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

ZEFES - Deliverable report

D1.3 ZEFES Ecosystem Specification

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Publishable Summary

Europe's commitment to be the first CO2-neutral continent by 2050 is going to impact the road transport industry, in part by requiring massive investments. To achieve EU CO2 reduction goals, research, policy, technology and industry need to cooperate and ensure a smooth transition to ZE-HDVs.

This document includes the ZEFES approach to gather input from the industry on needs and requirements so ZE-HDV can be implemented. It is crucial for the project, that in addition to demonstrating the technology, links with truck users and the broader ecosystem of zero-emission road transport are established, so the ZEFES project can respond to the industry's needs and concerns regarding decarbonisation and adopting ZE-HDVs.

A preliminary list of needs and requirements of truck operators is defined (Chapter 2) and matched with the ZEFES KPIs (Chapter 3.1) to evaluate if the project is relevant for the zero-emission ecosystem. Also, the methodology towards building a sustainable business case for long-haul ZE-HDVs will be discussed.

In the following pages, the reader can obtain insights from the preliminary results of the analysis, namely the survey conducted, targeted interviews and user stories by industry outliers who have already gained experience with ZEVs.

External factors impacting the future adoption of ZE-HDVs were studied in an analysis of EU legislation related to ZE-HDVs (both legislative efforts to promote those vehicles and discourage the use of ICEs) and a literature review on the latest and most relevant TCO methodologies will lay the groundwork for the next project milestones.

Upcoming reports such as deliverable D1.5 will follow-up on the work linked to this report including the final results of the needs and requirements for ZE-HDVs.

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Abbreviations and Definitions

Abbreviation	Explanation
BE-HDV	Battery Electric Heavy-Duty Vehicle
BEV	Battery Electric Vehicle
CCS	Combined Charging System
D	Dolly
DT	Digital Twin
DTP	Digital Twin Platform
e-D	Electric dolly
EMS	European Modular System, HDV carrying standardised loading units for intermodal freight transport
e-ST	Electric semi-trailer
FCE-HDV	Fuel Cell Electric Heavy-Duty Vehicle
FCEV	Fuel Cell Electric Vehicle
GCW	Gross Combination Weight
HDV	Heavy-Duty Vehicle
HRS	Hydrogen Refuelling Station
ICE	Internal Combustion Engine
ISO	Interchangeable container as defined in the ISO-Norm 668
MCS	Megawatt Charging System
OEM	Original Equipment Manufacturer
R	Rigid unit
Reefer	Loading unit to transport temperature-controlled cargo
ST	Semi-trailer
SWAP	Interchangeable container accommodating Euro-pallets for road and rail transport
T	Tractor unit
TCO	Total Cost of Ownership
tkm	Tonne kilometres
TR	Trailer
USP	Unique Selling Proposition (uniqueness of ZEFES use cases)
VECTO	Vehicle Energy Consumption Calculation Tool
vkm	Vehicle kilometres
WPL	Work Package Leader within ZEFES project
ZE-HDV	Zero tailpipe Emission Heavy-Duty Vehicles
ZEV	Zero tailpipe Emission Vehicle
	Abbreviations of project partners, see chapter 8 acknowledgement

1 Introduction

Previous project reports have covered the needs and requirements related to the ZEFES truck demonstrations. Descriptions of the needs and requirements of the vehicles (with a focus on the powertrain) can be found in report D1.1 while needs and requirements of the actual use cases are discussed and elaborated in D1.2 (Defined Use Cases, Target metrics and needs).

The current report (D1.3) focuses on gathering, analysing and presenting the preliminary needs and requirements derived from user experiences, expectations, and concerns focused on the categorisation of the ZEFES ecosystem stakeholders (shippers, transport operators, logistics site operators, truck OEMs, trailer OEMs, infrastructure operators (charging/HRS), infrastructure manufacturers (charging/HRS), research, authorities and policy).

The methodology followed in Tasks 1.3 and 1.4 is presented in this deliverable. Moreover, a thorough analysis at factors that are external yet impactful for the project and the deployment of ZE-HDV - such as the regulatory frameworks around ZE-HDVs at EU level, the TCO calculation and the business case examples already in place - are included in the analysis.

The project collected and analysed user needs and requirements from key stakeholder groups with expertise in heavy goods transportation and demonstrated experience in ZE-HDVs. Targeted interviews also provided the project team with more detailed findings. The ZEFES symposium organised in October 2023 will include a dedicated session to present the preliminary results and receive feedback from experts. Final results of the user needs and requirements together with the developed business cases will be part of the upcoming report D1.5.

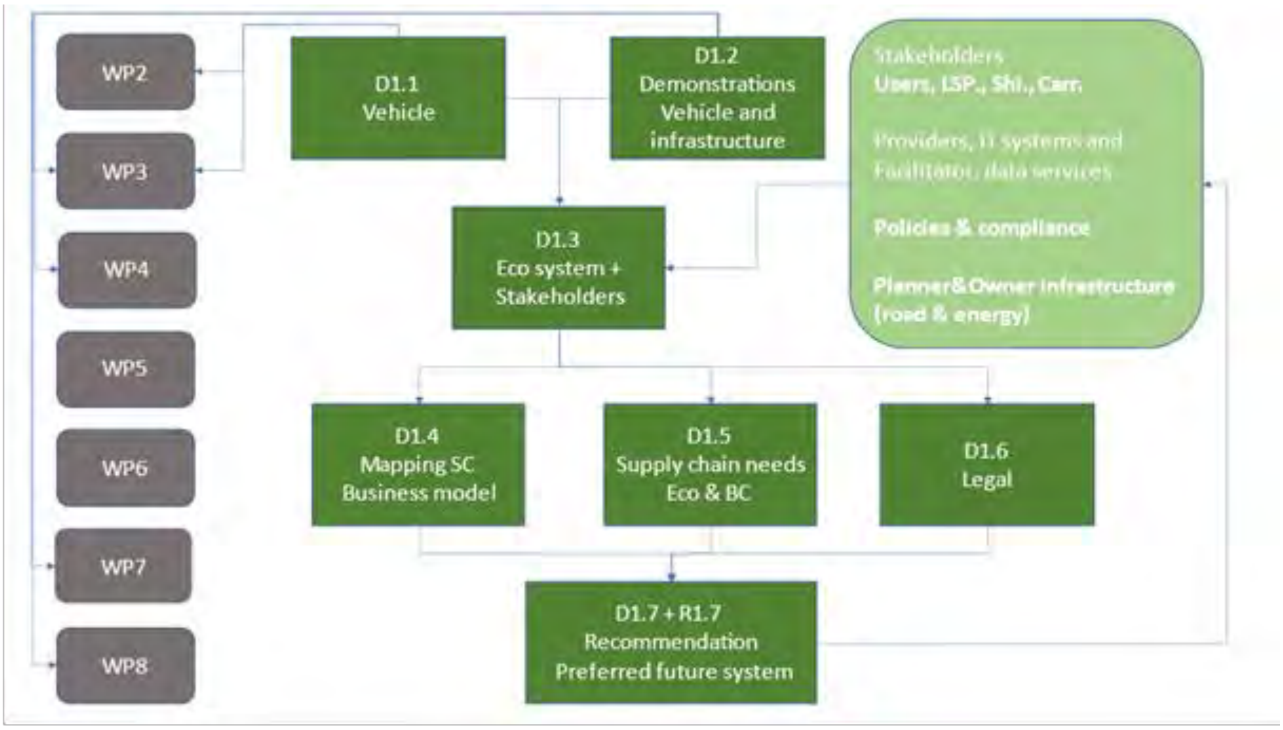

Figure 1: Interconnections in Work Package 1

The present report is part of the first ZEFES work package which aims at identifying needs and requirements for the vehicles (T1.1), ZEFES use cases and demonstrations (T1.2), ecosystem (T1.3), business model (T1.4), supply chain (T1.5) and legal issues (T1.6). Following the vehicle and demonstration needs and requirements, this report is serving as a link to the real-world commercial operations and the actors involved in them. The partners reached logistic operators that have already tested ZE-HDVs through the survey, interviews and workshops, and consulted a variety of other sources such as literature review, industry publications and internal project expertise.

This deliverable focuses on **the needs and requirements of the ZEFES project**. We discuss how the needs and requirements for both ZE-HDVs and the use cases of the project are converted to characteristics which are feasible within the project timeline. Secondly, we will look to the **needs and requirements of the full ZE-HDV ecosystem** more broadly and **on a longer timeline**. Relevant stakeholder groups were identified, and the following seven stakeholder groups were organised to gather their needs and requirements: **shippers, transport operators, logistic site operators, infrastructure operators, truck manufacturers, trailer manufacturers, authorities**. Two other stakeholder groups (research and policy makers) were also identified as important, but they are more accurately described as facilitators – while their needs and requirements do not apply to the ZE-HDV ecosystem, they should help to reach them.

The needs and requirements for all stakeholder categories and for both a short-term and long-term outlook were gathered in an online survey and through dedicated interviews. The methodology as well as the response data are found in Chapter 2.

In chapter 3, a GAP analysis is conducted (Section -6052299362.1) and Section 3.2 presents an overview and analysis of EU legislation that creates the enabling framework for ZEVs and seeks to decarbonise the road transport industry. Section 3.3 is including user stories delivered by industry outliers who have already tested ZE-HDVs.

The last chapters of this deliverable include an effort to analyse the business requirements in order for ZEFES to shape its business case(s), the conclusions and information related to risks and deviations. The three appendices include the survey, all the results of the analysis on the user needs & requirements and the detailed literature review on the TCO.

The project is going to link the findings with the ZEFES KPIs that will be used to assess the use-cases and project results in WP8. At the end of the project, an assessment of which needs and requirements have been covered by the project will take place, and steps that still need to be taken for the successful development of ZE-HDV business cases will be reported so that research and the industry can take further steps in achieving market deployment.
A comparison of the most recent TCO methodologies linked to the ZEFES ambitions is presented, and recommendations for a ZEFES TCO are developed.

2 Stakeholder Needs and Requirements

In this section, the needs and requirements of the ZE-HDV ecosystem are identified and listed. In a first step, the stakeholders of the ZE-HDV ecosystem are defined. Next, the procedure to gather needs and requirements is presented, together with the results of a literature review focussing on existing surveys on needs and requirements for ZE-HDV and the followed survey methodology. Finally, the preliminary list with identified needs and requirements is discussed. These needs and requirements are primarily based on the viewpoints of ZE-HDV end-users.

2.1 ZE-HDV ecosystem

An overview of the ZE-HDV ecosystem and stakeholders is presented in Figure 2. The ecosystem was derived from discussions with relevant logistic companies which have experience in implementing and demonstrating ZE trucks. They were asked to identify other, relevant stakeholders or services and concepts on which their operations depend.

The purpose of ZE-HDV is to transport goods. The transport process is organized by **shippers** (defined as the owner of the goods) and **transport operators** (who can assign the mission to a carrier or can execute the mission themselves). We mention the driver specifically as a stakeholder, as he/she will be the primary user of ZE-HDV, and the capabilities and characteristics of the vehicle will directly affect the job and comfort of the driver. The goods will be transported between **logistic sites**, so the operator of these sites is also a stakeholder in the process. The possibility to charge or fuel trucks at logistic hubs will affect the way ZE trucks can be implemented and is therefore relevant in the ecosystem.

The ZE-HDV itself and the trailer are the assets that are used for the logistic operation. The capabilities of both will be defined by the needs and requirements of the shipper, transport operator, and driver. Whether the capabilities are feasible will be defined by the **OEMs of the truck and trailer**. The OEMs will have additional needs and requirements, which are also gathered, but will not be the focus of this deliverable.

The planning of logistic missions can be done by software. Since the capabilities of ZE-HDV are different from conventional diesel trucks, the method to plan missions will need to change. Digitalisation is added because communication between assets and software will be key to implement ZE-HDV in logistics operations. In addition, integrating one ZE-HDV can be done by current means, but new planning software that takes opportunities and limitations into account will be necessary to obtain an optimal logistics operation of a ZE-HDV fleet.

The energy sources used to propel ZE-HDV are electricity and hydrogen. A network of charging and hydrogen fuelling stations (HRS) will be needed. Therefore, the needs and requirements for this to-be-developed infrastructure from the viewpoint of the transport operator, logistic site operator, driver, **infrastructure operator**, and truck-trailer OEM are gathered.

Other stakeholder groups belonging to the ZE-HDV ecosystem are **researchers**, **authorities** (road, traffic and type approval) and legislative as well as regulatory entities that define the **regulatory framework**. These stakeholders are key to solve some technical or regulatory barriers.

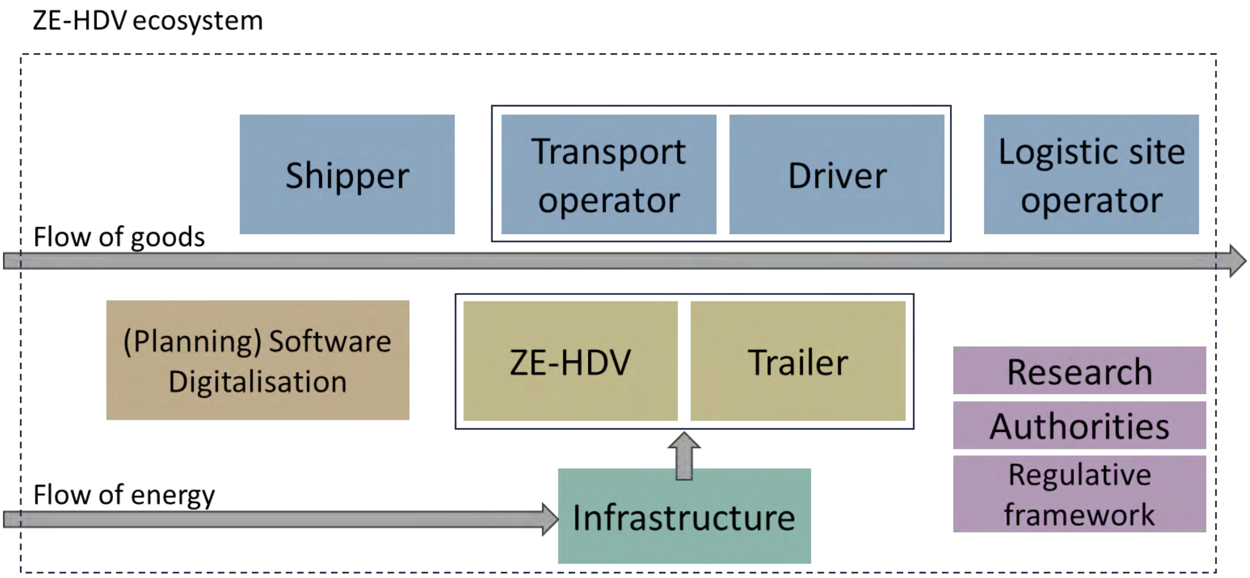

Figure 2: Stakeholders of the ZE-HDV ecosystem

2.2 Existing surveys

We gathered surveys on needs and requirements for ZE HDVs by identifying (European) R&I projects or associations that have conducted surveys about the implementation of ZE-HDV and the related ecosystem. We found limited relevant scientific papers defining survey-based needs and requirements from the viewpoint of the truck end-user.

A paper using the Delphi method to define factors affecting the purchasing decision and operation of alternative fuel-powered trucks in Germany found that reliability and fuelling/charging infrastructure are the factors with the highest relative importance related to daily practicability.[1] Melander et al. used structured interviews to define drivers and barriers for the implementation of electric trucks, which are related to but not identical with the end-users needs and requirements.[2]

Konstantinou conducted surveys and interviews and made some interesting conclusions[3]. She found indications that ZE-HDV trucks will be implemented first in fleets that are for hire and have critical mass (more than 26 trucks). Also use cases, with predictable and return to base mission are more likely to adopt ZE-HDV.

We identified four projects where needs and requirements of end-users were gathered. There are few surveys that focus on stakeholder requirements compared to a larger number of publications on how experts expect the market to change.

A first project started in 2014. The Flemish Institute for Logistics conducted a survey under the **Powering Logistics 2020** project[4]. Fourteen companies were consulted to determine the fuel of the future. The survey contained questions about the characteristics of the missions and routes, payload,

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[1] Benedikt Anderhofstadt et al., Factors affecting the purchasing decision and operation of alternative fuel-powered heavy-duty trucks in Germany – A Delphi study, Transportation Research Part D 73 (2019) 87-107 https://www.sciencedirect.com/science/article/abs/pii/S1361920918310599?via%3Dihub

[2] https://www.sciencedirect.com/science/article/pii/S1361920922001456

[3] https://hammer.purdue.edu/ndownloader/files/36427380

[4] https://vil.be/project/powering-logistics-2020/

type of goods and common practices of fuelling and buying criteria. At that time, they concluded that only CNG, LNG and hybrid drive trains were potential alternative fuel options. Technology has evolved, and findings of this study are not relevant anymore. We are therefore focussing on recent projects.

The **H2Share** project demonstrated a hydrogen fuel cell electric rigid truck (GWV 27t) in several use cases together with a mobile hydrogen refuelling station (HRS)[5]. One of the main outputs was technical user requirements for hydrogen trucks. Since the vehicle was used for several use cases, the determination of the vehicle capabilities was not straightforward, and a middle ground solution was implemented.

The project has two public deliverables, one on the design specifications of a mobile refuelling station[6] and one on end-user experiences of the demonstration.[7] Most of the end-user experience focussed on truck improvements. However, it is stated that trained drivers are important and should be able to contact service people at all times. Unambiguous and simple instructions are necessary. You cannot expect drivers to be able to describe technical problems correctly, since ZE-HDV technology is completely new to them.

In 2019, **Hydrogen Europe** presented the results of their end-user questionnaire focussing on the status of the FC truck market and expected developments in the next decade. A total of 40 companies were interviewed. The survey targeted logistic companies and asked them about their operations, sustainability strategies, and their opinions on several statements about hydrogen fuel cell trucks. The respondents identified the expected longer driving range and shorter fuelling time of FC trucks compared to other ZE technologies as the main strengths of FC trucks. Nevertheless, they also stated that the lack of refuelling infrastructure, vehicles, and a higher-than-expected TCO (related to the cost of green H2) are the main weaknesses.

The respondents were also interviewed about their refuelling habits. They recognised that a driving range of 500 to 1000 km would be suitable, if an appropriately dense refuelling network were available. A short refuelling time of 10-15 minutes was preferred, and respondents were open to adjusting their refuelling preferences for a transition period.

A third study, **'My eRoads'** (2021), wants to build an advice tool for electric trucks and busses and the related infrastructure, so companies can check that these commercially available vehicle models are suitable to be used in existing operations.[8] A survey was conducted to assess the current framework conditions for alternative truck drives.[9] Both the operational aspects and monetary aspects were considered in the survey. There were six insights form the study:

- Funding is necessary, but should be designed on a degressive basis to create an incentive to reduce the cost of the technology
- The current funding focuses on vehicle acquisition and the related infrastructure. This should shift to funding for the overall system, including grid connection/upstream infrastructure.
- As long as FCE-HDV are not cost-competitive with BE-HDV they will play a niche role, even if they have operational advantages.
- Many actors are not aware of the significant differences in the climate impact of alternative drives in the medium-term horizon. This sometimes results in expectations of government frameworks that run counter to effective climate policy.

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[5] https://vb.nweurope.eu/projects/project-search/h2share-hydrogen-solutions-for-heavy-duty-transport/

[6] https://vb.nweurope.eu/media/5797/del-i2-1-1-report-with-design-specifications-mobile-refueler-final.pdf

[7] Deliverable T2.3.1 Report on monitoring and end-user experience data per demonstration - nr 1

[8] https://www.my-e-roads.de/de-DE/ and https://www.ifeu.de/en/project/my-eroads/

[9] https://www.ifeu.de/fileadmin/uploads/2022-03-03_-_Zusammenfassung_Onlinebefragung__1_My_eRoads.pdf

- The development of an efficient public charging infrastructure for battery trucks is a no-regret measure.
- A path decision for the direct use of electricity in truck traffic as the most cost-effective option can basically be made today and thus significantly reduce investment uncertainties for all stakeholders. A basic infrastructure for H2 can still be maintained if necessary to ensure international interoperability.

Of the four identified studies, Hydrogen Europe's study is closest to what we want to achieve with the ZEFES needs and requirements survey. We want to identify needs and requirements of the truck end-users and hope to convert some of them to practical KPIs.

2.3 ZEFES survey on needs and requirements

In this section we will discuss the followed procedure to derive the needs and requirements and the applied methodology to compose the online survey. Some preliminary results of the survey will be discussed as well.

2.3.1 Procedure to derive the needs and requirements

After the definition of the stakeholder groups, we decided to develop different surveys for each stakeholder group because they all have different views on zero-emission road transport as well as different needs and requirements. The survey questions are based on insights of the ZEFES partners, combined with insights from interviews with logistic companies. All survey questions, organised by stakeholder group, can be found in APPENDIX I.

During the discussion and drafting of the survey, the ZEFES partners and logistic companies already formulated their specific needs and requirements. The survey questions are posed in such way as to check how relevant the needs and requirements are for the other members of the same stakeholder group. More on the methodology of the survey can be found in Section 2.3.2.

In addition to general needs and requirements, we also asked for target values or KPIs. In this way we are able check if the targets and KPIs are the same for different stakeholders. That would mean that everyone is working towards the same goal and that products in development meet market needs.

Once the questions were defined, the online survey was built (using Gravity Forms software) and published publicly on the ALICE website. Interested respondents from the ZEFES project partners and ALICE members were asked to fill in the survey by personal mail. We also asked to publish the ZEFES survey in relevant newsletters to attract respondents. We aimed for substantive responses rather than a high number of respondents.

By September 28, 2023, 31 respondents had filled out the survey. Of these, 10 identified themselves as truck end-users, 4 as shippers, 5 as logistic site owners or operators, 5 as truck OEMs, 2 as trailer manufacturers, 7 as infrastructure operators or manufacturers, 2 as policy makers, 4 from authorities, and 6 as researchers. Some respondents selected more than one stakeholder group. The answers of the respondents were imported in Excel and further analysed in this way.

We divided the identified needs and requirements into six categories: (i) truck-trailer technology, (ii) integration in the logistic operation, (iii) social acceptance: safety and sustainability, (iv) legal barriers, (v) infrastructure and (vi) viable business case. Some of the responses are discussed in Section 2.3.3. The preliminary list of identified needs and requirements can be found in APPENDIX II. Whether the ZEFES project can help to realise the identified needs and requirements is assessed in Section 3.1.

In a next step, the survey answers will be validated during the ZEFES Symposium of 25th of October, in Session I 'Supply chain needs'. The list with needs and requirements will be shared with the participants prior to the event, so they can formulate feedback. The Session will consist of two parts. First, a panel discussion will be held with representatives from logistic companies that have already implemented at least one zero-emission truck in their operations. A question from each of the six identified categories will be discussed. After the panel discussion an interactive session will be held, where the participants (both in person and online) can convey feedback and rank the needs and requirements per topic by importance and relevance. We will conclude the session with the main take away messages and finalise the needs and requirements list. The findings of the Session and final list with needs and requirements will be published in D1.5.

2.3.2 Survey methodology

In this paragraph we will go deeper into why some of the questions are asked, and what methods are used to define whether a need or requirement is relevant.

Overall guidelines

Open questions are avoided to keep the survey short and the answers uniform. None of the questions are mandatory. The respondents can decline when they find the information too sensitive to share. They have the option to select 'I don't know' as well as the option to add responses to predefined lists when they select 'other'. In this way, we can capture unforeseen responses. Also, open text answer boxes will be provided to capture remarks and feedback on the survey questions.

Identified stakeholder groups

The online survey is structured in such a way that the respondents are divided into different stakeholder groups at the start:

- Shipper
- Transport operator
- Logistics site operator
- Truck OEM
- Trailer OEM
- Infrastructure operator (charging / HRS)
- Infrastructure manufacturer (charging / HRS)
- Research
- Authorities
- Policy

Once the respondents have selected stakeholder groups they identify with, a tailor-made survey will be displayed. They can select multiple stakeholder groups, but this will elongate the survey. At the end of each question page, they have the option to save their answers and proceed at a later time.

Level of Expertise

At the beginning of the survey, the level of expertise and experience in the field is asked.

In this way, if the answers differ between level of expertise, we can assess if the answers of more experienced respondents are more appropriate. When relevant, more in-depth interviews with relevant companies can be organised, and methods like Delphi[10] can be applied to further define specific target values and KPIs.

Geographical location

The geographical location of the respondents' company activity is asked, since the incentives to implement ZE-HDV differ between countries, and we want to assess if this influences the respondents' needs and requirements.

Statements

Some needs and requirements are stated as statements, especially reasons to buy/not buy ZE-HDVs. The respondents can indicate whether they agree or disagree. Other options are 'not relevant' or 'I don't know'. Results of the buyer decision statements are provided in Section 2.3.3.

MoSCoW-method

The relevance of certain predefined needs and requirements will be checked. A prioritization of the needs and requirements based on the MoSCoW-method is requested.[11] The acronym MoSCoW stands for four categories:

M	Must have	Mandatory need or requirement
S	Should have	Important need or requirement that is not vital, but has a significant added value
C	Could have	Nice to have need or requirement, that will have a small impact when not implemented
W	Would have	Needs and requirements that are not a priority

We applied the method to assess the importance of some capabilities or services related to ZE-HDV and their related infrastructure. By selecting one of the categories, the respondent can indicate the importance of the capability or service.

Survey boundaries and definitions

We define zero-emission heavy-duty vehicles as **vehicles that have an electrical powertrain and a GCW of 40+ tons**. ZE-HDVs could be battery electric and fuel cell electric trucks. Hydrogen is assumed as fuel for the fuel cell electric trucks, as other Renewable Fuels from Non Biological Origin (RFNBO) suitable for fuel cell technology, like ammonia and methanol, are still in the research phase.

The survey will not include vehicles with an internal combustion engine. We acknowledge that a significant reduction in greenhouse gasses (GHG) can be achieved by using biofuels and RFNBO as fuel for an ICE truck, but this technology is beyond the scope of the ZEFES project.

