D3.1 Design guidelines & framework for structured assessment

Project ref. no.	HORIZON-CL5-2024-D5-01-06 GA. N.º 101192375
Project title	Shifting to zero-emission logistics with right-sized, mission-focused, N1 eLCVs
Project duration	1st January 2025 – 30th June 2028 (42 months)
Related WP/Task	WP3 / T3.1
Dissemination level	PUBLIC
Deliverable type	REPORT
Document due date	M9 (30/09/2025)
Actual delivery date	29/09/2025
Deliverable leader	RWTH
Document status	Submitted

Co-funded by the European Union

The Shift2Zero project has received funding from the European Union Horizon Europe Programme: project num. 101192375. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA Neither the European Union nor the granting authority can be held responsible for them.

Deliverable information sheet

Version	Date	Author	Document history/approvals
0.1	08/08/2025	Lukas Seibertz, Matthias Korten (RWTH-IKA)	Draft version
0.2	01/09/2025	Emilia Romero (IDI), Lamberto Salvan (ALKE)	Revision by cross readers
1.0	23/09/2025	Lukas Seibertz (RWTH-IKA)	Validation and release of final version
1.0	26/09/2025	Project Coordinator (EUT)	Last checks
1.0	29/09/2025	Project Coordinator (EUT)	Submission

Executive summary

Project summary

Shift2Zero, Shifting to zero-emission logistics through right-sized, mission-focused, N1 e-LCVs

Current market dynamics in EU reveal a gap between supply - existing N1 vehicles, and demand - evolving needs of urban logistics and climate targets. In 2023, 1.2M new LCV registrations were diesel-powered, and only 108,200 battery electric. Last-mile logistics, the least efficient and most complex part of the supply chain, presents significant opportunities for improvements at vehicle and operations levels. Dynamic requirements and increasing environmental impact require innovative solutions from the automotive industry, both from high volume OEMs and new entrants. S2Z aims to capitalize on the benefits of both vehicle platforms in the N1 segment - represented by IVECO's eDaily multipurpose platform, and Alke's ATX design-for-purpose platform - ultimately contributing to "Shifting to zero-emission logistics through right-sized, mission-focused, N1 e-LCVs".

To achieve this vision, S2Z proposes a 4-step user- and mission-centric design approach placing end-users and their needs at the core of all project activities. To this end, S2Z involves 5 LSPs & mobility operators as partners: Gruber, DHL, Diakinisis, Clem, DPD. As a result, S2Z will co-develop and shape at least 6 novel N1 concepts with enhanced and safe functionalities leading to tighter market fit, particularly in the segments of e-commerce, returns and cold deliveries.

Innovative concepts, from modular cargo bodies to vehicle control strategies with optimized tyres & brakes, as well as dual transport of people & freight, will be physically prototyped and tested in real-life operations in 6 pilot sites (Belgium, Greece, Italy, 2 in Norway, Poland).

S2Z brings a multidisciplinary consortium of 30 partners from 10 countries to cover the complete automotive and logistics value chains, complemented by policymakers to effectively ensure route to market: overcoming barriers for the adoption of S2Z eLCVs, reducing operational costs and environmental impact in scalable urban & sub-urban operations.

D3.1 Executive summary

Deliverable 3.1 marks the starting point of Work Package 3 at project month 6 and aims to provide guidance for the subsequent development of innovations in Shift2Zero, beginning at project month 9. The results of this deliverable support the creation of vehicle concepts and innovations that are successful in the sense of the Shift2Zero objectives. To achieve this, a structured framework has been developed for the systematic assessment and evaluation of vehicle concepts and innovations. By deriving sub-criteria, the framework also provides design guidelines to directly support development activities.

The framework is based on four key factors: sustainability, modularity, circularity, and user acceptance. In this deliverable, these criteria are first explained in detail, including their interrelations and distinctions. Subsequently, sub-criteria are derived from the main factors, drawing on three knowledge sources: a comprehensive literature review, user feedback collected in Work Package 2, and expert input from the consortium. Combining these perspectives led to the identification of 52 specific design criteria that contribute to successful innovations in the field of N1 e-LCVs. These criteria then form the foundation of the final assessment framework.

The framework is designed to compare the current development status of Shift2Zero innovations against another concept. On one hand, this enables benchmarking against the state of the art to assess relevance and added value, while also identifying weaknesses and areas for improvement that can be addressed through iterative refinement during the project. On the other hand, the framework provides a basis for evaluating different solution alternatives that may arise during innovation development. This ensures an objective decision-making process that helps guide development towards the most promising outcome.

To ensure ease of application, a dedicated assessment table has been created, providing a structured overview of the key and sub-criteria, a detailed description and comparison of concepts, and a final summary including recommendations for each criterion.

The scope of Deliverable 3.1 ends with the definition of design guidelines and the development of the corresponding framework. This evaluation framework is now available using the evaluation table (see Annex 1) to accompany the iterative development and optimisation of the Shift2Zero innovations in Work Package 3.

