ESCALATE

Powering European Union Net Zero Future
by Escalating Zero Emission HDVs
and Logistic Intelligence

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Catalogue of Assessment Criteria

Project deliverable D2.1

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Project Executive Summary

ESCALATE, an EU funded Research and Innovation project, has been awarded funding under the HORIZON-CL5-2022-D5-01 call, highlighting its significance within the academic and scientific community. The primary objective of ESCALATE is to showcase and demonstrate the efficacy of high-efficiency zero-emission heavy-duty vehicle (z-HDV) powertrains, with a targeted increase of up to 10% in their overall efficiency. Specifically tailored for long-haul applications, these powertrains are designed to provide an impressive range of 750+ kilometres without the need for refuelling or recharging, while simultaneously ensuring consistent performance during daily operations over a period of six months or more under real-world conditions. To achieve these ambitious goals, ESCALATE focuses on the development of meticulously designed modular building blocks, which are intended to attain a Technology Readiness Level of 7 or 8. These modular components will serve as the foundation for three distinct types of z-HDVs, namely battery-HDV (b-HDV), fuel-cell-HDV (f-HDV), and range extender-HDV (r-HDV). The utilization of innovative business model innovations will be instrumental in optimizing the integration and utilization of these standardised and modular building blocks, further enhancing their efficiency and effectiveness. Moreover, the ESCALATE project aims to contribute valuable insights to the scientific community through the production of three comprehensive white papers. These papers will delve into various aspects of z-HDV technology, with one particular white paper focusing on defining a clear pathway to reduce well-to-wheel greenhouse gas emissions specifically from heavy-duty vehicles. The formulation of this pathway will be informed by rigorous analysis, utilizing both empirical results and policy assessments, thereby establishing a robust foundation for future efforts in reducing the environmental impact of HDVs. Through its multifaceted approach, ESCALATE strives to advance the knowledge and understanding of high-efficiency z-HDV powertrains, foster technological innovation, and contribute to the ongoing efforts of EU aimed at achieving sustainable and environmentally friendly transportation systems.

ESCALATE partners

List of participating countries:

- Belgium
- Denmark
- Germany
- Spain
- Estonia
- France
- Finland
- Greece
- Poland

- Portugal
- Austria
- Turkey
- UK

List of partners:

- FEV Europe Gmbh & FEV France (FEV) - Project Coordinator
- University of Surrey (USR) - Technical Coordinator
- Mercedes-Benz Turk As (MBT)
- Brussels Research and Innovation Center for Green Technologies (BRING)
- Teknologian Tutkimuskeskus Vtt Oy (VTT)
- Virtual Vehicle Research Gmbh (VIV)
- Aristotelio Panepistimio Thessalonikis (AUTH)
- Polis - Promotion of Operational Links with Integrated Services, Association Internationale (POLIS)
- Inegi - Instituto De Ciencia E Inovacao Em Engenharia Mecanica E Engenharia Industrial (INEGI)
- Deutsches Zentrum Fur Luft - Und Raumfahrt Ev (DLR)
- Rheinisch-Westfaelische Technische Hochschule Aachen (RWTH)
- BMC Otomotiv Sanayi Ve Ticaret Anonim Sirketi (BMC)
- Engie Energie Services (ENGIE)
- Commissariat A L Energie Atomique Et Aux Energies Alternatives (CEA)
- FEV TR Otomotiv Ve Enerji Arastirma ve Muhendislik Limited Sirketi (FEV TR)
- Ai4sec Ou (AI4SEC)
- Ballard Power Systems Europe As (BLRD)
- Kempower Oy (KEM)
- Hydrogen Europe (HEU)
- Ergtech Spolka Z Ograniczona Odpowiedzialnoscia (ERG)
- Pbx Gmbh (PBX)
- Primafrio Corporacion, S.A. (PRMF)
- Bsa Inno & Tech Gmbh (BSA)
- Oy Sisu Auto Ab (SISU)
- Valmet Automotive Ev Power Oy (VAL)
- Ortem Elektronik As (ORTEM)
- DHL Lojistik Hizmetleri As (DHL)
- Deutsches Institut Fuer Normung Ev (DIN)
- Kuljetus Ja Muutto O. Jylha Oy (TRJ)
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- FORD Otomotiv Sanayi Anonim Sirketi (FORD)
- Coventry University (CU)
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1 Deliverable executive summary

