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Clean and competitive solutions for all transport modes

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

ZEFES - Deliverable report

D1.1 Technical requirements
Needs and requirements for BEV and FCEV combinations

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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 requirements that apply for the vehicle units to support the missions in the use case demonstration. Based on the predefined use cases the relevant vehicle categories were derived that must be considered to create the vehicle combinations. All use cases demonstrate six battery electric vehicles (BEV) and three fuel cell electric vehicles (FCEV). The zero emission (ZE) vehicles are combined with standard semitrailers, e-trailers with a complete battery electric drivetrain, electric reefer trailers and battery trailers serving as a range extender for the prime mover. For each vehicle category a template was created to collect all vehicle and powertrain requirements and needs. The information and parameters to be collected are input to the developments and the assessment in the work packages 2, 3, 4, 5, 6 and 8. Thus, all the work packages had to be included in the compilation of the templates. The resulting template, its structure and the different sections are presented. Additionally, the powertrain-related verification criteria are summarized and the Key Performance Indicators (KPI) for the assessment are derived. Finally, conclusions and recommendations are given how to collect the required values for all ZEFES vehicles and trailers to achieve the objective of having a requirements document for each vehicle unit.

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Abbreviations & Definitions

Abbreviation	Explanation
AC	Alternating Current
BEV	Battery Electric Vehicles
CCS	Combined Charging System
CO2	Carbon dioxide
DC	Direct Current
DT	Digital Twin
ECE	Economic Commission for Europe
EMF	Electro Motive Force
EMS	European Modular System (HDV carrying standardised loading units for intermodal freight transport)
FCEV	Fuel Cell Electric Vehicles
GCW	Gross Combination Weight
HD	Heavy Duty
HDV	Heavy Duty Vehicle
HSCU	Hydrogen Storage Control Unit
HV	High Voltage
HVAC	Heating Ventilation Air Conditioning
ICE	Internal Combustion Engine
ICE	Internal Combustion Engine
ISO	International Organization for Standardization
KPI	Key Performance Indicator
MCS	Megawatt Charging System
OEM	Original Equipment Manufacturer
PE	Potential Equalization
RFCU	ReFilling Control Unit
SoC	State of Charge
SotA	State of the Art
TTW	Tank To Wheel
VC	Verification Criterion
VECTO	Vehicle Energy Consumption Calculation Tool
WP	Work Package
ZE	Zero Emission
ZEFES	Zero Emission flexible vehicle platform with modular powertrains serving the long-haul Freight Eco System
ZEV	Zero Emission Vehicles

1 Introduction

In the ZEFES work package 1 the specifications, requirements and needs for a zero-emission freight eco system from an environmental, health and safe, societal and logistics point of view are developed. This includes the specification of requirements for vehicles, use cases and logistics operations as well as logistics planning under consideration of the infrastructure (roads, charging and refuelling), operational business aspects and legislative & type approval aspects. The ZEFES use cases are defined in order to support the missions for the demonstration of battery electric vehicles (BEV) and fuel cell electric vehicles (FCEV). Additionally, the legal needs and requirements for a smooth operation of the demonstrations are investigated.

The following list shall clarify the context of deliverable D1.1:

D1.1: In this deliverable the overall system design of the distributed zero-emission powertrain including capabilities and features of the single vehicle units are described. Beside general vehicle parameters including power requirements based on gross and cargo weight, vehicle speed and acceleration, specific requirements on powertrain components and auxiliaries are collected as input to the following work packages.

D1.2: The deliverable defines the metrics for the use cases that demonstrate the heavy duty zero-emission vehicles in real life logistics missions. A use case menu card is developed that represents the VECTO long haul mission profile, covering main European corridors in a multi modal context and major logistics missions. Furthermore, KPIs per use case on energy savings and mission efficiency are derived.

D1.3: Within the deliverable “ZEFES ecosystem specification” the needs and requirements of different stakeholders regarding heavy duty (HD) zero emission vehicles (ZEV) are described that will be identified through a tailored survey for each stakeholder group. The stakeholder groups are the end users of HD ZEV, the logistic site owners/operators, the truck OEM, the charging and refuelling infrastructure manufacturers, suppliers, and operators as well as the regulative bodies. Additionally, KPIs will be derived to assess the impact of HD ZEV on the freight eco system and society.

D1.4: This deliverable on “Supply chain mapping” will present an end-to-end transportation model for ZEV within supply chain processes addressing the various parameters for mission operations. Furthermore, a mapping of ZEFES use cases on the supply chain model is performed in order to transfer the efficiency and energy saving benchmarks as presented in D1.2 into operational scenarios.

D1.5: The deliverable “Supply chain needs” will specify a procedure for optimization of mission planning aiming for a reduction of energy usage on the missions.

D1.6: The deliverable will present the legal and administrative requirements for application of HD ZEV in general and per use case. Based on inquiries and survey among EU and national administrations the use cases related legal regulations on national and cross border level are described.

D1.7: The “Book of recommendations” will include a description of gaps, barriers, and limitations encountered during the development of the ZEFES use cases. Recommendations will be derived to adapt the regulatory framework for the implementation of the ZEFES ecosystem beyond the project, serving as a guide for policy makers for future legislation and standards.

The position of deliverable D1.1 within WP1 and the relation to other deliverables and work packages is shown in Figure 1-1.

