by the characteristics of the driving situation. The increase of the traction power provided by the secondary powertrain is limited to avoid a jerk of the vehicle combination or an oscillation of the traction power. Further limits are set for the minimum acceleration/deceleration of the vehicle combination that allows a support by the secondary powertrain, and the minimum acceleration/deceleration that allows a support by the secondary powertrain with maximum power. Additionally, limits are set for the minimum road inclination that allows a support by the secondary powertrain, and the minimum road inclination that allows a support by the powertrain with maximum power.

Table 3-6: Parameters for optimization of the operational strategy of the e-trailer

Parameter description	Unit	Value 1	Value 2
Relative power of secondary powertrain depending on the tractive force in the joint of the secondary powertrain vehicle unit	-	0.125	
maximum increase of secondary traction power	1/s	0.2	
Minimum acceleration/deceleration for secondary powertrain support	m/s^2	0.01	
Minimum acceleration/deceleration for maximum secondary powertrain support	m/s^2	0.5	
Minimum road inclination for secondary powertrain support	%	0.1	
Minimum road inclination for maximum secondary powertrain supply	%	1	

4 Simulation results

In the following sections the simulation results according to the simulation test matrix described in section 3.5 are presented. The vehicle models are parameterized according to the vehicle specifications listed in chapter 10 Appendix A. These parameters include values regarding

- general vehicle information (vehicle dimensions etc.),
- characteristics of the HV battery,
- characteristics of the electric powertrain,
- rated power of the auxiliaries.

The energy storage units of the vehicle units are fully charged at the beginning of the simulated trips. The cargo weight of the different vehicle configurations refers to the vehicle combinations with a standard trailer. For the vehicle combinations with an e-trailer, the cargo weight is reduced due to the weight of the additional battery-electric powertrain including the energy storage unit.

4.1 Use case 7.3.1 – tractor-semitrailer

In Table 4-1 the simulation results of the tractor – semitrailer vehicle combinations with three different powertrain configurations are presented. The cargo weight is zero, which is why no energy efficiency is indicated.
The total distance reached by the vehicle combination is increased by the use of the e-trailer, which can also be seen in Figure 4-1. Since on the mission profile only a part of the energy content of the smaller e-trailer battery (PTC2: tractor – e-trailer with 205kWh) is used, the bigger e-trailer battery has no significant effect on the total distance of the vehicle combination.
For all three powertrain configurations the results show similar values for the recuperated energy. This is due to the mission profile and the very moderate driver model that makes use of the entire recuperation potential only with the powertrain of the towing vehicle. Thus, in this particular case the energy consumption of the vehicle combination cannot be decreased by the e-trailer.
The additional power provided by the e-trailer leads to the fact, that the deviation between the given speed profile and the speed profile realized by the driver model is smaller compared to this deviation realized by the tractor with standard semitrailer. Furthermore, the tare weight of the vehicle combination with the e-trailer is higher due to the additional powertrain. As a result, the overall energy consumption of the vehicle combination is slightly increased.

Table 4-1: Simulation results of tractor - semitrailer vehicle combinations, zero cargo weight, KPIs

ID	Powertrain configuration (PTC)	Total distance [km]	KPI1. energy consumption [kWh/km]	KPI2: energy efficiency [t km/kWh]	recuperated energy [kWh]
PTC1	tractor – standard semitrailer	401	1,40	-	-21,29
PTC2	tractor – e-semitrailer (205 kWh)	436	1,46	-	-22,42
PTC3	tractor – e-semitrailer (308 kWh)	441	1,48	-	-23,60

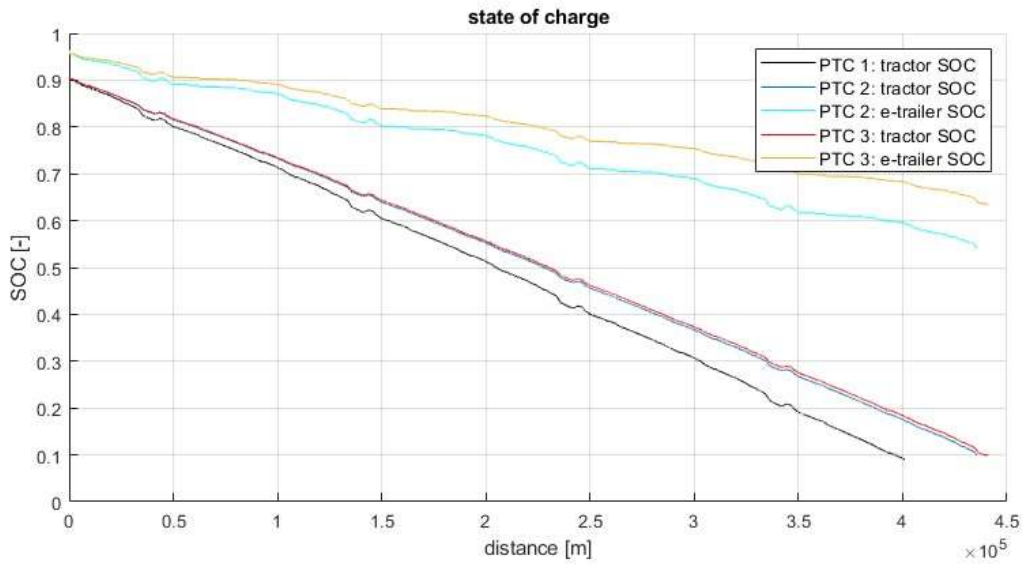

Figure 4-1: Simulation results of tractor - semitrailer vehicle combinations, zero cargo weight, state of charge over distance of single vehicle units

In Table 4-2 the simulation results of the tractor semitrailer vehicle combinations without cargo per vehicle unit are presented. It is obvious that the mission profile does not provide enough potential for the support by the e-trailer to use the whole energy content of the e-trailer energy storage unit (see also Figure 4-1). This explains the minor increase of the total distance resulting from the use of the e-trailer in the vehicle combinations (see Table 4-1).

Table 4-2: Simulation results of tractor - semitrailer vehicle combinations, zero cargo weight, results of vehicle units

ID	Powertrain configuration (PTC)	tractor			semitrailer		
		total energy consumption [kWh]	min. SOC [%]	DOD [%]	total energy consumption [kWh]	min. SOC [%]	DOD [%]
PTC1	tractor – standard semitrailer	593	9	81	-	-	-
PTC2	tractor – e-semitrailer (205 kWh)	587	10	80	90	54	43
PTC3	tractor – e-semitrailer (308 kWh)	587	10	80	105	64	33

In Table 4-3 the results for the same vehicle combinations and powertrain configurations with maximum cargo weight of 24 tonnes is presented. The range extension provided by the e-trailer is higher compared to the empty vehicle combinations. Due to the cargo weight the energy content of the smaller e-trailer battery (PTC2: tractor – e-trailer with 205kWh) is completely used before the energy storage of the tractor unit is empty. Thus, the bigger e-trailer battery has a positive effect on the total distance of the vehicle combination.
Although the total recuperated energy is increased by the e-trailer, the increased energy consumption by the driver model using the additional power of the e-trailer cannot be compensated. Due to reduced payload of the e-trailer, the energy efficiency is slightly higher than the one of a vehicle combination with a standard semitrailer.