This executive summary outlines the assessment criteria defined for three types of zero-emission heavy-duty vehicles (z-HDVs): battery electric (b-HDV), fuel cell electric (f-HDV), and range extender heavy-duty trucks (r-HDV). The objective is to develop a comprehensive catalogue of assessment criteria aligned with the high-level objectives of the ESCALATE project, which are Objective 1 and Objective 6. The assessment criteria, categorized into 5 key areas, enable a comprehensive evaluation of the z-HDVs' performance, economic viability, sustainability, infrastructure compatibility, and end-user satisfaction.

The aim is to define a catalogue of assessment criteria that provides a standardized framework for comparing b-HDVs, f-HDVs, and r-HDVs. This framework supports decision-making for stakeholders, promotes the adoption of zero-emission HDVs, drives innovation, and positions Europe as a global leader in the automotive, logistics, and infrastructure sectors. Concurrently, contributing to Europe's commitment to becoming the world's 1st climate-neutral continent by 2050 is a major priority. By prioritizing energy efficiency, range, and operational feasibility, the catalogue contributes to achieving the ESCALATE project's high-level objectives of developing high-efficiency, long-haul HDVs and driving the absolute zero-emission future.

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2 List of abbreviations and acronyms

Acronym	Meaning
b-HDV	Battery Electric HDV
f-HDV	Fuel Cell HDV
r-HDV	Range Extender HDV
z-HDV	Zero Emission HDV
CAN	Controlled Area Network
ECU	Electronic Control Unit
LIN	Local Interconnect Network
GVW	Gross Vehicle Weight
OBS	Optical Burst Switching
OEM	Original Equipment Manufacturer
TCO	Total Cost of Ownership
WP	Work Package

3 Purpose of the deliverable

3.1 Intended audience

Firstly, the primary audience consists of the ESCALATE project partners, encompassing all members participating in the consortium. The deliverable 2.1 directly relates to their involvement and contributions, providing them with valuable information and guidelines for the assessment process.

Secondly, the audience includes representatives from the Commission Services responsible for overseeing the project. These individuals play a vital role in ensuring ESCALATE compliance with the grant agreement and project objectives (Objective 1-Objective 6). Additionally, reviewers appointed by the Commission contribute to the evaluation of the project's progress and outcomes.

Lastly, the broader audience comprises policymakers, stakeholders, researchers and industry professionals in the field of sustainable transportation and zero-emission technologies. This document serves as a valuable resource for individuals seeking a comprehensive understanding of the assessment criteria, and framework for evaluating the performance, viability, and impact of the three different types of z-HDVs. It provides insights into the technical aspects, economic implications, and sustainability considerations related to the adoption of zero-emission heavy-duty vehicles. Additionally, policymakers, funding agencies, and decision-makers in the transportation sector may find this deliverable informative for strategic planning and investment decisions aimed at promoting sustainable and efficient transportation solutions.

These individuals may refer to Deliverable 2.1 as a comprehensive reference document for understanding the assessment criteria used to evaluate the performance and impact of the ESCALATE project.

3.2 Structure of the deliverable and links with other work packages and deliverables

Deliverable 2.1 plays a pivotal role in linking mainly work packages 3, 4, 6 and 7 and deliverables within the ESCALATE project. It sets the foundation for subsequent assessments and evaluations by outlining the comprehensive assessment criteria for the z-HDVs. The critical metrics identified in Deliverable 2.2 will further enhance this framework by mapping them to the specific pilots of ESCALATE, providing a targeted evaluation of the performance and effectiveness of the different types of z-HDVs in real-world operational conditions (Task 2.4).

The structured assessment criteria and critical metrics outlined in these deliverables, in collaboration with Work Package 6, will enable a systematic evaluation of the z-HDVs and their innovative components, encompassing battery electric (b-HDV), fuel cell electric (f-HDV), and range extender heavy-duty trucks (r-HDV). This approach ensures a comprehensive analysis of the progress, innovation, and impact of the vehicles, considering factors such as performance, economic viability, sustainability, infrastructure compatibility, modularity, and end-user acceptance.