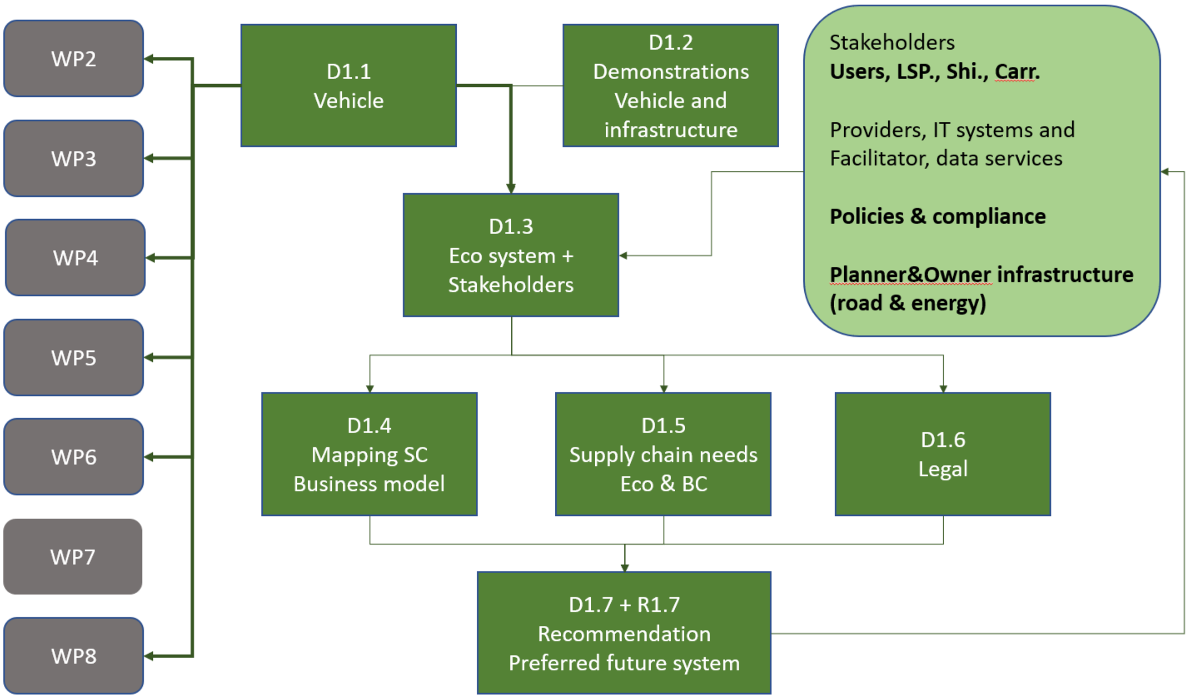

Figure 1-1: Relation of deliverable D1.1 to deliverables of WP1 and other WPs

Chapter 2 of the present document describes the procedures that were used to create a template for an overall vehicle and component requirements specification. The resulting templates are presented on a higher level by explaining the structure (spreadsheets) and the different parameter groups (topics).

In chapter 3 all ZEFES vehicles, be it a zero emission prime mover or a non-standard trailer, are derived, for which requirements and needs must be defined in the beginning of the project.

In chapter 4 the requirements and needs are described in more detail according to the structure of the templates. Parameters are introduced and an explanation of its interest for other work packages or tasks is given. Furthermore, the target metrics and KPIs for the assessment of the technical and practical performance of the ZEFES powertrains and vehicles are derived.

Chapter 5 draws conclusions and gives recommendations how to proceed with the developed templates and collect all necessary information and parameters.

Appendix A presents the templates for each vehicle category.

2 Methods and procedures

2.1 Procedures

Based on the predefined use cases the relevant vehicle categories were derived (Table 2-1) that must be considered to create the vehicle combinations.

Table 2-1: vehicles categories to be considered in the description of powertrain requirements and needs

Vehicle category	Type
Zero emission prime mover	Truck with battery electric drivetrain
	Tractor with battery electric drivetrain
	Truck with fuel cell electric drivetrain
	Tractor with fuel cell electric drivetrain
e-trailer	Trailer with battery electric drivetrain
	Converter dolly with battery electric drivetrain
	Electric reefer trailer with generator axle and battery to power the electric cooling unit
b-trailer	Trailer with high voltage battery serving as range extender for the prime mover

For each vehicle category a template was created to collect main vehicle and powertrain requirements and needs. The information and parameters to be collected will be input to the work packages 2, 3, 4, 5, 6 and 8. Thus, all the work packages had to be included in the compilation of the templates.

The first draft was derived from the experience of the partners AVL and Fraunhofer on the requirements and needs of simulations of zero emission powertrains and vehicles.

In a second step this first draft was aligned with the WP2 partners to include their requirements for the simulations with the design optimization tool/framework. WP2 will use the performance requirements as target values to optimize the vehicle powertrain concepts with right component size. Additionally, component specific requirements will be used by WP5 and WP6 to verify the final design specification of each battery electric and fuel cell electric vehicle by correlation with the optimization results of WP2.

In a second step the templates were aligned with the WP3 partners to include their requirements on charging and refuelling infrastructure to guarantee compatibility with the ZEFES zero-emission vehicles.

Finally, the requirements and needs defined by WP4 and WP8 were included to enable the implementation of digital twins of the vehicles in demonstration and the assessment of the technical and practical performance of the ZEFES powertrains and vehicles.

2.2 Templates for vehicle and powertrain requirements

The templates for the definition of vehicle and powertrain requirements and needs are created as Excel files. The template is structured by using the spreadsheets described in Table 2-2.

Table 2-2: Structure (spreadsheets) of template for vehicle and powertrain requirements and needs

Spreadsheet	Description	Vehicle category (template)
Vehicle – Parameters	Information and parameters on vehicle and component level	all
Vehicle – Fuel Cell Curve	Fuel cell and balance-of-plant (BoP) component characteristics	ZE prime mover
Vehicle – E-Drive Curve	Characteristics of electric motor generator (EMG) and inverter	ZE prime mover, e-trailer
Vehicle – Battery Curve	Characteristics on battery and cell level	all
Drive Cycle Data	Definition of reference driving cycle	all

The information and parameters on vehicle and component level at the spreadsheet "Vehicle – Parameters" are further divided into the following topics:

- Use case;
- general vehicle information;
- driving and braking performance;
- range;
- charging and fueling;
- ambient conditions;
- fuel cell;
- high voltage battery;
- e-drive;
- auxiliaries.

The detailed parameters of each topic are described in chapter 4.
For each parameter the following information must be provided:

- value;
- unit;
- description;
- purpose;
- requestor – WP#.

3 Overview vehicle units

Having identified the vehicle categories in section 2.2, all ZEFES vehicles, be it a zero emission prime mover or a non-standard trailer, must be derived from the use cases.

3.1 Use Cases and vehicle combinations

The use cases and logistics missions were defined in the proposal phases and detailed in the beginning of the ZEFES project. Currently conventional trucks/tractors and standard trailer units are used in these use cases. To replace it with zero-emission vehicles, 16 different vehicle combinations were defined to meet the needs and requirements. The vehicle combinations are realized with six battery electric and three fuel cell electric trucks and tractors together with several trailer units. Among the trailer units are standard semi-trailers, container semi-trailers (for ISO and swap bodies), reefer semi-trailers and low-liner semi-trailers. The trailer configurations include complete battery electric powertrains, additional high-voltage batteries as range extender for a battery electric towing vehicle as well as generator axles to power an electric cooling unit of a reefer trailer.

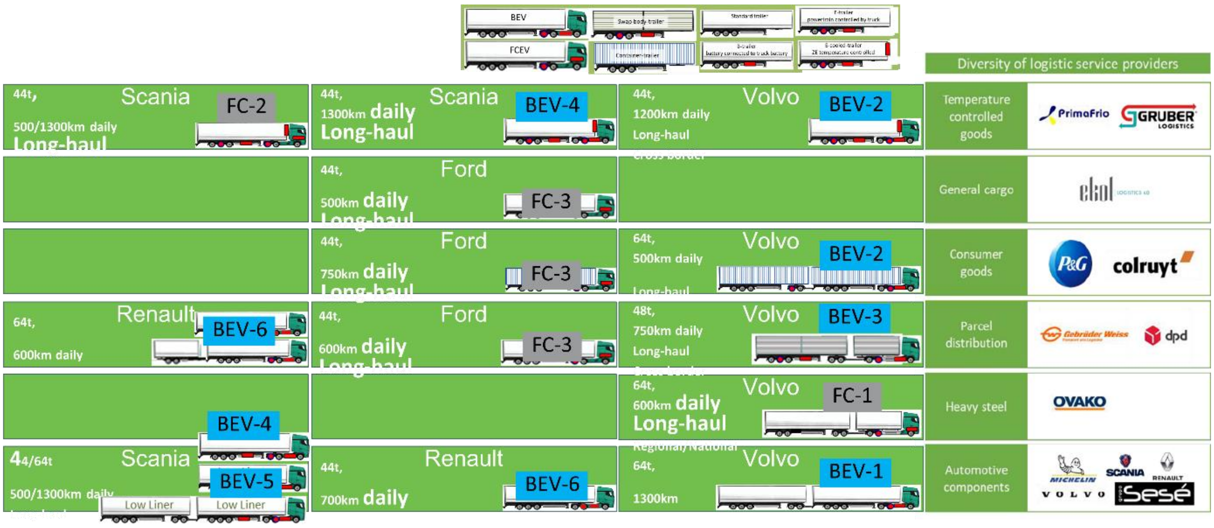

Figure 3-1: Overview vehicle combinations and logistics missions

3.2 ZEFES vehicle

The following sections contain a short description of every vehicle that must be specified in terms of needs and requirements according to chapter 4.