Table of contents

List of figures

List of tables

Terminology and Acronyms

CE	*Circular Economy*
CEAP	*Circular Economy Action Plan*
CSR	*Corporate Social Responsibility*
CTAM	*Car Technology Acceptance Model*
CVAM	*Connected Vehicle Acceptance Model*
D	*Deliverable*
EC	*European Commission*
(e)HDV	*(electric) Heavy Duty Vehicle*
(e)LCV	*(electric) Light Commercial Vehicle*
EU	*European Union*
EPA	*Europe's Environmental Protection Agencies*
ESG	*Environmental, Social and Governance*
FP	*Framework Programme*
ifaa	*Institute of Applied Industrial Engineering and Ergonomics (german: "Institut für angewandte Arbeitswissenschaft")*
LCA	*Life Cycle Assessment*
LCC	*Life Cycle Costing*
LCSA	*Life Cycle Sustainability Assessment*
LEZ	*Low Emission Zone*
N1	*Vehicles used for the carriage of goods and having a maximum mass not exceeding 3.5 tonnes*
OEM	*Original Equipment Manufacture*
R-strategies	*Strategies in circular economy approaches starting with the letter R (reduce, refuse, repair, …, recycle)*
ROI	*Return on Investment*
S2Z	*Shift2Zero*
S-LCA	*Social Life Cycle Assessment*
TAM2	*Technology Acceptance Model 2*
UN	*United Nations*
UTAUT 2	*Unified Theory of Acceptance and Use of Technology 2*
WCED	*World Commission on Environment and Development*
WP	*Work Package*
ZEZ	*Zero Emission Zone*

1. Introduction

A successful vehicle concept in line with the Shift2Zero objectives depends on the consideration and fulfilment of numerous interrelated factors. To systematically analyse these factors and integrate them early in the development process, a dedicated framework for the methodological assessment of vehicle concepts has been developed as part of Task 3.1. This framework is based on four key criteria: sustainability, modularity, circularity, and user acceptance. Each of these elements is further elaborated through a set of sub-criteria and integrated into a structured evaluation metric. Deliverable D3.1 documents the development of this assessment framework and outlines how it will be applied to support and guide subsequent stages of the vehicle concept development within the Shift2Zero project.

1.1 Objectives of the deliverable

Deliverable D3.1 provides the innovation developers in WP3 with a detailed overview of the success factors of a vehicle concept in terms of sustainability, modularity, circularity, and user acceptance. Furthermore, the developed framework supports the evaluation of different concepts at a very early stage of the development process. These evaluations serve as a basis for decision-making in selecting the most promising concepts, which will be further developed within WP3 and ultimately implemented as prototypes in WP4. By using this framework, the application supports the development of solutions with maximum impact by highlighting the key factors and enabling comparability with other solutions.

1.2 Structure of the deliverable

The deliverable first describes the methodological approach for developing the framework in Chapter 2. Chapter 3 then defines and distinguishes the main criteria: sustainability, usability, modularity, and user acceptance. These criteria are further broken down into sub-criteria in Chapter 4. Each sub-criterion is examined in detail, showing how it contributes to and can be implemented in relation to the overarching criterion. After all sub-criteria have been described, they are brought together into the final framework, which is explained in Chapter 5. Finally, Chapter 6 summarizes the content developed and provides an outlook on how the framework will be applied in the further project work within Shift2Zero.

2. Methodological approach

This chapter outlines the methodological approach used to enable a criteria-based evaluation of vehicle concepts. In order to ensure a clear focus and consistent orientation, the objectives of the evaluation framework are defined at the outset. The definition of objectives is necessary to clearly outline the scope and purpose of the comparison. Only with a clear set of objectives is it possible to determine relevant criteria and steer the comparison in a direction that will later allow for usable conclusions. In this context, the following mission statement is formulated to concisely express the overall objective of the framework:

The aim of the framework is to systematically compare two vehicle concepts or innovations in terms of the key success factors sustainability, modularity, circularity and user acceptance in order to present their strengths and weaknesses in a structured manner.

Once the goal has been defined, the scope of the framework is established. This scope is already described in more detail in the mission statement and is limited to the evaluation of vehicle concepts or innovations as part of a vehicle concept. In the case of the current development task at Shift2Zero, which aims to optimize N1 e-LCVs for logistics, the framework will also specialize in evaluating vehicle concepts and innovations in the logistics sector. This way, an optimal application of the framework along the development process of Shift2Zero innovations can be achieved.

To this end, the four key criteria: sustainability, modularity, circularity, and user acceptance are first defined more closely, delineated from one another, and categorized within the context of vehicle concepts in logistics. This step will be detailed in Chapter 3.