The focus will be on trucks which can complete a mission independent from road infrastructure. The possibility to charge while driving, e.g., e-highways with charging by catenary infrastructure or photo-voltaic panels on the truck and/or trailer, are not considered in this survey.

It is assumed that all energy (in the form of electricity or hydrogen) provided to the truck is renewable.

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[10] Benedikt Anderhofstadt et al., Factors affecting the purchasing decision and operation of alternative fuel-powered heavy-duty trucks in Germany – A Delphi study, Transportation Research Part D 73 (2019) 87-107 https://www.sciencedirect.com/science/article/abs/pii/S1361920918310599?via%3Dihub

[11] https://www.productplan.com/glossary/moscow-prioritization/

We are aware that the zero-emission transport discussion is also about energy efficiency, life cycle assessment (LCA), import of energy, additionality, etc. Nevertheless, the focus of this survey is on the implementation of innovative trucks, not the full energy transition.

2.3.3 Preliminary results and insights from the survey

Since the survey focusses on the truck end-users, we will discuss their preliminary survey responses. As of September 28, 2023, 10 truck end-users responded to the survey. Together they operate more than 10000 trucks all over Europe. All respondents operate trucks with a GVW above 16t. Four respondents did not have experience with ZE-HDV, but six respondents are demonstrating or have purchased ZE-HDV. In total they have purchased 226 ZE-HDV (all battery electric trucks, no hydrogen fuel cell electric trucks).

We asked respondents who have not purchased or demonstrated ZE-HDV for the main reasons why they are not investing (Figure 3). We will only discuss BE-HDV because we noticed that the knowledge of FCE-HDV is limited. They agree that BE-HDV are commercially available, but they did not give a uniform answer on the proposed reasons why they are not making the transition. Some of the respondents state that the driving range of the commercially available BE-HDV is not sufficient. Nevertheless, no correlation with the type of mission (international long haul, regional, round-trip missions) has been found. Other reasons are that charging infrastructure is missing, that the CAPEX investment is too high, or that it is unclear how the logistic operation will be affected. Nevertheless, none of these reasons were selected by all respondents.

The respondents agreed that the technology is safe and societally accepted. They also believe that BE-HDV technology will lead to lower emissions.

The main reasons to invest in ZE-HDV according to the respondents (n=6) is that they want to learn (100%).

On the other hand, they still stated some limitations (n=6) (*Figure 4*):

- Not deployable in all missions (100%)
- Driving range is not sufficient (100%)
- Transport capacity is restricted (90%)
- Charging time is too long (100%)
- Charging and refueling equipment is not available (90%).

All responses are shown in Figure 2 and 3. For some of the statements, the respondents selected ‘not relevant’/‘I don’t know’. We decided to keep the survey online until the validation session of 25th October and will try to gather more responses.

The survey goes beyond reasons to (not) invest in ZE-HDV. We also assessed whether respondents are looking to other technologies and operational solutions to lower emissions - and they do.

We asked if they are interested in other fuel technologies or are willing to change their logistic operations to lower their emissions (Figure 4). Only one respondent was not investigating other fuel options (biomethane, HVO, H2 combustion engines), while seven of the respondents are assessing HVO as an alternative to ZE-HDV to lower emissions. Nine of the ten respondents admit that they are willing to change their logistic operations to lower emissions. Implementing more multimodal transport is the most common answer.

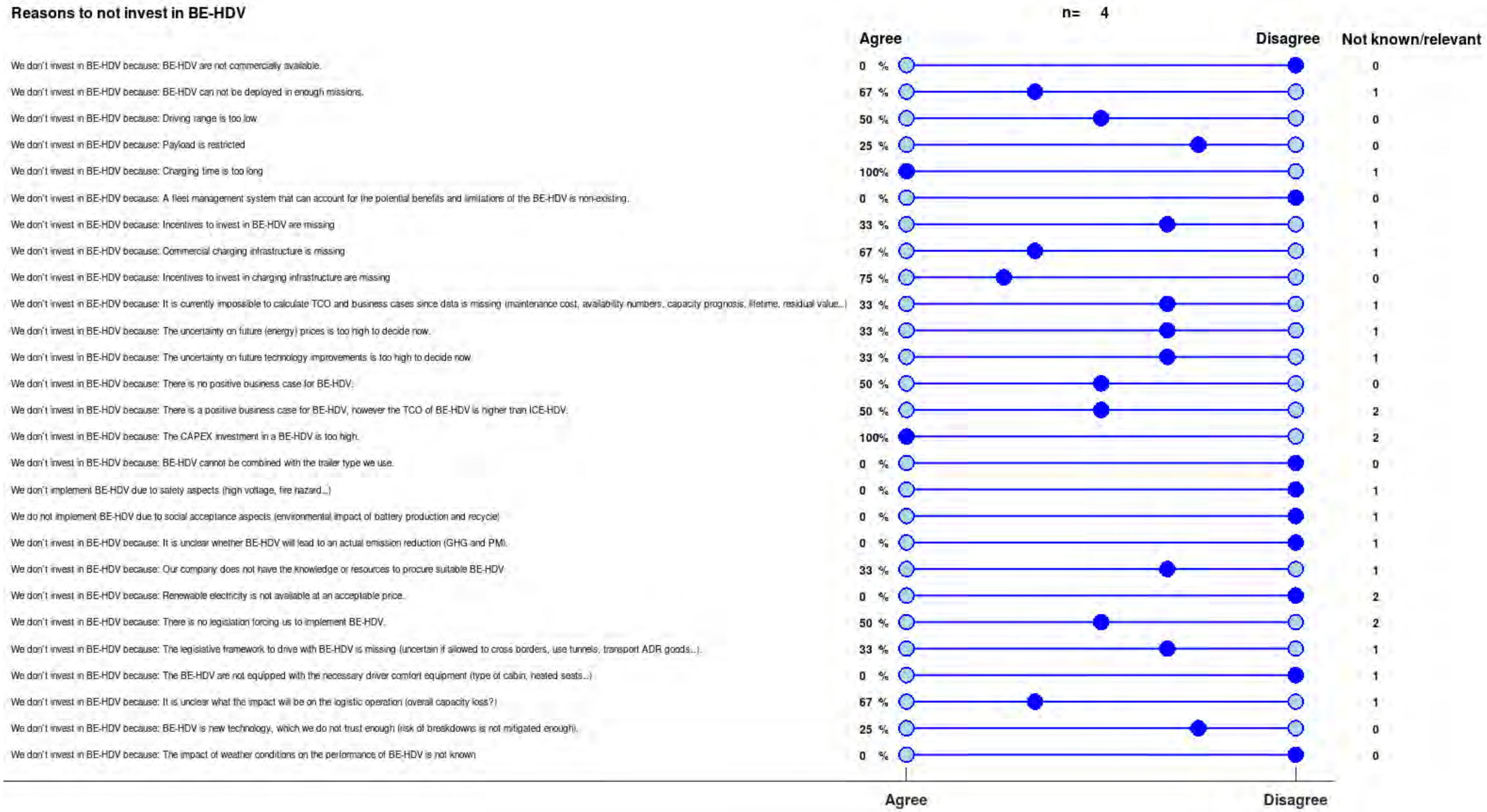


Figure 3: Opinion about reasons to NOT invest in BE-HDV from 4 respondents that have not purchased BE-HDV

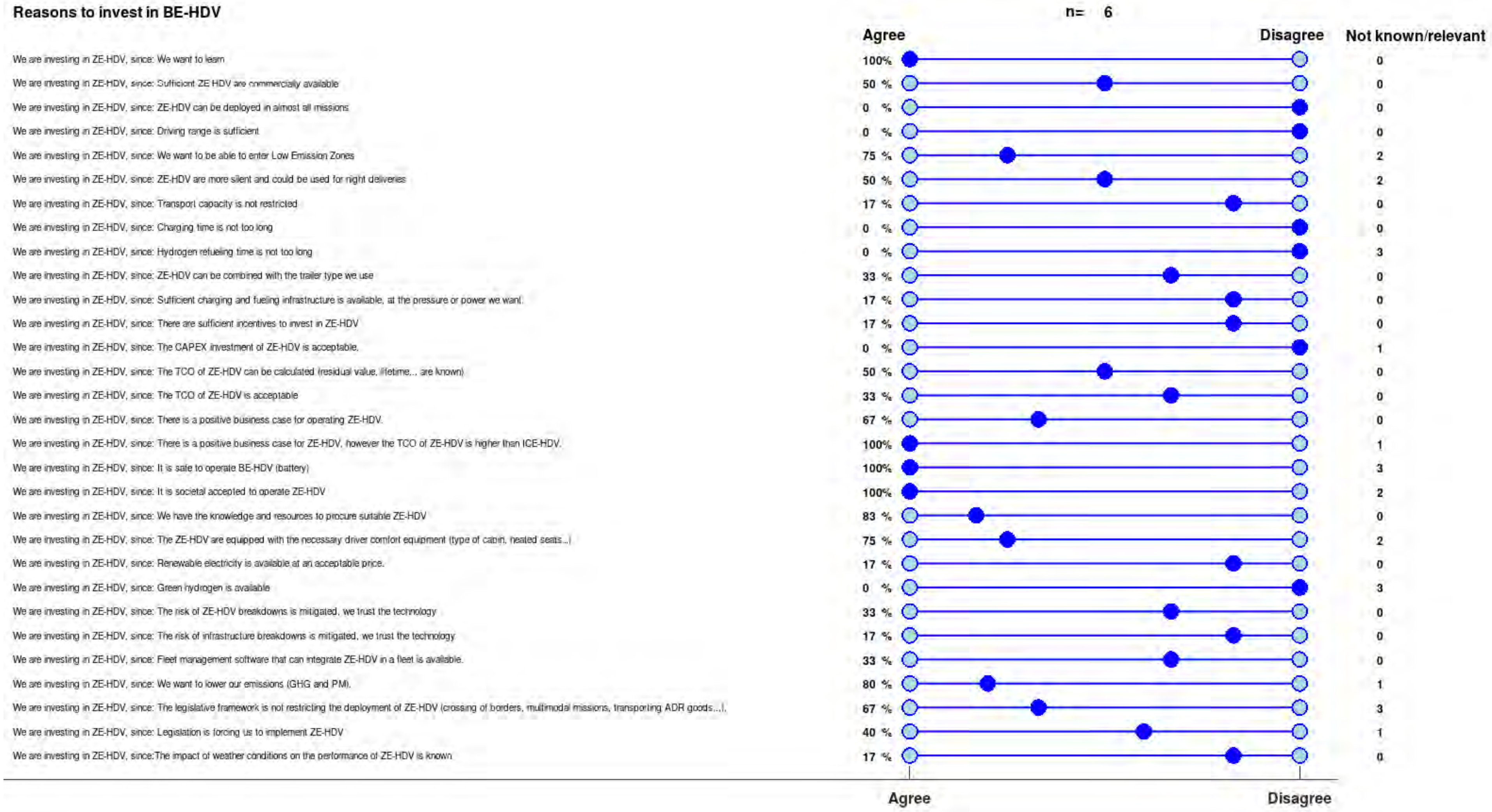


Figure 4: Opinion about reasons to invest in BE-HDV from 6 respondents that have purchased BE-HDV

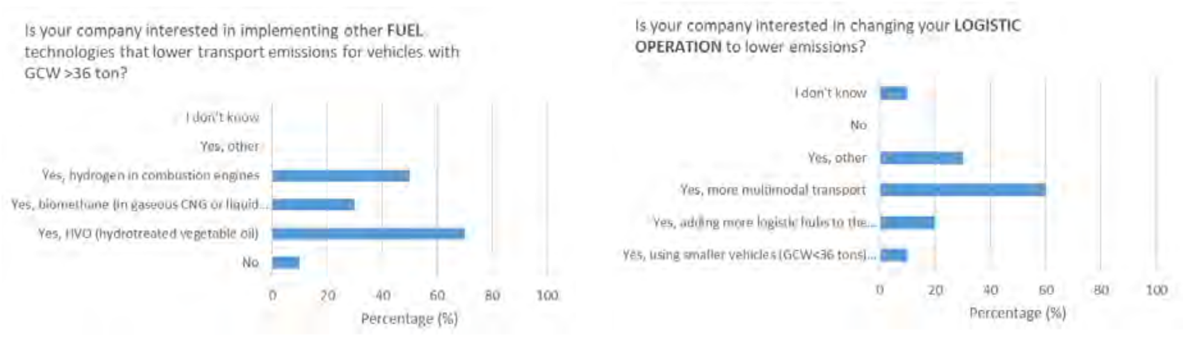


Figure 5: Preliminary survey responses on whether the respondents are assessing alternative fuels and/or changes in logistic operations to lower emissions (n=10)

2.3.4 Identified needs and requirements

The input from the interviews with experts and the survey are used to derive a list of needs and requirements from the viewpoint of the truck end-user. The needs and requirements are divided over the six categories defined earlier:

(i) truck-trailer technology: can the mission be done from a technical point of view?
14 identified needs and requirements
(ii) integration in the logistic operation: can ZE-HDV be integrated in logistic (fleet) operation?
4 identified needs and requirements
(iii) social acceptance: is it safe and sustainable to use ZE-HDV?
6 identified needs and requirements
(iv) legal barriers: can logistic companies use the ZE-HDV as they want without legal barriers?
1 identified, overarching need and requirement
(v) infrastructure: will ZE-HDV be able to refuel or charge?
25 identified needs and requirements
(vi) viable business case: without it, there will be no implementation of ZE-HDV.
9 identified needs and requirements

The list of needs and requirements can be found in ANNEX II.

3 Needs and Requirements Gap Analysis

In this section, we assess whether the ZEFES project is helping to achieve the identified needs. We broadly distinguish between operational requirements and the policy/legal framework – the former can be considered endogenous factors for a freight mission whereas the latter are externally imposed requirements on operators and other stakeholders. A third section provides user stories related to needs and requirements provided by end users through interviews or partner contributions. Those needs and requirements are mostly coming from industry outliers that have already tested ZE-HDVs.

2.1 Operational requirements

The needs and requirements are divided into six categories. We assess for each category what the targets of ZEFES and the KPIs are in order to evaluate if they meet the expectations of the surveyed stakeholders.

3.1.1. ZEFES KPIs

The ZEFES KPIs are divided into three categories: Logistics, Vehicle and Powertrain. The KPIs are described in more detail in Deliverable 1.1 and 1.2 of the ZEFES project. In Table 1 we show the KPIs defined in D1.2. They are used to compare the performance of a ZE-HDV with a diesel truck (ICE-HDV). The selected KPIs focus on the comparison of the full logistic operations, not only the performance of the truck. Specific KPIs for the infrastructure are not formulated, since the performance, availability and cost of infrastructure is linked to the duration of the trip and delivery cost of the trip.

Table 1: ZEFES Stakeholder´s KPIs use cases evaluation and assessment

		KPIs, comparison BE-, FCE-, and ICE-HDV long-haul vehicles		
		KPI description	**Value**	**Target**
Logistics	L1	Duration of trip	hr:min	Same as ref. vehicle (ICE)
	L2	Duration (un)loading	hr:min	Same as ref. vehicle (ICE)
	L3	Delivered quantity during trip	ton / m3	Same as ref. vehicle (ICE)
	L4	Delivery cost of trip	€	Same as ref. vehicle (ICE)
	L5	Number and duration of stops and stop type (fueling / charging / resting / maintenance / (un)loading/other)	n, hr:min	Same as ref. vehicle (ICE)
Vehicle	V1	Range @ 40t GCW on VECTO long-haul profile	km	750km
	V2	Charging during parking 45min	kWh/min	400km @ 40t GCW on VECTO long-haul profile
	V3	Payload	ton	Min 90% as ref vehicle (ICE)
	V4	Load factor	%	% of available m3 or ton
	V5	Repair and maintenance (€)	€/km and €/tkm	% ref vehicle (ICE)
Powertrain	P1	CO2 credits VECTO Vehicle Group		
	P2	Energy use per km	kWh/km	Achieve range of 750km respectively 400km
	P3	Energy use per weight cargo	kWh/tkm – kWh/ton	% ref vehicle (ICE)
	P4	Tires usage drive axle wear and driven kilometres	µg/km - km	% ref vehicle (ICE)
	P5	Number of drive axles and axle weight during operation	n – t/n	% ref vehicle (ICE)

3.1.2. Truck-trailer technology

The KPIs for the vehicle and the powertrain defined in ZEFES match with the identified needs and requirements (Table 1, APPENDIX II). Driving range, transport capacity, energy consumption, energy storage, maintenance are the main KPIs mentioned in both. In the survey responses mentioned a driving range of 750 km as a need, which is also the target in the ZEFES project.

The needs and requirements in APPENDIX II go broader and mention requirements for connected ZE-HDV (V2X communication), modular ZE-HDV design, availability and reliability of ZE-HDV and trailers. Transport operators need to acquire the necessary knowledge, skills and resource to implement and operate ZE-HDV. The human factor (training, acceptance…) of the implementation may not be forgotten and is at this moment not implemented in the ZEFES KPIs. Further follow-up with people making the transition reality (drivers, engineers…) will be done in the ZEFES project (WP8). The use-case will not only be evaluated by technical KPIs, but the user acceptance of the vehicles, tools and charging infrastructure will be assessed by interviews of the involved stakeholders.

In addition, the effect of weather conditions on the performance of ZE-HDV should be clarified, just as possible contingency plans and the certainty that ZE-HDV can be used at all transport modes (link with legal barriers).

3.1.3. Integration in the logistic operation

The identified needs and requirements about integration in logistic operations, mention the need for a fleet management system, clarity on the locations of infrastructure and what the impact of the fuelling/charging, plus payload limitation will be on the operations. This is indirectly covered by the ZEFES KPIs, but more in detail by the work on the digital twin done in WP4, where a decision-making platform will be developed to help with the buying decision, mission planning, selection of the right vehicle for a duty and predictive maintenance.

3.1.4. Social acceptance: safety and sustainability

Six needs and requirements regarding safety and sustainability were captured (APPENDIX II). The needs and requirements regarding safety will be assessed during the ZEFES demonstration, so it could be possible that the ZEFES project could help to fulfil these requirements.

A life cycle analysis, including the environmental impact of the demonstrations, will be conducted during the ZEFES project (WP8) and should give more insights in the sustainability of ZE-HDVs. In addition, how zero-emission transport can be monitored and monetized should also be looked at.

3.1.5. Legal barriers

Only one legal barrier was identified, but it is a very broad one:

'Innovative technologies (trucks and infrastructure) can be implemented since a regulative framework exists'

Again, no KPIs from Table 1: ZEFES Stakeholder´s KPIs use cases evaluation and assessmentTable 1 are applicable, but the ZEFES consortium is currently preparing Deliverable 1.6 on 'Legal and administrative requirements', which should already give an answer how we want to solve the barriers during the ZEFES project. Also, more information about this topic is given in Section 3.2.

3.1.6. Infrastructure

Within the ZEFES project charging infrastructure and HRS will be used to perform the demonstrations. This will lead to several lessons learned, which could help to fulfil the identified needs and requirements.

The category infrastructure led to the most needs and requirements: twenty-four in total. We decided to also include needs and requirements from the viewpoint of the infrastructure operator and the logistic site operator, as we believe that both stakeholders will impact the future availability of infrastructure strongly. Most truck operators are depending on infrastructure operators to foresee the infrastructure. This leads to an extra layer of uncertainty, which can be an explanation why the category infrastructure has the highest number of 'needs and requirements'.

KPIs on infrastructure are not defined (Table 1). Nevertheless, the availability and reliability of infrastructure will indirect covered by the KPIs in Table 1. It needs to be assessed whether KPIs on the infrastructure are necessary to derive TCO and potential and impact assessment.

3.1.7. Viable business case

KPIs about the delivery cost per trip and the maintenance and repair of the truck are stated in Table 1. Nevertheless, the identified needs and requirements in this category indicate that a broader view will be necessary, taking into account incentives for both truck and infrastructure, innovative business models and scenarios to reach economies of scale. Also, the TCO of both trucks and infrastructure should be able to be calculated. At this moment, some parameters are uncertain. More on this topic is discussed in Chapter 4 and will be discussed in WP2 and WP8 of the ZEFES project.

2.1 Policy and legal framework for ZEVs

European efforts to provide a regulatory framework for ZEVs rest on several main pillars: CO2 emission standards, rules on weights and dimensions, alternative fuels infrastructure (AFIR), and a clean and efficient energy transition. The EU Emissions Trading System (ETS) is part of the Green Deal along with the renewables directive (which defines the fuels that are CO2 neutral).

Europe (before it became the European Union) has been regulating heavy-duty vehicle emissions since 1988 and formalized the process with the introduction of the “Euro” track four years later. These increasingly stringent standards (numbered with Roman numerals for heavy-duty and Arabic numerals for light-duty vehicles) are periodically updated. Euro VI is the current standard, but the European Commission proposed streamlined Euro 7 emission standards in November 2022 that apply to cars, vans, trucks and buses. Under these standards, ZEVs are defined as vehicles with zero CO2 tailpipe emissions, which leaves particles from tyres and brakes subject to regulatory limits.

With the Green Deal, presented in December 2019, the EU seeks to become the first CO2-neutral continent by 2050. An important component of this commitment is the “Fit for 55” package, which includes a target of reducing net greenhouse gas emissions by at least 55% (compared to 1990 levels) by 2030. ZEVs for long-distance heavy transport are expected to make a significant contribution towards this and other sustainability targets. The following sections outline specific regulations for these types of vehicles to provide a more thorough understanding of the regulatory landscape within which the ZEFES project operates.

Weights and Dimensions Directive

HDVs in Europe are subject to certain rules on weights and dimensions to ensure road safety, safeguard road infrastructure, and ensure fair competition in the road transport sector. These rules can be found in Council Directive 96/53/ECEN, also known as the Weights and Dimensions Directive, and have been amended in subsequent years by Directive (EU) 2015/719EN, Decision (EU) 2019/984EN and Regulation (EU) 2019/1242EN. The amendments allow for derogations from the maximum authorised weights and dimensions of vehicles and vehicle combinations to facilitate the use of alternatively fuelled (including zero-emission) powertrains, improve vehicle aerodynamics, support trials of modular systems (including European Modular Systems) and incentivise intermodal transport operations.

On 11 July 2023, the European Commission proposed its latest revision of the Weights and Dimensions Directive (COM(2023) 445). According to the EC, the proposal aims to address four issues:

1. "remove regulatory and technical barriers and provide stronger incentives for the uptake of the zero-emission technologies and energy saving devices in the HDV sector",
2. "facilitate intermodal operations",
3. "clarify the rules on the use of longer and/or heavier HDVs in cross-border operations", and
4. "make enforcement more effective and efficient"

The revision also contains the following derogations for alternative fuel and zero-emission vehicles:

- a) Weight of combinations
    - a. A weight derogation of maximum 1 tonne is granted to vehicle combinations including alternative fuel vehicles other than zero-emission vehicles (Annex 1, subsection 2.2).
    - b. A weight derogation of maximum 2 tonnes is granted to vehicle combinations including zero-emission vehicles (maximum authorised weight = 36 tonnes) (Annex 1, subsections 2.2.3 and 2.2.4).
    - c. A weight derogation of maximum 4 tonnes is granted to vehicle combinations including zero-emission vehicles (maximum authorised weight = 40-44 tonnes) (Annex 1, subsections 2.2.1 and 2.2.2).
- b) Weight of motor vehicles
    - a. A weight derogation of maximum 1 tonne is granted to alternative fuel vehicles (trucks, buses and coaches) other than zero-emission vehicles (Annex 1, points 2.3.1, 2.3.3 and 2.3.4 of subsection 2.3).
    - b. A weight derogation of maximum 2 tonnes is granted to zero-emission vehicles (trucks, buses and coaches) (Annex 1, subsection 2.3).
    - c. A weight derogation of maximum 1 tonne is granted to alternative fuel vehicles (buses and coaches) other than zero-emission vehicles (Annex 1, subsection 2.4).
    - d. A weight derogation of maximum 2 tonnes is granted to zero-emission vehicles (buses and coaches) (Annex 1, subsection 2.4).
- c) Axle weights
    - a. The driving axle of zero-emission vehicles mentioned in points 2.2.1 and 2.2.2 and zero-emission 2-axle buses can have a maximum authorised weight of 12.5 tonnes (Annex 1 subsection 3.4).
- d) Length
    - a. Additional vehicle length is allowed for vehicles provided that their cabins deliver improved aerodynamic, energy-efficiency and safety performance. Any excess in maximum authorised length (not to exceed 90 cm) may also be used to install zero-emission technology (Article 9a.1 and Article 10b.2).

Specifically for the purposes of this deliverable and the ZEFES project generally, the proposed changes for alternative fuel and zero-emission vehicles suggest several opportunities and challenges:

- a) Opportunities
    - a. The additional weight derogations for zero-emission vehicles will allow road transport operators to better compensate for load capacity losses due to the weight of the zero-emission technology.
    - b. Adding length for zero-emission vehicles will also allow operators to address hydrogen technology and safety concerns, including in the carriage of dangerous goods.
- b) Challenges
    - a. Since the weight derogation is capped, it will be essential to ensure that the additional weight of zero-emission technology is further reduced rather than increased and vehicle autonomy improved. The anticipated uptake of ZEVs should neither sacrifice load capacity nor lead to more HDVs on the road.

b. Contrary to the assumption of the legislative proposal, different entities may own and control motor vehicles, trailers, and semi-trailers. This could lead to conflicts about how to divide available weight derogations between zero-emission motor vehicles and more energy-efficient trailers and semi-trailers. Future revisions may therefore require a more precise description of such a division, for example by determining the maximum authorised weight of both trailer and semi-trailer.
c. Since zero-emission technology is not only available for tractors but also for trailers, the uptake of ZEVs can be accelerated by facilitating the type-approval of trailers and semi-trailers with an auxiliary propulsion system, including e-trailers and semi-trailers.
d. As with almost all EU regulations, alignment in the implementation among EU Member States is essential to avoid delays in technology uptake or the emergence of anti-competitive behaviour.