3.2.1 Trucks and tractors

For use case 7.2.1 Volvo provides a fuel cell electric rigid truck (Figure 3-2) that will be used in a Swedish EMS1 vehicle combination. The truck needs to be a 6x2 rigid with an average range of 550 km at a gross combination weight of 44 t.

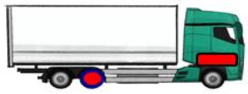

Figure 3-2: Volvo 6x2 fuel cell electric truck as part of the FC-1 vehicle combination for use case 7.2.1

For use case 7.2.2 Volvo provides a battery electric tractor (Figure 3-3) that will be used in an EMS2 vehicle combination (tractor – semitrailer – dolly – semitrailer) with a gross combination weight of 64 t or in a tractor – semitrailer vehicle combination with a gross combination weight of 44 t. The tractor needs to be a 6x2 vehicle with an average range of 400 km at a gross combination weight of 44 t.

Figure 3-3: Volvo 6x2 battery electric tractor as part of the BEV-1 vehicle combination for use cases 7.2.2

For use case 7.2.3 Volvo provides a battery electric tractor (**Error! Reference source not found.**) that will be used in an EMS2 vehicle combination (tractor – container-trailer – e-dolly – container-trailer) with a gross combination weight of 64 t and a tractor - semitrailer vehicle combination with a gross combination weight of 44 t. The tractor needs to be a 6x2 vehicle with an average range of 400 km at a gross combination weight of 44 t.

Figure 3-4: Volvo 6x2 battery electric tractor as part of the BEV-2 vehicle combination for use cases 7.2.3

For use case 7.2.4 Volvo provides a battery electric rigid truck (Figure 3-5) that will be used in an EMS1 vehicle combination. The truck needs to be a 6x2 rigid with an average range of 400 km at a gross combination weight of 44 t.

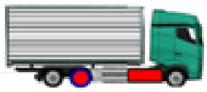

Figure 3-5: Volvo 6x2 battery electric rigid truck as part of the BEV-3 vehicle combination for use case 7.2.4

For use cases 7.3.1 and 7.3.3 Scania provides a battery electric tractor (**Error! Reference source not found.**) that will be used in a tractor – semitrailer vehicle combination. The tractor needs to be a 6x2 vehicle with an average range of 400 km at a gross combination weight of 44 t.

Figure 3-6: Scania 6x2 battery electric tractor as part of the BEV-4 vehicle combination for use cases 7.3.1 and 7.3.3

For use cases 7.3.2 and 7.3.3 Scania provides a fuel cell electric tractor (Figure 3-7) that will be used in a tractor – semitrailer vehicle combination. The tractor needs to be a 6x2 vehicle with an average range of 550 km at a gross combination weight of 44 t.

Figure 3-7: Scania 6x2 fuel cell electric tractor as part of the FC-2 vehicle combination for use case 7.3.2 and 7.3.3

For use case 7.3.4 Scania provides a battery electric tractor (**Error! Reference source not found.**) that will be used in a tractor – semitrailer vehicle combination and an EMS2 vehicle combination (tractor – container-trailer – dolly – container-trailer). The tractor needs to be a 6x2 low-liner vehicle with an average range of 400 km at a gross combination weight of 44 t.

Figure 3-8: Scania 6x2 battery electric low liner tractor as part of the BEV-5 vehicle combination for use case 7.3.4

For use cases 7.4.1, 7.4.2 and 7.4.3 Renault provides a battery electric tractor (**Error! Reference source not found.**) that will be used in a tractor – semitrailer vehicle combination with a gross combination weight of 44 t and in an EMS1 vehicle combination (tractor – semitrailer – trailer) with a GCW of 60 t. The tractor needs to be a 6x2 vehicle with an average range of 400 km at a gross

Figure 3-9: Renault 6x2 battery electric tractor as part of the BEV-6 vehicle combination for use cases 7.4.1, 7.4.2 and 7.4.3

combination weight of 44 t.

For use cases 7.6.1, 7.6.2 and 7.6.3 Ford provides a fuel cell electric tractor (Figure 3-10) that will be used in a tractor – semitrailer vehicle combination. The tractor needs to be a 6x2 vehicle with an average range of 550 km at a gross combination weight of 44 t.

Figure 3-10: Ford 6x2 fuel cell electric tractor as part of the FC-3 vehicle combination for use cases 7.6.1, 7.6.2 and 7.6.3

3.2.2 e-trailers

For use case 7.2.4 Van Eck Trailer, Kaesbohrer and ZF provide a battery electric trailer (Figure 3-11) that will be used in an EMS1 vehicle combination. The trailer needs to have a complete battery electric drivetrain including a usable battery capacity of 210 kWh.

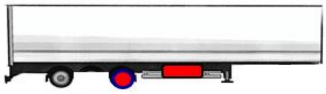

Figure 3-11: VET/ZF e-trailer as part of the BEV-3 vehicle combination for use case 7.2.4

For use case 7.3.2 Gruber Logistics provides a battery electric reefer trailer (Figure 3-12) that will be used in a tractor – semitrailer vehicle combination. The trailer includes a battery to power the electric cooling unit and an electric generator axle to recuperate brake energy that is used to extend the operating time of the cooling system.

Figure 3-12: electric reefer trailer as part of the BEV-2 vehicle combination for use cases 7.3.2

For use case 7.3.3 PrimaFrio provides an electric reefer trailer (Figure 3-13) that will be used in a tractor – semitrailer vehicle combination.

Figure 3-13: electric reefer trailer as part of the BEV-4 and FC-2 vehicle combinations for use case 7.3.3

For use case 7.2.4 Van Eck Trailer and Fraunhofer provide a battery electric converter dolly (Figure 3-14) that will be used in an EMS1 vehicle combination.…

Figure 3-14: e-dolly as part of the BEV-3 vehicle combination for use case 7.2.4

3.2.3 b-trailers

For use case 7.3.1 Van Eck Trailer and Kaessbohrer provide a battery trailer () that will be used in a tractor – semitrailer vehicle combination.