In Chapter 4 that follows, further sub-criteria will then be derived according to the key criteria. Key criteria and sub-criteria serve to structure and detail the assessment framework. They help systematically capture complex key criteria and create a uniform basis for evaluation. The sub-criteria have been derived from three different sources (see Figure 1). Initially, a targeted literature review filtered for criteria that contribute to fulfilling the four key criteria. These sub-criteria are supplemented by user feedback from WP2. For this purpose, user statements from T2.1 and T2.2 that emerged during interviews and user workshops with stakeholders have been further analysed. Based on these statements, additional sub-criteria can be derived. By taking into account interviews and user workshops, there is thus a direct consideration of user needs in the sub-criteria. Lastly, when creating the sub-criteria, opinions from numerous experts from the Shift2Zero consortium were also incorporated. These experts brought different perspectives from OEMs, logistics companies, consulting firms, and research institutions to complete the sub-criteria.

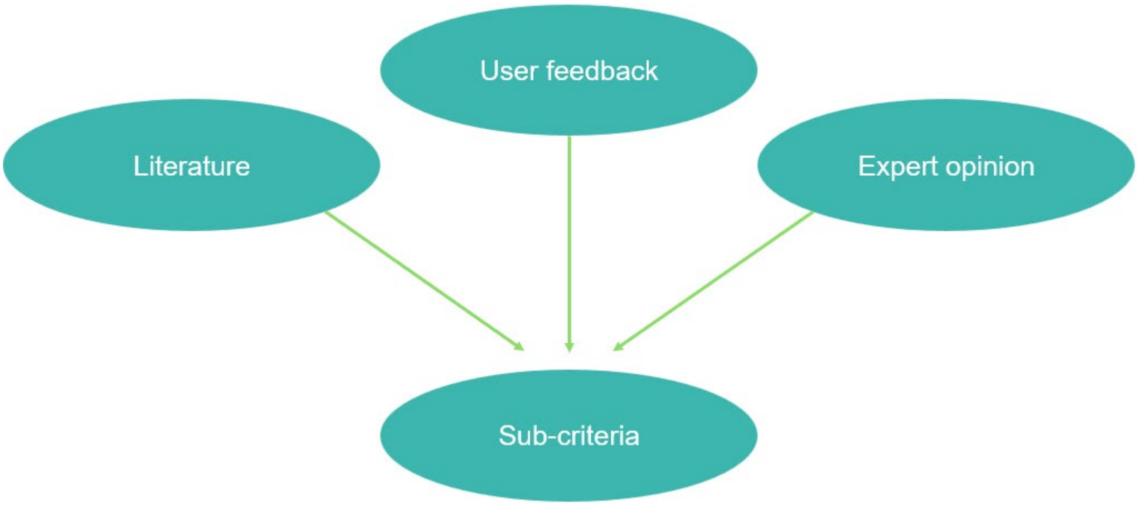

Figure 1. Origin of the sub-criteria

Each of the established sub-criteria is also explained in detail. It outlines why the criterion is important and how the sub-criterion contributes to the key criterion. Finally, specific recommendations are provided on how the criterion can be implemented.

These sub-criteria serve not only to provide a basis for evaluation for later comparison but also to be used as design guidelines by those developing innovations. By observing and adhering to the sub-criteria, a successful vehicle concept can be supported.

In conclusion, the criteria will then be finalized and integrated into an assessment and evaluation framework (see Chapter 5). This framework is based on a criteria-based comparison of the previously derived criteria. With this method, two different vehicle concepts or innovations can be compared. Each sub-criterion is examined individually, and a brief, objective, fact-based description is formulated for each concept. Following this, a direct comparison is made for each criterion, along with an assessment per criterion that includes possible improvement ideas to fulfil the criterion. After all criteria have been processed, a final summary and a set of recommendations for action will follow.

3. Definition and delimitation of key criteria

In the context of evaluating vehicle concepts and innovations, the four key criteria of sustainability, modularity, circularity, and user acceptance have been selected. These criteria are now be defined in more detail, described in the context of vehicle concepts in logistics, and the interrelationship between the criteria is illustrated.

3.1 Sustainability

Sustainability represents the overarching objective, encompassing ecological, economic, and social dimensions. The European Union adopts a three-pillar approach to sustainability, coordinating actions across the economic, environmental, and social spheres[1]. The scope for action is significantly influenced by the state of available technologies. According to the Institute of Applied Industrial Engineering and Ergonomics (ifaa), technology constitutes the foundation upon which the three pillars rest. These pillars, in turn, metaphorically support the roof representing the overarching concept of sustainability (see Figure 2).

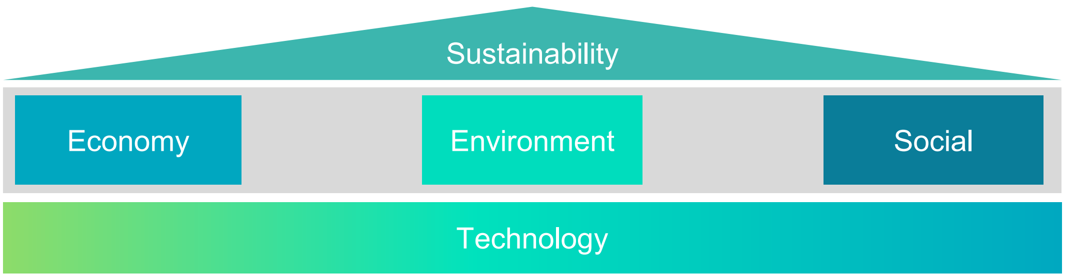

Figure 2. Three pillar model of sustainability according to ifaa[2]

[1] https://policy.trade.ec.europa.eu/development-and-sustainability/sustainable-development_en, last access 12th august 2025

[2] Eisele, O. (2024). Verständnis von Nachhaltigkeit. In: Nachhaltigkeitsmanagement - Handbuch für die Unternehmenspraxis.