Regulation on Deployment of Alternative Fuels Infrastructure (AFIR)

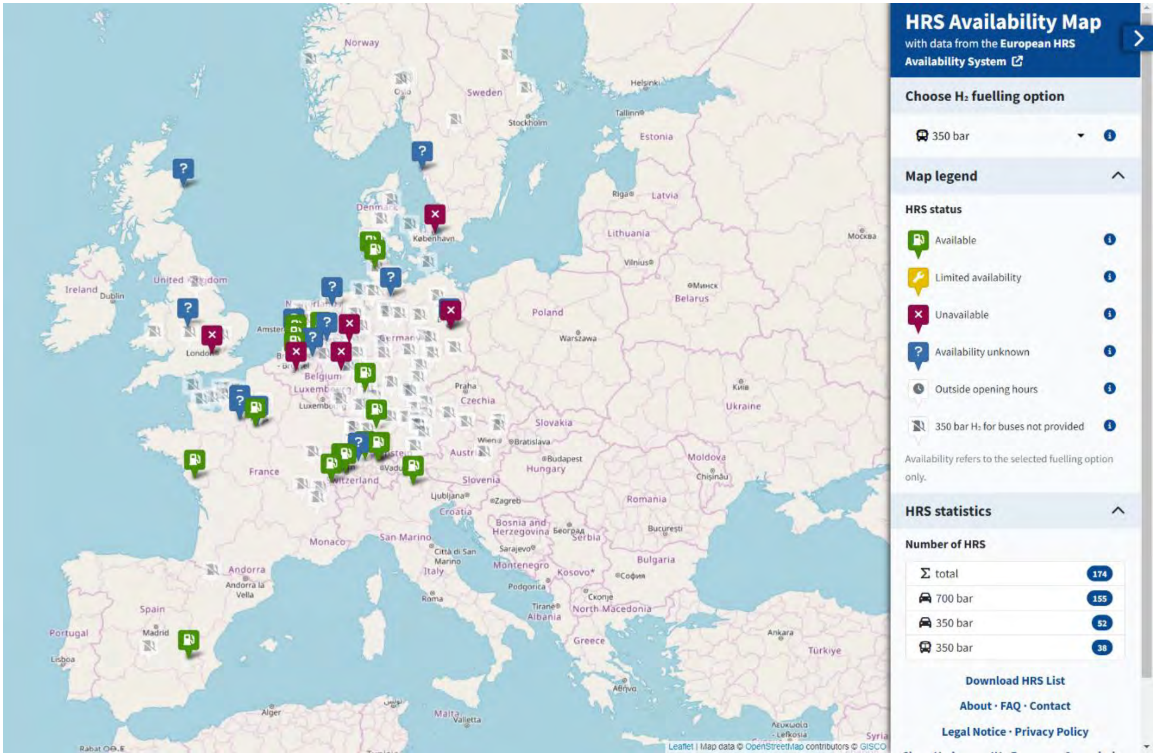
Formally adopted on July 25, 2023, the Alternative Fuels Infrastructure Regulation (AFIR) sets specific targets for the deployment of alternative fuels infrastructure. Provisions with particular relevance for HDVs include the following:

a) HDV recharging stations with a minimum output of 350kW will need to be deployed every 60 kilometres along the TENT-T core network and every 100 kilometres on the larger TEN-T comprehensive network, beginning in 2025 and offering complete network coverage by 2030. For a schematic map of the TEN-T network consisting of nine core network corridors, see.
b) HDV recharging stations will need to be deployed in safe and secure truck parking areas: at least two publicly accessible stations with an individual power output of at least 100 kW by 2027, and at least four with the same specifications by 2030. It remains to be seen whether these targets are sufficient.
c) Hydrogen refuelling stations for both cars and trucks must be deployed in all urban nodes and every 200 kilometres along the TEN-T core network from 2030 onwards. The current version of AFIR does not establish targets for the comprehensive network and does not address hydrogen refuelling in safe and secure truck parking areas.
d) Users of battery electric or hydrogen-fuelled vehicles (cars and trucks) must be able to pay at recharging or refuelling stations with payment cards or contactless devices, without requiring a subscription, and with full price transparency.
e) Operators of such stations must provide their customers with full information through electronic means on the availability, waiting time, or price at different stations.
f) Each EU Member State is required to prepare, and share with the EC, a draft national policy framework, including the development of the market concerning alternative fuels in the transport sector and the deployment of the infrastructure. The draft national policy framework must be prepared and sent to the EC by December 31, 2024.
g) Similarly, to report on the progress of the implementation of their national policy framework, EU Member States must submit a progress report to the EC by December 31, 2027 (and every two years thereafter). The report must provide status updates on deployment targets for electric recharging and hydrogen refueling infrastructure.

AFIR directly addresses a main challenge for ZEFES: Can the current recharging and refuelling infrastructure support the use cases for this project (see also ZEFES D1.2 Defined Use Cases, Target metrics and needs)?

Various mapping/data tools (see Figure 7) show that the existing network for hydrogen fuelling has significant gaps, particularly in southern and eastern Europe, where FCEV-compatible infrastructure does not exist. The supply of recharging stations for BEVs is generally better, but still insufficient. An additional complication inherent in AFIR are the derogations for Member States to build less infrastructure or limit their power output.

The discrepancy in the availability of hydrogen refuelling and battery recharging stations is also reflected in absolute numbers (see Figure 9). In 2022, there were only 44 low-pressure (350 bar) hydrogen refuelling stations in all 27 EU Member States. For the same year (2022, Q4), the European Alternative Fuels Observatory recorded a total of 447,099 recharging points (according to the AFIR classification) in the same geography. However, the currently available data for the charging/fuelling network is missing crucial information because it does not indicate which stations are accessible to HDVs, both in terms of physical size and dimensions as well as in terms of connectivity to energy (e.g., number of charging/fuelling posts and nozzle dimensions).



HRS Availability Map
with data from the **European HRS Availability System**

Choose H₂ fuelling option

350 bar

Map legend

HRS status

- Available
- Limited availability
- Unavailable
- Availability unknown
- Outside opening hours
- 350 bar H₂ for buses not provided

Availability refers to the selected fuelling option only.

HRS statistics

Number of HRS

Σ total	174
700 bar	155
350 bar	52
350 bar	38

Figure 6: Hydrogen fuelling stations for HDVs on TEN-T road network

Figure 7: Hydrogen fuelling stations in Europe, 350 bar for HDVs

Figure 8: Recharging points on TEN-T road network

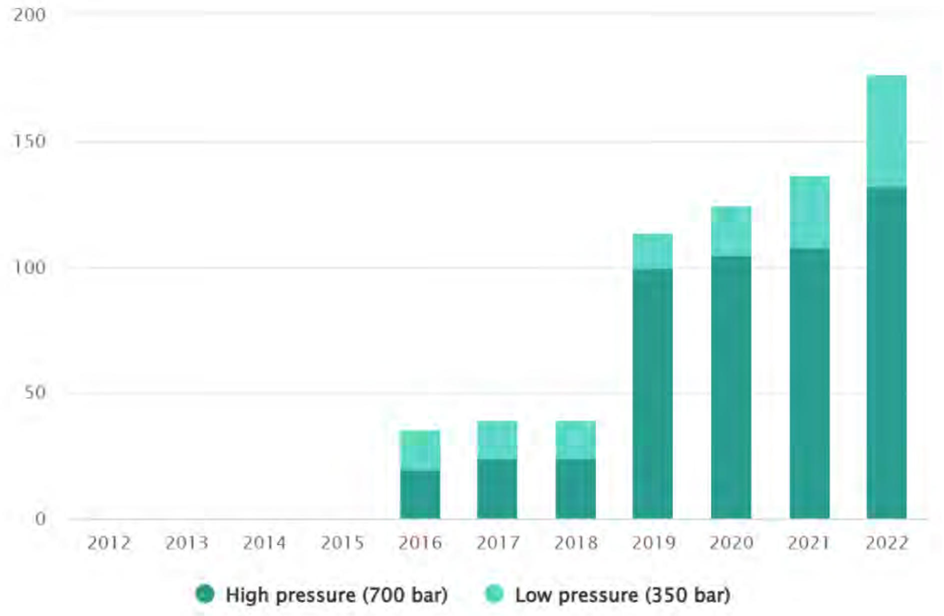


Figure 9: Total number of hydrogen (H2) refuelling points

The data shown here points to another policy challenge with relevance for the business case analysis in ZEFES: What is the most effective and (cost-)efficient way to grow the European alternative fuels infrastructure, both in terms of overall size of the network and in terms of equitable distribution to satisfy network density requirements outlined in AFIR? At a minimum, this discussion needs to proceed along three dimensions: 1) From a governance perspective, stakeholders in the charging/fuelling network should agree on a balance between incentives for the private sector to build the network and enforcement mechanisms by the public sector to sanction insufficient deployment. 2) As far as the physical environment is concerned, the uneven market penetration of battery electric versus fuel-cell HDVs is reflected in AFIR and thus offers opportunities for debate and revision. Current regulations include national targets for heavy-duty BEV infrastructure to be deployed "in each safe and secure parking area" (as defined by Commission Delegated Regulation (EU) 2022/1012) whereas there is no equivalent provision for hydrogen fuelling. 3) ZEFES stakeholders (and others) are missing critical data on the features of currently existing charging/fuelling infrastructure. Publicly available data tools and maps, such as those shown above, need to include additional information that allows stakeholders (including drivers *en route*) to determine whether any given stopping point can physically accommodate their HDVs.

CO2 Standards for HDVs

CO2 emission standards for heavy-duty vehicles in the EU are currently addressed in Regulation (EU) 2019/1242, which entered into force on 14 August 2019. According to these rules, manufacturers will have to meet targets set for fleet-wide average CO2 emissions of their new HDVs registered in a given calendar year from 2025 onwards. Stricter targets will apply five years later. The targets are expressed as a percentage reduction of emissions compared to the EU average in the reference period (1 July 2019–30 June 2020) and require a

- 15% reduction beginning in 2025
- 30% reduction beginning in 2030.

The 2025 target can be achieved using currently available technologies, whereas the 2030 target has been assessed as part of the review of the Regulation. As a first step, the CO2 emission standards cover heavy-duty vehicles (including trucks, buses and coaches), which represent around 6% of total CO2 emissions in the EU and about 25% of total road transport CO2 emissions. Without further action, the share of CO2 emissions from heavy-duty vehicles is expected to grow by around 9% between 2010 and 2030.

A revision of this regulation was proposed on February 14, 2023. This proposal envisions stricter CO2 emission standards for heavy-duty vehicles from 2030 onwards and would broaden the regulatory scope to cover smaller trucks, city buses, long-distance buses and trailers. New emissions targets are based on the initial EU-wide CO2 emission standards for heavy-duty vehicles issued in 2019. They aim to decrease CO2 emissions per km from new HDV by 90% by 2040, as compared to the reference period (1 July 2019 – 30 June 2020), with intermediate targets for 2030 (45%) and 2035 (65%).

While at first glance saying little about zero-emission technology, this legislative proposal still has two important implications for the ZEFES project. 1) The European Commission's intention to include trailers has the potential to overcome market barriers for the adoption of cost-effective trailer technologies. Low- and zero-emission technology used in powered trailers and semi-trailers to support the towing vehicle can make a significant contribution to advance decarbonisation. 2) Since the HDV sector is cost-competitive and has low profit margins, road transport operators make operational decisions based on profitability and total cost of ownership (TCO, which will be addressed in greater detail in Section 4.1 Cost model development - of this deliverable). ZE-HDVs are currently far more expensive than ICE-HDVs. If their market uptake is seen as politically desirable due to their environmental benefits, it might be necessary to incentivise purchases at scale with tax credits or subsidies. A complementary form of support concerns the development of the charging/fuelling infrastructure, which is insufficient in its present state as illustrated above in the discussion of AFIR. This may include providing incentives to reduce grid connection costs in areas with many charging posts.

EU Emissions Trading System (ETS) – CO2 Accounting

Launched in 2005, the EU Emissions Trading System (EU ETS) is the world's first international emissions trading system and initially covered CO2 emissions from power generators and energy-intensive industries. In May 2023, the EU adopted a new, separate ETS for the building and road transport sectors (Directive 2003/87/EC). It complements other Green Deal policies that regulate fuel suppliers. The new system is designed to operate as of 2027 (auctioning of allowances from 2027 onwards, surrendering of allowances as of 2028), while monitoring and reporting will start in 2025. Revenues from the auctioning of emissions allowances beyond contributions to a new Social Climate Fund go directly to Member States and have to be spent on climate and social purposes. The latest revision constitutes an essential element of the "Fit for 55" package and seeks to influence the market for ZE-HDVs by increasing the cost of operating ICE-HDVs and conversely making zero-emission alternatives more competitive.

However, zero-emission technology is still developing at a slower pace for HDVs than for other vehicle categories. It is therefore unrealistic to expect commercial road transport operators to pay the full CO2 price when they have no alternative options to change their fleet composition in the short term. A possible solution for this challenge could be to gradually pass on the CO2 price, as set by the ETS legislation, to commercial transport operators over a multi-year transition period with periodic re-evaluations. The starting point and the evaluation process should depend on the availability of alternative fuel technology and infrastructure as well as the speed of deployment of sufficient numbers of ZE-HDVs (which are interdependent developments). As the above section on AFIR indicated, the deficient charging/fuelling network for zero-emission HDVs is a barrier for growth in the deployment of vehicles. The ETS funding mechanism could offer a solution if it included more specific stipulations for Member States to reinvest revenues from ETS emission auctioning for road transport in the alternative fuel infrastructure network.

TEN-T Regulation (multimodal freight terminals – requirements to build charging/fuelling stations for HDVs)

The Trans-European Transport (TEN-T) Network Regulation aims to support the establishment of an effective EU-wide multimodal network of rail, inland waterways, short sea shipping routes and roads which are linked to urban nodes, maritime and inland ports, airports, and terminals across the EU. On 14 December 2021, the European Commission (EC) adopted a new proposal to revise EU rules on the development of the TEN-T network, as part of the Efficient and Green Mobility Package. The TEN-T proposal modifies the existing TEN-T guidelines and will replace Regulation (EU) 1315/2013. Since the TEN-T network remains a work in progress, the EC introduced deadlines for the completion of the core network by the end of 2030, the extended core network by the end of 2040, and the comprehensive network by the end of 2050.

The proposal sets targets for the development of multimodal freight terminals in urban nodes. Urban nodes are defined as urban areas where elements of the transport infrastructure of the TEN-T network (such as passenger terminals, airports, railway stations, bus terminals, logistic platforms and facilities and freight terminals, located in and around the urban area) are connected with other elements of that infrastructure and with the infrastructure for regional and local traffic. According to the EC, Member States must develop at least one multimodal freight terminal allowing for sufficient transhipment capacity within or in the vicinity of the urban node by the end of 2040. Moreover, the proposal includes a target for Member States to deploy at least one electric charging station in each multimodal freight terminal by 31 December 2030.

Safe and secure truck parking areas are also covered by the ongoing revision of the TEN-T Regulation. The proposal specifies that Member States are to ensure safe and secure truck parking areas are available at a maximum distance of 100 km from each other by the end of 2040 on the core network and by the end of 2050 on the comprehensive network. The role of these parking areas for the availability of alternative fuel infrastructure will be enhanced by the requirements set out in AFIR (as discussed above).

Apart from the stipulations discussed in the preceding paragraphs, the current TEN-T Regulation is remarkably vague on the availability of alternative fuel infrastructure along the network. Member States are merely encouraged to "make possible the decarbonisation of all transport modes by stimulating energy efficiency, introduce zero and low emission solutions, including hydrogen and electricity supply systems, as well as other new solutions such as sustainable fuels, and provide corresponding infrastructure" (Article 44). There are no further numerical targets.

The revision of the TEN-T Regulation is relevant for ZEFES considering the multimodal element of the project. Several of the project's use cases have either electric recharging or hydrogen refuelling infrastructure available at rail and hub terminals. Based on the results from the piloting activity expected to take place throughout the project, ZEFES is uniquely placed to provide operational experiences on charging/refuelling at terminals.

Combined Transport Directive

The Combined Transport (CT) Directive (Council Directive 92/106/EEC) seeks to promote the competitiveness of combined transport, defined as "transport of goods between Member States where the lorry, trailer, semi-trailer, with or without tractor unit, swap body or container of 20 feet or more uses the road on the initial or final leg of the journey and, on the other leg, rail or inland waterway or maritime services." In this function, it is supported by the Weights and Dimensions Directive discussed above, which provides for Member States to permit the movement of heavier intermodal load units by road when using combined transport.

The CT Directive is rather limited in scope, as it only defines the carriage of 20- and 40-foot containers and swap bodies. The road leg of a CT operation is strictly defined as being "within a radius not exceeding 150 km as the crow flies from the inland waterway port or seaport of loading or unloading." For rail transport, the journey can go to the "nearest suitable terminal", but a non-road leg must be at least 100 km to be recognised as CT.

Although the Directive purports to encourage combined transport "by freedom from all quantitative restrictions and by the elimination of various administrative constraints which still exist in the field of road transport", a different set of rules (specifically Regulation 1072/2009, Art. 10.7) on access to the road haulage market allows Member States to impose quantitative restrictions on the domestic road legs of a combined transport operations.

Finally, the EU provides fiscal incentives (tax reductions and reimbursements) for certain CT operations, but each Member State is responsible for their implementation. In order to be eligible for the provisions within the Directive, the movement of goods must meet a number of specific criteria regarding types of load units and distances, as partially outlined in the definition of CT above.

As a general challenge for the ZEFES project, it can be argued that the CT Directive is outdated, which has implications for current technologies, funding mechanisms, and operational compatibility.

Having been formulated prior to large-scale policy shifts such as the Green Deal, the Directive understandably lacks references to alternative fuels and/or zero-emission vehicles and therefore does not address recent technological advances that are both essential to the ZEFES project and to reducing the negative externalities inherent in freight transport.

A 2015 public consultation report reflects stakeholders' perceptions that the CT Directive is an important tool to promote sustainable transport that has resulted in fewer trucks on the road and reduced CO2 emissions. At the same time, more could be done. In particular, majorities of stakeholders identified the harmonisation of administrative procedures among Member States (65% of respondents), the introduction of additional fiscal incentives (61%), and exempting CT operations from road driving bans (54%) as the most impactful measures to facilitate the use of CT.

Finally, there is a mismatch between the CT Directive and the Weights and Dimensions Directive, which affects international freight operations using high-capacity transport vehicles, or the European Modular System (EMS). While the Weights and Dimensions Directive harmonises cross-border road transport with standard combinations and creates a framework for cross-border transports with EMS (including rules on the carriage of 45-foot containers in intermodal transport), the CT Directive does not accommodate the latter. This omission also affects related operational issues such as charging/fuelling options for e-trailers and e-dollies on trains. As a result of these complications, the ZEFES project could be able to make a case for the harmonisation of certain technical criteria and procedures for all types of EMS and road operations, including combined transport.

2.1 Needs and requirements derived from user stories

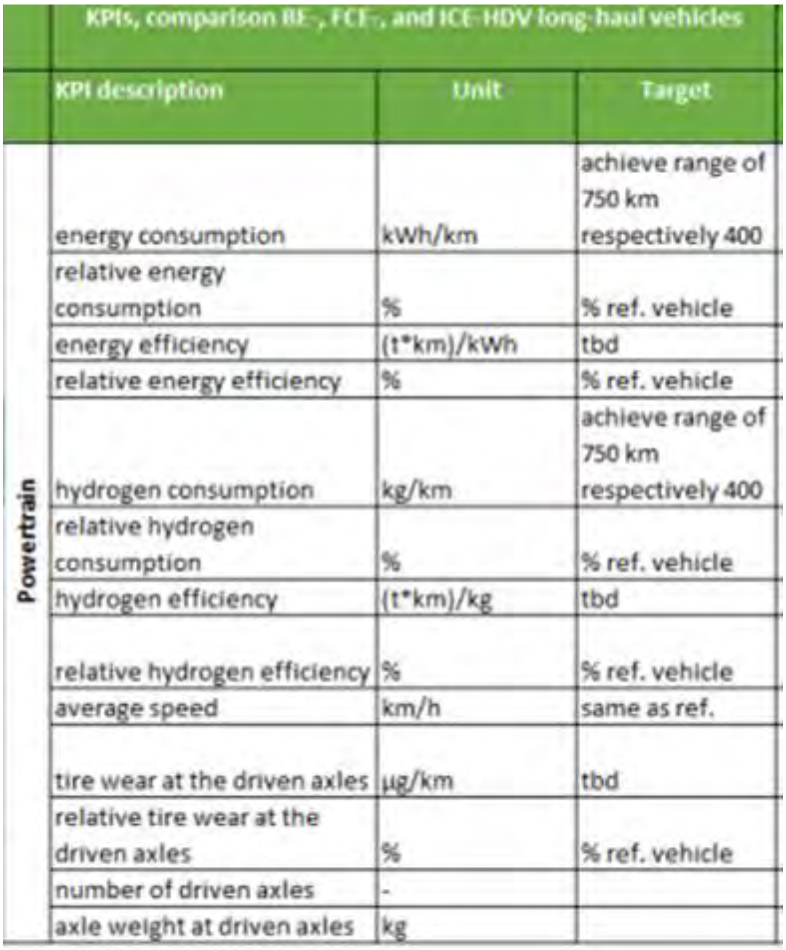
ZEFES user stories are provided by 15 pilot demonstrations composed of different and modular tractor trailer combinations. The pilot demonstrations are described in detail in ZEFES Deliverables D1.2 "Defined Use Cases, Target metrics and needs" and D1.5 "Supply Chain Mapping". The pilot demonstrations are designed and developed in order to:

- Test technical possibilities and limitations in real life operational processes
- Be able to assess cost models and performance parameters, especially on cost and emissions of ZEV in modular combinations
- Exploit optimization possibilities by means of artificial intelligence and enhanced prediction procedures of zero emission road freight transport.

Digital twin

The ZEFES Digital Twin shall be read as a 'live digital coupling of the state of a physical asset to a virtual representation with a functional output'. Within the ZEFES context, these will typically be complete vehicle or individual vehicle systems, for example the vehicle battery pack, where live data can be processed to generate system status information, which in turn can be used to inform the future state and guide operational decisions.

ZEFES Deliverable D1.1 provided the main requirements simulation of an overall system to optimize the system and powertrain for the creation of the digital twin (DT) and parameterization of the assessment framework. D1.1 provided a full list of KPIs regarded as crucial to achieve the overall efficiency targets and future improvements of BEV and FCEV. The specific parameters for the powertrain units are shown in the figure below:



	KPIs, comparison BE-, FCE-, and ICE-HDV long-haul vehicles		
	KPI description	Unit	Target
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	

Figure 10: KPIs on powertrain

The managerial tools as defined and developed in WP4 are to address these overall efficiency parameters and develop solutions to plan and optimize ZEV operations. The functional tools are to address the following topics:

- Buying decision: a platform that helps to find a suitable ZEV fleet for certain fleet operations
- Mission planning: a platform that optimizes the routing for a certain mission by using an operator's fleet specification
- Match between vehicle and mission: a platform that selects the most suitable vehicles from the fleet for certain operations and addresses the problem of different weight and safety restrictions for European Modular Systems (EMS) deployment
- Predictive Maintenance: a platform can predict vehicle maintenance needs by means of dynamic correlations (testing the accuracy of the Digital Twin Model).

The Digital Twin platform architecture as represented in the figure below is to ensure a seamless data flow within the overall ZEFES ecosystem.

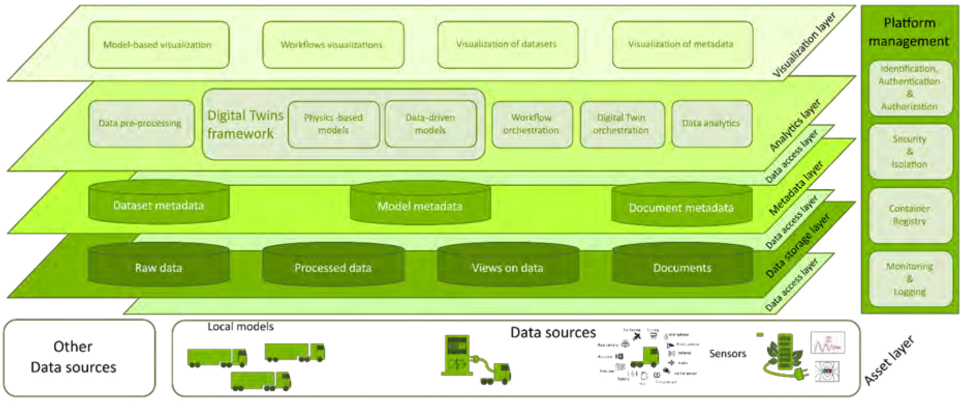


Figure 11: Layered version of the ZEFES Digital Twin Platform architecture

ZEFES Deliverable D4.1 describes the technical layout and the main layers (Asset, Data Storage, Metadata, Analytics, and Visualization) in detail. The first three data related layers are accompanied by a data access layer, for controlling access to the data. SThe analytics layer contains the workloads that ingest, process and potentially create this data. Data pre-processing is part of the data ingestion process, where data flowing into the platform needs to be made useable, for example by decompressing or filtering incoming data. The Digital Twins framework supports physics-based and data-driven models with their execution and data access. Tools providing key functionalities for zero emission heavy duty vehicles are to be realised and tested in the context of the Digital Twin framework, namely:

- Buying decision to support decision making for ZEV fleets
- Mission planning to find the best route for ZEV
- Right vehicle in right duty to allocate the right vehicle to the shipment instructions
- Dynamic correlation to improve accuracy of Digital Twin models
- Predictive Maintenance to facilitate prediction of ZEV and vehicle components

ZEFES D1.3 is to specify the needs and requirements towards the Digital Twin framework. An ecosystem is to be provided that describes the interaction the various relationships of ZEV in a systemic way.