Figure 3-15: battery trailer as part of the BEV-4 and BEV-5 vehicle combination for use case 7.3.1

4 Needs and requirements

For each of the previously described ZEFES vehicles the needs and requirements of vehicle specification must be collected to enable:

- simulation and optimization of vehicles and components (WP2);
- compatibility of the zero emission vehicles to the charging and refueling infrastructure (WP3);
- verification of the final design specification of each battery electric (WP5) and fuel cell electric vehicle (WP6);
- implementation of digital twins of the vehicles in demonstration (WP4) and the assessment of the technical and practical performance of the ZEFES powertrains and vehicles (WP8).

The following section shall illustrate the scope of requirements and needs that must be defined. In Figure 4-1 shows a system sketch of a combination of a BEV-Truck with a B-Trailer as well as the possible related infrastructure. The considered systems are indicated by rounded rectangles with different background colours. Interfaces are indicated by small symbols attached to the system boundary. The symbols must match each other with the adjacent system. For the vehicles the power flow is indicated starting from the interface for transferring energy to the vehicle on the left until propulsion power on the right boundary. Design of the system can be different and subsystems like brake chopper must be considered as well. To ensure compatibility to the infrastructure as well as compatibility of the towing vehicle to trailer the interfaces must be identified. The example with the B-Trailer is used to illustrate the basic requirements for mechanical connection (e.g. kingpin to fifth wheel), the common interfaces like air for braking system, low voltage (LV) for consumers like lights or for data for exchanging signals of the braking system. In case of a B-Trailer additional requirements for the high voltage (HV) connection are needed which is the HV interface itself, an interface for potential equalization (PE) and additional requirements for common interfaces like additional signals for the data interface.

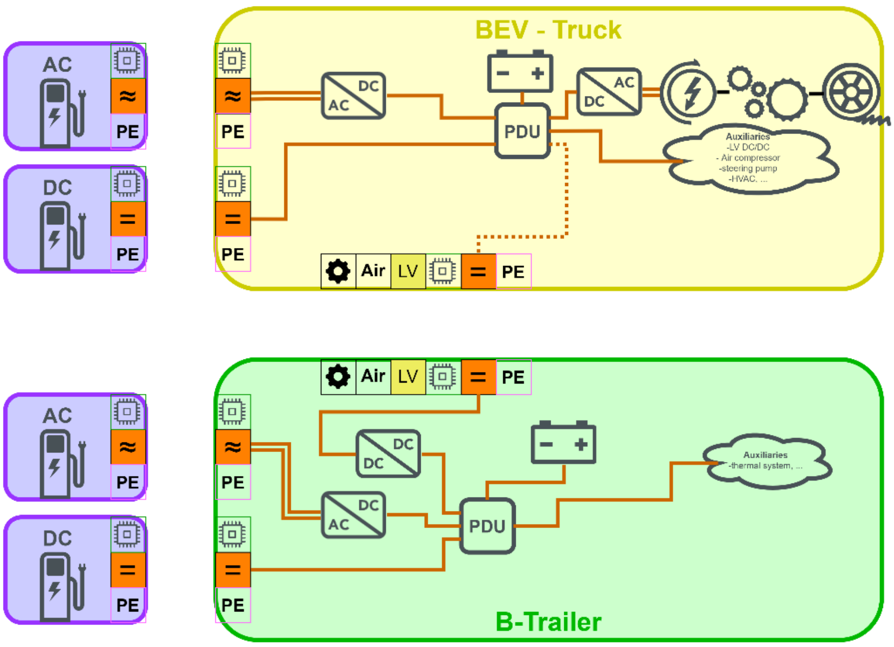

Figure 4-1: system sketch with interfaces for BEV with B-Trailer and Infrastructure for charging of truck and trailer

Beside the above illustrated vehicle combination, a FCEV truck as well as an E-Trailer are illustrated in Figure 4-2 and Figure 4-3 in a basic design. For example, also a plug-in charging for the FCEV truck could be an option. Several vehicle combinations are possible including conventional trailers that are not illustrated in this section.

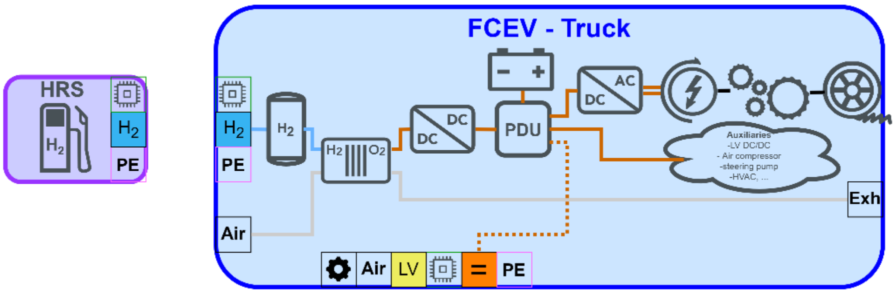

Figure 4-2: system sketch with interfaces for FCEV with refilling infrastructure

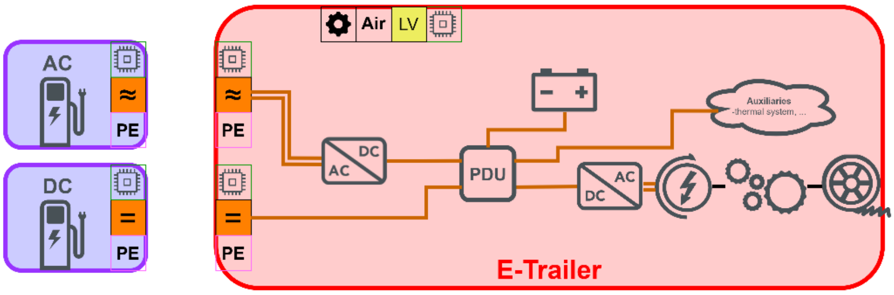

Figure 4-3: system sketch with interfaces E-Trailer and Infrastructure for charging

There are different types of requirements. On the one hand there are stakeholder-requirements which specify "what is wanted or needed" by the different stakeholders like customers or legal regulations. In the ZEFES context one stakeholder requirement is the range of 400 km between recharging stops as stated in objective 1.2. These requirements are independent on the system specification or design. On the other hand, there are system-requirements which specify attributes of systems, subsystems, elements, or their interactions. In the above-mentioned example of required range, a subsystem-requirement could be a dedicated capacity in kWh of the subsystem traction battery. Translating stakeholder-requirements into system-requirements depends on the specification of the system and its structure. As simplified example the same truck combination, just with a different drag coefficient, would require a different value for the system-requirement "battery capacity" to meet the same stakeholder-requirement of the dedicated range.

Attributes of systems, subsystems, elements, and their interaction influence the translation from stakeholder-requirements into system-requirements. The more detailed the attribute of the system is known, the more accurate the system-requirements can be specified. Therefore, a simulation-based approach was chosen as target in the ZEFES project. A challenge is that system attributes do mutual influence each other, and loops increase accuracy. In different phases of the project some system attributes are not available. A knowledge-/experience-based approach must be chosen to close this gap.

As stated, the more detailed system attributes are defined the more accurate the stakeholder-requirements can be translated into system requirements. A certain limit must be defined. The approach in T1.1. is to group system attributes to “mandatory” and “low priority” to define a two-stage process in terms of simulation-based approach.