Table 4-3: Simulation results of tractor - semitrailer vehicle combinations, maximum cargo weight (24t), KPIs

ID	Powertrain configuration (PTC)	Total distance [km]	KPI1: energy consumption [kWh/km]	KPI2: energy efficiency [t km/kWh]	recuperated energy [kWh]
PTC1	tractor – standard semitrailer	297	1,88	0,082	-44,02
PTC2	tractor – e-semitrailer (205 kWh)	386	1,92	0,084	-55,99
PTC3	tractor – e-semitrailer (308 kWh)	401	1,94	0,085	-57,10

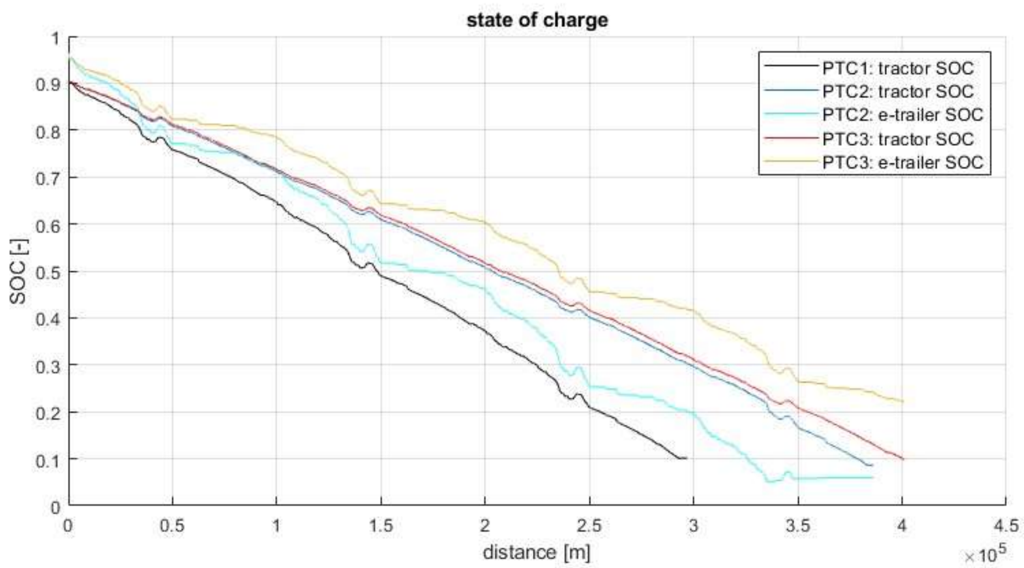

Figure 4-2: Simulation results of tractor - semitrailer vehicle combinations, maximum cargo weight (24t), state of charge over distance of single vehicle units

In Table 4-4 and Figure 4-2 the simulation results of the tractor semitrailer vehicle combinations with maximum cargo weight per vehicle unit are presented. As a result of the cargo weight, the potential of the e-trailer can be used to a greater extent.

Table 4-4: Simulation results of tractor - semitrailer vehicle combinations, maximum cargo weight (24t), results of vehicle units

ID	Powertrain configuration (PTC)	tractor			trailer		
		total energy consumption [kWh]	min. SOC [%]	DOD [%]	total energy consumption [kWh]	min. SOC [%]	DOD [%]
PTC1	tractor – standard semitrailer	586	10	80	-	-	-
PTC2	tractor – e-semitrailer (205 kWh)	596	9	81	187	5	92
PTC3	tractor – e-semitrailer (308 kWh)	588	10	80	231	22	75

4.2 Use case 7.2.4 – EMS1

In Table 4-5 the simulation results of the EMS1 vehicle combinations with three different powertrain configurations are presented. The cargo weight is zero, which is why no energy efficiency is indicated.
The total distance reached by the vehicle combination is increased by the use of the e-trailer, which can also be seen in Figure 4-3. Similar to the tractor – semitrailer vehicle combination, on the mission profile only a part of the energy content of the smaller e-trailer battery (PTC5: EMS1 with e-trailer with 205kWh) is used. Therefore, the bigger e-trailer battery has no effect on the total distance of the vehicle combination.
For all three powertrain configurations the results show similar values for the recuperated energy. This is due to the mission profile and the very moderate driver model that makes use of the entire recuperation potential only with the powertrain of the towing vehicle. Thus, in this particular case the energy consumption of the vehicle combination cannot be decreased by the e-trailer.
The additional power provided by the e-trailer leads to the fact, that the deviation between the given speed profile and the speed profile realized by the driver model is smaller compared to this deviation realized by the tractor with standard semitrailer. Furthermore, the tare weight of the vehicle combination with the e-trailer is higher due to the additional powertrain. As a result, the overall energy consumption of the vehicle combination is slightly increased.

Table 4-5: Simulation results of EMS1 vehicle combinations, zero cargo weight, KPIs

ID	Powertrain configuration (PTC)	Total distance [km]	KPI1. energy consumption [kWh/km]	KPI2: energy efficiency [t km/kWh]	recuperated energy [kWh]
PTC4	EMS1 with standard semitrailer	246	1,43	-	-26,85
PTC5	EMS1 with e-semitrailer (205 kWh)	284	1,49	-	-27,85
PTC6	EMS1 with e-semitrailer (308 kWh)	284	1,50	-	-28,67

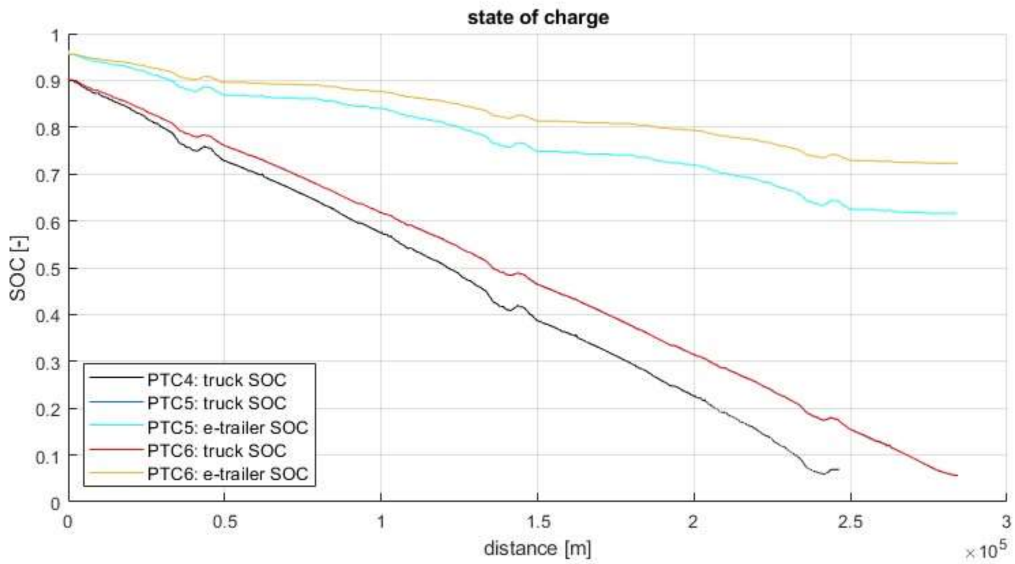

Figure 4-3: Simulation results of EMS1 vehicle combinations, zero cargo weight, state of charge over distance of single vehicle units

In Table 4-6 the simulation results of the EMS1 vehicle combinations without cargo per vehicle unit are presented. Again, the results show that the mission profile does not provide enough potential for the support by the e-trailer to use the whole energy content of the e-trailer energy storage unit (see also Figure 4-3).

Table 4-6: Simulation results of EMS1 vehicle combinations, zero cargo weight, results of vehicle units

ID	Powertrain configuration (PTC)	tractor			semitrailer		
		total energy consumption [kWh]	min. SOC [%]	DOD [%]	total energy consumption [kWh]	min. SOC [%]	DOD [%]
PTC4	EMS1 with standard semitrailer	377	6	84	-	-	-
PTC5	EMS1 with e-semitrailer (205 kWh)	378	6	84	74	62	36
PTC6	EMS1 with e-semitrailer (308 kWh)	378	6	84	78	72	26

In Table 4-7 the results for the same vehicle combinations and powertrain configurations with a cargo weight of 25 tonnes are presented. The range extension provided by the e-trailer is higher compared to the empty vehicle combinations. Similar to the empty EMS1 vehicle combination, on the mission profile only a part of the energy content of the smaller e-trailer battery (PTC5: EMS1 with e-trailer with 205kWh) is used. Therefore, the bigger e-trailer battery has no effect on the total distance of the vehicle combination.
Although the total recuperated energy is increased by the e-trailer, the increased energy consumption by the driver model using the additional power of the e-trailer cannot be compensated. In combination with the reduced payload of the e-trailer, the energy efficiency is slightly higher than the one of a vehicle combination with a standard semitrailer.