The Digital Twin ecosystem is a multi-party and multi-dimensional system of actors and functions to plan and execute transport operations within a zero-emission context. Actors comprise transport operators operating trucks and e-trailers to execute a specific mission. The mission is determined by transportation needs of shippers and managed by forwarders. Zero emission transport operations need to rely on electric charging and hydrogen refuelling infrastructure connected to the energy supply system. Policy will govern infrastructure access and pricing by means of taxes and road toll charges. The relationship as well as the data feeds and needs to plan, monitor and optimise ZE transport operations in a supply chain context are shown in the Figure 11 below:

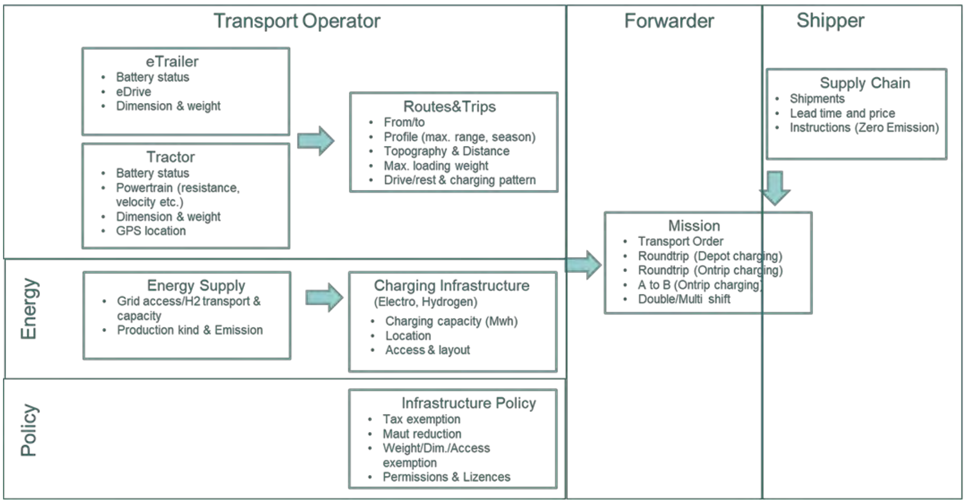


Figure 11: Links of ZE transport operations in a supply chain context

The Digital Twin needs and requirements from different actor perspectives are provided in the following insights as well as development paths towards each specific category.

Digital Twin ecosystem user stories

Electric power supply

For the energy production to be addressed in ZEFES there is a need to select locations along the ZEFES pilot corridors that would provide an “easy” power/grid access. With regards to power production, solar would be “easier” and pragmatic. Wind might not be feasible. For reliability reasons only sourcing via grid is possible. Therefore, locations that provide access to the grid need to be found. H2 has advantages where grid access is not given/possible.

Specific location layouts need to be provided. Locations need to secure a vehicle positioning place, charging infrastructure, energy storage (battery, hydrogen tank), grid connection or hydrogen receiving point or electrolyser, driver rest area, access roads, and payment infrastructure.

For electric energy production, specific benchmarks might be taken into account. A cost/benefit analysis should be a standardised required process when new logistics depots are built. Autarch energy production and supply is not possible, and grid access is needed to secure 24h supply while storage in the needed capacity is considered as too expensive.

Different kinds of locations can be considered: depots for logistics (or similar activities) and locations for charging; locations owned by the truck operator or service provider, loading and un-loading locations of customers (retailer, shipper) and other locations (ferry, rail terminals), public charging locations (OEM, gas stations, and others).

Charging implementation in (own) depot is considered to be the fastest option depending on grid capacity and upgrade costs on available power tariffs, possibility for local production (solar), possibility for charging time shifting (grid load, energy production, dynamic pricings). In addition, dynamic pricing models might be appropriate to lower charging costs.

Charging stations can be installed in loading and unloading locations. A co-use of existing charging infrastructure for incoming/outgoing trucks might be followed. Similar to aircraft recharging at the gate, loading time can be used for re-charging. A different operator model is the collaborative deployment of charging infrastructure, e.g., at terminal, ports, parking area or warehouses. The charging infrastructure provider can be a shipper, LSP/terminal operator, site owner or third party. Charging can take place while waiting in dedicated parking areas (charge as you wait).

Public charging: when charging on a trip, the business model depends on the capacity of charging infrastructure use or utilization factor (similar to car charging). The investment costs can be distributed over the number and volume of energy users. A (dynamic) reservation system is needed to enable high utilisation factors.

OEM might also act as charge point operators, providing a dedicated on-trip charging network for customers or user groups. A price differentiation by user groups can be made as part of the service model.

The business case is highly dependent on the time and duration of incoming/outgoing trucks at location and how they can be linked to the charging infrastructure. There is a need for steering and synchronising of vehicle departure/arrival times and/or charging times within trip planning.

The charging infrastructure efficiency is determined by technical parameters such as outgoing versus incoming power and the related loss of power. Further influencing factors are the maximum charging power (peak and sustainable charging power), price at charging post, reliability (out of order per year), physical dimensions as well as how compatible the system is to MCS and CCS2 equipment,

Hydrogen power supply

Hydrogen production and supply needs require a specific setup. Hydrogen will be sold per kg (independent of production form) and would require a dedicated fuelling infrastructure. Depot based fuelling stations will not be possible before 2035 serving more than 50 trucks. A public network for public refuelling is under development.

Own production units have risks, especially under reliability considerations. A supply strategy by means of tubes and cartouches is favoured. Pipeline gas or truck delivery of liquid hydrogen is a realistic/pragmatic scenario. Within ZEFES the focus is on (public) fuelling stations.

Key benchmarks for hydrogen production in logistics state that a capacity of 250 kg per hour serving 5 trucks can be reached. Presently the network of fuelling stations is small and needs to be scaled up. 700 bar stations are needed (only 1 in Europe available).

Various business models are presently under discussion for transport and logistics. Realistically, a hydrogen supplier will invest in local fuelling stations and operate them (similar to gas station model). A price per kg will be provided. The supply chain model would be to deliver hydrogen and liquid hydrogen at site by means of pipelines or cartouches. Power to gas is not considered realistic in the short time. Production will take place on a large scale and with dedicated delivery models (pipelines or truck)

Service providers will provide fuelling packages in different formats (e.g., hydrogen and truck included price), but there is no clear model yet to see.

Logistics

Colruyt Group is a pioneering force in the retail industry when it comes to embracing and promoting zero-emission transport solutions. As part of its steadfast commitment to sustainability and reducing its environmental footprint, the company has taken significant strides in adopting eco-friendly transportation practices.

Electric Vehicle Fleet: Colruyt Group has been a frontrunner in incorporating electric vehicles (EVs) into its transport fleet. It has made investments in 6 electric trucks, which are used for various transportation purposes, including delivering goods to its stores (Colruyt) and to B2B customers (through B2B Branche Solucious). This transition to EVs reduces greenhouse gas emissions, air pollution, and noise levels in urban areas.

Hydrogen-Powered Vehicles: In addition to electric vehicles, Colruyt Group has explored hydrogen-powered vehicles as part of its zero-emission transport strategy. Hydrogen fuel cell vehicles promise the advantage of longer ranges compared to battery-electric vehicles, making them a viable option for long-distance transportation. The possible benefit in an increased payload and quicker refuelling is yet to be proven: the advantage of currently available technologies is not yet leading to benefits. In addition, green hydrogen fuel with ultra-pure quality suitable for fuel cells is still very expensive.

Renewable Energy Sources: Colruyt Group recognizes the importance of sourcing renewable energy to power its electric vehicles. The company has made efforts to generate renewable energy through wind and solar installations, enabling the production of clean energy for its transportation needs. This approach further reduces the carbon footprint of its zero-emission vehicles.

Charging Infrastructure: To support its electric vehicle fleet, Colruyt Group is investing in charging infrastructure at its distribution centres. With 3 distribution centres being equipped with 180kW chargers, this network of charging stations ensures that EVs can be charged conveniently and efficiently, enabling seamless operations. Upcoming actions involve the installation of 350 kW chargers at every distribution centre, followed by a transition to MCS chargers.

Hydrogen Refuelling Infrastructure: To support hydrogen-powered transport, Colruyt Group invested as part of the European funded H2HAUL project in the realization of a hydrogen refuelling infrastructure at its distribution centres in Ollignies. This infrastructure is crucial for the widespread adoption of heavy-duty hydrogen vehicles. Hydrogen refuelling technologies are still limited in performance (throughput capacity, back-to-back fuelling,), are extremely expensive, and standardisation is still in development. Infrastructure siting and permitting is also rather complex.

Transport use cases

Colruyt's Outbound Transportation Operations: Outbound transport operations involve the shipment of goods from central distribution centres to a network of 522 stores. This process necessitates approximately 1,200 daily journeys. To carry out this extensive task, Colruyt relies on articulated truck-trailer combinations with a Gross Combined Vehicle Weight (GCVW) of 44 tons. On a daily basis, around 400 skilled drivers are responsible for executing these trips.

Of these 400 drivers, 80 are dedicated employees of Colruyt Group who operate a fleet of 40 trucks, organized in two shifts for seamless coverage. The remaining drivers, approximately 320 in number, are affiliated with external transport companies, each equipped with their own trucks. Notably, many of these external drivers optimize their truck utilization by employing a two-driver shift operation, ensuring the efficient usage of their asset.

Transport planning is efficiently organized to ensure that a truck departs from a distribution centre with a fully loaded trailer. The journey begins with a direct route to a specific store, where the driver proceeds to unload the cargo and reload return goods into the trailer. This loading and unloading process takes approximately 45 minutes at the store.

After completing the store-related tasks, the driver then returns to one of five distribution centres. At the distribution centre, the trailer is uncoupled, and a new assignment is given to the driver. In this fresh assignment, the driver couples with another trailer, already loaded with goods and prepared for departure, and embarks on the journey to deliver to another shop.

The allocation of assignments is manually performed by a dispatcher who carefully considers various factors:

- The tasks already accomplished by the driver during the day.
- The remaining legal driving time available to the driver.
- The readiness of assignments that are either fully prepared or nearly ready for departure.

Consequently, a driver is usually tasked with covering an average of three trips per shift covering a daily distance of approximately 350 kilometres. When two drivers collaborate in a two-shift operation, the annual mileage for their truck exceeds 120,000 kilometres. When compared to the European averages for truck mileage, our regional distribution activity stands out for its distinct long-haul characteristics (>115,000km/year).

Challenges ahead and future requirements

To achieve a 42% reduction in greenhouse gas emissions by 2030, compared to the levels in 2021, one of the most significant sources of emissions, which is transport, will be addressed. By the year 2030, Colruyt Group is committed to transitioning internal freight transport operations to utilize zero-emission vehicles, either powered by battery-electric technology or hydrogen-electric technology, thereby eliminating all emissions. Taking a further step by 2035, we will ensure that our entire goods transport network operates exclusively on green electricity and hydrogen sources. This commitment to achieving zero-emission transportation extends beyond our own fleet; we aim to engage our suppliers and transport collaborators in this endeavour. By 2035, all transportation conducted by our drivers, suppliers, and transport partners working with Colruyt Group will be entirely emission-free. This includes the transportation of goods to our distribution centres, stores, and customers.

While technology is advancing rapidly, several key developments have been identified as crucial for the successful implementation of the Zero Emission roadmap. These encompass both technical and operational aspects:

1) Technical:

Optimized Driveline Power: Ensuring the correct sizing of the entire driveline power system is essential, striking a harmonious balance between engine power, battery power capacity, and, when applicable, FuelCell power.

Reliability/uptime of trucks and of infrastructure:

Trucks: Although all OEMs offer commercial BEVs, Colruyt Group is experiencing that their availability and uptime is still lower than their diesel equivalents. For FCEVs, the situation is even worse due to the additional hydrogen systems on top of the battery-electric power train

Infrastructure: Similarly, Colruyt Group is experiencing that hydrogen refuelling stations experience lower availabilities/uptimes compared to diesel tank stations due to the higher complexity and lower track record and operational experience

High-Capacity Charging and Refuelling Infrastructure:

MCS chargers: To accommodate 24/7 trucking operations for Battery Electric Vehicles (BEV), it's imperative to implement Megawatt Charging systems (MCS). These allow electric truck recharging during driver breaks or between shifts, reducing the need for extensive charging infrastructure and parking spaces.

Strategic Charging Locations: Identifying suitable opportunity charging sites, such as unloading bays, aligned with regular truck operations can enhance efficiency.

Hydrogen Infrastructure: The application of high-capacity direct fill hydrogen refuelling stations above 5 ton per day tanking capacity and with rapid flow rates (e.g., >= 120g/s @ 700bar) will be essential to capitalize on reduced refuelling times. This technology is in development.

Modular Vehicle Configurations: This entails enabling modular vehicle designs that facilitate customization to meet specific use case requirements for range and payload. Particularly in terms of payload capacity, the added weight of the batteries and FCEV system has an impact on the available payload. It is advisable to examine new axle configurations as a means to address this concern. Advancement in battery and fast charging technology, combined with the modularity of the vehicles, should enable us to optimize the vehicles according to logistics requirements and subsequently reduce the overall cost of transport operations.

1) Operational:

Planning and Dynamic Trip Allocation: Dispatchers will need to dynamically allocate trips, taking into account the constraints associated with Zero Emission technology. These constraints encompass considerations such as range, payload capacity, and optimization based on real-time State of Charge (SOC) data from the vehicles. Planning and dispatching tools need to be created to provide assistance and automation in trip allocation processes. Additional assistance for drivers' on-route activities, such as pre-booking public recharging infrastructure, should be integrated into these tools. These tools aim to optimize the overall transportation cost.

4. Business Case Development

The road freight sector is working towards decarbonising its activities following the European Union's roadmap to decrease HDV emissions by 30% by 2030. Additionally, cities are requiring zero emission vehicles to address urban air pollution. The current business model for road freight transport will not achieve these goals. In turn, the entire supply chain will need to adapt by applying different solutions to different business cases. Battery Electric and Hydrogen Fuel Cell electric vehicles can provide zero emission and zero carbon solutions, which, as a concept can work even for HDVs carrying a heavy payload and using EMS combinations. However, the technology is not yet widely adopted and thus is still expensive. This issue can be overcome by scaling up from the early prototype phase we are in today to a genuine first fleet deployment, which paves the way for large scale production in the late 2020s. This will require global truck original equipment manufacturers (OEMs) to deliver a reliable product, produced at scale, to reach the desired emission targets. Fuel cell products need to be proven, and supply chains for mass production need to be developed. At the same time, there is a need to develop new high-capacity refuelling station infrastructures in a network which works for freight users, which is to say in a network of safe and secure truck parking areas and along routes with the heaviest freight traffic flows. Maturing technology is a decade-long process, and its successful roll-out requires a supportive policy and regulatory framework. However, different technologies have been scaling up and replacing already existing business models in the last decades. It is expected that ZE-HDVs (either BEVs or FCEVs) will at some point replace most of the existing fleet. There are several risks in such a large-scale transition, which can harm consumers and leave supply chains disrupted if left unaddressed. As a result, different parameters will be taken into consideration by transport operators before deciding to invest in new equipment:

- Economic costs and TCO (cost of purchase, cost of operating, road charging costs, refueling/recharging cost, maintenance and taxation costs)
- Operation and efficiency of the truck (range, payload,
- Time savings (time for charging – waiting lines and actual charging,
- LCA and ensuring that the vehicles will emit as little as possible
- Availability of charging/refueling infrastructure and prices that are affordable in all countries (charging possible at depots, TEN-T corridors and other locations

The ZEFES project is going to take all these parameters into consideration while demonstrating the 15 use-cases. The objective to prove the business case for ZE-HDVs successful will be in line with whether the needs and requirements for ZE-HDVs will be satisfied and favourable KPIs will be measured.

4.1 Cost model development

Zero-emission HDVs need to be financially competitive with currently dominant technologies to achieve mass market uptake. Cost modelling (which includes a variety of approaches) can assist in the determination whether and when BEVs and FCEVs can reach this stage.

Desk research of cost models comparing HDVs with battery electric, fuel-cell electric and/or conventional diesel powertrains yielded seven recent academic studies and “grey literature” (Heliyon 2022, H2Accelerate 2022, ICCT 2022a, ITS 2022, ICCT 2022b, Applied Energy 2022, ITF 2022), for which a literature review was conducted (see Table 14 in APPENDIX III – TCO studies literature review below). The following three sections summarise these studies in terms of their methodology, findings, and policy recommendations, followed by a fourth section with suggestions for TCO components adapted to ZEFES use cases and best practices for TCO modelling.

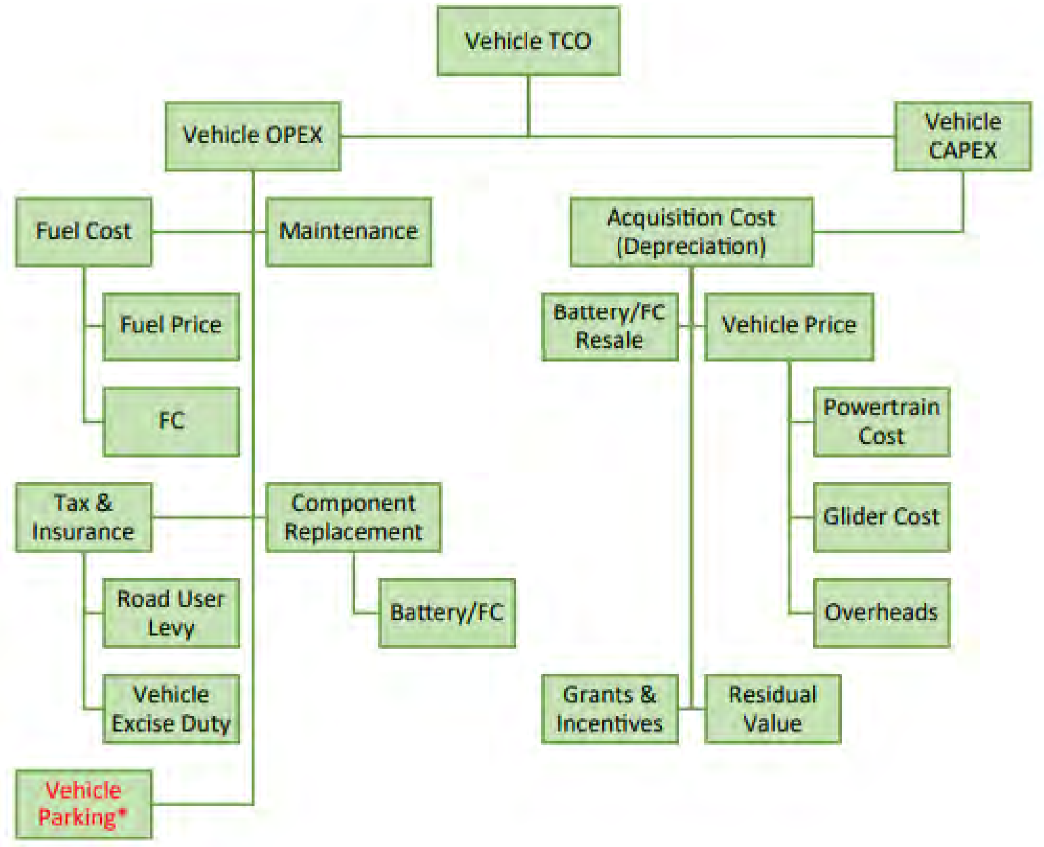
Methodology - TCO Components

Total cost of ownership (TCO) is arguably one of the most important metrics for purchasing decisions and the adoption of new technologies in the commercial vehicle sector. This deliverable analyses selected total cost of ownership models, which are generally (and theoretically) considered to be a comprehensive and comparable measure across different studies and use cases. However, the most important methodological finding of this review is that the TCO models summarized in Table 11 in APPENDIX III – TCO studies literature review) employ a broad range of components and vary in complexity to such an extent that comparisons between them are of limited utility. This constellation also suggests that there is no single TCO number that can be identified as a benchmark result – it would be more accurate to speak of a TCO spectrum or corridor.

While all seven studies use a version of capital and operating expenditures as a TCO baseline, the actual composition of each differs significantly. For example, all models consider the acquisition cost of the vehicle (including its residual value), but some include additional specifications based on options for different components, such as the powertrain or energy storage. Similarly, operating expenditures uniformly cover fuel/energy costs, but not necessarily subsidies, insurance premiums, or road tolls.

Table 2 below illustrates the challenge of comparing TCO calculations across the studies presented here: Even a relatively complex model (Heliyon 2022) omits highly dynamic variables such as vehicle parking, driver wages, and opportunity costs associated with refuelling/charging.

Table 2: Example of TCO model components (Heliyon 2022)



The problem of limited comparability between TCO models extends to other variables:

- **Vehicle type**: the use of HDVs was one of the inclusion criteria for this literature review, but there are few commonalities in the studies beyond this rather underspecified type. Several studies did not provide details on vehicle configurations, and one study (Heliyon 2022) did not have a long-haul use case.
- **Vehicle lifetime**: while three of the seven studies use a five-year vehicle lifetime, which makes them directly comparable for this parameter, other TCO models are either unspecified or assume lifetimes of seven to ten years.
- **Time horizon of the study**: differences in projection ranges complicate attempts to identify comparable TCOs between studies. Three of the seven studies end their analysis in the year 2030 as an important benchmark in alignment with EU emission goals for HDVs, with one of these six extending its timeline to 2040 and two to 2050 (one study (Applied Energy 2022) conducted a present-state analysis).
- **Geography**: the prevalence of European countries in the seven studies is self-explanatory for this deliverable. Five of seven studies include either “Europe” or the “European Union”, two of which provide lists of specific European countries. The two studies that analyse use cases in the USA or UK can be useful to determine the competitiveness of EU versus non-EU TCOs.
- **Sensitivity analysis**: although not always explicitly labeled as such, all studies under consideration here conducted analyses to account for uncertainty. However, the number of

parameters included varies from four to 16. This is an important observation to shape realistic expectations of these and similar (future) studies: plausible business cases for zero emission HDVs are likely made as a range of options based on upper and lower bounds with additionally specified mean and/or median values. Given the rapid evolution of technology and other context-specific dynamics that affect TCO model inputs, any study presenting singular TCO numbers should be interpreted with an important caveat: such seemingly unambiguous results are potentially intended as advocacy communications, meaning that they are politically desirable, if not empirically researched. To put it differently, change is the only constant we have in the current environment, and any modeling done for the ZEFES project should reflect this insight.

Main Findings/Break-Even Analysis

Break-even analysis represents the practical implication of the more theoretical cost model development presented above by answering the question of when and under which conditions different types of zero-emission HDVs are cost-competitive with ICE-HDVs. However, the studies under consideration in this literature review differ not only in whether and how they present break-even points, but also in their respective emphases on other parameters. Again, this limits our ability to compare results across studies, much less across use cases they cover. The following paragraphs present select findings of the literature review conducted here. The focus will be on the key variables of the TCO comparison as well as the timelines associated with cost-competitiveness between different powertrain technologies.

The studies provide a wide variety of dates identified as break-even points, i.e., when BE-HDVs and FCE-HDVs are considered to be cost-competitive with conventional powertrains. At present, neither of these two zero-emission technologies reaches TCO parity with conventional trucks in the long-haul sector. The earliest expected break-even point is 2030, but there are variations depending on vehicle powertrain, vehicle weight, and location of use case (ITS 2022, ICCT 2022a).

A differentiated analysis suggests that by 2050, FCEVs and BEVs will outperform diesel trucks in terms of TCO, but BEVs will have the lowest operating cost per km (unless specific FCEV incentives are implemented) (Heliyon 2022). Similarly, another study found that FCEVs are only cost-competitive with other zero-emission technologies in select cases that require ambitiously low hydrogen fuel costs and very conservative assumptions for BEVs. The same study analyses TCOs by vehicle weight and states that the smallest zero-emission vehicle categories already deliver TCO parity with diesel vehicles, but larger road freight vehicles are more likely to be cost-competitive around 2035 (IFT 2022). Fuel cell trucks are also at a competitive disadvantage due to greater uncertainty in their TCO calculations because the technology is still relatively immature, leading to high variations in the input parameters for these vehicles (H2Accelerate 2022). Finally, a study that distinguishes between country-specific use cases identifies Switzerland as the exception to the rule that FCET vehicles are too expensive, while BET vehicles show competitive TCO values compared to ICE-D vehicles in Norway, Sweden, and Germany. However, there is an important caveat in that these results come about due to subsidies and tolling that are not technology-neutral impacts on operating costs (Applied Energy 2022).

Policy Recommendations

Four of the seven studies under consideration in this deliverable provide policy recommendations. All of them argue that the achievement of TCO parity between zero-emission and conventional trucks can be accelerated by the introduction of policy interventions in market mechanisms. These operate primarily at the level of 1) operating costs (rather than capital expenditures), 2) infrastructure, and 3) at the vehicle level.

Policies to reduce operating expenditures are recommended because they tend to be more effective in enabling the competitiveness of zero-emission commercial vehicles than targeting capital cost parameters (Applied Energy 2022). Possible measures include the increased taxation of diesel fuel and conversely subsidies for hydrogen as well as differential road tolling that favours zero-emission options over fossil fuel-based vehicles (H2Accelerate 2022, ICCT 2022a, ITF 2022).

As shown above in the discussion of the regulatory framework, the mass market uptake of zero-emission technology depends on enabling infrastructure. Policymakers are urged to accelerate the deployment of charging/fuelling stations with financial support and simplified permitting processes. Existing vehicle standards can also be amended to promote energy-efficiency, for instance by mandating certain aerodynamic improvements. Taken together, all of these measures are likely to reduce stakeholders' uncertainty surrounding TCO calculations (ITF 2022).