4.1 Requirements

The following sections discuss different requirements and conclude with specific requirements needed for the further work in other work packages. The main criteria are requirements which are needed for simulation of the overall system to optimize the system and powertrain, for creation of the digital twin (DT) and for parameterization of the assessment framework.

4.1.1 General vehicle requirements

General requirements are mainly caused by the environment of the vehicle. As the vehicle is used on roads, criteria like vehicle dimensions (height, width, length), weight, axle loads, maximum speed, maximum gradeability must be mentioned. Temperatures, operating heights, operating conditions (water, dust, salt) are also crucial.

For the simulation-based approach requirements for attributes related with driving resistances are important. Literature distinguishes between 4 main driving resistances called drag resistance, rolling resistance, slope resistance and acceleration resistance.

Relating to the drag resistance the requirements for the frontal area and the drag coefficient are included in the table. A value for air density is excluded, as an average value can be used and is independent from the vehicle. A velocity is depending on the respective driving cycle. Analogical also requirements for other influencing values for other driving resistances are included in the table, like weights. For a comprehensive view further parts which consume electrical energy must be considered. These consumptions are for example auxiliary systems, systems for temperature management of the system or for the cabin and further consumers.

Other general requirements like axle loads are included to ensure compliance with legal regulations. A more detailed view on legal aspects can be found in task 1.6.

4.1.2 FCEV requirements

Special requirements for FCEVs are linked to the infrastructure, environment, or system itself.

For the infrastructure the refuelling nozzle, hydrogen pressure level, additional grounding during refuelling, operational protocol between hydrogen storage control unit (HSCU) and the refuelling control unit (RFCU), hydrogen quality and further must be specified. Effects from the environment and how to deal with them are also important.

For simulation tasks the hydrogen amount needed depending on the range target, and the efficiency over power curve of the whole fuel cell system is crucial.

Values like energy consumption of auxiliaries depending on the power of the stack can be used for digital twin models. With these parameters an optimized operation strategy for power split of fuel cell and battery can be implemented.

Other requirements as described in the BEV requirements section also apply for FCEVs.

The main requirements can be found in the table in Appendix A – Templates.

4.1.3 BEV requirements

Infrastructure related requirements for BEV are related to charging. In the ZEFES project the requirements are divided into alternating current (AC) and direct current (DC). The DC charging

requirements were further split into combined charging system (CCS) and megawatt charging system (MCS). System related requirements mainly focus on the battery like voltage ranges or temperature ranges. On system level isolations resistance values or Y-capacity values are derived from regulations or standards.
Simulative powertrain optimization requires values for the inner resistance over state of charge (SoC) for first approximation. Dependency on several dimensions like cell temperature or ageing value would further improve the quality of the simulation but are excluded due to complexity reasons at this stage. Of greater importance are values for maximum currents for charging and discharging over SoC to limit power in driving cycles. Other dependencies on temperature or ageing are excluded.
The main requirements can be found in the table in Appendix A – Templates.

4.1.4 Trailer requirements

The trailer requirements must be separated into b-trailers and e-trailers.
For b-trailers additional to the vehicle requirements the high voltage connector to the trailer is crucial. This includes performance related values like currents, and voltage, durability values like plugging cycles and safety values like isolation resistance. As the connection voltage of towing vehicle and trailer must be almost equal a DC/DC converter is assumed. Concerning isolation monitoring device, isolation resistance, and Y-capacities a galvanic isolated DC/DC converter is beneficial. The different possible combinations would otherwise require fix values (e.g. isolation resistance) for all parts of the vehicle combinations and limit design possibilities. For the battery system there must be a master controller calculating overall battery system values. This enables the system to draw like charge or discharge currents depending on e.g. the availability and status of different traction batteries of the towing vehicle and the trailer or other limitations like maximum current of the DC/DC.
Beside the current limits of this DC/DC and the control of this DC/DC the same curves like for the battery system of the vehicle are needed for the simulations.
The main requirements can be found in the table in Appendix A – Templates.
Most requirements of the b-trailer, except the ones for the high voltage connection, also apply for the e-trailer. Additionally, the torque split must be specified which could affect vehicle dynamics. For the safety of the overall system short circuit of motor phases, power down of the inverter, or back EMF depending on the motor type must be considered in the vehicle combination. In terms of powertrain simulation, the powertrain efficiency maps of inverter and motor as well as battery are included in the table.
The main requirements can be found in the table in Appendix A – Templates.

4.2 Operational Strategies of the distributed drivetrain

Distributed drivetrains enable a further degree of freedom in operational strategies.
The combination of a towing vehicle (tractor or rigid truck) with an e-trailer (where at least one axle could be powered) enable different optimization possibilities.
First the planning of the routes in logistic context can be adapted. For example, if the towing vehicle should continue driving after an e-trailer was disconnected, the e-trailer could previously contribute to a higher percentage in the propulsion. In that case the energy storage device of the towing vehicle

is utilized in a lower amount and therefore able to be used for a greater range after disconnecting the e-trailer as without any optimization.
A second possibility for optimization is to maximize the efficiency of the distributed drivetrain. By knowing the efficiency maps of fuel cell, batteries, inverters, motors, transmission, and the slippage of the tires of the towing vehicle and the e-trailer, an optimization of the overall efficiency can be made and the propulsion power split in the respective way.
By a split of the propulsion power of the towing vehicle and the e-trailer also the wear of the tires can be divided by the operational strategy.
Of great importance is the possibility to deal with in stationary processes. One example is the heat up of the powertrain system. In particular to reduce aging of batteries it is important to operate them within dedicated temperature ranges and reduce the load depending on the temperature. With the split of the propulsion power the load to the batteries as well as their heat up can be influenced.

The variety of single optimization characteristics or their combinations which are used to calculate enable a multi-dimensional system for optimization. For comparison of the different dimensions for optimization the financial aspect can also be considered.
Task 5.1. will focus on detailed system specification for distributed powertrains and their operational strategies to improve the overall powertrain efficiency under the operational conditions and constraints of the use cases. Thus, no details about the operational strategies are given in task 1.1. The templates only provide the requirements and needs on component level to further investigate the operational strategies of the distributed powertrain in work packages 2 and 5.

4.3 Requirements for safety and homologation

Legal and administrative needs will be covered in detail by task 1.6.
Requirements of particular importance have been included in the tables in Appendix A – Templates and partly mentioned in this deliverable. One example would be the isolation resistance related to the ECE R100.

4.4 Target metrics and KPIs

ZEFES aims to improve the total efficiency of the zero emission vehicles (trucks/tractors) by up to 8 % due to different measures. This target value is defined by the sub-objective 1.1 "increase the efficiency of electrically powered vehicles" under the verification criterion (VC) 1 that is given in the ZEFES proposal:

- VC 1: improvement of the total efficiency of the vehicles by between 4 and 8 % compared to the baseline vehicles, which are the 2022 state of the art BEV and FCEV of the different OEMs.