These three areas are relevant both for society and from an economic perspective. The following table summarises the most important points from both perspectives.

	Economy	Environment	Social
Society	Securing the prosperity of the community	Preservation of the ecological basis of life	Preservation of social peace, health and freedom
Economic	Securing the economic success of the company	Preservation of the company's operating basis and resources	Well-being and satisfaction of stakeholders, including employees

Table 1. Societal and business perspective of the three pillars of sustainability[2]

The division into separate dimensions of sustainability provides a structured framework for defining criteria to assess the impacts of products. The Life Cycle Sustainability Assessment (LCSA) represents a method for evaluating sustainability throughout the entire life cycle of a product. This approach considers the ecological, economic, and social dimensions by analysing each phase, from raw material extraction, transportation, and production to distribution, use, and end-of-life management, in terms of its impact on the three sustainability pillars.

Figure 3 illustrates the three core assessment methods aligned with each dimension: Social Life Cycle Assessment (S-LCA) addresses social impacts, Life Cycle Costing (LCC) evaluates economic aspects, and Life Cycle Assessment (LCA) is widely used to assess environmental impacts.

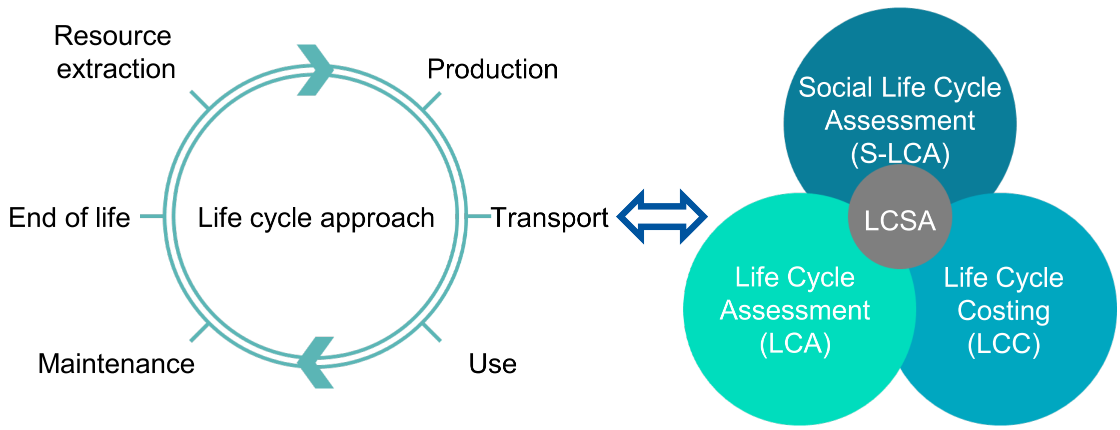

Figure 3. Life cycle approach with corresponding sustainability assessment methods

It is important to note that these areas are not strictly separable. Environmental effects, for example, often have social and economic consequences as well. Accordingly, the figure highlights the overlaps between the different assessment methods. While a detailed discussion of the methodological limitations of LCSA is beyond the scope of this section, the three pillars nonetheless offer a useful classification scheme when evaluating innovations in the logistics sector. In this context, the three dimensions serve as overarching categories under which more specific sub-criteria can be organized. It should be emphasized that any evaluation of this type conducted prior to the actual implementation of an innovation must rely on assumptions and projections.

Economy

LCC plays a central role in the economic assessment of investments. It encompasses all monetary costs associated with a product or system over its entire life cycle, including acquisition, operation, maintenance, and disposal costs. In this context, the Total Cost of Ownership (TCO) serves as a key indicator for evaluating the economic viability of innovations. However, it must be noted that TCO calculations, particularly in the early stages of innovation assessment, are necessarily based on assumptions rather than empirical data. Assumedly conducting a comprehensive LCC for every potential innovation is not feasible due to resource constraints and uncertainties in forecasting. Therefore, simplified or model-based estimations are often used to support decision-making in practice.