TCO Formula, Components, and Best Practices for ZEFES Use Cases

An example of a TCO formula is shown in Equation 1 below. Most studies considered in the literature review for this deliverable present a variation of this formula with adjusted parameter labels.

$$TCO_{t,a,g} = \frac{\left(CAPEX_{t,a} - SUB_{t,a,g} - \frac{SV}{1+i_g}\right) \cdot CRF + 1/N_a \sum}{AKT_a, g}$$

Equation 1: Example of TCO formula (Applied Energy 2022)

This example features the following cost components (with corresponding units in parentheses):

- TCO is the total cost of ownership per kilometer (in EUR/km).
- CAPEX is the capital expenditure or initial purchase cost of the vehicle (EUR).
- SUB is the subsidy on the initial vehicle purchase (EUR).
- SV is the scrap/residual value (EUR).
- OPEX is the operating expenditure or annual operating cost (EUR).
- N is the lifetime of the vehicle (years).
- AKT is the annual kilometers travelled (km).
- For the discounting terms, CRF is the capital recovery factor = (i(1 + i) N)/((1 + i) N − 1), and i is the discount rate.
- Subscripts t, a, and g refer to the powertrain technology, application (or use case in the language of the ZEFES project), and geography dimensions respectively.

To analyse and compare TCO results, it is important to note that:
1) each parameter uniquely influences the TCO and that

2) each parameter is influential along one or several different dimensions (specifically referring to subscripts t, a, and g). Figure 12 below illustrates how TCO parameters can be broken down and which dimensional dependencies exist for them.

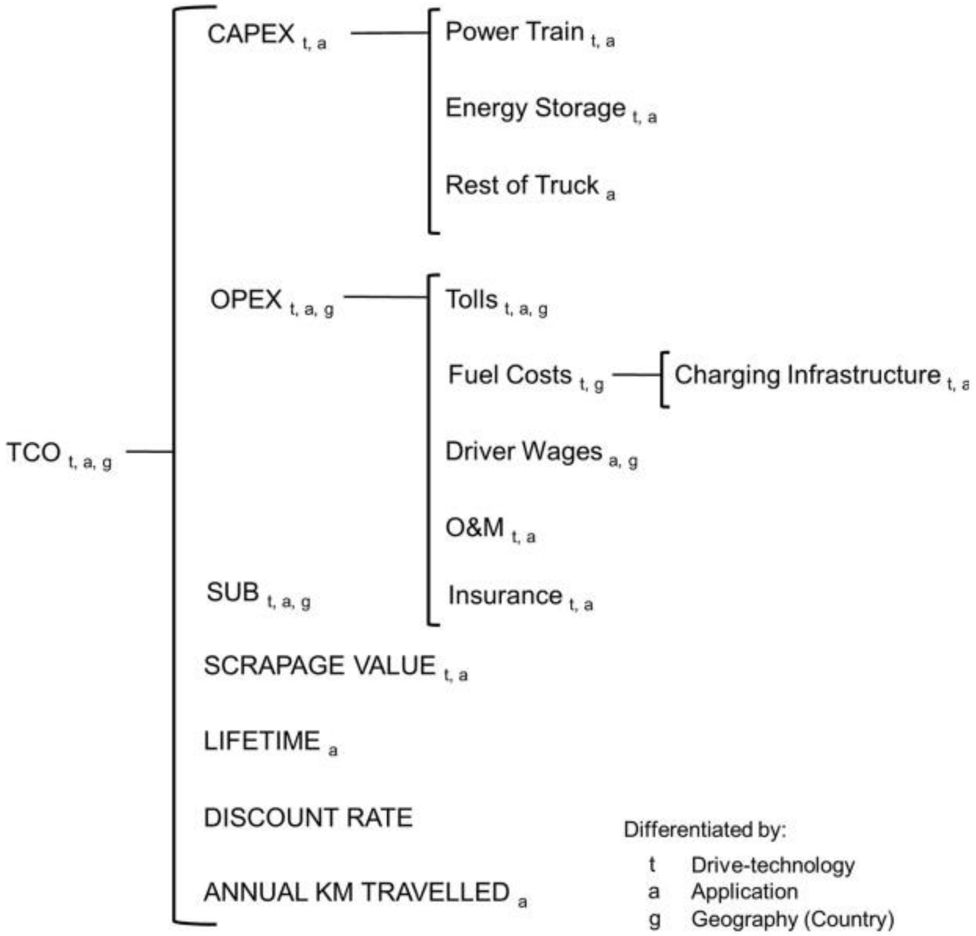


Figure 12: Example of parameter tree identifying differentiation by framework dimensions (Applied Energy 2022)

Table 3 summarizes TCO components based on a synthesis of variables found in the literature review for this deliverable. It is important to note here that this is not an exhaustive list of all possible cost components and their subcategories. ZEFES stakeholders can use this table as a starting point for their own TCO calculations, but they may want to add or subtract components as needed to achieve the desired balance between parsimony (i.e., does the model accomplish the desired level of explanation with as few variables as possible?) and fit (i.e., how well does the model reproduce the observed data, or how closely does it match the empirical evidence?). Adding or subtracting components inherently involves a trade-off between parsimony and fit, which in turn has implications for the applicability of a TCO model across different use cases.

Table 3: Synthesis of TCO components

TCO Model Components by Vehicle Type			
Vehicle Type	**BEV**	**FCEV**	**ICE-D**
Capital Expenditures (CAPEX)			
Cost Component	**Subcomponent**		
Vehicle Purchase	Powertrain		
	Glider		
	Overheads		
	Vehicle Financing		
	Taxes (e.g., registration, ownership, fixed vignettes)		
	Subsidies, Grants, and Other Incentives		
Vehicle Lifetime/Depreciation	Scrap/Residual Value		
	Battery Resale	Fuel Cell Resale	
Operating Expenditures (OPEX)			
Maintenance	Services		
	Repairs		
	Road Worthiness Tests (e.g., safety, emissions)		
Fuel Cost	Electricity Price	Hydrogen Price	Fuel/Diesel Price
	Fuel Consumption		
Insurance and Taxes	Vehicle/Fleet Insurance		
			Carbon Tax
Levies and Tolls	Road Use Charge (by distance, truck class, emission category)		
Component Replacement	Battery	Fuel Cell	
Additional/Optional Costs	Driver Wages		
	Vehicle Parking		

Based on the preceding analysis, including tables and figures, we can summarize the following best practices for TCO modelling in ZEFES:

- Transparency: it is imperative to make assumptions in the model explicit and explain why certain assumptions are made. This allows other stakeholders to identify when a given TCO model incorporates available data and when it has to rely on estimates, including projections for future costs. Knowing the difference enhances our understanding of the extent to which a model reflects uncertainty.
- TCO models should include a sensitivity analysis to account for change over time and changes across national borders (if applicable). This recommendation implies that a break-even analysis should be expressed as a range rather than a singular number because it includes upper and lower bounds as well as mean/median values. Figure 13 below exemplifies a particular challenge when analysing TCO models. It shows break-even hydrogen prices to achieve TCO parity by 2030 between fuel cell electric and diesel trucks in select countries. However, such a decontextualized result only provides a snapshot in time and cannot be compared to other studies because underlying assumptions differ widely in quantity and quality (if they are made

explicit). This raises the question whether data is used to represent empirical evidence or to reflect a desirable policy outcome. Suffice it to say that the ZEFES project should avoid the latter.

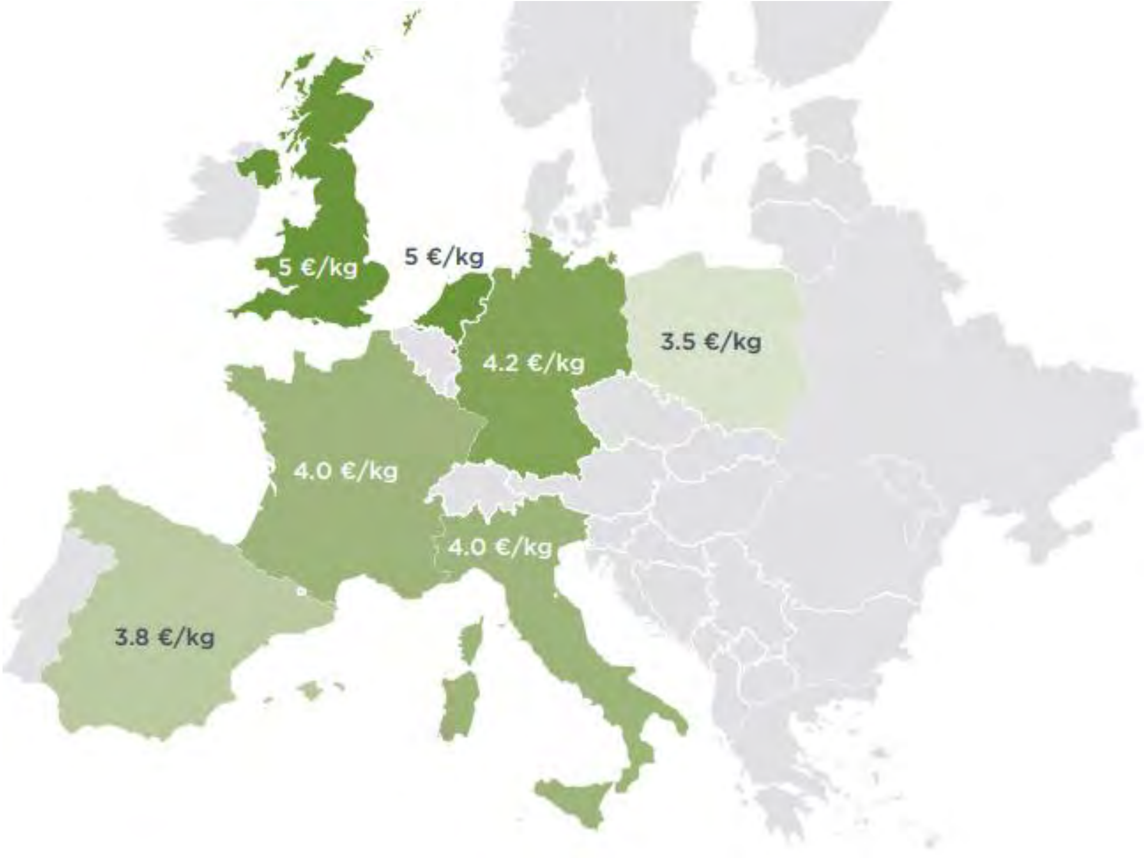


Figure 13: Example of break-even hydrogen price to achieve total cost of ownership parity by 2030 between fuel cell electric and diesel trucks in selected countries (ICCT 2022a)

- If possible, choose the same parameters, definitions, and assumptions (incl. uncertainty/sensitivity analysis) across use cases to facilitate comparability.
- If possible, refine the model (i.e., render it more realistic) by including opportunity costs. Although TCO focuses on financial costs associated with owning and operating a vehicle or fleet, the model could be improved by quantifying non-financial costs and highlighting their impacts. These may include payload losses from batteries, productivity losses due to charging times for BEVs, and changes to operating routes (and therefore distance driven) based on the location of fueling stations/charging points, for example.
- Integrate the modularity of the model by calculating and presenting values for CAPEX and OPEX separately: this allows users to distinguish between use cases
- Anticipate changes in business models. Current TCO models tend to start with the acquisition of the vehicle, but a future best practice might be to start with the use case and then to identify the vehicle/vehicle combination best suited for the operation.

4.2 Operational approaches

Scenarios for charging/fuelling

The gradual phasing out of ICE vehicles will require a parallel transition away from the current business model where oil refuelling supports the vast majority of the market. Traditional refuelling stations will need to transform into charging stations or hydrogen refuelling stations while different alternatives and operating models will co-exist (e.g., hydrogen refuelling, electricity at depot, truck parking or refuelling station, while loading/unloading, at truck parkings during rest time etc.) However, there have been challenges in the process. Drivers may have to interrupt their rest at night and change the position of the truck to allow others to charge. Multiple trucks will need to charge at the same time which raises the need for additional infrastructure. ZEFES is going to study those challenges and propose operationally tested methods on how to overcome them.

List parameters that determine business case?
For example:

1) Recharging/refuelling can be part of a company's capital expenditure if they prefer or need to build their own infrastructure on private property. The business case for this kind of infrastructure depends on the location of the company, which in turn affects the price for connecting charging stations to the electric grid. Other factors to take into consideration: availability or investment in renewables, capacity of the grid, space availability, who has priority, waiting times, etc.
2) Recharging/refuelling is part of a company's operating cost if public stations are used. The most influential factor to determine the business case for public charging is likely the unit price of hydrogen and/or electricity. Other factors to take into consideration: Availability of charging/ refueling stations at truck parkings and slots available during regular rest time, availability in the congested freight traffic network, availability of space for trucks versus private cars, availability of megawatt chargers or 700bar hydrogen refuelling, payment methods that are aligned with company policies (DKV etc.)

Operational model

The operational model for goods transport by road, especially in Europe is quite straight forward. There are clear and homogenous answers to the question "What does the operation look like now?" even though some differences might exist due to mainly geographical differences or the nature of the products.

But when discussing about ZE-HDVs, the answer changes. While building a business case for ZE-HDVs, the industry will need to take several requirements into account. The technological limitations can create a different operational profile for each technology based on its limitations (range, weather conditions that can impact battery capacity, etc.).

Where and when to refuel/charge the vehicle is a major factor while considering a route. Changes can also occur when the vehicle is not used (overnight charging at depot, rest at truck parking). Consequently, there are opportunity costs of refuelling/charging if this process cannot be combined with other activities, such as loading/unloading, rest time for driver, etc.

Special safety measures related to hydrogen/battery will need to be examined and proven technologically.

Transport operators investing in ZE-HDVs will need to get informed about all the advantages and disadvantages of the technology while trying to serve their customers' needs.

OEMs and (e-)trailer

OEMs need to know that it will be possible to recover all the R&D investment and the new production lines necessary to produce new vehicles. The production of ZE-HDVs needs to be scaled up and this is not a short-term investment. Another challenge for vehicles manufacturers is whether it would be affordable or not to focus on building new or retrofitting some existing equipment.

ZE-HDV and interactions to other operational requirements

While transporting goods by road can be complicated itself, it is not only the truck that will need to be transformed. Other factors include the employment, the facilities and the software updates. Reskilling of employees (not only drivers but also warehouse managers to be able to e.g. operate charging systems) will be required. Investment and upgrade of the facilities but also fleet management systems and other software related to charging and refuelling.

5. Conclusions

This report outlined the ZEFES ecosystem specifications by collecting and listing needs and requirements of the ZEFES project with a particular focus on end-users and organised in the six categories as defined below:

i. truck-trailer technology: can the mission be done from a technical point of view?
ii. integration in the logistics operation: can ZE-HDVs be integrated in logistic (fleet) operation?
iii. social acceptance: is it safe and sustainable to use ZE-HDV?
iv. legal barriers: can logistic companies use the ZE-HDVs as they want without legal barriers?
v. infrastructure: will ZE-HDVs be able to refuel or charge?
vi. viable business case: without it, there will be no implementation of ZE-HDVs.

The information was generated in literature reviews, a project survey, gap analysis (incl. policy analysis), user stories provided by industry outliers, and an initial business case development attempt or a description of the factors impacting whether the business case of ZE-HDVs can be commercially deployable or not.

After the submission of this report, a workshop will take place where stakeholders relevant to the project (either from the ZEFES stakeholder group or outside the project) will validate the results of the work done by now.

Since the ZEFES ecosystem is composed of a variety of stakeholders who are both agents of change and subject to technical, operational and regulatory requirements, the findings diverge based on the stakeholder group. A summary of conclusions is presented in Table 4 below. Blank fields indicate that the content of certain chapters does not apply to specific stakeholders.

Table 4: Conclusions summary

ZEFES D 1.3 Conclusions Summary by section and stakeholder group				
	Operators and Shippers	**OEMs (truck and trailer)**	**Energy Infrastructure Operators**	**Authorities and Policymakers**
Ch. 2 Stakeholder Needs and Requirements				
2.1 ZE-HDV ecosystem	Operators and shippers are the central stakeholders for the uptake of ZE HDVs	OEMs define ZE-HDV capabilities, but this group is not the focus of this deliverable	These operators shape energy supply, but will they lead the market or wait for incentives?	Regulatory bodies can help solve technical and legal problems arising from operational experience
2.2 Existing surveys	Lit review identified concerns about reliability, driver training, high TCO and charging/fuelling infrastructure for ZE HDVs			
2.3 ZEFES survey on needs and requirements	ZEFES survey responses in D1.3 focus on this group: respondents are considering several technological and operational solutions to reduce emissions. Survey identified six categories of needs and requirements		One of the categories is infrastructure. We identified the most needs and requirements for this category. It seems to be the part of the zero-emission ecosystem with the highest uncertainty.	Truck end-users want certainty on what mission are possible with ZE-HDV. They also want uniform regulations, so cross-border missions are possible.
Ch. 3 Needs and Requirements Gap Analysis				
3.1 Operational requirements	Alignment of ZEFES objectives and KPIs with expectations of surveyed stakeholders shows that the obj/KPIs are in line with the stakeholders need. KPIs taking in the human factor, safety and			

	sustainability could be added.			
3.2 Policy and legal framework for ZEVs	Lack of charging/fuelling infrastructure limits operations, regulatory barriers limit efficient and flexible transport business models	Currently available technology has outpaced regulations (esp. on trailers)	Need for regulatory certainty prior to large-scale investments in energy infrastructure	Need to provide incentives to increase ZE HDV uptake (incl. deployment of energy infrastructure), harmonise and update regulations to incorporate new technologies
3.3 Needs and requirements list/user stories	The digital twin and user stories help clarify needs and requirements, also reiterate challenges related to technical reliability and fuelling/charging infrastructure			
Ch. 4 Business Case Development				
4.1 Cost model development	TCO for ZE HDVs currently higher than for ICE	ZE HDVs are more expensive than ICE models, high prices prevent mass uptake	TCO is affected by fuel cost, but not necessarily by infrastructure supply (but infrastructure supply is correlated with demand for ZE HDVs)	Need to balance taxation and subsidy levels to induce uptake of ZE HDVs and infrastructure deployment
4.2 Operational approaches	Charging/fuelling ZE HDVs requires operational changes and incurs different opportunity costs compared to ICE HDVs	OEMs face challenge of producing ZE HDVs (and equipment like trailers) at scale	Transition to ZE fuelling/charging infrastructure may entail uncertainty and experimentation	Regulations need to facilitate interoperability of systems (e.g., vehicle combinations, multimodal transport, fuelling/charging interfaces) with new requirements for standardisation

6. Risks and interconnections

6.1 Risks/problems encountered

No risks were identified with a link to this report and the respective activities performed by the project partners. The focus of this deliverable is procedures and methodology and gathering the preliminary results to validate the quality of the methodology. A special attention was needed in contacting the relevant profiles to participate in the survey where experts in the field and a representative sample of the ecosystem was required in identifying the users' needs and requirements for the scope of the ZEFES project. Moreover, during the course of the project, the partners' needs and requirements need to be fully understood and translated at technical level. Active involvement in translating the users' needs and requirements into technical needs will be required.

6.2 Interconnections with other deliverables

A close alignment with the rest of the Work Package 1 tasks and the Work Packages 2, 3, 4, 7, and 8 has already resulted in addressing topics, user needs and requirements at an early stage in the ZEFES project. This report is going to provide input into the different project activities such as the digital twinning platform (WP4) and the preparation and piloting of the trucks. The evaluation of the pilots will reflect the needs and requirements set by transport operators and other stakeholders representing the whole supply chain (shippers, OEMs, charging and refuelling etc.) with the objective of giving feedback to the industry on the advantages and limitations of BEVs and FCEVs. All the final results and analysis of the user needs and requirements survey will be presented, and the final business cases will be further detailed in D1.5. The needs and requirements of this report will be translated into technical requirements and implemented in WP2,3,4,5,6; then demonstrated in WP7 and assessed in WP8, (Assessment of requirements on use-case level in D8.3, LCA in D8.4, (societal) impact assessment in D8.5)

7 Deviations from Annex 1

No deviations from Annex 1 are seen in this report and the respective tasks.

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Project partners:

#	Partner short name	Partner Full Name
1	VUB	VRIJE UNIVERSITEIT BRUSSEL
2	FRD	FORD OTOMOTIV SANAYI ANONIM SIRKETI
3	KAE	KASSBOHRER FAHRZEUGWERKE GMBH
4	REN	RENAULT TRUCKS SAS
5	SCA	SCANIA CV AB
6	VET	VAN ECK TRAILERS BV
7	VOL	VOLVO TECHNOLOGY AB
8	ABB	ABB E-MOBILITY BV
8.1	ABP	ABB E-MOBILITY SPOLKA Z OGRANICZONAODPOWIEDZIALNOSCIA
9	AVL	AVL LIST GMBH
10	CM	SOCIEDAD ESPANOLA DE CARBUROS METALICOS SA
10.1	APG	AIR PRODUCTS GMBH
11	HEPL	HITACHI ENERGY POLAND SPOLKA Z OGRANICZONA ODPOWIEDZIALNOSCIA

12	MIC	MANUFACTURE FRANCAISE DES PNEUMATIQUES MICHELIN
13	POW	PLASTIC OMNIUM NEW ENERGIES WELS GMBH
14	RIC-CZ	RICARDO PRAGUE S.R.O.
14.1	RIC-DE	RICARDO GMBH
15	UNR	UNIRESEARCH BV
16	ZF	ZF CV SYSTEMS HANNOVER GMBH
17	ALI	ALLIANCE FOR LOGISTICS INNOVATION THROUGH COLLABORATION IN EUROPE
18	DPD	DPD (NEDERLAND) B.V.
19	COL	ETABLISSEMENTEN FRANZ COLRUYT NV
20	GRU	GRUBER LOGISTICS S.P.A.
21	GBW	GEBRUEDER WEISS GESELLSCHAFT M.B.H.
22	PG	PROCTER & GAMBLE SERVICES COMPANY NV
22.1	PGP	PROCTER AND GAMBLE POLSKA SPOLKA Z OGRANICZONA ODPOWIEDZIALNOSCIA
22.2	PGA	PROCTER & GAMBLE AMIENS
23	PRI	PRIMAFRIO CORPORACION, S.A.
24	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

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APPENDIX I – User needs and requirements survey

In this Appendix all the questions of the online survey are given per stakeholder group.

General Questions

Table 5: Survey - general questions

1	Dividing the respondents in stakeholder groups + contact information	
	Questions	**Predefined answers / type of answer**
1.1	I'm interested in zero-emission heavy-duty road transport as a … **(more than one answer possible, keep in mind that selecting multiple answers will lengthen the survey)**	- Truck end-user: road transport operator (with or without own fleet) or logistics service provider - Shipper - Logistic site owner or operator (terminals) - Truck OEM - Trailer manufacturer - Renewable fuel infrastructure manufacturer (hydrogen) - Renewable fuel infrastructure manufacturer (fast charging) - Renewable fuel infrastructure operator (hydrogen) - Renewable fuel infrastructure operator (fast charging) - Policy maker - Researcher - Road, traffic or type approval authority
1.2	Which company or organisation are you representing?	- Open answer
1.3	I'm considering myself … in the field of zero-emission heavy-duty road transport. **(one answer possible)**	- **Expert,** as I have been actively developing and/or implementing these technologies in actual logistics operations for a couple of years. - **Beginner,** as we have just started, or we plan to start using these technologies in the next 3-6 months max. - **Informed,** as we are assessing the maturity of technologies and the market to identify medium-term (1-2 years) implications for our business. - **A novice,** as I know this may have an impact on my company, but I have not yet gone into details.
1.4	May we contact you for follow-up questions? **(yes/no question)**	- Yes/no **Requesting contact information (mail address) if answer is yes**
1.5	In which European countries is your company/organization active? **(fill in box)**	- Respondent can fill in one or more countries - 'Open answer'
1.6	Consent personal data management	- Yes, I have read and agree to the ALICE privacy policy and the particular terms included in the personal data management clause below
	"ALICE is organizing this survey in collaboration with the ZEFES project. We may need to share the data you have provided in this survey with them for preparatory reasons. ALICE will use the data provided for the organization and follow up of the survey as well as to keep your contact details in our distribution list so we can inform you on future events in case you grant us permission for that. We inform you that the answers you provide to this survey will be used further within the ZEFES project. For more information: Read ALICE Privacy Policy. In case you do not agree to this clause, but you still wish to participate, contact us at info@etp-logistics.eu"	

Survey 'Transport Operator' (end users ZE-HDV)

Table 6: Survey questions for end users of ZE-HDV

2	**Getting to know the company of the respondent**	
	Questions	**Predefined answers / type of answer**
2.1	What is the Gross Vehicle Weight (GVW) or Gross Combination Weight (GCW) of the vehicles your company is currently using? **(More than one option possible)**	- <3.5 t GVW - 3.5-12t GVW - 12-16t GVW - >16t GVW / >36t GCW - I don't know
2.2	What type of trucks is your company using? **(More than one option possible)**	- High-Capacity Vehicle - Semi-tractors 4x2 - Semi-tractors 6x2 - Rigid trucks - Others, [fill in] - I don't know
2.3	What type of trailers is your company using? **(More than one option possible)**	- Standard trailer - Low liner trailer - Temperature conditioned trailer, reefer - None - Others, [fill in] - I don't know
2.4	Does your company own **trucks**?	- Yes/no
2.4.1	*If yes:* What is the current number of motor vehicles (including diesel and LNG/CNG trucks) that your company owns? Order of magnitude is ok.	- Numeric value - I don't know
2.5	Does your company own **trailers**?	- Yes/no
2.5.1	*If yes:* What is the current number of trailers that your company owns? Order of magnitude is ok.	- Numeric value - I don't know
2.6	Does your company own logistic sites? **(Only one option possible)**	- Yes, only one - Yes, multiple - No
2.6.1	*If yes (link logistic site owner):* Does your logistic site(s) offer fuelling or charging options for ZE-HDV?	- Yes/ no - I don't know
2.6.2	*If yes (link logistic site owner):* Do you have (or plan to install) on-site renewable energy generation and/or stationary energy storage?	- Yes/no - I don't know
2.6.3	*If yes (link logistic site owner):* Will the electric power connection of your logistic site(s) limit the amount of charging infrastructure that can be installed?	- Yes/No - I don't know
2.7	Is a significant part of your transports multimodal (e.g., are goods transported by at least two means of transport (truck, rail, ship, air)) in one freight order? **(Only one option possible)**	- Yes, this is our core business - Yes, some of our transports - No, only in exceptional cases or never
2.7.1	*If yes:* Are the goods accompanied during their multimodal trip?	- Yes, always - Yes, sometimes - No