Table 4-7: Simulation results of EMS1 vehicle combinations, cargo weight (25t), KPIs

ID	Powertrain configuration (PTC)	Total distance [km]	KPI1: energy consumption [kWh/km]	KPI2: energy efficiency [t km/kWh]	recuperated energy [kWh]
PTC4	EMS1 with standard semitrailer	186	1,93	0,081	-36,34
PTC5	EMS1 with e-semitrailer (205 kWh)	232	1,99	0,084	-47,78
PTC6	EMS1 with e-semitrailer (308 kWh)	232	2,00	0,085	-48,43

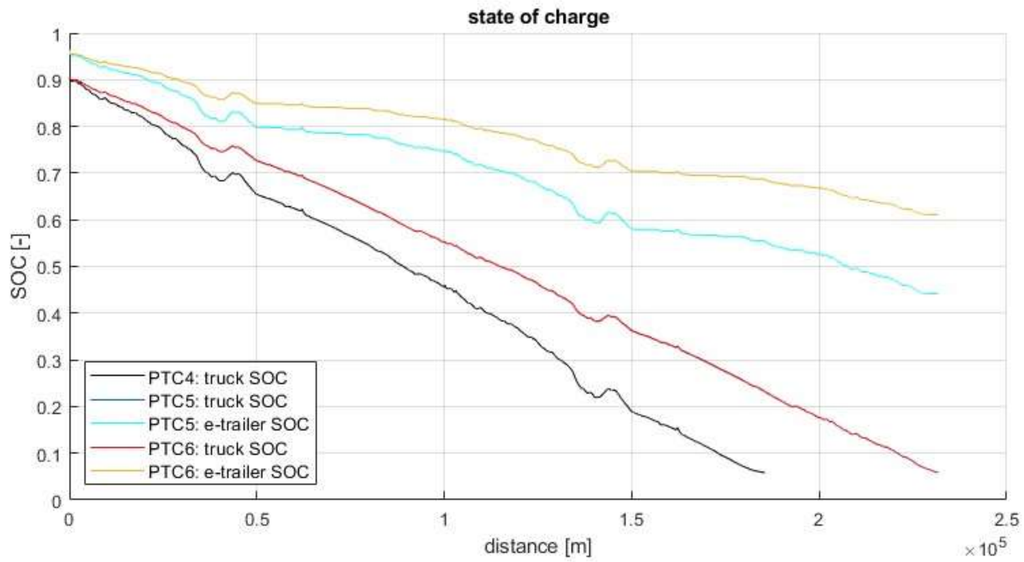

Figure 4-4: Simulation results of EMS1 vehicle combinations, cargo weight (25t), state of charge over distance of single vehicle units

In Table 4-8 and Figure 4-4 the simulation results of the EMS1 vehicle combinations with 25 tonnes of cargo weight are presented per vehicle unit. The total energy consumption of the e-trailer shows that its energy capacity is only partially used.

Table 4-8: Simulation results of EMS1 vehicle combinations, cargo weight (25t), results of vehicle units

ID	Powertrain configuration (PTC)	tractor			trailer		
		total energy consumption [kWh]	min. SOC [%]	DOD [%]	total energy consumption [kWh]	min. SOC [%]	DOD [%]
PTC4	EMS1 with standard semitrailer	377	6	90	-	-	-
PTC5	EMS1 with e-semitrailer (205 kWh)	377	6	90	110	44	54
PTC6	EMS1 with e-semitrailer (308 kWh)	377	6	90	113	61	37

4.3 Use case 7.2.3 – EMS2

In Table 4-9 the simulation results of the EMS2 vehicle combinations with two different powertrain configurations are presented. The cargo weight is zero, which is why no energy efficiency is indicated.

The total distance reached by the vehicle combination is increased by the use of the e-dolly, which can also be seen in Figure 4-5. Due to the small energy storage unit in the e-dolly, almost the whole energy capacity is used on the mission profile. The recuperation capability of the long vehicle combination is higher compared to the tractor – trailer and the EMS1 vehicle combination and cannot be used by the tractor unit alone. Nevertheless, the energy consumption of the EMS2 vehicle combination is slightly higher due to the increased acceleration capability used by the driver model and the weight of the additional powertrain.

Table 4-9: Simulation results of EMS2 vehicle combinations, zero cargo weight, KPIs

ID	Powertrain configuration (PTC)	Total distance [km]	KPI1. energy consumption [kWh/km]	KPI2: energy efficiency [t km/kWh]	recuperated energy [kWh]
PTC7	EMS2 with standard dolly	311	1,81	-	-35,56
PTC8	EMS2 with e-dolly (73 kWh)	330	1,85	-	-40,69

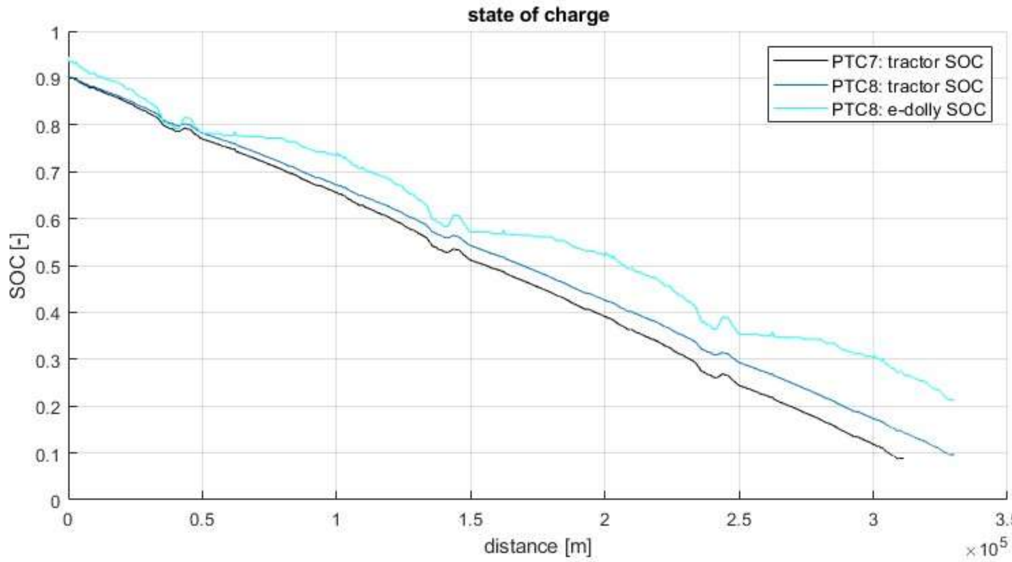

Figure 4-5: Simulation results of EMS2 vehicle combinations, zero cargo weight, state of charge over distance of single vehicle units

In Table 4-10 the simulation results of the EMS2 vehicle combinations without cargo per vehicle unit are presented. Again, the results show that already the empty vehicle uses a significant amount of the energy capacity in the e-dolly.

Table 4-10: Simulation results of EMS2 vehicle combinations, zero cargo weight, results of vehicle units

ID	Powertrain configuration (PTC)	tractor			semitrailer		
		total energy consumption [kWh]	min. SOC [%]	DOD [%]	total energy consumption [kWh]	min. SOC [%]	DOD [%]
PTC7	EMS2 with standard dolly	595	9	81	-	-	-
PTC8	EMS2 with e-dolly (73 kWh)	589	10	80	55	21	74

In Table 4-11 the results for the same vehicle combinations and powertrain configurations with a cargo weight of 42 tonnes are presented. The range extension provided by the e-trailer is higher compared to the empty vehicle combination. Due to the cargo weight the whole energy capacity installed in the e-dolly can be used. Additionally, the EMS2 vehicle combination has a high recuperation potential even on the moderate VECTO long-haul cycle.
Although the total recuperated energy is increased by the e-dolly, the increased energy consumption by the driver model using the additional power of the e-trailer cannot be compensated.