Environment

LCA is an established method for evaluating the environmental impacts of products or systems across their entire life cycle. Applied consistently, it enables comparisons of similar products by quantifying emissions and resource use, which are then allocated to various environmental impact categories. Among these, the Global Warming Potential over 100 years (GWP100) is the most widely recognized indicator. GWP100 expresses the climate impact of a given emission relative to one kilogram of CO_2 over a 100-year timeframe, facilitating comparability between different substances. To ensure meaningful comparisons, results are normalized to the product's functional unit, which defines the quantified performance of the product system under study. Other common impact categories include Ozone Depletion Potential (ODP) and acidification potential of soil and water bodies. Ideally, all relevant environmental effects should be covered; however, due to the inherent complexity of natural systems and their interdependencies, the selection of impact categories is challenging. Therefore indirect effects on the environment are considered, no definitive recording of all influences is claimed.

In the context of innovation assessment, applying LCA requires consistent system boundaries and comparable conditions across alternatives. However, collecting the necessary input data is often time-intensive and resource-demanding. Therefore, while full LCAs may not be practical for rapid comparison of innovations, the life cycle perspective remains useful for gaining a general understanding of the environmental implications of different innovations.

Social

S-LCA evaluates the social and socio-economic impacts of products, services, and systems across their entire life cycle. In analogy to environmental LCA, S-LCA investigates issues such as working conditions, including occupational health and safety, working hours, fair wages, non-discrimination, the prevention of child and forced labour, as well as broader concerns related to human rights, livelihood security, and equitable access to resources. In addition to individual-level impacts, S-LCA also addresses effects on local communities, such as job creation, economic contributions, cultural impacts, and potential influences on public health. This broader scope makes it particularly relevant for assessing innovations that may affect multiple stakeholder groups.

While S-LCA and environmental LCA share similar methodical structures and require comparable levels of data collection and analysis effort, the assessment of social impact categories is associated with significantly higher uncertainty. Social impacts are often context-specific, qualitative in nature, and difficult to quantify consistently across cases. As a result, it is generally not feasible to conduct a complete S-LCA for every innovation under consideration.

Summary

There are several efforts to standardize the assessment methods like the EU Project “TranSensus”. However, it should be noted that independently compiled LCSAs are not yet directly comparable with each other, as it is not possible to ensure that the initial data was of the same quality or that the impact categories were evaluated equally[3].

The DIN EN ISO 14040 standard (Environmental management - Life cycle assessment - Principles and framework) emphasizes the importance of clearly defining the assessment goal and establishing system boundaries at the outset of any LCA[4]. However, for the selection of innovations in the logistics sector, a universally accepted target definition is still lacking. Moreover, contextual factors such as geographic location introduce further variability, making standardization difficult in practice.

Therefore, an LCSA or even its individual components, cannot be relied upon as the sole decision-making tool for innovation selection. Rather, having a clear understanding of the broad sustainability impact categories is crucial for fostering awareness among developers. This awareness enables a more focused and in-depth examination of relevant categories in specific cases, ultimately supporting more informed decisions regarding sustainable design, production strategies, and policy development.

3.2 Modularity

Modularity serves as both a technical and strategic approach to implementing circularity and sustainability principles. It can be defined as the design of a system composed of distinct, interchangeable components that can be replaced, upgraded or reconfigured without necessitating modifications to the entire system.

Adopting a modular design facilitates the extension of asset lifespans, reduces waste generation, and enhances adaptability to evolving requirements or emerging technologies. This inherent flexibility not only optimizes resource utilization but also contributes to long-term resilience and environmental stewardship.

Furthermore, modular configurations can delay the need for acquiring new equipment, thereby lowering investment demands. Designing for modularity may also simplify maintenance procedures, offering potential economic benefits. The specific advantages realized depend largely on the particular technical implementation and context.

[3] TranSensus LCA. (2023). Deliverable D1.2: Analysis of needs and gaps for the development of a harmonised LCA/S-LCA approach in the electromobility industry.
[4] German Institute for Standardization (DIN). (2021). DIN EN ISO 14040:2021-02 – Environmental management - Life cycle assessment - Principles and framework.

3.3 Circularity

Circularity provides a comprehensive strategy to promote sustainable operations across multiple product life cycles. One practical realization of sustainable development is the Circular Economy (CE). However, no universally accepted definition exists by now. A review of over 200 CE definitions reveals that the concept is most often addressed at a macro level[5]. At the macro level, CE encompasses cities, regions or entire nations, focusing on large-scale systems such as infrastructure, policy frameworks, and societal transitions towards circularity. The micro level concentrates on how companies design, produce, and market goods or services to enable reuse, repair, recycling, and sustainable consumption. Meanwhile, the nano level pertains to materials, components, and specific processes, examining how resources are selected, transformed, and retained within the system.

This deliverable does not propose a novel definition but adopts the one from the Europe's Environmental Protection Agencies (EPA) network's Bellagio Declaration, developed to assist national and European authorities in monitoring progress toward the EU's Circular Economy Action Plan (CEAP)[6].

"A circular economy is an economy where the value of products, materials and resources is maintained in the economy for as long as possible. All outputs from one process are input for another. Thus, a move towards a circular economy entails reducing the intake of virgin materials and reducing the generation of waste."* – Bellagio Decleration[6] (* - grammatically corrected)

Figure 4 illustrates the contrast between the circular economy and the traditional linear economic model. The linear economy follows four sequential phases: *take* (resource extraction), *make* (production), *use* (consumption), and *dispose* (waste management). This linear flow results in continuous resource consumption and waste generation.