This overall target is reached by the implementation of different measures, which are also given with certain sub-targets in the proposal:

- VC 2: HVAC systems giving a 0.1 to 0.2 %-point tank to wheel (TTW) efficiency gain;
- VC 3: maximized recuperation during braking, giving a 0.8 to 1.2 %-point TTW efficiency gain;
- VC 4: integration of improved inverter & DC/DC technologies, giving 0.3 to 0.5 %-point TTW efficiency gain;
- VC 5: optimized thermal and energy control systems expected to give a 0.4 to 0.6 %-point TTW efficiency gain.

Based on the maximum target improvement of vehicle efficiency (8 %) and the estimated improvement of battery energy density till 2026 (see Annex 1, section 1.1.4), Table 4-1 shows the characteristics of a generic ICE vehicle in 2020, the baseline BEV in 2022 and the expected BEV in 2026. The improvement of the total efficiency of the vehicle is indicated in the bottom line “energy consumption”. Together with the expected increase of battery energy density it results in another target value: 90% payload for a BEV with 750 km range in 2026 compared to an ICE vehicle in 2020.

Table 4-1: characteristics of ICE vehicle, baseline 2022 BEVs and future theoretical BEVs (combination of prime mover and trailer) according to Annex1, section 1.1.4

	2020 baseline ICE vehicle	**2022 BEV, 340 km range**	**2022 BEV, 750 km range**	**2026 BEV, 750 km range**	**2026 BEV, 550 km range**
GCW (kg)[1]	40,000	40,000	42,000	42,000	42,000
Battery capacity (kWh)[2]		540	1,191	1,096	804
80 % usable battery capacity (kWh)		432	953	877	643
Energy density incl. casing weight (Wh/kg)[3]		150	150	190	190
Weight battery pack incl. casing (kg)		3,600	7,941	5,787	4,244
Curb weight prime mover + second mover (kg)[4]	17,000	15,600	15,600	15,600	15,600
Delivery load (kg)	23,000	20,800	18,458	20,613	22,156
Delivery load compared to SotA vehicles (%)	100	90	80	90	96
Energy consumption (kWh/km)[5]		1.27	1.27	1.17	1.17

The verification criteria 2 to 5 given at the beginning of this section can only be assessed by the OEMs, as the necessary information at component level will not be available for the consortium partners due to confidentiality of data and technological details.
Based on the verification criterion 1, the following Key Performance Indicators are defined to assess the performance of the battery electric vehicles and its innovations. For the suitable comparison of the vehicles, it is always assumed that they are operated under the same conditions, e.g. use case, route, environmental conditions. The same applies to the fuel cell electric vehicles.

- KPI 1: energy consumption in [kWh/km] and its corresponding percentage energy consumption reduction compared to the baseline vehicle (to compare different vehicle configurations carrying the same payload)

[1] 40 ton as standard vehicle weight, 42 ton according to EU2019/1242
[2] calculation based on 80 % usable battery capacity
[3] see assumptions about the battery energy density in Annex 1, section 1.1.4
[4] estimation of weights, assuming the weight reduction of 1,400 kg for an electric powertrain
[5] estimation based on the current BEVs on the market and a target reduction in ZEFES of 8 % for 2026

- 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
  - equations absolute numbers: $\frac{payload\ [t] * distance\ [km]}{absolute\ energy\ consumption\ [kWh]}$
  - equation relative numbers:
$\frac{fuel\ efficiency\ ZEFES\ vehcile\ \left[\frac{t*km}{kWh}\right] - fuel\ efficiency\ baseline\ vehicle\ \left[\frac{t*km}{kWh}\right]}{fuel\ efficiency\ baseline\ vehicle\ \left[\frac{t*km}{kWh}\right]} * 100\%$

The following Key Performance Indicators are defined to assess the performance of the fuel cell electric vehicles and its innovations.

- KPI 3: hydrogen consumption in [kg/km] and its corresponding percentage hydrogen consumption reduction compared to the baseline vehicle (to compare different vehicle configurations carrying the same payload)
  - equation absolute numbers: $\frac{absolute\ hydrogen\ consumptioin\ [kg]}{distance\ [km]}$
  - equation relative numbers:
$\frac{hydrogen\ consumption\ baseline\ vehicle\ \left[\frac{kg}{km}\right] - hydrogen\ consumption\ ZEFES\ vehicle\ \left[\frac{kg}{km}\right]}{hydrogen\ consumption\ baseline\ vehicle\ \left[\frac{kg}{km}\right]} * 100\%$
- KPI 4: hydrogen efficiency in [(t-km)/kg] and its corresponding percentage hydrogen efficiency gain compared to the baseline vehicle
  - equations absolute numbers: $\frac{payload\ [t] * distance\ [km]}{absolute\ hydrogen\ consumption\ [kg]}$
  - equation relative numbers:
$\frac{hydrogen\ efficiency\ ZEFES\ vehcile\ \left[\frac{t*km}{kg}\right] - hydrogen\ efficiency\ baseline\ vehicle\ \left[\frac{t*km}{kg}\right]}{hydrogen\ efficiency\ baseline\ vehicle\ \left[\frac{t*km}{kg}\right]} * 100\%$

Further Key Performance Indicators apply for both zero emission vehicles.

- KPI 5: average speed in [km/h] as a relevant value for appropriate comparison of fuel consumption on a specific cycle
  - equation absolute numbers: $\frac{distance\ of\ cycle\ [km]}{time\ to\ complete\ cycle\ [h]}$

The new powertrain concepts of ZEFES are distributing the loads and torques differently between the vehicle axles compared to ICE powertrains, thus, causing a significant impact on the operating conditions of the tires. On the pulling unit a combination of higher loads is expected, coupled on the drive axle with higher driving torques and significantly more braking torque. The new concepts of the trailers will also require higher load capacity. In addition, electrified axles on the trailers will imply a new driving and braking torque on the trailer tires. To assess the performance of the advanced tires suited for ZEV drive axles, the following KPIs are introduced:

- KPI 6: tire wear at the driven axles of a vehicle combination in [µg/km] and its corresponding percentage tire wear compared to the baseline tires
  - equation absolute numbers: $\frac{absolute\ tire\ wear\ [\mu g]}{distance\ [km]}$
  - equation relative numbers: $\frac{tire\ wear\ ZEFES\ tire\ \left[\frac{\mu g}{km}\right] - tire\ wear\ baseline\ tire\ \left[\frac{\mu g}{km}\right]}{tire\ wear\ baseline\ tire\ \left[\frac{\mu g}{km}\right]}$

To visualize the KPIs a table is created showing the relation of the KPIs, the vehicle configuration and technology, and the logistics missions. The target values need to be aligned by the OEMs, the shippers, and the research to enable a proper validation and assessment.
Additional KPIs derived from other stakeholder’s requirements, e.g. logistics providers, are defined in deliverables D1.2 and D1.3. All KPIs will be collected in a table following the structure depicted in **Error! Reference source not found.**, and will be further specified in task 8.1 and the corresponding deliverable D8.1.