In combination with the reduced payload of the e-trailer, the energy efficiency is slightly higher than the one of a vehicle combination with a standard dolly.

Table 4-11: Simulation results of EMS2 vehicle combinations, maximum cargo weight (42t), KPIs

ID	Powertrain configuration (PTC)	Total distance [km]	KPI1: energy consumption [kWh/km]	KPI2: energy efficiency [t km/kWh]	recuperated energy [kWh]
PTC7	EMS2 with standard dolly	207	2,70	0,067	-60,89
PTC8	EMS2 with e-dolly (73 kWh)	235	2,76	0,069	-78,88

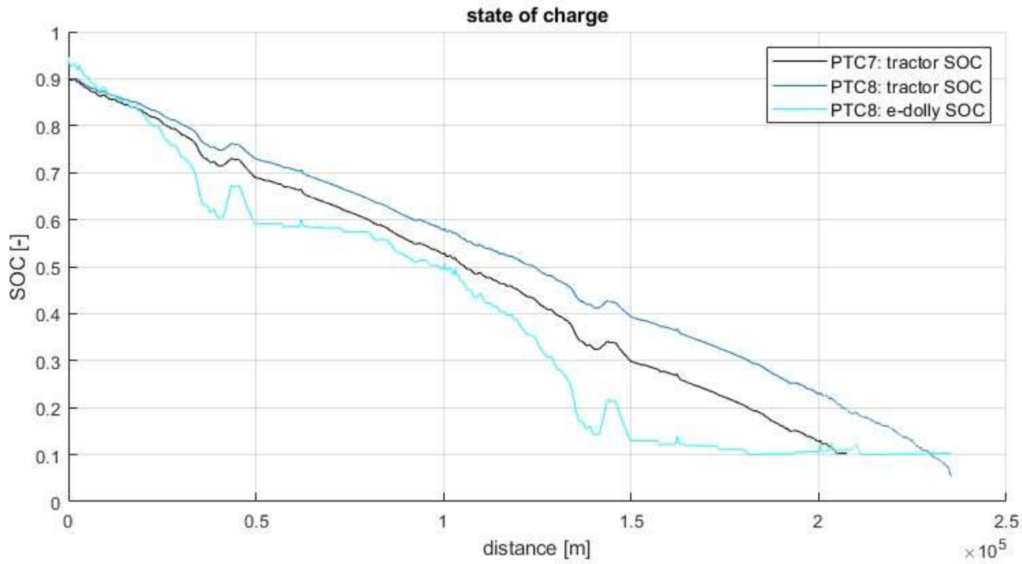

Figure 4-6: Simulation results of EMS2 vehicle combinations, maximum cargo weight (42t), state of charge over distance of single vehicle units

In Table 4-12 and Figure 4-6 the simulation results of the EMS2 vehicle combinations with 42 tonnes of cargo weight are presented per vehicle unit.

Table 4-12: Simulation results of EMS2 vehicle combinations, maximum cargo weight (42t), results of vehicle units

ID	Powertrain configuration (PTC)	tractor			trailer		
		total energy consumption [kWh]	min. SOC [%]	DOD [%]	total energy consumption [kWh]	min. SOC [%]	DOD [%]
PTC7	EMS2 with standard dolly	585	10	80	-	-	-
PTC8	EMS2 with e-dolly (73 kWh)	617	5	85	63	10	85

5 Conclusions and recommendations

As expected, the simulation results of all vehicle combinations show that the application of an e-trailer or an e-dolly provides a range extension for the battery-electric towing vehicles. The amount of additional range that can be provided depends on the characteristics of the mission profile. On the moderate VECTO long-haul cycle with a greater number of sections with constant speed (85 km/h), the energy capacity of the e-trailer cannot completely be used before the energy storage unit of the towing vehicle runs empty.

Furthermore, the simulations show no positive effect of the e-trailers on the energy consumption or the energy efficiency of the vehicle combinations. This can be influenced if the total recuperation potential of the e-trailer can be exploited.

Therefore, the following investigations should be done together with the vehicle manufacturers:

- simulation of the vehicle combinations on the real mission profiles of the ZEFES use cases,
- alignment of the vehicle performance with the expectations of the vehicle manufacturers and adaptation of the vehicle specifications,
- alignment of the operational strategy of the e-trailers with ZF.

The simulation results presented in chapter 4 can only be seen as preliminary results, since the total distances reached by all simulated vehicle combinations deviate from the values given by the vehicle manufacturers during the planning of the use cases. The results provide an indicator in terms of the range extension that can be reached with the e-trailer, the absolute numbers need to be adapted by the investigations listed above. This should be done till M21 of the ZEFES project.

After the revision of the verification results these findings will also be used to update the simulation platform in WP2 that will be released to partners to be further used in the evaluation and verification of the final design specifications according to the real-world mission long-haul profiles.

6 Contribution to the project

6.1 Contribution to project (linked) Objectives

The work done in task 5.1 and documented in this deliverable contributes reaching several objectives that have been defined in the ZEFES description of action. The verified system specifications of the battery-electric vehicles are input to task 5.3 and task 5.4 that realize the next generation battery-electric trucks, tractors, and trailers.

The collection of information and parameters of the battery-electric vehicles and their components in the vehicle specification templates provided by WP1 provides not only the basis for the simulation-based verification in task 5.1, but also serves for the parameterization of the digital twins (DT) for each of the BEV combinations used in the ZEFES project (Sub-objective 3.1). Furthermore, the vehicle specifications will be used to parameterize the assessment framework, which will identify the impact that is caused by the introduction of ZEVs for the heavy-duty transport in long-haul missions (Objective 6).

The simulation results mainly support the development of the vehicle units for the demonstration in the use cases (Sub-objective 1.1) by verifying the improvements of efficiency that can be gained with the modular, multi-powertrain concept. Additionally, the planning of the use cases and mission profiles is supported by the investigation of driving range, selection of charging points and estimation of charging times.

6.2 Contribution to major project exploitable result

The work done in task 5.1 and the documentation in this deliverable indirectly contributes to the projects exploitable results. The vehicle specification of the BEVs enables the parameterization of the digital twin as part of the digital and fleet management tool for HD ZEVs. Furthermore, it enables a targeted optimization and development of vehicles that serve the logistics missions demonstrated in the use cases.

7 Risks and interconnections

7.1 Risks/problems encountered

Risk No.	What is the risk	Probability of risk occurrence[1]	Effect of risk[1]	Solutions to overcome the risk
WP5.1	The values for several parameters in the vehicle specification templates were not provided by the OEMs (see section 2.2). This leads to less accurate results of the simulations.	1	2	The vehicle specifications completed with generic values were checked by the OEMs to guaranty that the parameterized models represent the real vehicles.

1) Probability risk will occur: 1 = high, 2 = medium, 3 = Low

7.2 Interconnections with other deliverables

This deliverable is closely interconnected to the deliverables D5.3 “Powertrain components and control systems for next generation zero emission trucks” and D5.4 “Next generation battery-electric trailers”, since the verified vehicle specification and the derived recommendations shall be considered in the developments presented in these documents. Furthermore, the content of this deliverable influences all deliverables of the work packages 4 and 8 that are using the vehicle specifications as an input.

8 References

[1] B. Kraaijenhagen, P. Bengtsson, C. Thoren und L. Gonnet, „ZFES Deliverable D1.2: Defined Use Cases, Target metrics and needs," Brussels, 2023.

[2] H. Wittig und R. Schmid, „ZEFES Deliverable D1.1: Technical requirements - Needs and requirements for BEV and FCEV combinations," Brussels, 2023.