2.8	Does your company transport temperature-conditioned goods?	- Yes, 100% conditioned goods - Yes, but also other goods - No
2.8.1	*If yes:* Is preconditioning a must?	- Yes - No
2.8.2	*If yes:* Do you plan to use an electrical connection to precondition in order to avoid taking energy from the vehicle and impacting the driving range	- Yes - No
2.9	What kind of missions does your company carry out? **(more than one option possible)**	- International long-haul missions - National missions (+400 km) - National round-trip missions (+400 km) - Regional missions (below 400 km) - Regional round-trip missions (below 400 km) - I don't know
2.10	Does your company execute missions under extreme conditions?	- Yes, extreme cold conditions (-20°C) - Yes, extreme hot conditions (+40°C) - Yes, extreme elevation profile (mountains) - Yes, extreme weather conditions (snowstorms, wind…) - No - I don't know
2.11	Are the missions limited by weight or by volume? (More than one option possible)	- weight limited - volume limited - I don't know
2.12	When are your ICE trucks refuelled during a normal workday?	- Only when it is necessary to complete the trip, preferably at a refuelling station nearby the (own, private) logistic site - Only when it is necessary to complete the trip, at a commercial diesel station along the route - Standard at the start or end of each shift at a refuelling station nearby the (own, private) logistic site - I don't know - Other, [fill in]
	Status of implementation ZE-HDV in the logistic company	
2.13	Has your company purchased or demonstrated ZE-HDV (GCW 40 ton) (defined as battery electric or hydrogen fuel cell electric)?	- Yes/no
2.14	What type of ZE-HDV (GCW >36 tons) are you implementing in your fleet? **(More than one option possible)**	- BE-HDV - FCE-HDV
2.15	How many ZE-HDV (GCW>36 ton) have you purchased or are you demonstrating?	- numerical
2.16	Is your company interested in implementing other FUEL technologies that lower transport emissions for vehicles with GCW 40 ton? **(More than one option possible)**	- No - Yes, HVO (hydrotreated vegetable oil) - Yes, biomethane (in gaseous CNG or liquid LNG state)

		- Yes, hydrogen in combustion engines - Yes, other [fill in] - I don't know
2.17	Is your company interested in changing their LOGISTICS to lower emissions?	- Yes, using smaller vehicles (GCW<36 tons) which are easier to electrify - Yes, adding more logistic hubs to the network to achieve shorter distances, which are easier to electrify - Yes, more multimodal transport - Yes, other - No - I don't know
2.18	Does your company have a clear sustainability strategy/target to reduce emissions from your truck operation?	- Yes/no - I don't know
2.18.1	*If yes:* Could you please provide the strategy/targets?	- Open answer
2.19	Knowing the higher cost of a ZE-HDV, would you still purchase a ZE-HDV?	- Yes/no
2.20	What type of incentives (or discouragements for fossil fuels) would be helpful to implement HD-ZEV?	- CAPEX subsidies for trucks - CAPEX subsidies for infrastructure - OPEX subsidies for extra cost of renewable energy (electricity + H2) - Exemptions of (road) taxes - Additional cost related to CO2 emission (tax) - Non-financial benefits (like priority lanes)
2.21	Are you aware of public, national funding schemes for ZE-HDV and the needed infrastructure?	- Yes - No - I don't know
2.21.1	*When yes:* Please, specify	-
2.22	Is your company open to new business models (like leasing ZE-HDV instead of buying, pay per use...)?	- Yes/no - I don't know

3	**No implementation of ZE-HDV** **Why is your company not implementing ZE-HDV?**
3.1	Indicate whether you agree or disagree with the following reasons **to not invest** in ZE-HDV. We will first ask for the reasons to not invest in BE-HDV, followed by the reasons related to FCE-HDV. The reasons will be similar and only apply to different ZE-HDV technologies. For which technology do you want to fill in the questionnaire: - BE-HDV - FCE-HDV - Both "We **do not** invest in ZE-HDV because:"

	Questions BE-HDV (battery electric)	**Agree**	**Disagree**	**Not relevant**	**I don't know**
3.1.1	BE-HDV are not commercially available.				
3.1.2	BE-HDV cannot be deployed in enough missions.				
3.1.3	Driving range is too low.				
3.1.4	Payload is restricted.				
3.1.5	Charging time is too long.				
3.1.6	A fleet management system that can account for the potential benefits and limitations of the BE-HDV is non-existing.				
3.1.7	Incentives to invest in BE-HDV are missing.				
3.1.8	Commercial charging infrastructure is missing.				
3.1.9	Incentives to invest in charging infrastructure are missing.				
3.1.10	It is currently impossible to calculate TCO and business cases since data is missing (maintenance cost, availability numbers, capacity prognosis, lifetime, residual value…).				
3.1.11	The uncertainty on future (energy) prices is too high to decide now.				
3.1.12	The uncertainty on future technology improvements is too high to decide now.				
3.1.13	There is no positive business case for BE-HDV.				
3.1.14	There is a positive business case for BE-HDV, but the TCO of BE-HDV is higher than HD-ICEV.				
3.1.15	The CAPEX investment in a BE-HDV is too high.				
3.1.16	BE-HDV cannot be combined with the trailer type we use.				
3.1.17	We do not implement BE-HDV due to safety aspects (high voltage, fire hazard…).				
3.1.18	We do not implement BE-HDV due to social acceptance aspects (environmental impact of battery production and recycling).				
3.1.19	It is unclear whether BE-HDV will lead to an actual emission reduction (GHG and PM).				
3.1.20	Our company does not have the knowledge or resources to procure suitable BE-HDV.				
3.1.21	Renewable electricity is not available at an acceptable price.				
3.1.22	There is no legislation forcing us to implement BE-HDV.				

3.1.23	The legislative framework to drive with BE-HDV is missing (not allowed to cross borders, use tunnels…).				
3.1.24	The BE-HDV are not equipped with the necessary driver comfort equipment (type of cabin, heated seats…).				
3.1.25	It is unclear what the impact will be on the logistic operation (overall capacity loss?).				
3.1.26	BE-HDV is new technology, which we do not trust it enough (risk of breakdowns is not mitigated enough).				
3.1.27	The impact of weather conditions on the performance of BE-HDV is not known				
3.1.28	Do you want to comment on some of your answers? Do you have other reasons for not investing in BE-HDV?	- Open question Not obligated to fill in			

	Questions FCE-HDV (hydrogen fuel cell electric)	**Agree**	**Disagree**	**Not relevant**	**I don't know**
3.2.1	FCE-HDV are not commercially available.				
3.2.2	FCE-HDV cannot be deployed in enough missions.				
3.2.3	Driving range is too low				
3.2.4	Payload is restricted.				
3.2.5	Fuelling time is too long.				
3.2.6	A fleet management system that can account for the potential benefits and limitations of the FCE-HDV is non-existing.				
3.2.7	Incentives to invest in FCE-HDV are missing.				
3.2.8	Commercial HRS are missing.				
3.2.9	Incentives to invest in HRS are missing.				
3.2.10	It is currently impossible to calculate TCO and business cases since data is missing (maintenance cost, availability numbers, capacity prognosis, lifetime, residual value…).				
3.2.11	The uncertainty on future (hydrogen) prices is too high to decide now.				
3.2.12	The uncertainty on future technology improvements is too high to decide now.				
3.2.13	There is no positive business case for FCE-HDV.				
3.2.14	There is a positive business case for FCE-HDV, but the TCO of BE-HDV is higher than HD-ICEV.				
3.2.15	The CAPEX investment in a FCE-HDV is too high.				
3.2.16	FCE-HDV cannot be combined with the trailer type we use.				

3.2.17	We do not implement due to safety aspects (fire hazard, high voltage…).				
3.2.18	We do not implement due to social acceptance aspects (impact of hydrogen production, impact of battery production and recycling).				
3.2.19	It is unclear whether the FCE-HDV will lead to actual GHG emission reductions.				
3.2.20	Our company does not have the knowledge or resources to select suitable FCE-HDV.				
3.2.21	Green hydrogen is not available.				
3.2.22	There is no legislation forcing us to implement FCE-HDV.				
3.2.23	The legislative framework to drive with FCE-HDV is missing (not allowed to cross borders, use tunnels…).				
3.2.24	The FCE-HDV are not equipped with the necessary driver comfort equipment (type of cabin, heated seats…).				
3.2.25	It is unclear what the impact will be on the logistic operation (overall capacity loss?).				
3.2.26	FCE-HDV is new technology, which we do not trust enough (risk of breakdowns is not mitigated enough).				
3.2.27	The impact of weather conditions on the performance of FCE-HDV is not known				
3.2.28	Do you want to comment on some of your answers? Do you have other reasons to not invest in FCE-HDV?	- Open question Not obligated to fill in			

	Implementation of ZE-HDV **Why is your company implementing ZE-HDV?**				
	Please indicate whether the following statements are reasons to implement ZE-HDV. **“We are investing in ZE-HDV, because…”**	**Agree**	**Disagree**	**Not relevant**	**I don’t know**
3.3.1	We want to learn.				
3.3.2	Sufficient ZE-HDV are commercially available.				
3.3.3	ZE-HDV can be deployed in almost all missions.				
3.3.4	Driving range is sufficient.				
3.3.5	We want to be able to enter Low Emission Zones				
3.3.6	ZE-HDV are more silent and could be used for night deliveries				
3.3.7	Transport capacity is not restricted				
3.3.8	Charging time is not too long.				
3.3.9	Hydrogen refuelling time is not too long.				
3.3.10	ZE-HDV can be combined with the trailer type we use.				
3.3.11	Sufficient charging and fuelling infrastructure is available.				

3.3.12	There are sufficient incentives to invest in ZE-HDV.				
3.3.13	The CAPEX investment of ZE-HDV is acceptable.				
3.3.14	The TCO of ZE-HDV can be calculated (residual value, lifetime... are known).				
3.3.15	The TCO of ZE-HDV is acceptable.				
3.3.16	There is a positive business case for ZE-HDV.				
3.3.17	There is a positive business case for ZE-HDV, but the TCO of ZE-HDV is higher than ICE-HDV.				
3.3.18	It is safe to operate BE-HDV.				
3.3.19	It is safe to operate FCE-HDV.				
3.3.20	It is socially accepted to operate ZE-HDV.				
3.3.21	We have the knowledge and resources to procure suitable ZE-HDV.				
3.3.22	The ZE-HDV are equipped with the necessary driver comfort equipment (type of cabin, heated seats…).				
3.3.23	Renewable electricity is available at an acceptable price				
3.3.24	Green hydrogen is available.				
3.3.25	The risk of ZE-HDV breakdowns is mitigated, we trust the technology.				
3.3.26	The risk of infrastructure breakdowns is mitigated, we trust the technology.				
3.3.27	Fleet management software that can integrate ZE-HDV in a fleet is available.				
3.3.28	We want to lower our emissions (GHG and PM).				
3.3.29	The legislative framework is not restricting the deployment of ZE-HDV (crossing of borders).				
3.3.30	Legislation is forcing us to implement ZE-HDV.				
3.3.31	The impact of weather conditions on the performance of ZE-HDV is known				
3.3.32	Do you want to comment on some of your answers? Do you have other reasons to invest in ZE-HDV?	- Open answer			

	Needs and requirements of the BE-HDV	
4.1	What should be the driving range of the BE-HDV?	- numerical
4.2	How long could the truck charge (expressed in hours) during the day without impacting the logistics operations? Please include the driver breaks only when you think it is feasible and socially accepted to charge during breaks. Please include loading and unloading only when you think it is feasible to charge.	- Numerical - I don’t know
4.2.1	*If number is given:* Are driver breaks included in the time available for charging?	- Yes/no
4.2.2	*If number is given:* Is (un)loading included in the time available for charging?	- Yes/no
4.3	At which remaining driving range (range anxiety) would you suggest your drivers to recharge.	- XXADD ANSWERS

4.4	How fast should the BE-HDV be able to charge from a minimum battery capacity (related to the minimum driving range selected above) to 80% (expressed in hours)?	- Numerical - I don't know
4.5	How should the BE-HDV be optimized? Rank the following properties of the BE-HDV by means of importance.	1. Lowest investment cost (CAPEX) 2. Lowest total cost of ownership 3. Longest driving range 4. Lowest energy consumption (includes efficiencies, aerodynamics…) 5. Max payload weight 6. Max payload volume 7. Lifetime of the truck 8. Driver comfort equipment (type of cabin, heated chairs…)
	Needs and requirements of the charging infrastructure	
4.6	The BE-HDV will be charged at … **(More than one option possible)**	- A normal power socket, AC/DC, max. 21 kW - Existing fast charging infrastructure < 300 kW (DC/DC) - Existing fast charging infrastructure ≥ 300 kW (DC/DC) - New to build fast charging infrastructure < 300 kW (DC/DC) - New to build charging infrastructure ≥ 300 kW (DC/DC) - New to build charging infrastructure ≥ 900 kW (DC/DC) - Not defined yet - I don't know
4.7	What would be the main location to charge the vehicle? **(Only one option)**	- At a logistic site at relatively low power (overnight, during (un)loading, depot charging…) - At a logistic site at high power during loading/unloading (opportunity charging) - At a logistic site at high power during driver breaks (opportunity charging) - A commercial charging station along the road (opportunity charging) - I don't know
4.8	How much of the charging will be done at the main charging location (percentage)?	- Numerical, %
4.9	What would be the ratio between slow (<350kW) and fast (>350kW) charging	- Numerical - I don't know

	Prioritizing properties of the Charging infrastructure by MoSCoW (select one, NR=not relevant)	**M**	**S**	**C**	**W**	**NR**
4.10	The BE-HDV can be easily connected to the charging infrastructure (length cable, automatic grounding, galvanic isolation…)					
4.10	Possibility to charge BE-HDV on the right- and lefthand side of the truck.					
4.10	The connection between BE-HDV and charger is standardised (one plug fits all)					
4.10	Charging station is adjusted to the turning cycle of long trucks-trailer combinations					
4.10	Renewable electricity is available					
4.10	Megawatt Charging System (>900MW) is available					

4.10	CCS (350 kW) and MCS (>900MW) available at the same station (price can differ between them, so option to opportunity charge at a lower price when time is not the limiting factor)					
4.10	Variable electricity prices related to the charging power (kW)					
4.10	Variable charging prices related to time of the day (charging during peak demand is more expensive)					
4.10	Communication between charger and the BE-HDV to optimize charging locally (power and time)					
4.10	Vehicle to grid (V2G) communication to optimize charging at grid level					
4.10	Bidirectional charging for (local) grid support services (peak managing, energy storage…)					
4.10	Pay by credit card or pay per use over digital platform					
4.10	Reservation of timeslot to charge (no waiting at the charger)					
4.10	Unambiguous pricing displayed					
4.10	Automated charging (connection between BE-HDV and infrastructure is made without interaction of the driver)					
4.10	Amenities for truck drivers					
4.10	Small footprint (both in area and in weight)					
4.10	Long-term (hours) parking available (possibility for depot charging)					
4.10	Power connection for conditioned trailers or e-trailers available					

	Needs and requirements of the FCE-HDV	
4.11	What should be the driving range of the FCE-HDV?	- numerical
4.12	How should the FCE-HDV be optimized Rank the following properties of the FCE-HDV by means of importance	1. Investment cost (CAPEX) 2. Total cost of ownership 3. Driving range 4. Energy consumption (includes efficiencies, aerodynamics…) 5. Max payload weight 6. Max payload volume 7. Lifetime of the truck 8. Driver comfort equipment (type of cabin, heated chairs…)
	Needs and requirements of the hydrogen refuelling stations (HRS)	
4.13	The FCE-HDV will be refuelled at	- An existing 350 bar HRS - An existing 700 bar HRS - A new to build HRS at 350 bar - A new to build HRS at 700 bar - A mobile HRS (350 bar) - A mobile HRS (700 bar)
4.14	What should be the maximum distance between HRS	- Numerical - I don't know
4.15	What should be the refuelling time of a FCE-HDV time expressed in minutes	- Numerical - I don't know
4.16	How should the HRS be optimized	- Lowest hydrogen cost - Fast hydrogen refueling - High availability, low downtime - High degree of filling, achieving State of Charge above 95%

		- Total mass of H2 that can be filled at once (>70 kg)				
	Prioritizing properties of the HRS by MoSCoW (select one, NR=not relevant)	**M**	**S**	**C**	**W**	**NR**
4.17.1	Ease of handling: length hose is sufficient.					
4.17.1	Ease of handling: no nozzle frozen onto FCE-HDV					
4.17.1	Possible to refuel FCE-HDV with H2 receptacles on the right and lefthand side of the truck.					
4.17.1	High refuelling speed = fast refuelling time (at least 120 g/s)					
4.17.1	Green hydrogen is available					
4.17.1	700 bar hydrogen available					
4.17.1	700 bar and 350 bar are available (price and refuelling rate can differ between them due to technical reasons. 350 bar could be less expensive per kilogram H2, however the total mass will be less, which results in smaller driving range)					
4.17.1	Variable hydrogen prices related to pressure fuelled (350 and 700 bar)					
4.17.1	Variable hydrogen prices related to time of the day (fuelling during peak demand is more expensive)					
4.17.1	Achieve State of Charge (degree of filling) above 95%					
4.17.1	Capable to refuel 100 kg of hydrogen at once (related to driving range of ±1000 km)					
4.17.1	Communication with the FCE-HDV to optimize fuelling (mass and time)					
4.17.1	Pay by credit card or automated payment by online platform					
4.17.1	Reservation of timeslot to fuel (no waiting at the pump)					
4.17.1	Unambiguous pricing displayed					
4.17.1	Estimation of the amount of hydrogen that can be refuelled (mass) is displayed before start of refuelling					
4.17.1	Automated fuelling (nozzle is connected by robot arm)					
4.17.1	Adjusted to turning cycle of longer truck-trailer combinations					
4.17.1	Amenities for truck drivers					
4.17.1	Power connection for conditioned trailers or e-trailers is available					

Survey ‘Logistic site owner or operator’

Table:7 Survey questions 'Logistic site owner'

5	**Needs and requirements Logistic site owner**	
	Questions	**Predefined answers / type of answer**
5.1	How many logistic sites is your company operating?	- Numerical - I don’t know
5.2	How many trucks (GCW >36 tons) are visiting your logistic sites on average at a daily basis? (order of magnitude)	- Numerical - I don’t know
5.3	Do you have any charging or hydrogen fuelling infrastructure installed at or nearby your logistic sites designed for ZE-HDV with GCW > 36 tons? **(Only one option possible)**	- Yes, charging stations and HRS - Yes, only charging stations - Yes, only HRS - No, none of them
5.3.1	*If yes:* How many of the logistic sites are equipped with this infrastructure?	- All of them - More than half - Less than half - Only a couple, it is exceptional - I don’t know
5.4	Are your clients requesting charging or hydrogen fuelling infrastructure at your sites? **(Only one option possible)**	- Yes, charging stations and HRS - Yes, only charging stations - Yes, only HRS - No, none of them
5.5	Will you install (additional) charging infrastructure in the near future (by 2028). **(Only one option possible)**	- Yes, charging stations and HRS - Yes, only charging stations - Yes, only HRS - No, none of them
5.6	Are renewable electricity production assets (PV panels and wind turbines) installed at your logistic sites?	- Yes, both wind and solar production - Yes, only solar production - Yes, only wind production - No
5.6.1	*If yes:* What is the power of the installed renewable electricity production assets on average (MW)?	- Numerical - I don’t know
5.7	Would the grid connection of your logistic sites limit the number of chargers and charging power that could be installed?	- Yes, it is already a limiting factor for our daily operations - Yes, it will be a limiting factor in the near future - No, grid connection will limit our daily operations.
5.8	Are you aware of public, national funding schemes for ZE-HDV and the needed infrastructure?	- Yes, please specify - No

5.8	**Why will charging or refuelling infrastructure not be installed at your logistic sites in the near future.**				
	Please indicated whether following statements are reasons to not implement infrastructure for ZE-HDV (GCW >36 tons) at logistic sites. **“We do not instal infrastructure at our logistic sites, since…’**	**Agree**	**Disagree**	**Not relevant**	**I don’t know**
5.8.1	The clients of the logistic site will not need it, they will charge/refuel somewhere else				

5.8.2	The time ZE-HDV spend at the logistic site is too short to charge/refuel				
5.8.3	There is no footprint available on the logistic site where the infrastructure could be installed on.				
5.8.4	The fast-charging technology is not commercially available				
5.8.5	The HRS technology is not commercially available				
5.8.6	Incentives to invest in infrastructure are missing				
	We don't trust the current technology (risks of breakdowns are not mitigated enough)				
	The technology will improve significantly in the future.				
5.8.7	The legislative framework to install the infrastructure is missing (permit requirements, standards…)				
5.8.8	There is no business case for installing **fast charging** infrastructure at logistic sites				
5.8.9	There is no business case for installing **HRS** at or nearby logistics sites				
5.8.10	We cannot find an operator for the infrastructure.				
5.8.11	There is no renewable electricity available at an acceptable price				
5.8.12	There is no green hydrogen available at the market				
5.8.13	The power connection of the logistic site makes the installation of the infrastructure challenging				
5.8.14	We don't have the knowledge or resources to procure the infrastructure within our company				
5.8.15	We don't install the infrastructure due to safety concerns (high voltage, fire hazard, SEVESO regulations, explosion risk…)				
5.8.16	We don't install the infrastructure since it is not clear these technologies will lead to emission reductions				
5.8.17	We don't install the infrastructure, since these technologies are not social accepted (mining for materials, uncertain recycling methods…)				
5.8.18	We don't install the infrastructure, since the installation itself will impact the logistics operations too much (breaking up concrete, unavailable docking area…)				
5.8.19	Do you want to comment on some of your answers? Do you have other reason to not invest in charging or fuelling infrastructure?			-	

	When charging infrastructure is already installed at the logistic sites or will be installed in the near future.				
	Why did you install charging infrastructure for BE-HDV (GCW >36 tons) on your logistic sites?				
	Please indicated whether following statements are reasons to implement infrastructure for ZE-HDV (GCW >36 tons) at logistic sites **“We installed infrastructure at our logistics sites, since…”**	**Agree**	**Disagree**	**Not relevant**	**I don’t know**
	We wanted to learn				
	The clients were requesting it				
	We want to be ready for the future				
	There is a business case for charging or fuelling ZE-HDV at logistic sites				
	We found it an opportunity to use the existing, financial incentives to install the infrastructure				
	We will be legally obligated in the future				
	We want to be more sustainable				
	We trust the current technology				
	Do you want to comment on some of your answers? Do you have other reason to invest in charging or fuelling infrastructure?				
	Fast charging for BE-HDV (GCW >36 tons)				
	Did the installation of the charging infrastructure impact the daily operation on the logistic site? **(One option possible)**	- Yes, the impact was substantial - Yes, but manageable - No			
	When will the BE-HDV charge at the logistic site? **(More than one option possible)**	- Overnight, when the truck is parked for a long time (depot charging) - During loading and offloading (opportunity charging) - When necessary to fulfil the next mission (opportunity charging) - Other, [fill in]			
	What will be the power of most of the charging points **(More than one option possible)**	- Conventional power plug AC/DC, max 21 kW - DC/DC between 60-300 kW - DC/DC between 300-900 kW - DC/DC above 900 kW - I don’t know			
	Will additional charging infrastructure be foreseen for conditioned, electrically powered trailers (so that goods can be preconditioned)?	- Yes/no - I don’t know			
	Who will purchase the charging infrastructure (procurement and installation)?	- Yourself, the logistic site owner - An external party			
	Who will operate the charging infrastructure (maintain and bill the clients)?	- Yourself, the logistic site owner - An external party			
	How should the charging infrastructure be optimized? Rank the following options by importance	1. Minimal TCO 2. Minimal CAPEX investments 3. Minimal Operational costs			

		4. Maximal Charging power 5. Minimal Footprint 6. Maximal lifetime 7. Ease of handling and maintenance 8. High availability, low downtime
	Currently, fast charging is done by a cable and a plug. Do you expect that other concepts will be developed in the future?	- Yes/No - I don’t know
	If yes: Please select the other concepts you expect to be commercially developed in the near future.	- Catenary at the highway, e-highway - Charging by automated plug connector - Automated charging by pantograph connector at BE-HDV standing still (e.g., like electric trains and trams) - Inductive charging

	Prioritizing properties of the Charging infrastructure by MoSCoW Logistic site owner can only select one option (NR=not relevant)	M	S	C	W	NR
	The plug is easy to handle and, the length of cable is sufficient					
	The plug is standardized					
	Renewable energy is produced (partly) locally on site					
	Renewable energy can be bought on the market at an acceptable price					
	A booking tool for the clients is available, so the usage rate is known					
	A payment and billing tool for the clients is available					
	Incentives to install charging equipment					
	Electrical grid reinforcement					
	An energy management system to achieve optimal charging at the lowest price (avoidance of peaks)					
	Stationary energy storage to achieve optimal charging					
	Vehicle-2-Grid communication to achieve optimal charging					
	Bidirectional charging					
	Amenities for truck drivers					
	The installation is done without impact on the logistic activities					
	The footprint of the charging infrastructure is minimal (both in area as in mass)					
	Long-term (hours) parking available (possibility for depot charging)					
	Megawatt Charging System (>900MW) is available					
	CCS (350 kW) and MCS (>900MW) available at the same station (price can differ between them, so option to opportunity charge at a lower price when time is not the limiting factor)					
	Power connection for conditioned trailers or e-trailers available					

	HRS for FCE-HDV (focus on gaseous hydrogen)	
	What will be the state of the hydrogen **(more than one option possible)**	- Gaseous (350 bar) - Gaseous (700 bar) - Liquid hydrogen - Compressed cryogenic hydrogen - I don’t know
	How will the hydrogen be transported to the HRS **(more than one option possible)**	- Local hydrogen production on site - Tube trailer (200 bar) - Tube trailer (500 bar) - Tube trailer (liquid hydrogen) - Pipeline

		- I don’t know
	How should the HRS be optimized? Rank the following options by importance	1. CAPEX investments 2. Operational costs (including hydrogen cost) 3. Refuelling speed 4. Footprint and minimal safety perimeter 5. Ease of handling 6. Maintenance and low downtime 7. Lifetime 8. Always achieving a State of charge higher than 95% 9. Total amount of hydrogen that can be refuelled
	Who will purchase the HRS (procurement and installation)?	- Yourself, the logistic site owner - An external party - Co-investment of the site owner and an external party
	Who will operate the HRS (maintain and bill the clients)?	- Yourself, the logistic site owner - An external party

	Prioritizing properties of the HRS by MoSCoW Logistic site owner can only select one option	M	S	C	W	NR
	The length of the hose is adequate and easy to handle.					
	The nozzle is easy to connect and disconnect and cannot freeze onto FCE-HDV (-20 to -40°C cooled hydrogen)					
	Possible to refuel FCE-HDV on the right and lefthand side of the truck.					
	High refuelling speed = fast refuelling time (at least 120 g/s)					
	Green hydrogen is available					
	700 bar hydrogen is available					
	700 bar and 350 bar available (price and refuelling rate can differ between them due to technical reasons. 350 bar could be less expensive per kilogram H2, however the total mass will be less, which results in smaller driving range)					
	Variable hydrogen prices related to pressure fuelled (350 and 700 bar)					
	Variable hydrogen prices related to time of the day (peak demand or not)					
	Achieve State of Charge (degree of filling) above 95%					
	Capable to refuel 100 kg of hydrogen at once (related to driving range of ±1000 km)					
	Communication with the ZE-HDV to optimize fuelling (mass and time)					
	Pay by credit card or pay per use over digital platform					
	Reservation of timeslot to fuel (no waiting at the pump for the client)					
	Unambiguous pricing displayed					
	Adjusted to turning cycle of longer truck-trailer combinations					
	Amenities for truck drivers					
	Footprint and safety perimeter is minimised by the design of the HRS					
	Hydrogen mass on site is below the SEVESO limit.					