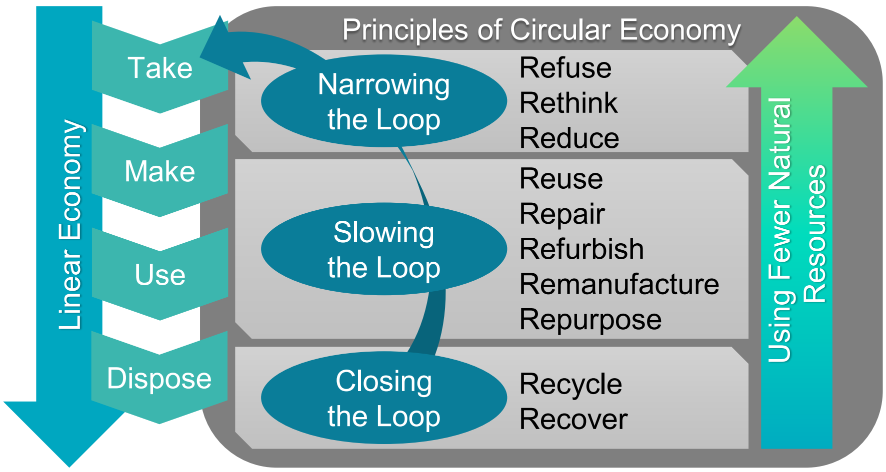

Figure 4. Elements of the linear economy allocated to principles of the circular economy and corresponding R-Strategies based on Potting et al. (2017) [7]

[5] Kirchherr, J. et al. (2023). Conceptualizing the circular economy: An analysis of 221 definitions.
[6] EPA Network, et al. (2021). Bellagio Declaration – Circular Economy Monitoring Principles.
[7] Potting, J. et al. (2017). Circular economy: Measuring innovation in the product chain.

In a circular economy, three key approaches are identified to reduce consumption and promote the sustainable use of materials and energy. R-strategies are linked to these approaches, the earlier they are applied in a product's life cycle, the greater the potential for resource savings [7]. These approaches can be understood as overarching categories for the more specific sub-criteria. The classification of subcategories is derived from the R-strategies.

Narrowing the loop

The primary aim of Narrowing the Loop is to increase production efficiency and reduce resource consumption. The associated R-strategies influence all processes involved in product creation and use. Pursuing the Refuse approach means that harmful materials or products are replaced by others that offer the same function[7]. Products that are not manufactured have not consumed any resources. The Reduce approach aims to decrease losses[7] and it can also mean producing fewer products, as a single vehicle can be used more efficiently and profitably in sharing, for example. The Rethink approach involves a detailed examination of product design and is employed when elements are removed or materials need to be substituted[7].

Slowing the loop

Slowing the Loop aims to extend the functional life of products. Strategies such as Reuse involve the direct use of a product by another customer without additional processing. Repair, refurbish, and remanufacture are strategies that involve reconstructing and restoring the product. Refurbish enhances the functionality of the product or updates it. Remanufacturing rebuilds parts to be used in new products. Repurposing is the process of transforming components for use in a different function.

Closing the loop

The Recover and Recycle strategies are only implemented when a product is no longer suitable for direct use. Energy can be recovered through the process of incineration, and materials can be recycled, reclaimed for the production of new products[7]. This supplies resources for new products and thus closes the loop. If the material is no longer suitable for the same use because its material properties have been degraded during the recovery process, this is referred to as downcycling.

3.4 User acceptance

The criterion of user acceptance describes the extent to which a new vehicle concept or technological innovation is adopted by actual or potential users. The focus here is on whether the target group is willing to use, purchase or integrate the innovation into existing operational processes. In the logistics sector, this primarily concerns two key user groups, each bringing distinct needs and perspectives: the fleet manager and the driver.

The fleet manager is primarily responsible for the selection, procurement and administration of the vehicle fleet. Although they are generally not in direct physical contact with the vehicles, they have significant influence over the introduction and implementation of new concepts within the organization. Their perspective is shaped by overarching operational, strategic and economic considerations. Decisions regarding new vehicles are typically made within the context of long-term corporate objectives.

In contrast, the driver is the direct user of the vehicle in day-to-day operations. They interact with the vehicle regularly and experience its functionality, handling and practical suitability firsthand. Their perspective is more closely aligned with specific usage situations and is often influenced by personal experiences, expectations and established routines. These two perspectives are reflected in the criterion of user acceptance.

The derivation of the criteria for user acceptance is based on established acceptance theories, which provide a solid foundation for the present application. Specifically, the Technology Acceptance Model 2 (TAM2) by Venkatesh & Davis and the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) by Venkatesh et al. are used as a basis. These theories include constructs that describe which factors are decisive for the acceptance of new technologies[8,9].