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Project partners:

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2	FRD	FORD OTOMOTIV SANAYI ANONIM SIRKETI
4	KAE	KASSBOHRER FAHRZEUGWERKE GMBH
5	REN	RENAULT TRUCKS SAS
6	SCA	SCANIA CV AB
7	VET	VAN ECK TRAILERS BV
8	VOL	VOLVO TECHNOLOGY AB
9	ABB	ABB E-MOBILITY BV
9.1	ABP	ABB E-MOBILITY SPOLKA Z OGRANICZONAODPOWIEDZIALNOSCIA
10	AVL	AVL LIST GMBH
11	CM	SOCIEDAD ESPANOLA DE CARBUROS METALICOS SA
11.1	APG	AIR PRODUCTS GMBH
12	HEPL	HITACHI ENERGY POLAND SPOLKA Z OGRANICZONA ODPOWIEDZIALNOSCIA
13	MIC	MANUFACTURE FRANCAISE DES PNEUMATIQUES MICHELIN
14	POW	PLASTIC OMNIUM NEW ENERGIES WELS GMBH
15	RIC-CZ	RICARDO PRAGUE S.R.O.
15.1	RIC-DE	RICARDO GMBH
16	UNR	UNIRESEARCH BV
17	ZF	ZF CV SYSTEMS HANNOVER GMBH
18	ALI	ALLIANCE FOR LOGISTICS INNOVATION THROUGH COLLABORATION IN EUROPE
19	DPD	DPD (NEDERLAND) B.V.
20	COL	ETABLISSEMENTEN FRANZ COLRUYT NV
21	GRU	GRUBER LOGISTICS S.P.A.
22	GBW	GEBRUEDER WEISS GESELLSCHAFT M.B.H.
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23.2	PGA	PROCTER & GAMBLE AMIENS
24	PRI	PRIMAFRIO CORPORACION, S.A.
25	PTV	PTV PLANUNG TRANSPORT VERKEHR GmbH
26	Fraunhofer	FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV
27	HAN	STICHTING HOGESCHOOL VAN ARNHEM ENNIJMEGEN HAN
28	IDI	IDIADA AUTOMOTIVE TECHNOLOGY SA
29	TNO	NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO

30	UIC	UNION INTERNATIONALE DES CHEMINS DE FER
31	CFL	CFL MULTIMODAL S.A.
32	GSS	Grupo Logistico Sese
33	HIT	Hitachi ABB Power Grids Ltd.
34	IRU	UNION INTERNATIONALE DES TRANSPORTS ROUTIERS (IRU)
35	RIC-UK	RICARDO CONSULTING ENGINEERS LIMITED

Disclaimer/ Acknowledgment

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10 Appendix A – Vehicle and powertrain specifications of battery-electric vehicles

10.1 4x2 tractor, use case 7.3.1

Parameter	Value
Sub Task ID	ST 7.3.1 + ST 7.3.3
vehicle combinations	tractor - e-trailer (UC7.3.1) 
vehicle combinations	tractor - e-cooled semitrailer (UC7.3.3) 
vehicle type	4x2 tractor 
licence plate number	

Figure 10-2: Use case information of 4x2 BE tractor

Parameter	Value	Unit
vehicle brand	-	-
axle configuration	4x2	-
tare weight	11000	kg
gross vehicle weight	64000	kg
Frontal area	10,2	m²
Drag coefficient	0,7	-
Wheelbase axle 1 – axle 2	4,150	m
Wheelbase axle 2 – axle 3	N.A.	m
Center of gravity from axle 1		m
horizontal distance of kingpin/coupling from axle 1	3.1	m
Permissible axle loads (front)	8000	kg
Permissible axle loads (rear)	10500	kg
Power brake choper	N.A.	kW
Front Tyre type / size	365/65R22,5	-
Rear Tyre type / size	365/65R22,5	-

Figure 10-1: Vehicle characteristics and dimensions of 4x2 BE tractor

Parameter	Value	Unit
AC charging standards	N.A.	-
AC connector	N.A.	-
On Board Charger(OBC): power (efficent)	N.A.	kW
OBC HV system: input voltage, output voltage	N.A.	V
OBC efficiency	N.A.	%
number of AC inlets (charging ports)	N.A.	-
position of AC inlets (charging ports)	N.A.	-
DC charging standards	DC PnC (ISO 15118 - 2 2016)	-
DC connector	CCS2 (EU)	-
DC charging voltage level	600-800 (Battery dependant)	V
DC charging power	500A	kW
number of DC inlets (charging ports)	1,00	-
position of DC inlets (charging ports)	CCS on right side	-
DC charging standards	ISO 15118-20	-
DC connector	MCS	-
DC charging voltage level	600-800 (Battery dependant)	V
DC charging power	1000A	kW
number of DC inlets (charging ports)	1,00	-
position of DC inlets (charging ports)	Left behind front wheel (Standard position)	-
Fueling pressure (350bar / 700 bar / both)	N.A.	bar
Fuel Receptacle Type	N.A.	-
Fueling protocol	N.A.	-
Location of fueling on vehicle (left / right / both)	N.A.	-
Nozzle Type	N.A.	-
Developments during demonstration - do you anticipate changing nozzle or protocol during the demonstration if advances allow, eg HF Nozzle?	N.A.	-
Hydrogen Purity requirement	N.A.	-

Figure 10-3: Charging/fuelling information of 4x2 BE tractor

Parameter	Value	Unit
Cell chemestry	Li-NMC	-
Cell type		-
Number of cells per row	186	-
Number of cell rows	7	-
Cell capacity	17760/3600	Ah
Battery installed energy capacity	104kWh per row	kWh
Operating temperature range for cont. discharge current	55	°C
Operating temperature range for cont. charge current	55	°C
Operating temperature range for max. discharge current	45	°C
Operating temperature range for max. charge current	45	°C
Optimum operating temperature range	<45	°C
Cont. charge current		A
Max. charge current		A
Max. time for max charge current		s
Cont. discharging current		A
Max. discharge current		A
Max. time for max discharge current		s
Ohmic resistance of cell dependent on temperature		Ω
Max. state of charge	90	%
Min. state of charge	7	%
Cooling system (air/liquid)	Liquid	-
Mounting position (battery center of gravity from axle1)	2.6	m
Battery weight	4118	kg
DC/DC converter (of battery) applicable	No. Battery is connected directly to the drive inverter	Y/N
DC/DC converter (of battery) max. charging current on battery side	N.A.	A
DC/DC converter (of battery) max. discharging current on battery side	N.A.	A
DC/DC converter (of battery) average efficiency	N.A.	%

Figure 10-4: HV battery characteristics of 4x2 BE tractor

Parameter	Value	Unit
electric machine type	PSM	-
Max. cont. torque	4500	Nm
Max. peak torque	4500	Nm
Max. cont. power, mech	400	kW
Max. peak power, mech	400	kW
Max. efficiency	96	%
Torque over speed		Nm over rpm
Average mech. Efficiency from E-drive output to wheel	97	%
E-machine configuration (center, wheel)	center	-
Number of gears	4 gears: 1: 18.6 2: 10.3 3: 5.0 4: 2.8	-
Ratio E-machine to wheel	2.31	-

Figure 10-5: Characteristics of the electric powertrain of the 4x2 BE tractor

Parameter	Value	Unit
Vehicle electrics (24 V), rated power	Presume total 24V consumption at 2kW average (in total 1 - 2kW measured, thus, 2kW is a conservative figure)	kW
cabin air conditioning (AC), rated power		kW
cabin heating, rated power		kW
Chiller (compressor + fan + pump) for battery cooling, rated power		kW
Cooling fan + pumps for high temperature circuit (EMG + power electronics), rated power		kW
fan + pumps for FC cooling circuit, rated power		kW
Steering pump, rated power		kW
Air compressor for brake, rated power	supplied from VCB network	kW
DC / DC for LV (24V / 12V), rated power		kW
DC / DC HV (between fuel cell and battery), rated power		kW
Brake chopper, rated power		kW
additional HV consumers (e.g. cooling of cargo), rated power		kW

Figure 10-6: Power consumption of the auxiliaries of the 4x2 BE tractor

10.2 6x2 rigid, use case 7.2.4

Parameter	Value
Sub Task ID	ST 7.2.4
vehicle combinations	truck - dolly - e-trailer 
vehicle type	6x2 rigid 
licence plate number	