Furthermore, the consideration of cost assessment criteria, as highlighted in the work packages 7 and 8, allows ESCALATE stakeholders to make informed decisions regarding the economic feasibility and viability of adopting z-HDVs. This evaluation of costs provides a comprehensive analysis of the financial implications and potential benefits associated with transitioning to zero-emission transportation, enabling the generation of lucrative business plans. The subsequent scale-up analysis will delve into forecasted or anticipated future developments in each cost category, exploring their impact and sensitivity concerning future mass deployment pathways. This information will support stakeholders in strategic decision-making and investment planning for the sustainable and economically viable deployment of z-HDVs.

4 Introduction

Assessment criteria are specific factors or metrics used to evaluate or measure the performance, effectiveness, or suitability of a particular subject or system. They provide a standardized framework for analysing and comparing different aspects of the subject being assessed. Assessment criteria help in making informed judgments or decisions based on objective and measurable criteria.

On the other hand, critical metrics are specific measurements or indicators that are considered crucial or essential in assessing the performance system, or process. These metrics often focus on key performance areas or objectives and provide a quantitative or qualitative measurement of progress, effectiveness, or quality.

In summary, assessment criteria encompass a broader set of factors or metrics used for evaluation, while critical metrics are a subset of those criteria that are deemed essential or critical to the success or evaluation of a specific product or system.

Therefore, within the scope of Deliverable 2.1, the assessment criteria for z-HDVs will be considered. These assessment criteria will provide a comprehensive framework for evaluating the performance and viability of z-HDVs in various aspects such as vehicle performance, cost, lifetime assessment, infrastructure, modularity, and end-user acceptance.

However, the critical metrics that specifically fall into each assessment category will be further detailed in Deliverable 2.2. This subsequent deliverable, aligned with Task 2.4, will map the critical metrics to the pilots of the ESCALATE. Doing so will provide a more specific and targeted assessment of the z-HDVs' performance and effectiveness within real-world operational conditions.

The comprehensive assessment criteria outlined in Deliverable 2.1, together with the critical metrics identified in Deliverable 2.2, will form a structured and standardized framework for evaluating the progress, innovation, and impact of the different types of z-HDVs, ranging from battery electric (b-HDV) to fuel cell electric (f-HDV) and range extender heavy-duty trucks (r-HDV) (WP6).

By defining the assessment criteria and critical metrics in separate deliverables, the ESCALATE project ensures a systematic approach to evaluate the z-HDVs, related infrastructure, and its innovative components, providing valuable insights into their performance, economic viability, sustainability, infrastructure compatibility, modularity, and end-user acceptance.

4.1 Background and Rationale

The aim of Deliverable 2.1 is to define critical assessment criteria for evaluating the performance and viability of three types of zero-emission heavy-duty vehicles (HDVs): battery electric (b-HDV), fuel cell electric (f-HDV), and range extender heavy-duty trucks (r-HDV). The criteria are aligned mainly with the two high-level objectives of the ESCALATE project.

Objective 1 (O1) focuses on developing and demonstrating high-efficiency, long-haul HDVs that meet specific criteria, including a minimum gross vehicle weight (GVW) of 40 tons and an unrefuelled/uncharged range of 750+ kilometres under real-world conditions.

Objective 6 (O6) aims to establish European leadership in the automotive, logistics, and infrastructure sectors while driving toward an absolute zero-emission future for the European Union. The defined assessment criteria contribute to this objective by evaluating performance, economic viability, sustainability, infrastructure compatibility, modularity, and end-user acceptance.

The assessment criteria are categorized into vehicle performance evaluation, vehicle cost assessment, life cycle assessment, infrastructure assessment, modularity assessment, and end-user acceptance. Metrics include energy efficiency, range, acceleration, towing capacity, maintenance costs, durability, service life, infrastructure requirements, modularity for component interchangeability or upgrades, and user experience.

These standardized criteria enable ESCALATE partners as well as z-HDV stakeholders to make informed decisions on adopting and deploying z-HDVs, promote technological advancements, and support Europe's transformation towards sustainability.