Survey ‘ZE-HDV manufacturers’

Table:8 Survey questions ‘ZE-HDV manufacturers’

6	**Survey ZE-HDV manufacturer – general questions**	
	Questions	**Predefined answers / type of answer**
	What is the zero-emission truck technology that your company is developing right now (GCW>36 tons)? **(More than one option possible)**	- Battery electric vehicles - Fuel cell electric vehicles on gaseous hydrogen - Fuel cell electric vehicles on liquid hydrogen - Hydrogen trucks with combustion engine - Other, [fill in box]
	If they did not select BE-HDV and FCE-HDV: Why are you not investing in both BE-HDV and FCE-HDV?	- Open answer
	Are you aware of national funding schemes for ZE-HDV and the related infrastructure	- Yes, specify… - No
	Survey BE-HDV manufacturer – focus GCW>36 ton	
	Is a BE-HDV (GCW >36 tons) commercially available?	- Yes/no
	If *no*: When will a BE-HDV (GCW >36 tons) be commercially available?	- Numerical - I don’t know
	What is (will be) the energy content of the battery (kWh)?	- Numerical - I don’t know
	How will the total installed battery capacity evolve in the future?	- It will stay the same - It will decrease - It will increase - I don’t know
	Do you believe that BE-HDV with different battery sizes (and therefore different purchase prices) will be brought on the market by your company?	- Yes/no - I don’t know
	What is (will be) the weight of the battery (kg)?	- Numerical - I don’t know
	Which battery technology is (or will be) used in the commercial BE-HDV?	- Open answer - I don’t know
	Will the battery technology change in the future?	- Yes - No - I don’t know
	If yes: What battery technology will be implemented in the future?	- Open answer
	What is the expected lifetime of the battery on a commercial truck (yearly milage ≥ 120 000 km) expressed in years?	- Numerical - I can disclose the number in other unit (charging cycles, other yearly milage…), [fill in box] - I don’t know
	Will Vehicle-2-Grid (V2G) communication be available?	- Yes/No - I don’t know
	If *no:* When will V2G communication be available?	- Open answer
	Will the truck be able to do bidirectional charging?	- Yes/no - I don’t know
	If no: When will bidirectional charging be available?	- In the near future, please specify [fill in] - It will not be available

			- I don’t know		
	Are legal weight limitations, restricting the BE-HDV specifications?		- Yes - No - I don’t know		
	Are legal length limitations, restricting the BE-HDV specifications?		- Yes - No - I don’t know		
	What will be the driver cabin of the BE-HDV? **(More than one option possible)**		- Day cabin - Sleep cabin - I don’t know		
	Will the BE-HDV be compatible with all trailer types		- Yes - No - I don’t know		
	Will data of the BE-HDV, like State of charge, be available for dispatching software?		- Yes - No - I don’t know		
	Is there a minimal SOC needed to start fast charging automatically?		- Yes, please specify - No - I don’t know		
	Challenges to develop BE-HDV BE-HDV can be commercially deployed, since…	**Agree**	**Disagree**	**Not relevant**	**I don’t know**
	All components are available and standardised				
	the lifetime of components is adequate				
	The maintenance of the BE-HDV can be organized by the existing dealer network in their workshops.				
	Enough trained technicians are available to maintain the BE-HDV.				
	The homologation process is clear and standardized				
	BE-HDV can be deployed in intermodal missions				
	BE-HDV can be deployed in international missions				
	The risks related to BE-HDV (high voltage, fire hazard…) can be technically mitigated				
	The needs of the end-users are clear, and the characteristics of the electric truck are adjusted to them.				
	Would you like to comment on your answers? Do you think of other challenges regarding the development of BE-HDV?		Open answer		
	Survey FCE-HDV manufacturer – focus GCW>36 ton gaseous H2 at 350 and 700 bar				
	When will a FCE-HDV (GCW>36 tons) be commercially available?	- Numerical - I don’t know			
	What will be the state of the hydrogen in the FCE-HDV? **(More than one option possible)**	- Gaseous (350 bar) - Gaseous (700 bar) - Liquid hydrogen - Compressed cryogenic hydrogen - I don’t know			
	What will be the **total mass** of hydrogen in a 350 bar FCE-HDV (kg)?	- Numerical - I don’t know			
	What will be the **available mass** of hydrogen in a 350 bar FCE-HDV (kg)?	- Numerical - I don’t know			

	What will be the **total mass** of hydrogen in a 700 bar FCE-HDV (kg)?	- Numerical - I don't know
	What will be the **available mass** of hydrogen in a 700 bar FCE-HDV (kg)?	- Numerical - I don't know
	What will be the fuel cell power installed at the vehicle (kW)?	- Numerical - I don't know
	What will be size of the battery (kWh)?	- Numerical - I don't know
	What will be the total weight of the hydrogen vessels skid, the fuel cell, and the battery (kg)?	- Numerical - I don't know
	What will be the expected lifetime of the fuel cell, expressed in hours?	- Numerical - I don't know
	What will be the driver cabin of the FCE-HDV? **(More than one option possible)**	- Day cabin - Sleep cabin - I don't know

	Challenges to develop FCE-HDV FCE-HDV can be commercially deployed, since…	**Agree**	**Disagree**	**Not relevant**	**I don't know**
	All components are available and standardised				
	the lifetime of components is adequate				
	The maintenance of the FCE-HDV can be organized by the existing dealer network in their workshops.				
	Enough trained technicians are available to maintain the FCE-HDV.				
	The homologation process is clear and standardized				
	FCE-HDV can be deployed in intermodal missions				
	FCE-HDV can be deployed in international missions				
	The risks related to FCE-HDV (high voltage, fire hazard…) can be technically mitigated				
	The needs of the end-users are clear and the characteristics of the FCE-HDV are adjusted to them.				
	Would you like to comment on your answers? Do you think of other challenges regarding the development of FCE-HDV?	Open answer			

	Prioritizing properties of the Charging infrastructure by MoSCoW (select one, NR=not relevant)	**M**	**S**	**C**	**W**	**NR**
	The BE-HDV can be easily connected to the charging infrastructure (length cable, automatic grounding, galvanic isolation…)					
	Charging is started automatically					
	Possibility to charge BE-HDV on the right- and lefthand side of the truck.					
	The connection between BE-HDV and charger is standardised (one plug fits all)					
	Charging station is adjusted to the turning cycle of long trucks-trailer combinations					
	Renewable electricity is available					

	Megawatt Charging System (>900MW) is available					
	CCS (350 kW) and MCS (>900MW) available at the same station (price can differ between them, so option to opportunity charge at a lower price when time is not the limiting factor)					
	Variable electricity prices related to the charging power (kW)					
	Variable charging prices related to time of the day (charging during peak demand is more expensive)					
	Communication between charger and the BE-HDV to optimize charging locally (power and time)					
	Vehicle to grid (V2G) communication to optimize charging at grid level					
	Bidirectional charging for (local) grid support services (peak managing, energy storage…)					
	Pay by credit card or pay per use over digital platform					
	Reservation of timeslot to charge (no waiting at the charger)					
	Automated charging (connection between BE-HDV and infrastructure is made without interaction of the driver)					
	Amenities for truck drivers					
	Small footprint (both in area and in weight)					
	Long term (hours) parking available (possibility for depot charging)					
	Power connection for conditioned trailers or e-trailers available					
	Would you like to comment on your answers? Do you think of other requirements of Charging infrastructure?					

	Truck OEM: Prioritizing properties of the HRS by MoSCoW (select one)	M	S	C	W
	The length of the hose is adequate and easy to handle.				
	The nozzle is easy to connect and disconnect and cannot freeze onto FCE-HDV (-20 to -40°C cooled hydrogen)				
	Possible to refuel FCE-HDV on the right and lefthand side of the truck.				
	High refuelling speed = fast refuelling time (at least 120 g/s)				
	Green hydrogen is available				
	700 bar hydrogen is available				
	700 bar and 350 bar available (price and refuelling rate can differ between them due to technical reasons. 350 bar could be less expensive per kilogram H2, however the total mass will be less, which results in smaller driving range)				
	Variable hydrogen prices related to pressure fuelled (350 and 700 bar)				
	Variable hydrogen prices related to time of the day (fuelling during peak demand is more expensive)				
	Achieve State of Charge (degree of filling) above 95%				

	Capable to refuel 100 kg of hydrogen at once (related to driving range of ±1000 km)				
	(IR) Communication with the ZE-HDV to optimize fuelling (mass and time)				
	Refuelling protocols are available				
	Pay by credit card or pay per use over digital platform				
	Reservation of timeslot to fuel (no waiting at the pump)				
	Automated fuelling (nozzle is connected by robot arm)				
	Adjusted to turning cycle of longer truck-trailer combinations				
	Amenities for truck drivers				
	Would you like to comment on your answers? Do you think of other requirements of HRS?				

Survey 'Infrastructure manufacturer and operators'

Table:9 Survey question 'Charging infrastructure manufacturer'

7	**Needs and requirements charging infrastructure manufacturer**	
	Questions	**Predefined answers / type of answer**
	What is the maximum power your commercial chargers can charge at, at this moment?	- Numerical - I don't know
	What will be the maximum power of the infrastructure in the near future?	- Numerical - I don't know
	Are clients demanding higher powers than you can provide today?	- Yes - No, please specify - I don't know
	Is all the needed hardware available for MCS?	- Yes/no - I don't know
	Are all the needed standards and protocols available?	- Yes/no - I don't know
	What type of charging equipment connection will be used in the future?	- Cable and plug, manually - Cable and plug, automated - Catenary above a road - Pantograph system at a logistic site or charging station - Inductive charging
	Are suitable land slots available to install charging infrastructure?	- Yes/no - I don't know
	Where will most of the charging infrastructure be installed?	- at the premises of the truck end users (truck depot) - at logistics sites - at commercial charging stations along the road - I don't know
	Is data available to predict the charging demand based on traffic density and flow data?	- Yes/no - I don't know
	Can trucks use the existing charging infrastructure for cars?	- Yes/no - I don't know
	If no, or no, not all:	- The plug is not compatible with BE-HDV. - The cable length will be limiting

	What are the main reasons trucks cannot use the charging equipment installed for passenger cars? (more than one option possible)	- The location is not accessible by trucks due to driving circle - The location is not accessible by trucks due to height restrictions
	Are you aware of national funding programs for charging infrastructure?	- Yes/no - I don’t know

	Prioritizing properties of the Charging infrastructure by MoSCoW (select one, NR=not relevant)	**M**	**S**	**C**	**W**	**NR**
	The BE-HDV can be easily connected to the charging infrastructure (length cable, automatic grounding, galvanic isolation…)					
	Charging is started automatically					
	Possibility to charge BE-HDV on the right- and lefthand side of the truck.					
	The connection between BE-HDV and charger is standardised (one plug fits all)					
	Charging station is adjusted to the turning cycle of long trucks-trailer combinations					
	Renewable electricity is available					
	Megawatt Charging System (>900MW) is available					
	CCS (350 kW) and MCS (>900MW) available at the same station (price can differ between them, so option to opportunity charge at a lower price when time is not the limiting factor)					
	Variable electricity prices related to the charging power (kW)					
	Variable charging prices related to time of the day (charging during peak demand is more expensive)					
	Communication between charger and the BE-HDV to optimize charging locally (power and time)					
	Vehicle to grid (V2G) communication to optimize charging at grid level					
	Bidirectional charging for (local) grid support services (peak managing, energy storage…)					
	Pay by credit card or pay per use over digital platform					
	Reservation of timeslot to charge (no waiting at the charger)					
	Automated charging (connection between BE-HDV and infrastructure is made without interaction of the driver)					
	Amenities for truck drivers					
	Small footprint (both in area and in weight)					
	Long-term (hours) parking available (possibility for depot charging)					
	Power connection for conditioned trailers or e-trailers available					
	Would you like to comment on your answers? Do you think of other requirements of Charging infrastructure?					

Table:10 Survey question 'HRS manufacturer'

8	Needs and requirements the HRS manufacturer	
	Questions	**Predefined answers / type of answer**
	What will be the state of the hydrogen at the HRS your company develops? **(more than one option possible)**	- Gaseous (350 bar) - Gaseous (700 bar) - Liquid hydrogen - Compressed cryogenic hydrogen - I don't know
	What will be the daily refuelling capacity of the future hydrogen refuelling stations (kg/day)?	- Numerical - I don't know
	If daily refuelling capacity is stated: What will the compressor capacity (kg/day) at such a HRS?	- Numerical - I don't know
	If daily refuelling capacity is stated: What will the installed power for hydrogen cooling at such a HRS?	- Numerical - Cooling will not be necessary - I don't know
	If daily refuelling capacity is stated: What will be the total installed power (cooling and compression) of such a HRS?	- Numerical - I don't know
	What will be the dispensing rate of commercial HRS for FCE-HDV in the near future? **(one possible answer)**	- 120 g/s - Above 300 g/s - The dispensing rate will be dependent on the properties of the FCE-HDV and the HRS - Other
	Are there the necessary refuelling standards and protocols available?	- Yes, please specify - No, please specify - I don't know
	If no: When do you expect that the necessary standards and protocols will be available?	-
	Is the necessary hardware available on the market?	- Yes, please specify - No, please specify - I don't know
	If no: When do you expect that the necessary hardware will be available?	-
	Are you aware of national funding programs for charging infrastructure?	- Yes, please specify - No - I don't know

	HRS manufacturer and operator **Prioritizing needs and requirements of the HRS by MoSCoW**	M	S	C	W
	The length of the hose is adequate and easy to handle.				
	The nozzle is easy to connect and disconnect and cannot freeze onto FCE-HDV (-20 to -40°C cooled hydrogen)				
	Possible to refuel FCE-HDV on the right and lefthand side of the truck.				
	High refuelling speed = fast refuelling time (at least 120 g/s)				
	Green hydrogen				
	700 bar hydrogen available				
	700 bar and 350 bar available (price and refuelling rate can differ between them due to technical reasons. 350 bar				

	could be less expensive per kilogram H2, however the total mass will be less, which results in smaller driving range)				
	Variable hydrogen prices related to pressure fuelled (350 and 700 bar)				
	Variable hydrogen prices related to time of the day (fuelling during peak demand is more expensive)				
	Achieve State of Charge (degree of filling) above 95%				
	Capable to refuel 100 kg of hydrogen at once (related to driving range of ±1000 km)				
	Communication between HRS and FCE-HDV to optimize fuelling (mass and time)				
	Pay by credit card or pay per use over digital platform				
	Reservation of timeslot to fuel (no waiting at the pump)				
	Unambiguous pricing displayed				
	Automated fuelling (nozzle is connected by robot arm)				
	Adjusted to turning cycle of longer truck-trailer combinations				
	Amenities for truck drivers				
	Estimation of the amount of hydrogen that can be refuelled (mass) is displayed before start of refuelling				
	Would you like to comment on your answers? Do you think of other HRS needs and requirements?				

Survey 'Infrastructure operator'

Table:11 Survey question 'Charging Infrastructure operator'

9	**Needs and requirements charging infrastructure manufacturer**	
	Questions	**Predefined answers / type of answer**
	What is the maximum power your commercial chargers can charge at, at this moment?	- Numerical - I don't know
	What will be the maximum power of the infrastructure in the near future?	-
	Are clients demanding higher powers than you can provide today?	-
	Is all the hardware available?	-
	Are all standards available?	-
	Standardised plug in Europe? Worldwide	-
	What type of charging equipment connection will be used in the future?	- Cable and plug, manually - Cable and plug, automated - Catenary above a road - Pantograph system at a logistic site or charging station - Inductive charging
	Are suitable land slots available to install charging infrastructure? - operator	-
	Will the charging infrastructure be installed at the premises of the end users?	-

	Is data available to predict the charging demand based on traffic density and flow data?	-
	Can trucks use the existing charging infrastructure for cars?	-
	If no, or no, not all: What are the main reasons trucks cannot use the charging equipment installed for passenger cars? (more than one option possible)	- The plug is not compatible with BE-HDV. - The cable length will be limiting - The location is not accessible by trucks due to driving circle - The location is not accessible by trucks due to height restrictions

Survey ‘Trailer manufacturer and leasing’

Table:12 Survey question ‘Trailer manufacturer and leasing’

11	**Needs and requirements Trailer manufacturer**				
	Questions	**Predefined answers / type of answer**			
	What type of trailers does your company manufacture or lease? (more than one option possible)	- Standard trailers - Cooled trailers, reefers - Conditioned trailers			
	Does your company own trailers?	- Yes - No - I don’t know			
	When yes: How many trailers does your company own?	- numerical			
	Are your clients demanding zero emissions solutions for conditioned trailers or trailers with an electrical tailgate?	- Yes - No - I don’t know			
	Which of the following technologies will be implemented on the future trailers?	- E-axle for regenerative braking together with battery - PV panels integrated on the trailers roof combined with a battery on the trailer - Only a battery that can be charged from the grid - Battery on the trailer connected with ZE-HDV to increase the driving range			
	Is your company developing or demonstrating e-trailers or e-dolly’s?	- Yes - No - I don’t know			
		Agree	**Disagree**	**Not relevant**	**I don’t know**
	We are developing e-trailers and e-dollies, since…				
	We want to learn.				
	Clients are requesting it.				
	There is a business case for e-trailer and e-dolly’s				
	It lowers the emissions.				
	It is more energy efficient than the current technologies				
	It can extent the driving range when combined with ZE-HDV				
4.1.29	Do you want to comment on some of your answers? Do you have other reasons to invest in e-trailers or e-dollies?	- Open answer			

Survey ‘Shipper’

Table:13 Survey questions ‘Shipper’

12	**Needs and requirements Shipper**				
	Questions	**Predefined answers / type of answer**			
	Are you interested in shipping goods by ZE-HDV	- Yes/no - I don’t know			
	Are you investigating other ways to lower the emissions of your transports?	- Yes, implementation of biofuels - Yes, multimodal transportation - Yes, other [fill in] - no			
	Are you willing to adjust your logistics to implement ZE-HDV?	- Yes/no - I don’t know			
	Are you willing to pay more to ship goods by ZE-HDV?	- Yes/no - I don’t know			
	Are you aware of public, national funding schemes for ZE-HDV and the needed infrastructure?	- Yes - No - I don’t know			
	When yes: Please, specify	- Open answer			
	Please indicate whether following statements are reasons to not use ZE-HDV **‘We do not ship goods by ZE-HDV, since’**	**Agree**	**Disagree**	**Not relevant**	**I don’t know**
	ZE-HDV are not commercially available.				
	The charging and fuelling infrastructure are not commercially available.				
	the risk of not delivering on time due to technical issues is not mitigated enough.				
	The shipping cost is higher.				
	We do not ship goods by ZE-HDV, since the goods cannot be transported by ZE-HDV due to technical or regulative reasons (ADR goods, multimodal missions, conditioned goods...)				
	it is unclear that it will lead to lower emissions.				
	Our clients are not requesting transport by ZE-HDV				
	due to safety aspects (high voltage, fire hazard…).				
	since it is not societal accepted (environmental impact of battery and hydrogen production)				
	Do you want to comment on some of your answers? Do you have other reasons for not shipping by ZE-HDV?				
	Reasons to use ZE-HDV	**Agree**	**Disagree**	**Not relevant**	**I don’t know**
	We want to learn from practice				
	Our clients are requesting transport by ZE-HDV				
	ZE-HDV have the advantage that they can enter certain Low Emission Zones for last mile delivery.				
	ZE-HDV have the advantage that they are quieter (less noise), which can positively impact delivery time windows				

	We want to lower our emissions				
	since we trust the ZE-HDV technologies and expect the goods to be delivered on time.				
	Do you want to comment on some of your answers? Do you have other reasons for shipping by ZE-HDV?				

APPENDIX II – List of identified ‘Needs and requirements’

The Needs and requirements are divided into six categories. At this stage of the validation process, we will give only the ‘Need or/and requirement’ and the status quo. During Session I of the ZEFES symposium the importance of the ‘Need or/and requirement’ will be assessed, together with potential risks. Also, it will be assessed if KPIs are missing

(i) truck-trailer technology: the truck-trailer combination is technically able to do the mission		
	Need or/and requirement	**Status quo / questions / more details**
T1	**Truck-trailer combination** is seen as **one asset** to determine whether a mission is feasible, since both assets can *consume* and *store* energy. The energy consumption for a mission is depending on the characteristics of both.	- A diesel truck can be combined with all types of trailers, can be refuelled in minutes and can drive more than 1000 km at once. Its capabilities are not limiting the logistic operations, it is a ‘one-solution-fits all’. - A ZE-HDV should provide energy to some trailer types (cooling / tailgate), therefore the energy balance should be made over the truck-trailer combination. - This ‘Need or/and requirement’ is more an assumption - In planning and dispatching software, the capabilities and needs of the combination must be taken into account (link F1).
T2	**Driving range** ZE-HDV is sufficient for the logistic operations of a transport company (can varies from use case to use case).	- Required driving range depends on the use cases. More than 750km driving range is a common request (cfr. Interviews and survey responses) - Driving range is not only dependent on the energy stored on the vehicle, but on the overall efficiency of the drive train and HVAC system, the payload, the route followed…
T3	**Transport capacity** is not limited, both in payload and availability of the truck	- What will be the impact on payload and availability when a ZE-HDV is used? - Less payload due to weight of the battery pack and hydrogen skid - More charging and refuelling time = less time to drive = less availability - Will you need more trucks to do the same work?
T4	**ZE trailers** are available (cooling and tailgate electrified)	- Trailer manufacturers are developing ZE trailers, and the first models are commercially available

T5	The truck-trailer combination is **modular**, and the specifications / capabilities can be adjusted to the needs of the end-user	- Diesel truck can be applied in all use cases, this is not expected for ZE-HDV (limited driving range/payload) - Will the market evolve to a customized truck, whose characteristics are defined by the missions it will do? - Will a range of trucks models with varying capabilities and CAPEX investments be available?
T6	**The energy stored** on the truck-trailer combination is known by the driver can be predicted	- The characteristics of the components and energy vector are more depending on the weather (batteries, hydrogen storage), which means that the energy storage can alter from day to day, and therefore also the driving range - Drivers are not familiar with the concept of State of Charge (for both H2 and batteries). - FCE-HDV: energy is stored in a battery, plus the mass of hydrogen on the truck, how can it be converted to one, understandable parameter. - Is stating the expected driving range enough?
T7	**Energy consumption** of the truck-trailer combination can be predicted.	- An electric driveline is more energy-efficient than an ICE, however the characteristics of the components and the energy vector are more dependent on the weather (batteries, hydrogen storage), which means that the energy consumption can alter. - Also impact of regenerative braking and unplanned events - Will truck end-user be able to work with the variability in energy consumption throughout the year and type of mission.
T8	It is clear what the impact of **weather** would be on the capabilities of the truck trailer combination	Linked to T6 and T7
T9	Trucks and trailers are deployable in **different modes** (water and rail) *(Technical point of view)*	- Charging equipment for trailer preconditioning or for (slow) charging is available on ferry or train - The dimension of the ZE-HDV is appropriate for multi-modal transport -
T10	**Knowledge and resources available** in the logistic company to implement and operate ZE-HDV	- The transport operator can select and procure a suitable ZE-HDV option for its operations - The transport operator knows how to implement the ZE-HDV in the fleet - The transport operator can derive which missions are feasible with the ZE-HDV - The transport operator can assess the need for infrastructure - The transport operator is capable of calculating the TCO of ZE-HDV - The transport operator can organize maintenance - Drivers are trained, know the safety precautions specific for ZE-HDV, know how to refuel/charge and know what to do when an ZE-HDV breaks down
T11	The truck end-user **trusts** the new technology	- The end-user believes that the technology is safe - High availability of the truck-trailer combination, low downtime, is achieved during operations

T12	**Maintenance** can be organised	- The truck OEM organizes a network of dealers that can do the maintenance work, as it is now for conventional trucks
T13	The trucks are **connected** (digitalisation, communication – V2X is possible)	- The driving range of ZE-HDV is smaller and therefore significantly more charging/refuelling will be needed. - Communication with the dispatching/planning software will be needed to check whether charging/fuelling is necessary to fulfill the mission - Communication with infrastructure will be necessary to optimize the charging/fuelling
T14	A **contingency plan** can be drafted	- Some logistic companies have a contingency plan for disruptive events (p.e. oil crisis during the 1970s). - How can ZE-HDV be made more resilient to disruptive events (p.e. black out of the power grid)?