Figure 10-8: Use case information of 6x2 BE rigid

Parameter	Value	Unit
vehicle brand	-	-
axle configuration	6x2	-
tare weight	11.350	kg
gross vehicle weight		kg
Frontal area	10,2	m²
Drag coefficient	1	-
Wheelbase axle 1 – axle 2	4,3	m
Wheelbase axle 2 – axle 3	1,37	m
Center of gravity from axle 1	2,77	m
horizontal distance of kingpin/coupling from axle 1	7,73	m
Permissible axle loads (front)	7100	kg
Permissible axle loads (rear)	11500+7500	kg
Power brake choper	-	kW
Front Tyre type / size	385/65R22,5	-
Rear Tyre type / size	385/65R22,5	-

Figure 10-9: Vehicle characteristics and dimensions of 6x2 BE rigid

Parameter	Value	Unit
AC charging standards	Today	-
AC connector	CCS2	-
On Board Charger(OBC): power (efficent)	43,00	kW
OBC HV system: input voltage, output voltage	Today	V
OBC efficiency	—	%
number of AC inlets (charging ports)	1,00	-
position of AC inlets (charging ports)	Right side	-
DC charging standards	Today	-
DC connector	CCS2	-
DC charging voltage level	<750	V
DC charging power	350,00	kW
number of DC inlets (charging ports)	1,00	-
position of DC inlets (charging ports)	Right side	-
DC charging standards	Draft MCS	-
DC connector	MCS	-
DC charging voltage level	??	V
DC charging power	>500	kW
number of DC inlets (charging ports)	1,00	-
position of DC inlets (charging ports)	Right side acc to MCS standard	-
Fueling pressure (350bar / 700 bar / both)	N.A.	bar
Fuel Receptacle Type	N.A.	-
Fueling protocol	N.A.	-
Location of fueling on vehicle (left / right / both)	N.A.	-
Nozzle Type	N.A.	-
Developments during demonstration - do you anticipate changing nozzle or protocol during the demonstration if advances allow, eg HF Nozzle?	N.A.	-
Hydrogen Purity requirement.	N.A.	-

Figure 10-7: Charging/fuelling information of 6x2 BE rigid

Parameter	Value	Unit
Cell chemestry	Li-Ion NCA	-
Cell type		-
Number of cells per row	134	-
Number of cell rows	220	-
Cell capacity	17760/3600	Ah
Battery installed energy capacity	445	kWh
Operating temperature range for cont. discharge current	55	°C
Operating temperature range for cont. charge current	55	°C
Operating temperature range for max. discharge current	45	°C
Operating temperature range for max. charge current	45	°C
Optimum operating temperature range	<45	°C
Cont. charge current	4.1	A
Max. charge current	4.5	A
Max. time for max charge current	30	s
Cont. discharging current	4.95	A
Max. discharge current	5	A
Max. time for max discharge current	30	s
Ohmic resistance of cell dependent on temperature		Ω
Max. state of charge	95	%
Min. state of charge	5	%
Cooling system (air/liquid)	liquid	-
Mounting position (battery center of gravity from axle1)	2.6	m
Battery weight	2500	kg
DC/DC converter (of battery) applicable	Y	Y/N
DC/DC converter (of battery) max. charging current on battery side	365	A
DC/DC converter (of battery) max. discharging current on battery side	440	A
DC/DC converter (of battery) average efficiency	98	%

Figure 10-10: HV battery characteristics of 6x2 BE rigid

Parameter	Value	Unit
electric machine type	PSM	-
Max. cont. torque	4500	Nm
Max. peak torque	4500	Nm
Max. cont. power, mech	320	kW
Max. peak power, mech	320	kW
Max. efficiency	96	%
Torque over speed		Nm over rpm
Average mech. Efficiency from E-drive output to wheel	97	%
E-machine configuration (center, wheel)	center	-
Number of gears	1	-
Ratio E-machine to wheel	9,82	-

Figure 10-11: Characteristics of the electric powertrain of the 6x2 BE rigid

Parameter	Value	Unit
Vehicle electrics (24 V), rated power	0,25	kW
cabin air conditioning (AC), rated power	-	kW
cabin heating, rated power	-	kW
Chiller (compressor + fan + pump) for battery cooling, rated power	0,2 @ 0°C	kW
Cooling fan + pumps for high temperature circuit (EMG + power electronics), rated power		kW
fan + pumps for FC cooling circuit, rated power		kW
Steering pump, rated power	3,2	kW
Air compressor for brake, rated power	0,1	kW
DC / DC for LV (24V / 12V), rated power	0,25	kW
DC / DC HV (between fuel cell and battery), rated power		kW
Brake chopper, rated power	-	kW
additional HV consumers (e.g. cooling of cargo), rated power	0,5	kW

Figure 10-12: Power consumption of the auxiliaries of the 6x2 BE rigid

10.3 6x2 tractor, use case 7.2.3

Parameter	Value
Sub Task ID	ST 7.2.3
vehicle combinations	tractor - semitrailer - e-dolly - semitrailer 
	tractor - semitrailer 
	tractor - e-cooled semitrailer 
vehicle type	6x2 tractor 
licence plate number	

Figure 10-14: Use case information of 6x2 BE tractor

Parameter	Value	Unit
vehicle brand	-	-
axle configuration	6x2	-
tare weight	xxx	kg
gross vehicle weight	xxx	kg
Frontal area	10,2	m²
Drag coefficient	1,8 0,7	-
Wheelbase axle 1 – axle 2	3,2	m
Wheelbase axle 2 – axle 3	1,4	m
Center of gravity from axle 1	1	m
horizontal distance of kingpin/coupling from axle 1	3,13	m
Permissible axle loads (front)	xxx	kg
Permissible axle loads (rear)	xxx	kg
Power brake choper		kW
Front Tyre type / size	365/65R22,5	-
Rear Tyre type / size	365/65R22,5	-

Figure 10-13: Vehicle characteristics and dimensions of 6x2 BE tractor

Parameter	Value	Unit
AC charging standards	Today	-
AC connector	CCS2	-
On Board Charger(OBC): power (efficent)	43,00	kW
OBC HV system: input voltage, output voltage	Today	V
OBC efficiency	—	%
number of AC inlets (charging ports)	1,00	-
position of AC inlets (charging ports)	Right side	-
DC charging standards	Today	-
DC connector	CCS2	-
DC charging voltage level	<750	V
DC charging power	350,00	kW
number of DC inlets (charging ports)	1,00	-
position of DC inlets (charging ports)	Right side	-
DC charging standards	Draft MCS	-
DC connector	MCS	-
DC charging voltage level	??	V
DC charging power	>500	kW
number of DC inlets (charging ports)	1,00	-
position of DC inlets (charging ports)	Right side acc to MCS standard	-
Fueling pressure (350bar / 700 bar / both)	N.A.	bar
Fuel Receptacle Type	N.A.	-
Fueling protocol	N.A.	-
Location of fueling on vehicle (left / right / both)	N.A.	-
Nozzle Type	N.A.	-
Developments during demonstration - do you anticipate changing nozzle or protocol during the demonstration if advances allow, eg HF Nozzle?	N.A.	-
Hydrogen Purity requirement	N.A.	-

Figure 10-15: Charging/fuelling information of 6x2 BE tractor

Parameter	Value	Unit
Cell chemestry	Li-ion NCA	-
Cell type		-
Number of cells per row	180	-
Number of cell rows	220	-
Cell capacity	17760/3600	Ah
Battery installed energy capacity	728	kWh
Operating temperature range for cont. discharge current	55	°C
Operating temperature range for cont. charge current	55	°C
Operating temperature range for max. discharge current	45	°C
Operating temperature range for max. charge current	45	°C
Optimum operating temperature range	<45	°C
Cont. charge current	4,1	A
Max. charge current	4,5	A
Max. time for max charge current	30	s
Cont. discharging current	4,95	A
Max. discharge current	5	A
Max. time for max discharge current	30	s
Ohmic resistance of cell dependent on temperature		Ω
Max. state of charge	95	%
Min. state of charge	5	%
Cooling system (air/liquid)	liquid	-
Mounting position (battery center of gravity from axle1)	2,6	m
Battery weight	4118	kg
DC/DC converter (of battery) applicable	Y	Y/N
DC/DC converter (of battery) max. charging current on battery side	900	A
DC/DC converter (of battery) max. discharging current on battery side	1000	A
DC/DC converter (of battery) average efficiency	98	%