Ultimately, the ESCALATE project's critical assessment criteria align with Europe's goal of becoming the world's 1st climate-neutral continent by 2050, positioning Europe as a global leader in sustainable transportation, infrastructure, and modularity-driven innovation.

4.2 Purpose and Scope of Assessment Criteria

The assessment criteria play a pivotal role in shaping a harmonized framework, ensuring a fair evaluation and comparison of the three distinct types of zero-emission heavy-duty vehicles (z-HDVs): b-HDV, f-HDV, and r-HDV. With a keen focus on performance, economic viability, sustainability, infrastructure compatibility, modularity, and end-user acceptance, these criteria shed light on the unique attributes and challenges inherent to each vehicle type. By providing a structured roadmap, the assessment criteria enable stakeholders to navigate the intricate landscape of z-HDVs.

Embracing these criteria unlocks a realm of possibilities, paving the way for comprehensive evaluations that drive sustainable innovation and empower ESCALATE stakeholders to make informed decisions. This evaluation framework sets the stage for the development of high-efficiency, zero-emission long-haul HDVs, positioning Europe as a forerunner in the automotive, logistics, and infrastructure sectors.

5 Vehicle Performance Assessment Criteria

Performance-related assessment criteria refer to a set of specific parameters and metrics used to evaluate the operational effectiveness, efficiency, and capability of a heavy-duty vehicle in fulfilling its intended tasks and objectives. These criteria serve as measurable indicators that assess the z-HDV's ability to perform optimally in various performance domains, thereby enabling stakeholders to make informed judgments regarding its overall performance.

Within the context of ESCALATE, performance-related assessment criteria encompass quantitative and qualitative measures that directly impact the vehicle's functional performance. These criteria include:

Range: Assess the vehicle's range on a single charge or hydrogen fill-up to determine its ability to operate for an extended period without recharging or refueling.

Endurance: Refers to the ability of a vehicle to sustain continuous or prolonged operation without experiencing a decline in performance or the need for significant breaks, repairs, or refueling. It represents the duration or time that a vehicle can operate before requiring maintenance, or component recovery due to, for example, overheating, refueling, or recharging. Assessing and improving the endurance of heavy-duty vehicles is crucial to ensure their operational efficiency, productivity, and profitability, as well as to meet the demands of logistics.

Charging/Refueling Time: Evaluate the time required to recharge the battery or refill the hydrogen tank, as shorter charging/refueling times improve vehicle uptime and operational efficiency.

Payload Capacity: Measure the vehicle's ability to carry heavy loads while maintaining performance. It directly impacts its practical usability and suitability for commercial applications. Note that special conditions on GVW limits of z-HDV may apply.

Acceleration and Speed: Evaluate the vehicle's acceleration capabilities and maximum speed to ensure it can keep up with traffic and perform tasks efficiently. While acceleration is not the sole criterion for assessing the performance of HDVs, it is an important factor that influences operational efficiency, safety, productivity, and driver satisfaction.

Energy Efficiency: The amount of energy consumed per km (kWh/km), as well as the weight of hydrogen consumed per km (kg/km) for fuel cell vehicles, specific to a vehicle configuration (GVW) and operational mission/scenario and will be taken as a basis for efficiency calculations. Due to the degradation in the performance of energy sources such as batteries and fuel cells over time, efficiency values vary between Beginning of Life and End of Life, and the compatibility of relevant values with real-time road data will be evaluated during the project.

Reliability: Evaluate the vehicle's reliability under heavy-duty operating conditions to ensure it can withstand the demands of commercial applications.

Towing and Climbing Abilities: Assess the vehicle's ability to tow heavy loads and climb steep inclines, as these factors are crucial for heavy-duty applications.

Safety Features: Evaluate the presence of safety features such as advanced driver assistance systems (ADAS), collision avoidance systems, and stability control to ensure the vehicle meets safety standards.

Security Features: Evaluate the presence of security features such as cyber security in heterogeneous data transmission, vehicle-to-cloud communication, user and node authentication, and potential cyber protection against intended or unintended data leakages, unauthorized access, and breaches.