Table 4-2: ZEFES powertrain KPIs

	KPIs, comparison BE-, FCE-, and ICE-HDV long-haul vehicles			7.2.1		7.2.2		7.4.2		7.6.1		7.6.2		7.6.3	
	KPI description	Unit	Target	ICE	FCE	ICE		CE	BE	ICE	FCE	ICE	FCE	ICE	FCE
Powertrain	energy consumption	kWh/km	achieve range of 750 km respectively 400												
	relative energy consumption	%	% ref. vehicle												
	energy efficiency	(t*km)/kWh	tbd												
	relative energy efficiency	%	% ref. vehicle												
	hydrogen consumption	kg/km	achieve range of 750 km respectively 400												
	relative hydrogen consumption	%	% ref. vehicle												
	hydrogen efficiency	(t*km)/kg	tbd												
	relative hydrogen efficiency	%	% ref. vehicle												
	average speed	km/h	same as ref.												
	tire wear at the driven axles	µg/km	tbd												
	relative tire wear at the driven axles	%	% ref. vehicle												
	number of driven axles	-													
	axle weight at driven axles	kg													

4.5 Contribution to project (linked) Objectives

The work done in Task 1.1 and documented in this deliverable contributes reaching several objectives that have been defined in the ZEFES description of action. As described in section 2.1 the list of requirements and needs regarding the ZEV and their powertrain are input to several work packages.
The templates provide the powertrain requirements and needs that must be considered in developing and realizing the battery electric and fuel cell electric vehicles and trailers for the demonstration in the use cases (Sub-objective 1.1).
The templates provide the starting point for the optimization of the vehicle powertrains with right component size, considering the interaction with the charging/refuelling and energy infrastructure for long-haul trucks (Sub-objective 1.3).
The definition of requirements for charging in the templates aim to guarantee the compatibility of vehicles and infrastructure to enable the demonstration of hardware and its communication interface for ultra-fast charging of prime movers and e-trailers (Objective 2).
The templates enable a detailed specification of the ZEV and their powertrain components and thus, providing the basis for parameterization of the digital twins (DT) for each of the nine truck-trailer combinations used in the ZEFES project (Sub-objective 3.1). Furthermore, the vehicle specification

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).

4.6 Contribution to major project exploitable result

The work done in Task 1.1 and the documentation in this deliverable indirectly contributes to the projects exploitable results. The developed templates define the requirements and needs of the different stakeholders within the ZEFES project and beyond regarding the vehicles and its powertrains. This enables an initial parameterization of physical models for modular and flexible ZEV powertrain concepts, a targeted optimization and development of vehicles that serve the logistics missions demonstrated in the use cases.

5 Conclusion and Recommendation

The deliverable provides a comprehensive overview of the requirements and needs of different work packages regarding the vehicles and their powertrains/components. The resulting templates for the requirements specification must be used as living documents. This means that it has to be further detailed by the work packages. Furthermore, the concrete values and information for each parameter in the templates have to be identified in cooperation with the vehicle and trailer OEMs. In the first stage the content will consist of generic vehicle information as starting point for vehicle and trailer OEMs as well as simulation activities in WP2. In the second stage the parameter and information must be specified according to the realized vehicle units to verify performance of the developed innovations (WP5, WP6), parameterize, and calibrate the digital twin tool (WP4) and give input to the assessment framework (WP8).
This work will be done by work packages 2, 5 and 6, providing continuity as FHG and AVL, being the subtask leaders of task 1.1, are work package leaders of WP5 and WP6 respectively.

As briefly described in the deliverable the specification of the e- and b-trailers is highly dependent of the certain use case and the logistics mission. Therefore, a working group on a trailer concept for Europe was already initiated including the vehicle and trailer OEMs as well as the research partners in WP5 and 6. This working group will investigate market segments on the European market and derive a feasible e-trailer concept for Europe that will be implemented during the ZEFES project. It will further give an outlook on a sophisticated e-trailer concept based on the upcoming developments in vehicle and component technology as well as vehicle-to-vehicle interface standardisation. The working group is organized within WP5.

6 Risks and interconnections

6.1 Risks/problems encountered

Table 6-1: Risks/problems encountered

Risk No.	What is the risk	Probability of risk occurrence[1]	Effect of risk1	Solutions to overcome the risk
WP1.1	Essential requirements could be missing in the current templates. Especially in the context of requirements for interfaces this could lead to problems at the interface or in worst case lead to incompatibility of two systems (truck, trailer, infrastructure).	2	1	Alignment with other work packages was done and the requirement template is a living document that will be improved in the course of the project when necessary. Application of standards wherever possible (e.g. communication protocols for charging)
WP1.2	components are not available due to confidentially reasons. Thes values would be needed to calculate requirements.	1	3	simplified values can be taken instead. This would lead to less accurate results.
WP1.3	Requirements are mutually exclusive, e.g. a big and, consequently, heavy battery because of range targets and a high payload.	1	3	Communication between all stakeholders.

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

6.2 Interconnections with other deliverables

This deliverable is closely interconnected to deliverables D1.2 and D1.3, which contribute to a complete list of KPIs to be assessed in WP8.

7 Deviations from Annex 1

No deviations from Annex 1 were made. However, as stated in chapter 5, the e-trailer concept might be deviating from Annex 1. This will be further investigated in the working group established in WP5.

8 References

[1] O. H. e. al., *ZEFES - Zero Emission, flexible vehicle platforms with modular powertrains serving the long-haul Freight EcoSystem,* Brussels, 2022.

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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.
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21	GRU	GRUBER LOGISTICS S.P.A.
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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
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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)
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10 Appendix A – Templates

The upper part of the vehicle template of the spreadsheet "Vehicle – Parameters" is shown for illustration purpose. Makeup of the templates and spreadsheets is described in chapter 2.2.