Figure 10-16: HV battery characteristics of 6x2 BE tractor

Parameter	Value	Unit
electric machine type	PSM	-
Max. cont. torque	4500	Nm
Max. peak torque	4500	Nm
Max. cont. power, mech	495	kW
Max. peak power, mech	495	kW
Max. efficiency	96	%
Torque over speed		Nm over rpm
Average mech. Efficiency from E-drive output to wheel	97	%
E-machine configuration (center, wheel)	center	-
Number of gears	1	-
Ratio E-machine to wheel	9,82	-

Figure 10-17: Characteristics of the electric powertrain of the 6x2 BE tractor

Parameter	Value	Unit
Vehicle electrics (24 V), rated power	0,2	kW
cabin air conditioning (AC), rated power	today	kW
cabin heating, rated power	Today	kW
Chiller (compressor + fan + pump) for battery cooling, rated power	0,2 @ 0°C	kW
Cooling fan + pumps for high temperature circuit (EMG + power electronics), rated power		kW
fan + pumps for FC cooling circuit, rated power	-	kW
Steering pump, rated power	3,2	kW
Air compressor for brake, rated power	0,2	kW
DC / DC for LV (24V / 12V), rated power	0,25	kW
DC / DC HV (between fuel cell and battery), rated power	-	kW
Brake chopper, rated power	-	kW
additional HV consumers (e.g. cooling of cargo), rated power	0,2	kW

Figure 10-18: Power consumption of the auxiliaries of the 6x2 BE tractor

10.4 e-trailer, use case 7.3.1

Parameter	Value
Sub Task ID	ST 7.3.1
vehicle combinations	tractor - e-trailer 
vehicle type	e-trailer 
licence plate number	

Figure 10-19: Use case information of e-trailer for UC7.3.1

Parameter	Value	Unit
vehicle brand	-	-
axle configuration	3	-
tare weight	9500	kg
gross vehicle weight	36000	kg
payload capacity		kg
Frontal area	8,5	m²
Drag coefficient		-
total length	13,6	m
Wheelbase axle 1 – axle 2	1,31	m
Wheelbase axle 2 – axle 3	1,31	m
Center of gravitiy from axle 1	0,78	m
horizontal distance of kingpin from axle 1	6,39	m
horizontal distance of coupling from axle 1	5,9	m
Permissible axle load axle 1	8000	kg
Permissible axle load axle 2	8000	kg
Permissible axle load axle 3	8000	kg
Power brake choper		kW
Tyre type / size axle 1	385/65 R22.5	-
Tyre type / size axle 2	385/65 R22.5	-
Tyre type / size axle 3	385/65 R22.5	-

Figure 10-20: Vehicle characteristics and dimensions of e-trailer for UC7.3.1

Parameter	Value	Unit
AC charging standards	AC HLC (ISO 15118 - 2 2013/2016)	-
AC connector	Type 2 CCS2	-
On Board Charger(OBC): power (efficent)	22 kW	kW
OBC HV system: input voltage, output voltage	400V / 750V	V
OBC efficiency	>94	%
OBC features	liquid cooled ; EVCC integrated	-
number of AC inlets (charging ports)	1	-
position of AC inlets (charging ports)	right / middle	-
DC charging standards	DC PnC (ISO 15118 - 2 2016)	-
DC connector	CCS2	-
DC charging voltage level	500-750	V
DC charging power	<140	kW
number of DC inlets (charging ports)	1	-
position of DC inlets (charging ports)	right / middle	-

Parameter	Value	Unit
Cell chemestry	NMC	-
Cell type	NMC	-
Number of cells per row	180	-
Number of cell rows	4	-
Average battery power	205,6	kW
Cell capacity	156	Ah
Battery installed energy capacity	205,6	kWh
Operating temperature range for cont. discharge current		°C
Operating temperature range for cont. charge current		°C
Operating temperature range for max. discharge current		°C
Operating temperature range for max. charge current		°C
Optimum operating temperature range		°C
Nominal voltage	659	V
min. voltage	504	V
max. voltage	765	V
Cont. charge current	312	A
Max. charge current	516	A
Max. time for max charge current	10	s
Cont. discharging current	312	A
Max. discharge current	516	A
Max. time for max discharge current	10	s
Ohmic resistance of cell dependent on temperature		Ω
Max. state of charge	90%	%
Min. state of charge	10%	%
Cooling system (air/liquid)	liquid	-
Mounting position (battery center of gravity from axle1)	1,5	m
Battery weight	1080	kg
DC/DC converter (of battery) applicable	N	Y/N
DC/DC converter (of battery) max. charging current on battery side	n.a.	A
DC/DC converter (of battery) max. discharging current on battery side	n.a.	A
DC/DC converter (of battery) average efficiency	n.a.	%

Figure 10-22: HV battery characteristics of e-trailer for UC7.3.1

Parameter	Value	Unit
electric machine type	PM	-
Max. cont. torque	12.100	Nm
Max. peak torque	26.000	Nm
Max. cont. power, mech	210	kW
Max. peak power, mech	300	kW
Max. efficiency	98	%
maximum speed		rpm
Torque over speed	TBD	Nm over rpm
Max coolant temperature at outlet of E-machine	55	°C
Average mech. Efficiency from E-drive output to wheel	98	%
E-machine configuration (center, wheel)	center	-
Number of gears	2+0	-
Ratio E-machine to wheel	xxx	-

Figure 10-23: Characteristics of the electric powertrain of the e-trailer for UC7.3.1

Topic	Parameter	Value	Unit
Vehicle electrics (24 V)	Rated power	0,3kW	kW
	Average power	0,2kW	kW
Chiller (compressor + fan + pump) for battery cooling	Rated power	2kW	kW
	Average power	1kW	kW
Cooling fan + pumps for high temperature circuit (EMG + power	Rated power	1kW	kW
	Average power	0,4kW	kW
Hydraulics	Rated power	n.a.	kW
	Average power		kW
DC / DC for LV (24V / 12V)	Rated power	3KW	kW
	Average power	1,5kW	kW
DC / DC HV (e.g. 400V)	Rated power	n.a.	kW
	Average power		kW
Brake chopper	Rated power	n.a.	kW
	Average power		kW
ernal HV consumers (e.g. cooling of car	Rated power	n.a. for ZEVES	kW
	Average power		kW

Figure 10-24: Power consumption of the auxiliaries of the e-trailer for UC7.3.1

10.5 e-trailer, use case 7.2.4

Parameter	Value
Sub Task ID	ST 7.2.4
vehicle combinations	truck - dolly - e-trailer 
vehicle type	e-trailer 
licence plate number	

Figure 10-25: Use case information of e-trailer for UC7.2.4

Parameter	Value	Unit
vehicle brand	-	-
axle configuration	3	-
tare weight	7300	kg
gross vehicle weight	39000	kg
payload capacity		kg
Frontal area	8,5	m²
Drag coefficient		-
total length	13,6	m
Wheelbase axle 1 – axle 2	1,31	m
Wheelbase axle 2 – axle 3	1,31	m
Center of gravity from axle 1	0,78	m
horizontal distance of kingpin from axle 1	6,19	m
horizontal distance of coupling from axle 1	5,9	m
Permissible axle load axle 1	9000	kg
Permissible axle load axle 2	9000	kg
Permissible axle load axle 3	9000	kg
Power brake choper	-	kW
Tyre type / size axle 1	385/65 R22.5	-
Tyre type / size axle 2	385/65 R22.5	-
Tyre type / size axle 3	385/65 R22.5	-