This perspective is further extended through the Car Technology Acceptance Model (CTAM) by Oswald et al. and the Connected Vehicle Acceptance Model (CVAM) by Acharya & Mekker. These theories contribute additional domain-specific insights into user acceptance of vehicle technologies and connected mobility[10,11].

Finally, these factors were complemented with the perspectives of drivers and fleet managers from the logistics sector collected in WP2.

Based on this combined approach, the following six sub-criteria for user acceptance were identified:

Fundamental factors

Fundamental factors are crucial because they determine whether an innovation can be implemented at all. Without regulatory compliance, economic feasibility, and alignment with organizational frameworks, even technically superior solutions fail to achieve acceptance.

Functional factors

Functional factors are important because they ensure that the innovation delivers practical value in real-world operations. Users are more likely to adopt solutions that reliably improve efficiency, reduce effort or address relevant operational needs.

Social influence

Social influence matters because perceptions, norms, and reputational considerations shape user attitudes toward new technologies. Acceptance increases when innovations are seen as socially legitimate and aligned with organizational or societal expectations.

[8] Venkatesh, V., et al. (2000). A Theoretical Extension of the Technology Acceptance Model: Four Longitudinal Field Studies.
[9] Venkatesh, V., et al. (2012). Consumer acceptance and use of information technology: Extending the unified theory of acceptance and use of technology.
[10] Osswald, S., et al. (2012). Predicting information technology usage in the car: Towards a car technology acceptance model.
[11] Acharya, S., et al. (2022). Public acceptance of connected vehicles: An extension of the technology acceptance model.

Ease of use

Ease of use is critical because innovations that are difficult to learn or operate quickly face resistance. Low cognitive and operational effort encourages faster adoption and consistent usage.

Enjoyment

Enjoyment is important because positive experiences increase motivation, satisfaction, and willingness to engage with the technology. Drivers experience reduced stress and higher well-being, while fleet managers gain higher acceptance rates, increased productivity, and smoother integration into workflows.

Safety

Safety is essential because users must feel protected and confident when interacting with the innovation. Drivers rely on functional safety and security to perform tasks reliably, while fleet managers need trust in the system's reliability and compliance to minimize operational and legal risks.

Overall, user acceptance is therefore a decisive success factor for the market penetration of new concepts. It is the prerequisite for broader objectives such as sustainability, circularity and modularity to become effective in practice.

4. Derivation of sub-criteria

The following section lists the methodologically derived sub-criteria of sustainability, modularity, circularity and user acceptance and provides a detailed explanation of each. It outlines why each key criterion is important and how the respective sub-criterion contributes to it. Finally, recommendations are given on how the criterion can be implemented.

4.1 Sub-criteria of sustainability

The criterion of sustainability can fundamentally be subdivided into three central levels: economic sustainability, environmental sustainability and social sustainability. These levels enable a systematic examination and evaluation of how new vehicle concepts are helping to achieve the sustainability goals of the stakeholders.

4.1.1 Economic sustainability

Acquisition costs

The initial financial investment represents a critical factor when introducing an innovation. This includes not only the purchase price of components or systems but also the costs for installation, integration into existing infrastructure and potential adjustments to operational processes. Their evaluation is key to ensuring that adopting a new concept won't harm long-term financial stability and responsible resource allocation. Stakeholders should carefully assess these upfront expenditures.

Operating costs

These expenses include e.g. energy consumption, taxes, leasing fees and software subscriptions. A comprehensive understanding of operating costs allows for a realistic assessment of the long-term financial impact beyond the initial acquisition. By systematically assessing such ongoing expenditures, stakeholders can ensure that the chosen innovation supports stable and sustainable economic performance over its entire life cycle.

Maintenance costs

This criterion covers all costs associated with maintaining the functionality and reliability of an innovation, such as regular maintenance, failure probabilities and repair costs. It is essential for innovation developers to consider these aspects early in the design process. Especially in the case of untested concepts, failure rates and repair needs can only be estimated on the basis of simulations, expert assessments or analogue systems. Since companies rarely provide this data in advance, internal assessments are crucial. A comprehensive understanding and minimisation of potential maintenance costs helps to ensure that the developed innovation minimises downtime, maintains performance and supports long-term economic efficiency.

Personnel costs

Personnel costs are considered separately to ensure they receive appropriate attention during the evaluation of new vehicle concepts. These costs arise from training and qualification measures required during both the initial implementation and the continued operation of the innovation. For example, consider the ongoing personnel costs related to the innovation, such as recurring safety training and requalification. For developers, it is important to design or chose solutions that minimize training complexity while ensuring that the system remains intuitive and usable. Assessing these costs helps determine whether the workforce can effectively operate the innovation. Taking personnel costs into account in an early stage aligns the introduction of innovations with economic performance and operational readiness.