(ii) integration in the logistic operation: can ZE-HDV be integrated in logistic (fleet) operation?		
	Need or/and requirement	**Status quo**
F1	The ZE-HDV (fleet) can be implemented in an existing fleet by an **fleet management system** that takes the into account the capabilities of ZE-HDV	- Both for dispatching / day planning - Does the implementation strategy differ in relation to the share of ZE-HDV in the fleet?
F2	It is clear **where to** charge/fuel and how it will fit in the logistic operation	- Link to **Infrastructure** - Charging and fueling locations are missing - Booking time slots to charge
F3	It is clear what is **the impact** of charging/refuelling time will be on the logistics operation	- The time to charge/fuel without impacting logistic operations is limited. Some respondents of the survey stated to have only 1 hour per day to charge/fuel - It is unclear whether charging during the break of the driver will be practical feasible
F4	It is clear what is **the impact** of less payload and availability (maintenance time) will be on the logistics operation	- Not only the charging/fueling time will limit the deployability, also less payload and breakdowns will affect the operation

(iii) Social acceptance: is it safe and sustainable to use ZE-HDV		
	Need or/and requirement	**Status quo**
S1	A **methodology** to determine, if the ZE-HDV run on **renewable energy** (electricity and hydrogen) is available	- The emission reduction achieved by transitioning current fleet to an electric fleet (if market ready) with current energy mix in certain countries (e.g., Germany, Poland) would be very limited (less than 30%). Not all electricity on the grid is renewable - Most hydrogen is made from fossil fuels, less than 2% is made by electrolysis. Furthermore, the electricity used for electrolysis should be renewable.
S2	Emission over the **full life cycle** of a truck-trailer combination is known	- GLEC framework, CountEmissionEU - Shift from well-to-wheel analysis to full Life Cycle Analysis (LCA) approach - Transensus LCA project
S3	Vehicle has to be **safe,** both while driving and charging	- Special attention needs to be given to fire safety and education/research on how the fire can be extinguished. - The time that a truck can charge is limited and depends on the use case of the truck. Every opportunity to charge a BE-HDV should be taken. This means that for international, multiple-day missions the BE-HDV should be able to charge during the night, also when the driver is in the vehicle.
S4	It is clear how the **job of truck driver** will change, and the driver will be trained to do it in a safely manner	- Link with **T10**
S5	It is clear what to do in case of emergency.	- Drivers, first aid responders… are trained
S6	Safety regulations and precautions are known	- It is clear where battery and hydrogen trucks can drive, charge/fuel and park (underground, inside…) and if some precautions are necessary. - Link with **Legal barriers**

(iv) Infrastructure: will ZE-HDV be able to refuel or charge?		
	Need or/and requirement	**Status quo**
VIEW Truck end-user		
I1	Charging or fuelling infrastructure is **available.**	- Currently the availability of charging and fuelling infrastructure is a bottleneck. The current network is not sufficient - Logistic operations are delaying the implementation of ZE-HDV due to the uncertainty about the infrastructure
I2	Charging or fuelling a ZE-HDV should be **easy and safe.**	- manual action is easy to do, only one action to connect - clear manual - clear instructions in case of emergency - easy to pay
I3	**Driver amenities** are available at charging stations and HRS	- shops, restaurants, sanitary facilities… as it is now
I4	**Charging** can be combined with **overnight** parking	- charging during the 11-hour break should be feasible (at relatively lower power)
I5	Charging / fuelling infrastructure available at the **right location**	- the infrastructure is available at logistic hubs (ports, distribution centre, terminals…) and the corridor (highway) itself
I6	Charging / fuelling infrastructure available at the **right power/pressure**	- It is expected that the needs of the customer will differ in relation to the use cases the customer is fulfilling. - (International) long haul use cases will expect opportunity charging during the driver break of 45 min, while other use cases could use overnight low power charging - Time available for charging defines the power needed. Maybe optimization is possible when available charging time can be communicated to the infrastructure, for both truck end-user as infrastructure operator.

I7	**Waiting time** at the charging station/HRS is minimal (not waiting time during refuelling or charging, but waiting time to get a charger/refuelling nozzle)	- enough chargers or fuelling nozzles are available to meet peak demand - Link with **F2** – charging infrastructure can be booked. So the *load/capacity factor* of the infrastructure is known, which is also beneficial for the operator.
I8	**Availability and reliability** of the infrastructure is high	- Downtime should be minimal. Truck end-users are counting on infrastructure to work. There will be no/few alternatives during the start of the implementation. When infrastructure is down, the risk exists that ZE-HDV get stalled.
I9	The charging station/HRS is **accessible** by truck-trailer combination	- the location can accommodate truck-trailer combinations - turning circle, height of roof, strong floor, separated from passenger cars (safety), separated from conventional fuels: otherwise, stricter regulations (e.g., ATEX) - Also for EMS combinations
I10	Charging infrastructure for **trailers** is available	- Especially valid for cooled trailers where preconditioning is needed. Cooling with the ZE-HDV will affect the driving range.
I11	The charger/refuelling infrastructure is capable of fuelling/charging the wanted **amount of energy**	- This is especially important for HRS: an HRS should be able to refuel until a SOC above 95%. - This means that at peak demand (maximum back-2-back refuellings), the HRS (at 700 bar) is still capable of providing +75 kg of hydrogen - The compression capacity and local H2 storage of the HRS should be designed in such way that the demand can be met
I12	Connected ZE-HDV, **V2X communication**	- charging infrastructure: there is communication between vehicle and charger - HRS: vehicle can communicate temperature and pressure via infrared communication to the HRS, however more optimal fuelling would be possible if there are feedback loops, and more variable fuelling (update fuelling protocols is investigated cfr. PRHYDE)
I13	**Unambiguous pricing displayed** or communicated at the charging and refuelling stations	- Is stated in the AFIR regulation, but is for older infrastructure not always the case - Do we expect varying prices during the day? Will charging at peak moments be more expensive?
I14	At charging and fuelling stations can be **paid with conventional means** (credit card, pay per use over digital platform)	- Is stated in the AFIR regulation, but is for older infrastructure not always the case

I15	**Quality of the hydrogen** should be fuel cell grade	- Hydrogen from electrolysis is on paper fuel cell quality and has a superior quality compared to H2 from steam methane reforming. However, contamination along the way can happen (tube trailer, HRS). Common contaminants are water (should not be a real problem for the fuel cell, but if you cool down to -20/-40°C things get blocked by ice), nitrogen, oil and lubricants from the compressor (compressor should be engineered to minimize the risk). These contaminants can damage the fuel cell. - Currently a paper of the supplier says that the quality is ok, no obligation to do test
VIEW infrastructure operator		
I16	The need for charging/fuelling infrastructure is clear (location + demand). An expected daily consumption profile is available.	- Charging/HRS infrastructure operators will only invest in a location when enough demand is expected. - Charging/HRS operators need more insights on which are the important corridors and how the demand will increase in time - the business case for infrastructure is strongly dependent on the usage. - High capacity factor (usage rate) will lead to a better business case, and possibly lower prices for the end customer - the design of the infrastructure is optimal when based on the actual demand profile - Modularity in infrastructure design will be key
I17	It is economically feasible to operate the infrastructure	- Price of hydrogen / electricity should cover the molecule/energy price, operational costs and CAPEX depreciation; however, it should be a price that the logistic operators are willing to pay.
I18	It is technically feasible to operate the infrastructure	- All hardware is available and reliable (HRS 700 bar and MCS, no monopoly) - Maintenance can be organized - All protocols and software are available - Can the charging power be adaptable?
I19	**Suitable land slots** are available	- for both HRS and charging stations the location impacts the economic viability - at corridor/hub for enough demand - Charging: sufficient power connection - HRS: source of green hydrogen, supply by tube trailer or pipeline, power connection

I20	The infrastructure can be expanded in a **modular** way	- The capacity of the infrastructure should grow together with the demand (ZE-HDV fleet size) - Investments spread in time are better for the infrastructure business case - modularity can improve the reliability/availability
I21	Optimisation of charging/fuelling both technical and financial	- V2X can be used to optimize the charging from the view of the end-user = as fast as possible, but V2X can also be used to optimise the charging from operators' point of view (energy management) - Optimization of HRS operation should also be feasible. So the cost of compression and cooling is minimized. When hydrogen is produced on site, energy management can be beneficial.
I22	Quality of hydrogen can be tested fast and in an easy way	- Contaminants should be detected fast, otherwise the fuel cells of your clients can be affected. - Inline, continuous detection would be best option, but technical not feasible and expensive - sampling can be done, but limited laboratories that offer this service (+expensive)
I23	Reliable GREEN hydrogen supply to the HRS Reliable renewable energy supply to the charging infrastructure	- hydrogen can be supplied to the HRS by tube trailer or pipeline (for both on and off-site production). - you can only attain a high availability for the HRS as the supply is reliable - e.g., Swiss demonstration Hyundai was affected by a shortage of renewable hydrogen/tube trailers - Renewable energy is more available, but still a small share of the market.
VIEW logistic site operator that wants to install infrastructure on its own sites		
I24	Minimal impact of installation of infrastructure on logistic operations	- When infrastructure is installed on logistic site, the impact of the installation itself should be minimal, in combination with a small footprint
I25	Minimal impact of operation of infrastructure on logistic operations	- Space will need to be allocated to charging vehicles. Are there enough parking spaces available?

(v) Viable business case: without it, there will be no implementation of ZE-HDV.

	Need or/and requirement	Status quo
B1	**TCO** of ZE-HDV can be calculated	- Fleet ownerships is very fragmented with most of the owners with fleets below 10 trucks therefore, investing in these trucks is very risky particularly with a questionable business model - It is unclear what the CAPEX, yearly mileage, capacity, fuel/energy cost, lifetime, residual value, funding, insurance, maintenance cost will be… In its uncertain how the market evolves (vehicles and energy)
B2	Assessment of **new business models for ZE-HDV**	- New business models as pay per use, transport as a service (TaaS), mutualization/sharing of assets are emerging
B3	Realistic scenarios to reach **economies of scale** are drafted and defined in time	- Logistic companies have sustainability targets. Will the market mature fast enough?
B4	Incentives to invest in ZE-HDV and related infrastructure are available	- Discouragements for fossil fuels - Maut throughout Europe known
B5	The **emission reduction** can be monetized	- Advantages both in kind (entrance low emission zones) and financial could help to implement ZE-HDV. - Are the clients/shippers willing to pay more for zero-emission transport - Difficult to justify a premium cost to customers when using electric trucks - Trust in emissions reduction reporting and pricing
B6	Renewable electricity and hydrogen should be affordable for logistic companies	
B7	Incentives for charging and fuelling infrastructure	
B8	TCO / business case can be calculated for the infrastructure	- all the necessary parameters are known

B9	New business model to operate infrastructure are assessed	- How does Pay per use, TaaS affect the way you finance infrastructure - joint ventures of front runners

(vi) Legal barriers: can logistic companies use the ZE-HDV as they want without legal barriers?		
	Need or/and requirement	Status quo/ questions
L1	Innovative technologies (trucks and infrastructure) can be implemented since a regulative framework exists	- Directive, authorities and local permitting governments provide a clear regulative framework. At the moment this can be missing. - Fast chargers and HRS are relatively new technologies, and a standardized permitting procedure is not available in all countries. The technology is unknown by local authorities, which can affect the permit request - Can battery electric truck be on ferries? All transport modes are accessible for ZE-HDV - Can you drive with hydrogen in a low emission zone or a tunnel? All roads are accessible for ZE-HDV

APPENDIX III – TCO studies literature review

Table 14: Literature review summary - TCO

	Heliyon 2022	**H2Accelerate 2022**	**ICCT 2022a**	**ITS 2022**	**ICCT 2022b**	**Applied Energy 2022**	**ITF 2022**
Full Title	A comparative total cost of ownership analysis of heavy duty on-road and off-road vehicles powered by hydrogen, electricity, and diesel	Analysis of cost of ownership and the policy support required to enable industrialisation of fuel cell trucks	Fuel-Cell Hydrogen Long-Haul Trucks in Europe: A Total Cost of Ownership Analysis	Evaluation of the Economics of Battery-Electric and Fuel Cell Trucks and Buses: Methods, Issues, and Results	A meta-study of purchase costs for zero-emission trucks	Analyzing the competitiveness of low-carbon drive-technologies in road-freight: A total cost of ownership analysis in Europe	Decarbonising Europe's Trucks: How to Minimise Cost Uncertainty
Author(s)	Cameron Rout, Hu Li, Valerie Dupont, Zia Wadud	not specified	Hussein Basma, Yuanrong Zhou, and Felipe Rodríguez	Andrew Burke, Marshall Miller, Anish Sinha, Lew Fulton	Ben Sharpe, Hussein Basma	Bessie Noll, Santiago del Val, Tobias S. Schmidt, Bjarne Steffen	Matteo Craglia
Publication Date	December 2022	September 2022	September 2022	August 2022	February 2022	January 2022	2022
URL	https://www.sciencedirect.com/science/article/pii/S2405844022037057	https://h2accelerate.eu/wp-content/uploads/2022/09/H2A-Truck-TCO-and-Policy-Support-Analysis-VFinal.pdf	https://theicct.org/wp-content/uploads/2022/09/eu-hvs-fuels-evs-fuel-cell-hdvs-europe-sep22.pdf	https://escholarship.org/uc/item/1g89p8dn	https://theicct.org/wp-content/uploads/2022/02/purchase-cost-ze-trucks-feb22-1.pdf	https://www.sciencedirect.com/science/article/pii/S0306261921013659?via%3Dihub	https://www.itf-oecd.org/sites/default/files/docs/decarbonising-europes-trucks-minimise-cost-uncertainty.pdf

Methodology/TCO components	vehicle operating expenses (incl. fuel cost, maintenance, tax and insurance, component replacement)	capital cost depreciation (incl. sensitivity analysis for truck capital cost, vehicle lifetime and residual value)	fixed costs (vehicle price, residual value, financing, taxes, vignette)	initial purchase cost of vehicle	key component costs for battery-electric and hydrogen fuel cell trucks (incl. energy storage system, electric drive system, accessories, safety components, structural elements, cost estimates for manufacturing and assembly, manufacturer indirect costs) and profit	capital expenditure (initial purchase cost of vehicle, incl. powertrain, energy storage, rest of truck, subsidy for initial purchase, scrappage value, discount rate based on lifetime)	capital expenditure (incl. vehicle glider and components, residual value)
	vehicle capital expenses (essentially acquisition cost, incl. vehicle price, battery/fuel cell resale, grants and incentives, residual value)	fuel cost (with sensitivity analysis for fuel consumption)	operating costs (hydrogen price, diesel price, maintenance costs, road tolls)	energy use cost		operating expenditure (annual operating cost, incl. fuel, infrastructure, tolls, wages, operation and maintenance, insurance)	operating expenditure (incl. energy and infrastructure cost, operational cost, maintenance, vehicle financing)
				maintenance cost			
				time-based discount rate and residual value			

Vehicle type(s)	mixed fleet of on-road and off-road FCEVs against BEV and ICEV equivalents using a captive fleet (Leeds City Council (LCC)) and an off-road fleet (Leeds Bradford Airport (LBA)) as the case studies	fuel cell and diesel truck (large rigid and articulated vehicles, no further specifications)	4x2 long-haul tractor-trailers (42-tonne FCET and 40-tonne diesel tractor-trailer)	various types and classes of medium-duty and heavy-duty battery-electric and hydrogen fuel cell vehicles, incl. US class 8 box trucks and long-haul tractor trailer trucks	tractor-trailers (US class 8 long-haul trucks and their equivalent class 5 long-haul tractor trucks in Europe)	5 drive technologies, incl. battery electric truck and fuel cell electric truck (HDT- long haul vehicle with weight of 32 tonnes and 14 tonnes total payload capacity)	battery electric vehicles (BEV), electric road system vehicles (ERSV), fuel cell electric vehicles (FCEV) across European vehicle groups 1-5 and 9-12 (incl. HDVs)
Vehicle lifetime	10 years	5 years	5 years	2 scenarios (5-year initial ownership, 15-year societal cost)	not specified	8 years for HDT-long haul segment	7 years
Study time horizon	present year (2021) to 2050	present year (2021) to 2030	present year (2022) to 2030	2020 to 2040	2020 to 2030	present year (2021)	present year to 2050
Geography	UK	European Union	7 European countries (France, UK, Germany, Italy, Spain, the Netherlands, Poland)	United States	North America and Europe	10 European countries (France, Germany, Italy, Netherlands, Norway, Poland, Spain, Sweden, Switzerland, UK)	Europe
Sensitivity analysis	Yes, for 5 parameters	Yes, for 4 parameters	Yes, for 5 parameters	Yes, for 5 parameters	Yes, for 6 parameters	Yes, for 5 parameters	Yes, for 16 model inputs

Main findings	For all vehicles considered in the study, the lowest TCO recorded in 2021 under base case conditions used electricity as the power source, suggesting BEV technology powered from renewable sources offers cost advantages over electrolytic and non-electrolytic hydrogen powered vehicles, as well as diesel. However, a number of hydrogen powered vehicle types still offered a lower TCO than diesel in 2021. These included buses, trucks, tippers, and forklifts using hydrogen from 100% RES hydrogen generated on-site.	In the first two phases of deployment (R&D and deployment phase, industrial scale-up), fuel cell trucks are not able to compete with the incumbent diesel vehicles on a pure ownership cost basis under only the policy mechanisms available today (RED II credits and excise tax on diesel).	Fuel cell long-haul trucks can reach TCO parity with their diesel counterparts by 2030 in Europe if the at-the-pump green hydrogen fuel price is around 4 €/kg.	Battery-electric and fuel cell heavy-duty vehicles will be close to cost competitive with engine-powered vehicles around 2030.	Upfront costs for battery-electric and hydrogen fuel cell tractor trucks can vary by up to a factor of four.	A CAPEX cost comparison reveals similar relative costs between drive-technologies in each application segment - BET and FCET vehicles compete for the most expensive option, and the three fossil fueled technologies observe the least expensive options. This trend scales aptly in the light- and medium-duty segments but becomes acutely more exaggerated in the long-haul segment.	This analysis finds that zero-emission vehicles should generally become cost-competitive with diesel-propelled trucks between 2030 and 2040 across all vehicle sizes. When exactly zero-emission vehicles will become cost-competitive with traditional trucks varies with vehicle size: the smallest vehicle categories could reach parity on total cost of ownership with diesel vehicles in 2022. Larger road freight vehicles are more likely to be cost-competitive around 2035.

	Results from the sensitivity analysis show all vehicle types have the potential to become more cost competitive than diesel if using hydrogen from 100% RES as their fuel, with several other hydrogen fuels also leading to lower TCOs than ICEV and even BEV counterparts in some cases, when subject to specific hydrogen-based conditions like fuel price reductions and purchase grants.	While in the sustainable growth and full industrialisation phases, the probable case TCO for fuel cell trucks is still higher than the probable case for diesel trucks, [but] the lower bound scenario for fuel cell vehicles is lower than the diesel probable case.	Hydrogen fuel subsidies will be needed to justify the business case for FCETs in Europe during this decade.	For both battery and fuel cell vehicles, thanks to technology cost reductions, the initial cost generally decreases markedly in the period 2020-2030 and more modestly for 2030-2040.	At present, electric propulsion systems for zero-emission tractor trucks make up roughly 85% to 90% of total truck costs, but this is expected to fall to 75% to 85% as battery pack and fuel cell system costs are estimated to drop by 50% and 65%, respectively, over the next decade.	Country-level variance in competition of the two zero-emission vehicles, BET and FCET, is stark. Except in Switzerland, FCET vehicles are largely too expensive to consider in this segment. The current fuel cell stack and hydrogen fueling costs prove again to be prohibitively high. For the most part, BET vehicles are equally uneconomical, though not always. In fact, three countries [Norway, Sweden, Germany] show highly competitive BET TCO values as compared to the incumbent ICE-D vehicles.	Based on the scenarios explored, hydrogen fuel cell electric vehicles (FCEVs) are less competitive than the other two zero-emission technologies. FCEVs are cost competitive in only a small number of marginal cases that assume ambitiously low hydrogen fuel costs and very conservative assumptions for BEVs. This suggests that FCEVs might play a niche role in the future fleet of heavy-duty road vehicles, which in turn raises doubts about whether large-scale hydrogen refuelling infrastructure would be sufficiently utilised.

	By 2050, FCEVs running on a number of the hydrogen fuel scenarios will have a TCO lower than diesel, but for the majority of vehicles considered, BEVs remain the lowest in cost per km, unless specific FCEV incentives are implemented.	Fuel cell trucks exhibit much greater uncertainty in their TCO over the coming years than diesel trucks. This is due to the relative immaturity of the sector, leading to high variations in the upper and lower bound input parameters for these trucks.			For battery-electric trucks, the 600kWh battery pack makes up roughly 60% of the total vehicle cost, not including manufacturer’s indirect costs and profit markup. The entire electric propulsion system, including the battery pack and the power electronics, is estimated to account for 85% percent of vehicle costs in 2020.		
					For the fuel cell tractor truck, cost distribution was even more heavily weighted to the electric propulsion system. Together, the fuel cell unit and hydrogen storage system are estimated to make up nearly 80% of the total vehicle cost in 2025.		

Recommendations (if applicable)		[EU] Member state implementation of a favourable RED II framework for hydrogen is essential. In addition, within the RED III proposals, a long term and appropriately ambitious transport sub-target for renewable fuels of non-biological origin (RFNBOs) (which will treat green hydrogen in the same way 'advanced biofuels' are already treated) will help create and sustain the business case for green hydrogen production and the associated hydrogen refuelling stations.	Increase the ambition of the heavy-duty vehicle CO2 standards as more stringent standards are needed to comply with the EU Climate Law.			Policy instruments that target OPEX parameters are considerably more effective than instruments that target CAPEX parameters in enabling competitiveness of zero-emission commercial vehicles. Examination of the HDT-Long Haul segment distinctly shows that countries who display cost competitiveness of BET vehicles manage to counterbalance high battery costs, not by subsidizing the CAPEX itself, but by introducing targeted OPEX subsidies.	Ensure that policies to promote direct electrification of trucks remain technology-neutral. Both battery-electric vehicles and electric road system vehicles can be cost-effective replacements for diesel trucks. Battery electric trucks are well placed to be adopted in the short term in certain market segments.

		Introduction of differential road tolls to favour hydrogen and other zero emission options over fossil fuel-based vehicles. The modelling suggests road tolls of €0.40/km for diesel vehicles and €0.10/km for zero emission vehicles would help to create demand for hydrogen trucks.	Expedite the implementation of the Eurovignette directive into national law and fully exempt zero-emission trucks from road tolls.			Certain key policy influencing parameters, such as tolls, fuel costs, and CAPEX subsidies, more effectively alter TCO results. Of these three parameters we observe the two OPEX parameters, tolls and fuel costs, to most efficiently affect the TCO. Policy makers intending to increase the prevalence of zero-emission road-freight vehicles on the road would be wise to address these parameters first and foremost. However, coordinated policy designs that employ a combination of the three parameters offer additional options to enabling drive-technology competition.	Further investigate decarbonisation technologies for particularly challenging road freight applications. Electrifying heavy-duty road freight with battery electric trucks or electric road systems may be challenging for certain niche use cases. Further investigations are needed to better understand how other technologies could provide a complementary role to electrification in decarbonising such road freight applications.

		Taxation of fuels which recognises the changing landscape towards more decarbonised and zero carbon fuels and zero emission vehicles, which does not disadvantage hydrogen and other sustainable fuels until their business case is established.	Incentivize the purchase of zero-emission trucks and limit these incentives to their early market uptake phase.			HDT-Long Haul requires a more coordinated effort with multiple targeted parameters, but must, at the very least, have zero-emission vehicle advantaging toll policies for BETs to be competitive.	Introduce policies that help zero-emission vehicles become cost-competitive sooner. Accelerating the adoption of zero-emission vehicles requires targeted policy support. The high upfront purchase costs of zero-emissions vehicles present a barrier to large-scale adoption, particularly for small trucking companies. Differentiated purchase subsidies and low-interest loans for the purchase of zero-emission vehicles, together with road pricing and carbon taxation, would make them cost competitive with diesel trucks before 2030 and help accelerate the decarbonisation of the road freight sector.

		A carbon tax on diesel starting at a minimum of €30/tonne CO2 and increasing through time to a minimum of €60/tonne (based on proposed prices in the German carbon pricing scheme for transport and buildings), in addition to the tax currently applied on diesel today.	Incentivize demonstration projects of fuel cell trucks in real-world applications.				Accelerate the deployment of zero-emission vehicle infrastructure. The adoption of zero-emission vehicles will not be possible without enabling infrastructure. Policy makers should set clear and ambitious targets for its deployment. They should provide targeted financial support and accelerate procedures for planning permission where possible. In doing so, they can create market confidence and help reduce uncertainty.

							Strengthen regulations that make trucks more energy efficient. Many ways exist to improve the energy efficiency of trucks, including aerodynamic improvements and vehicle weight reduction. Promoting energy-efficiency improvements (e.g., by strengthening CO2 emissions standards) protects against rising energy costs and reduces uncertainty regarding the total cost of ownership of vehicles. Efficiency improvements can also help to accelerate the viability of zero-emission vehicles by increasing the vehicle range.

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