Durability: Refers to the ability of a vehicle/components to withstand the rigors, stresses, and wear and tear associated with prolonged or heavy-duty usage. A durable vehicle is designed and built to withstand challenging operating conditions, including rough terrains, heavy loads, and extended hours of operation, without suffering significant or unforeseen damage or performance degradation. In brief, durability focuses on the ability of the vehicle to withstand harsh conditions and heavy use without suffering significant damage or wear.

Reliability and Availability: Refers to the consistency and dependability of a z-HDV's performance over time. It measures the vehicle's ability to consistently operate as intended without unexpected failures, breakdowns, or malfunctions. A reliable vehicle with high availability is one that can be trusted to perform its functions consistently, adhering to predetermined standards, and meeting operational requirements so that the end user can rely on it to complete the required transport missions. Regarding infrastructure, availability is a measure of the ability and reliability of the charging stations and H2 dispensers to provide power and hydrogen whenever the z-HDV connects and there is a demand for it.

In brief, reliability focuses on the z-HVD's consistent and dependable performance over time, without unexpected failures/disruptions.

By comprehensively evaluating these performance-related assessment criteria, partners can holistically assess and compare the performance capabilities of zero-emission heavy-duty vehicles, facilitating informed decision-making regarding their selection, adoption, and deployment in various operational contexts.

6 Vehicle Cost Assessment Criteria

Cost assessment criteria for z-HDVs refer to the specific factors or metrics used to evaluate the economic viability and cost-effectiveness of these advanced vehicles. Considering the costs associated with adopting, operating, and maintaining z-HDVs is essential for decision-making and comparing them with conventional vehicles. The cost assessment criteria for z-HDVs that will be considered within the scope of ESCALATE are:

Vehicle Acquisition Cost: Evaluating the initial purchase cost of z-HDV compared to conventional heavy-duty vehicles. This includes considering any price premiums associated with the technology, components, auxiliaries, and sub-systems used in zero-emission vehicles.

Total Cost of Ownership: Assessing the overall costs associated with owning and operating z-HDV throughout their lifecycle. TCO includes not only the purchase price but also factors such as fuel or energy costs, maintenance and repair expenses, insurance, financial parameters, residual value, and any additional costs specific to zero-emission technology (e.g., battery replacement, hydrogen fuelling infrastructure).

Energy Costs: Evaluating the costs associated with powering z-HDV. This includes considering electricity costs for battery electric HDVs in different charging and energy management scenarios (e.g., fast opportunity charging, slow overnight charging) or hydrogen fuel costs for fuel cell electric HDVs. It is important to assess the energy efficiency of the vehicles and compare the energy costs to the fuel costs of conventional vehicles.

Infrastructure Costs: Evaluating the costs of deploying and operating the charging and H2 refilling infrastructures necessary for the operation of the z-HDVs. A part of the evaluation is to assess which part of the total infrastructure investment should be allocated to the demonstration or deployed z-HDVs.

Maintenance and Repair Costs: Assessing the costs associated with maintaining and repairing z-HDV, for example, the replacement of some powertrain components. This includes considering the complexity of the technology, availability of qualified technicians, and any specialized tools or equipment required for maintenance and repairs.

Incentives and Subsidies: Considering available government incentives, or subsidies that can offset the costs of z-HDV. This includes evaluating financial support programs aimed at promoting the adoption of clean transportation technologies.

Residual Value: Assessing the expected resale or residual value of z-HDV at the end of their useful life. Understanding the potential value of these vehicles after a certain period helps in evaluating the long-term financial impact. Also, some components replaced in the z-HDV may have some residual value in the 2nd hand market.

Costs of Cyber-physical Security Governance at The Vehicle Level: Absorbing the cost of a cyber incident is inherently more financially disruptive than paying for cyber-physical security that prevents cyber incidents (breaches, anomalies, intrusions, etc.) dealing with HDVs. Factors that determine the cost of cyber-physical security are multi-faceted as all HDVs are connected to some IT backend systems through their telemetry services, ECUs, and other interfaces (CAN, LIN, OBS, etc.). Thus, there can be costs determined by security vulnerability assessments, endpoint protection, network, or cloud (edge, fog, etc.) security, data storage, access and identity management, trustworthy data communication, authorization, and user profiling issues, etc.