Figure 10-26: Vehicle characteristics and dimensions of e-trailer for UC7.2.4

Parameter	Value	Unit
AC charging standards	AC HLC (ISO 15118 - 2 2013/2016)	-
AC connector	Type 2 CCS2	-
On Board Charger(OBC): power (efficent)	22 kW	kW
OBC HV system: input voltage, output voltage	400V / 750V	V
OBC efficiency	>94	%
OBC features	liquid cooled ; EVCC integrated	-
number of AC inlets (charging ports)	1	-
position of AC inlets (charging ports)	right / middle	-
DC charging standards	DC PnC (ISO 15118 - 2 2016)	-
DC connector	CCS2	-
DC charging voltage level	500-750	V
DC charging power	<140	kW
number of DC inlets (charging ports)	1	-
position of DC inlets (charging ports)	right / middle	-

Figure 10-27: Charging/fuelling information of e-trailer for UC7.2.4

Parameter	Value	Unit
Cell chemestry	NMC	-
Cell type	NMC	-
Number of cells per row	180	-
Number of cell rows	6	-
Average battery power	308,40	kW
Cell capacity	156	Ah
Battery installed energy capacity	308.4	kWh
Operating temperature range for cont. discharge current		°C
Operating temperature range for cont. charge current		°C
Operating temperature range for max. discharge current		°C
Operating temperature range for max. charge current		°C
Optimum operating temperature range		°C
Nominal voltage	659	V
min. voltage	504	V
max. voltage	765	V
Cont. charge current	468	A
Max. charge current	774	A
Max. time for max charge current	10	s
Cont. discharging current	468	A
Max. discharge current	774	A
Max. time for max discharge current	10	s
Ohmic resistance of cell dependent on temperature		Ω
Max. state of charge	90%	%
Min. state of charge	10%	%
Cooling system (air/liquid)	liquid	-
Mounting position (battery center of gravity from axle1)	1,5	m
Battery weight	1620	kg
DC/DC converter (of battery) applicable	N	Y/N
DC/DC converter (of battery) max. charging current on battery side	n.a.	A
DC/DC converter (of battery) max. discharging current on battery side	n.a.	A
DC/DC converter (of battery) average efficiency	n.a.	%

Figure 10-28: HV battery characteristics of the e-trailer for UC7.2.4

Parameter	Value	Unit
electric machine type	PM	-
Max. cont. torque	12.100	Nm
Max. peak torque	26.000	Nm
Max. cont. power, mech	210	kW
Max. peak power, mech	300	kW
Max. efficiency	98	%
maximum speed		rpm
Torque over speed	TBD	Nm over rpm
Max coolant temperature at outlet of E-machine	55	°C
Average mech. Efficiency from E-drive output to wheel	98	%
E-machine configuration (center, wheel)	center	-
Number of gears	2+0	-
Ratio E-machine to wheel	xxx	-

Figure 10-29: Characteristics of the electric powertrain of the e-trailer for UC7.2.4

Topic	Parameter	Value	Unit
Vehicle electrics (24 V)	Rated power	0.3kW	kW
	Average power	0.2kW	kW
Chiller (compressor + fan + pump) for battery cooling	Rated power	2kW	kW
	Average power	1kW	kW
Cooling fan + pumps for high temperature circuit (EMG + power electronics)	Rated power	1kW	kW
	Average power	0.4kW	kW
Hydraulics	Rated power	n.a.	kW
	Average power		kW
DC / DC for LV (24V / 12V)	Rated power	8kW	kW
	Average power	1.5kW	kW
DC / DC HV (e.g. 400V)	Rated power	n.a.	kW
	Average power		kW
Brake chopper	Rated power	n.a.	kW
	Average power		kW
external HV consumers (e.g. cooling of cargo)	Rated power	n.a. for ZEFES	kW
	Average power		kW

Figure 10-30: Power consumption of the auxiliaries of the e-trailer for UC7.2.4

10.6 e-dolly, use case 7.2.3

Parameter	Value
Sub Task ID	ST 7.2.3
vehicle combinations	tractor - semitrailer - e-dolly - semitrailer 
vehicle type	e-dolly 
licence plate number	

Figure 10-31: Use case information of the e-dolly for UC7.2.3

Parameter	Value	Unit
vehicle brand	-	-
axle configuration	2 axle	-
tare weight	4700	kg
gross vehicle weight	4700	kg
payload capacity	0,00	kg
Frontal area	-	m²
Drag coefficient	-	-
total length	ca. 4	m
Wheelbase axle 1 – axle 2	1698	m
Wheelbase axle 2 – axle 3	-	m
Center of gravity from axle 1	0,8	m
horizontal distance of kingpin from axle 1	2650	m
horizontal distance of coupling from axle 1	850	m
Permissible axle load axle 1	12000	kg
Permissible axle load axle 2	13000	kg
Permissible axle load axle 3		kg
Power brake choper	-	kW
Tyre type / size axle 1	385/55 R 22.5	-
Tyre type / size axle 2	385/55 R 22.5	-
Tyre type / size axle 3	-	-

Figure 10-32: Vehicle characteristics and dimensions of the e-dolly for UC7.2.3

Parameter	Value	Unit
Cell chemestry	Li-Ion NMC	-
Cell type		-
Number of cells per row	180	-
Number of cell rows	3	-
Average battery power		kW
Cell capacity	37	Ah
Battery installed energy capacity	73,5	kWh
Operating temperature range for cont. discharge current	-25 ... 58	°C
Operating temperature range for cont. charge current	-25 ... 58	°C
Operating temperature range for max. discharge current	-25 ... 58	°C
Operating temperature range for max. charge current	-25 ... 58	°C
Optimum operating temperature range	15 ... 35	°C
Nominal voltage	661,00	V
min. voltage	540,00	V
max. voltage	756,00	V
Cont. charge current	185	A
Max. charge current	333	A
Max. time for max charge current	10	s
Cont. discharging current	165	A
Max. discharge current	498	A
Max. time for max discharge current	10	s
Ohmic resistance of cell dependent on temperature		Ω
Max. state of charge	100	%
Min. state of charge	20	%
Cooling system (air/liquid)	liquid (water/glycol = 50/50)	-
Mounting position (battery center of gravity from axle1(		m
Battery weight	750	kg
DC/DC converter (of battery) applicable		Y/N
DC/DC converter (of battery) max. charging current on battery side		A
DC/DC converter (of battery) max. discharging current on battery side		A
DC/DC converter (of battery) average efficiency		%

Figure 10-33: HV battery characteristics of the e-dolly for UC7.2.3

Parameter	Value	Unit
electric machine type	2 x ASM	-
Max. cont. torque		Nm
Max. peak torque	2 x 11000	Nm
Max. cont. power, mech	2 x 60	kW
Max. peak power, mech	2 x 125	kW
Max. efficiency		%
maximum speed	11100,00	rpm
Torque over speed		Nm over rpm
Max coolant temperature at outlet of E-machine	65,00	°C
Average mech. Efficiency from E-drive output to wheel		%
E-machine configuration (center, wheel)	wheel + gear stage (17,8)	-
Number of gears	1	-
Ratio E-machine to wheel	17,8	-

Figure 10-34: Characteristics of the electric powertrain of the e-dolly for UC7.2.3

Topic	Parameter	Value	Unit
Vehicle electrics (24 V)	Rated power		kW
	Average power		kW
Chiller (compressor + fan + pumps) for battery cooling	Rated power	4.5	kW
	Average power		kW
Cooling fan + pumps for high temperature circuit (EMG + power electronics)	Rated power	18.3	kW
	Average power		kW
Hydraulics	Rated power	8	kW
	Average power		kW
DC / DC for LV (24V / 12V)	Rated power		kW
	Average power		kW
DC / DC HV (e.g. 400V)	Rated power		kW
	Average power		kW
Brake chopper	Rated power	-	kW
	Average power	-	kW
external HV consumers (e.g. cooling of cargo)	Rated power	-	kW
	Average power	-	kW

Figure 10-35: Power consumption of the auxiliaries of the e-dolly for UC7.2.3