Topic	Parameter	Value	Unit	Description	Purpose	Requestor - WP#
Use Case	Sub Task ID	ST 7.2.3	-		Mission / Usage	WP2 / WP8
	vehicle combinations	tractor - semitrailer - dolly - semitrailer 	-	vehicle combonation the vehicle unit described in this document will be part of	Mission / Usage	WP2 / WP8
		tractor - semitrailer 	-		Mission / Usage	WP2 / WP8
			-		Mission / Usage	WP2 / WP8
	vehicle type		-	e.g. 6x2 tractor, truck, ...	Vehicle Specification	WP2 / WP8
	licence plate number		-		Assessment	WP8
General vehicle information	vehicle brand		-		Assessment	WP8
	axle configuration		-		Assessment	WP8
	cabin type		-		Assessment	WP8
	tare weight		kg		Assessment	WP8
	gross vehicle weight		kg		Assessment	WP8
	payload capacity		kg		Assessment	WP8
	Frontal area		m²	Value in combination with standard trailer? Value for vehicle combination of use case?	Vehicle Specification	WP2 / WP8
	Drag coefficient		-	Value in combination with standard trailer? Value for vehicle combination of use case?	Vehicle Specification	WP2 / WP8
	Wheelbase axle 1 – axle 2		m		Vehicle Specification	WP2 / WP8
	Wheelbase axle 2 – axle 3		m		Vehicle Specification	WP2 / WP8
	Center of gravitiy from axle 1		m		Vehicle Specification	WP2 / WP8
	horizontal distance of kingpin/coupling from axle 1		m		Vehicle Specification	WP2 / WP8
	Permissible axle loads (front)		kg		Vehicle Specification	WP2 / WP8
	Permissible axle loads (rear)		kg		Vehicle Specification	WP2 / WP8
	Power brake choper		kW		Vehicle Specification	WP2 / WP8
Tyre information of vehicle	Front Tyre type / size		-	type, size, brand, energy consumption label	Vehicle Specification	WP2 / WP8
	Rear Tyre type / size		-	type, size, brand, energy consumption label	Vehicle Specification	WP2 / WP8
Max. vehicle velocity	Max. Velocity with continuous power: ≥ **tbd** kph with continuous power for ≥ **tbd** min				Powertrain Efficiency	WP2 / WP8
	Acceptable overspeeding: < **tbd** kph		km/h		Powertrain Efficiency	WP2 / WP8
	Reverse velocity: **tbd** kph		km/h		Powertrain Efficiency	WP2 / WP8
Gradeability	Drive Away Gradeability Peak: > **tbd** %		%		Powertrain Efficiency	WP2 / WP8
	max. gradeability an 80 km/h		%		Powertrain Efficiency	WP2 / WP8
	cont. gradeability at 80 km/h		%		Powertrain Efficiency	WP2 / WP8
	max. continuous speed at 8% grade		km/h		Powertrain Efficiency	WP2 / WP8
Acceleration	Fully loaded vehicle (Peak power): accelerate from 0 kph to 80 kph in ≤ **tbd** s		s		Powertrain Efficiency	WP2 / WP8
	Fully loaded vehicle (Peak power): accelerate from **tbd** kph to **tbd** kph in ≤ **20** s		-		Powertrain Efficiency	WP2 / WP8
Deceleration	Fully loaded vehicle (brake perfomance): decelerate from 80 kph to 0 kph in ≤ **tbd** s		s		Powertrain Efficiency	WP2 / WP8
Durability braking	Fully loaded vehicle (Constant Speed): **tbd** kph at a downhill slope of **tbd** %.		-		Powertrain Efficiency	WP2 / WP8
All Electric Range	Range on defined cycle (driving cycle to be named)		km	Drive cycle	Powertrain Efficiency	WP2 / WP8
Vehicle Energy Consumption	Specific Energy Consumpion on defined driving cycle (driving cycle to be named)		kWh/100km		Powertrain Efficiency	WP2 / WP8
Real Life Range	Range in defined real-life driving (VECTO Cycle)		km		Powertrain Efficiency	WP2 / WP8
Real Life Energy Consumption	Real Life Energy Consumption in defined real life driving (VECTO Cylce)		kWh/100km		Powertrain Efficiency	WP2 / WP8
AC Charging Requirements	AC charging standards		-	AC HLC (ISO 15118 - 2 2013/2016), AC HLC Plug&Charge (ISO 15118 - 2 2016), AC without HLC (IEC 61851-1) or New ISO 15118-20	Infrastructure Specification	WP3 / WP5
	AC connector		-	Type1-CCS1 (NA) or Type2-CCS2 (EU)	Infrastructure Specification	WP3 / WP5
	On Board Charger(OBC): power (efficent)		kW		Infrastructure Specification	WP3 / WP5 /WP8
	OBC HV system: input voltage, output voltage		V		Infrastructure Specification	WP3 / WP5
	OBC efficiency		%		Infrastructure Specification	WP3 / WP5
	OBC features		-	liquid cooled, IP67, bidirectional, DC/DC converter integrated	Infrastructure Specification	WP3 / WP5
	number of AC inlets (charging ports)		-		Infrastructure Specification	WP3 / WP5
	position of AC inlets (charging ports)		-		Infrastructure Specification	WP3 / WP5
DC Charging Requirements (CCS)	DC charging standards		-	DC EIM (DIN 70121 or ISO 15118-2 2013), DC PnC (ISO 15118 - 2 2016) or New ISO 15118-20	Infrastructure Specification	WP3 / WP5
	DC connector		-	CCS1 (NA), CCS2 (EU)	Infrastructure Specification	WP3 / WP5
	DC charging voltage level		V		Infrastructure Specification	WP3 / WP5
	DC charging power		kW		Infrastructure Specification	WP3 / WP5 / WP8
	number of DC inlets (charging ports)		-		Infrastructure Specification	WP3 / WP5
	position of DC inlets (charging ports)		-		Infrastructure Specification	WP3 / WP5
DC Charging Requirements (MCS)	DC charging standards		-	DC EIM (DIN 70121 or ISO 15118-2 2013), DC PnC (ISO 15118 - 2 2016) or New ISO 15118-20	Infrastructure Specification	WP3 / WP5
	DC connector		-	MCS	Infrastructure Specification	WP3 / WP5
	DC charging voltage level		V		Infrastructure Specification	WP3 / WP5
	DC charging power		kW		Infrastructure Specification	WP3 / WP5 / WP8
	number of DC inlets (charging ports)		-		Infrastructure Specification	WP3 / WP5
	position of DC inlets (charging ports)		-		Infrastructure Specification	WP3 / WP5
Hydrogen Fueling Requirements	Fueling pressure (350bar / 700 bar / both)		bar		Infrastructure Specification	WP3 / WP6
	Fuel Receptacle Type		-	as far as affects fueling, eg type 3 or 4	Infrastructure Specification	WP3 / WP6
	Fueling protocol		-		Infrastructure Specification	WP3 / WP6
	Location of fueling on vehicle (left / right / both)		-		Infrastructure Specification	WP3 / WP6
	Nozzle Type		-		Infrastructure Specification	WP3 / WP6

Figure 10-1: Spreadsheet "Vehicle – Parameters"

As example the spreadsheet “Vehicle – Battery Curve” is shown. There are several spreadsheets like this for more detailed information beside the main “Vehicle Parameter” spreadsheet as described in chapter 2.2.

Cell Characteristics	Open circuit voltage			Cell resistance			
	state of charge	OCV single cell - charge	OCV single cell - discharge	state of charge	Ohmic Resistance CHARGE	state of charge	Ohmic Resistance DISCHARGE
	[%]	[V]	[V]	[%]	[mOhm]	[%]	[mOhm]
	0			0		0	
	5			10		10	
	10			20		20	
	15			30		30	
	20			40		40	
	25			50		50	
	30			60		60	
	35			70		70	
	40			80		80	
	45			90		90	
	50			100		100	
	55						
	60						
	65						
	70						
	75						
	80						
	85						
	90						
	95						
	100						

Battery power characteristics	charge						discharge			
	cont			peak			cont		peak	
	state of charge	power	max. current	state of charge	power	max. current	state of charge	power	state of charge	power
	[%]	[kW]	[A]	[%]	[kW]	[A]	[%]	[kW]	[%]	[kW]
	0			0			0		0	
	10			10			10		10	
	20			20			20		20	
	30			30			30		30	
	40			40			40		40	
	50			50			50		50	
	60			60			60		60	
	70			70			70		70	
	80			80			80		80	
	90			90			90		90	
	100			100			100		100	

Figure 10-2: Spreadsheet "Vehicle - Battery Curve"