By considering these cost assessment criteria, ESCALATE stakeholders can make informed decisions regarding the economic viability and feasibility of adopting z-HDV. Assessing the costs allows for a comprehensive analysis of the financial implications and potential benefits associated with transitioning to zero-emission transportation as well as generating lucrative business plans (WP7-WP8). A part of the subsequent scale-up analysis will be to look into forecasted or anticipated future development in each of the cost categories, and their impact on and sensitivity with regard to future mass deployment pathways.

7 Vehicle Life Cycle Assessment Criteria

Assessment criteria for life cycle assessment (LCA) refer to the specific criteria used to evaluate the environmental impacts and sustainability performance of the ESCALATE demonstrator vehicles and components throughout its entire life cycle. The aim is to provide a structured framework for conducting the assessment and analysing the expected outcomes of the ESCALATE. Furthermore, they will be used as a guide in the selection of relevant materials, and component to improve their environmental aspects.

The list of assessment criteria that will be used to evaluate the LCA of z-HDVs are:

Raw Material Acquisition: Assess the environmental impacts associated with the extraction, processing, and transportation of raw materials used in vehicle manufacturing.

Vehicle Manufacturing: Evaluate the energy consumption, emissions, and waste generated during the manufacturing process of the vehicle, including the production of components and assembly.

Vehicle Use: Consider the energy consumption and emissions associated with the vehicle's operation, including fuel or energy consumption and its specific emissions, and maintenance requirements.

Vehicle End-of-Life: Analyse the environmental impacts of vehicle disposal or recycling, including the recycling rate, energy consumption, emissions, and waste generated during the end-of-life phase.

Vehicle Components: Assess the environmental impacts associated with the production, use, and disposal of individual vehicle components, such as batteries, fuel cells, electronics, and other materials.

Fuel or Energy Source: Consider the life cycle impacts of the fuel or energy source used to power the vehicle, including the extraction, production, transportation, and conversion processes.

Emissions and Pollution: Evaluate the emissions of greenhouse gases (e.g., carbon dioxide), air pollutants (e.g., nitrogen oxides, particulate matter), and other pollutants associated with the vehicle's life cycle.

Energy Efficiency: Assess the energy efficiency of the vehicle throughout its life cycle, considering the energy consumed during manufacturing, use, and end-of-life stages.

Circular Economy Considerations: Evaluate the potential for recycling, remanufacturing, or reusing vehicle components to reduce waste and resource consumption.

Noise Pollution: Consider the noise emissions associated with the vehicle's operation, which can have environmental and health impacts.

These assessment criteria will provide a comprehensive understanding of the environmental impacts associated with the life cycle of ESCALATE demonstrator vehicles and components, enabling partners to identify areas for improvement and make more informed decisions toward more sustainable options.

8 Infrastructure Assessment Criteria

Assessment criteria for infrastructure refer to the specific factors or metrics used to evaluate the suitability, effectiveness, and compatibility of ESCALATE infrastructure systems. In the context of z-HDVs, infrastructure assessment criteria focus on evaluating the charging or refuelling infrastructure required to support the operation of these advanced vehicles. The infrastructure assessment criteria that will be considered within the scope of ESCALATE are:

Infrastructure Existence and Accessibility: Assessing the existence and accessibility of charging stations or refuelling facilities within a given geographical area. This includes evaluating the coverage and distribution of ESCALATE demonstrator infrastructure to ensure it meets the operational needs of targeted z-HDVs.

Charging/Refuelling Capacity: Evaluating the capacity of infrastructure systems to handle the demand for charging or refuelling z-HDVs. This includes considering the number of charging stations or refuelling points available and their ability to handle multiple z-HDVs simultaneously and provide the necessary power (kW) or hydrogen flow (kg/H2/min).

Charging/Refuelling Speed: Assessing the charging or refuelling speed of the infrastructure. Faster charging or refuelling times are desirable to minimize downtime and improve operational efficiency.

Interoperability: Evaluating the compatibility and interoperability of infrastructure systems with different vehicle types and charging or refuelling standards. This ensures that HDVs can use the infrastructure regardless of their specific technology or manufacturer.

Energy Efficiency: Analysing the efficiency of the charging or refuelling process in terms of energy usage. This helps optimize the energy-to-range ratio, ensuring the vehicles achieve optimal performance and maximize their range capabilities.

Cost: Considering the cost associated with hydrogen refuelling or battery megawatt charging. This includes evaluating the initial infrastructure investment, ongoing operational expenses, and the potential for future scalability and cost reduction. *(See Chapter 4)*

Scalability: Considering the scalability potential of the infrastructure to accommodate an increasing number of z-HDVs as the market grows. This includes assessing the flexibility to expand the infrastructure network based on future demand.

Compatibility and Standardization: Evaluating the compatibility and standardization of charging/refuelling protocols and equipment across different manufacturers and models to ensure seamless interoperability and widespread adoption.

Availability, Reliability, and Redundancy: Assessing the reliability of infrastructure systems to ensure consistent availability and functionality. This includes considering backup power systems, backup hydrogen supply options, or redundancy measures to mitigate downtime and maintain operational continuity.

Modularity: Refers to the ability to easily expand, upgrade, or modify the infrastructure system. Modularity allows for flexibility and adaptability to future technological advancements and changing operational requirements.

Integration with Grid or Energy Systems: Evaluating the integration of charging or refuelling infrastructure with the electrical grid or energy systems. This includes assessing the impact on the grid and optimizing energy management for efficient and sustainable operation.

Safety: Assessing the safety protocols and standards implemented in the charging/refuelling process to ensure the protection of both the vehicle and personnel involved.

Security: Evaluating the presence of security features such as cyber-physical security in vehicle-to-grid-cloud communication, user, and node (e.g., vehicles, chargers, refuelling equipment, etc.) authentication and potential cyber protection against intended or unintended data leakages, unauthorized access, and breaches.

By considering these infrastructure assessment criteria, i.) ESCALATE partners can determine the feasibility and effectiveness of hydrogen refuelling and battery megawatt charging systems for z-HDVs (WP4), ii) not only ESCALATE partners but also all the stakeholders can make informed decisions regarding the planning, development, and implementation of charging or refuelling infrastructure to support the deployment and operation of z-HDVs, and iii) the transition towards sustainable transport solutions will be promoted.

9 Modularity Assessment Criteria

Modularity assessment criteria for z-HDVs and their components involve evaluating the extent to which the design and manufacturing allow for modularity and interchangeability. These criteria consider factors that enable scalability, transferability, efficient assembly, maintenance, repair, and potential upgrades or replacements. The key modularity assessment criteria that will be considered within the scope of ESCALATE are:

Standardization: Assess the degree of standardization of components, software, and interfaces across the demonstrator vehicle or developed component or system. This includes standardized connectors, mounting points, dimensions, and protocols, enabling easy interchangeability (WP3-WP7).

Interchangeability: Evaluate the ease of replacing or upgrading components without requiring significant modifications or adaptations. The aim is to assess the compatibility of different components or subsystems, enabling plug-and-play functionality.

Component Accessibility: Evaluate the ease of access to components for maintenance, repair, or replacement. Consider factors such as component location, accessibility of fasteners, and the need for specialized tools.

Component Compatibility: Assess the compatibility of components with different vehicle models or configurations within the same product line or platform. This allows for flexibility and scalability in adapting vehicles for various applications.

Modular Design: Evaluate the extent to which components are designed as modular units that can be easily assembled, disassembled, and replaced. This facilitates efficient manufacturing processes, reduces downtime for repairs, and supports future upgrades or customization.

Plug-and-Play Integration: Assess the ease of integrating modular components or subsystems into the vehicle's overall system. This includes considerations of electrical connectors, communication protocols, and mechanical interfaces.

Scalability: Consider the ability to scale the vehicle's capacity, range, power, or prime mover by adding or removing modular components. This allows for customization according to specific operational requirements.

Design for Disassembly and Recycling: Assess the design features that facilitate easy disassembly and separation of components for recycling or reuse at the end of the vehicle's life cycle. This supports circular economy principles and reduces waste.

Traceability: Assess the traceability of the components and modules during the design and manufacturing phases by considering who is doing what and how the processes are recorded in a trusted and immutable way.

These modularity assessment criteria enable evaluating and optimizing the design, manufacturing, and operational aspects of ESCALATE demonstrator vehicles and their components. By promoting modularity, original equipment manufacturers (OEMs) will enhance flexibility, efficiency, and sustainability throughout the vehicle's life cycle, which is directly aligned with the ESCALATE O1-O6.

10 End User Assessment Criteria

End-user acceptance assessment criteria for z-HDVs refer to the specific factors or metrics used to evaluate the acceptance, satisfaction, and usability of these advanced vehicles by end users (fleet operators and drivers). These criteria are important to understand the practical considerations and user experience associated with adopting and operating z-HDVs. The list of end-user acceptance assessment criteria for z-HDVs within the scope of ESCALATE as mentioned in previous sections, are:

1. Performance
2. Range
3. Charging/Refuelling Convenience
4. Total Cost of Ownership
5. Reliability
6. Availability
7. Durability

However, in addition to these criteria, there are four additional assessment criteria that will be considered, which are:

Maintenance and Support: Evaluating the availability and quality of maintenance services and technical support for z-HDVs. This includes considering factors such as service network coverage, response time, availability of spare parts, and the efficiency of maintenance processes.

Safety: Assessing the safety features and performance of z-HDVs to ensure they meet or exceed regulatory requirements and provide a safe working environment for drivers and other road users. This includes evaluating safety systems, crashworthiness, etc.

Driver Comfort and Ergonomics: Evaluating the comfort, ergonomics, and overall driver experience of z-HDVs. This includes factors such as noise levels, climate control, and user-friendly controls. Ensuring a comfortable and ergonomic environment can contribute to driver satisfaction, and hence acceptance.

Training and Familiarization: Assessing the availability and effectiveness of training and resources to ensure end users are properly trained on the operation and maintenance of z-HDVs. This includes evaluating the comprehensiveness of training materials, and the effectiveness of training programs in preparing drivers and technicians to handle the specific requirements of z-HDVs.

Connectivity: Evaluating the integrated technology and communication systems to enable real-time data monitoring, remote diagnostics, and seamless communication with fleet management systems. It allows fleet managers to efficiently track vehicle performance, manage maintenance schedules, and optimize operations.

Privacy: Assessing the GDPR compliance and protection of the personal data of the users especially when collecting their feedback, analysing their personal opinions, and interpreting the level of technology acceptance and their willingness and intention to use the offered solutions.

Ethics & Trustworthiness: Assessing the ethics guidelines, especially for AI-powered solutions by considering the Ethics Guidelines for Trustworthy AI published by the European Commission (High-Level Expert Group on AI, 2019).

These assessment criteria will provide insights into factors such as maintenance, safety features, driver experience, and training programs. By considering these criteria, stakeholders can ensure that z-HDVs meet the practical needs, expectations, and safety requirements of end users, contributing to their acceptance and successful implementation.

11 Conclusions

In conclusion, Deliverable 2.1 of the ESCALATE project provides a comprehensive analysis and extraction of the most significant assessment criteria for evaluating progress and innovation in three different types of zero-emission long-haul heavy-duty trucks, ranging from battery-powered to fuel cell, including range extender technologies. These assessment criteria serve as valuable benchmarks for assessing the performance, efficiency, and environmental impact of these next-generation trucks, innovative components, and the related infrastructure contributing to the overarching goal of ESCALATE. The ESCALATE project drives advancements in sustainable transportation solutions by evaluating factors such as range, charging/fuelling infrastructure, energy efficiency, the total cost of ownership, emissions reduction, and reliability. Through the deployment and adoption of zero-emission trucks, the project supports the decarbonization of the logistics industry and helps reduce greenhouse gas emissions, ultimately working towards making Europe the first emission-free continent.

The forthcoming deliverable (D2.2), followed by Deliverable 2.1, encompasses an in-depth analysis of the critical metrics associated with each assessment category. Building upon the preceding deliverable, this document will delve into a comprehensive exploration of the specific metrics and their mapping to the pilots within the project.

Overall, this upcoming deliverable will serve as a crucial foundation for the subsequent phases of the ESCALATE, providing the necessary metrics and mapping strategies to assess and enhance the performance of the pilots.

12 References

High-Level Expert Group on AI (2019). Ethics Guidelines for Trustworthy AI. European Commission