End-of-life costs

End-of-life costs refer to the financial expenditures associated with decommissioning, dismantling, transportation, disposal or recycling of an innovation once it reaches the end of its service life. Potential resource recovery through resale, reuse or repurposing by other companies may also be considered. Assessing these costs is essential to accurately determine the overall financial impact of an innovation while ensuring that its disposal complies with environmental regulations and resource recovery objectives. By incorporating end-of-life requirements from the planning stage, stakeholders can choose solutions that offer an optimal balance between cost-effectiveness and sustainable material management.

4.1.2 Environmental sustainability

Production interrelations

This criterion refers to the interactions between the production of an innovation and its broader ecological and resource systems. This includes the effects on energy and material consumption, emissions, waste generation, and ecosystem health throughout the supply chain. This information can be obtained from the companies' “corporate social responsibility” (CSR) or “environmental, social and governance” (ESG) reports and the available product data sheets. The evaluation of these interrelations enables stakeholders to identify innovations that minimize environmental impacts and support sustainable, resource-efficient production practices.

Usage interrelations

Understanding how an innovation interacts with its environment during operation is essential for sustainable development. This includes its influence on energy and resource efficiency, emission levels, waste streams, and potential ecological disturbances throughout the use phase. This approach also considers dependencies on external systems, such as energy grids or material inputs. The objective is to ensure that chosen innovations minimize environmental burdens while maintaining sustainable and resilient performance.

End-of-life interrelations

The environmental implications of an innovation do not end with its use phase. Particular attention must be paid to the impacts associated with its decommissioning, dismantling and disposal. These include immediate effects such as emissions, waste generation and pollution, as well as indirect impacts linked to resource recovery efficiency, secondary material markets and long-term ecosystem health. This information can be obtained from the companies' CSR or ESG reports and the available product data sheets.

4.1.3 Social sustainability

When assessing social sustainability criteria such as standards for users, the origin of the product or the reputation of the producer, it is important to acknowledge that social impacts are highly context dependent. When assessing social sustainability criteria such as standards for users, the origin of the product or the reputation of the producer, it is important to acknowledge that social impacts are highly context dependent. That constitutes a socially positive outcome can vary widely across cultural settings and may shift over time. The effects of these factors vary in their timing and visibility. While some social impacts are immediately noticeable, others only unfold gradually as societal norms, policies, and cultural values evolve. Relying on a static assessment may lead to blind spots, so it is essential to incorporate both cultural context and the evolving nature of social dynamics into the evaluation process.

Safety standards for users

This criterion covers the measures and regulations aimed at ensuring the safety of both personnel and their surrounding environment during the operation and handling of an innovation. Evaluating these standards is crucial to reduce workplace accidents, prevent harm to bystanders and the environment, and minimize legal risks and related costs. By prioritizing safety, stakeholders ensure that innovations support both employee well-being and responsible, sustainable operations.

Origin of the product

The geographic and socio-economic context of an innovation's production plays a significant role in its impact. Factors such as job creation, contributions to the local economy, and cultural influences are considered to understand how the product affects community and regional development. By taking these factors into consideration, stakeholders can select innovations that promote positive social and economic outcomes alongside technological advancement.

Certification and standards compliance of producer

Reputation of the producer reflects adherence to ethical and social standards during the manufacturing of an innovation. These standards include working conditions, occupational health and safety, regulated working hours, fair wages, non-discrimination, and the prevention of child and forced labour. International certificates are available to verify this. A thorough assessment of the producer's reputation is essential to ensure alignment of the innovation with responsible and sustainable business practices. Considering these factors enables stakeholders to prioritize products from manufacturers that uphold high social and ethical standards, thereby fostering long-term trust and credibility.

4.2 Sub-criteria of modularity

Physical modularity

Physical modularity is characterized by the composition of distinct, interchangeable physical units or modules and represents a critical factor in the evaluation and selection of innovations. From an economic standpoint, this design strategy enhances cost efficiency by enabling targeted replacement and upgrading of components, thereby avoiding comprehensive system overhauls. Environmentally, physical modularity contributes to resource conservation and waste reduction, ultimately extending the operational lifespan of vehicles and supporting circular economy objectives. Moreover, modular systems generally facilitate maintenance activities, further improving overall sustainability. Comparative assessments of innovations may consider the number and interchangeability of modular elements relevant to specific applications as key indicators of modularity's effectiveness.

Functional decoupling

This design approach is characterized by modules that possess clearly defined and independent functions. A prominent example is the separation of the cargo unit from the cabin in vehicle design. This characteristic serves as a critical criterion in the evaluation and selection of innovations. Economically, functional decoupling enables targeted upgrades or replacements of individual modules without affecting the entire system, thereby improving cost efficiency. From an ecological perspective, it supports optimized resource utilization by allowing adaptation or reuse of functional modules across different applications, which contributes to waste reduction. Additionally, functional decoupling enhances operational flexibility, improves user safety through task-specific module design, and creates opportunities for specialized maintenance and servicing, thereby strengthening the overall sustainability profile of the innovation.

Standardized interfaces

Standardized interfaces encompass the mechanical, electrical, and digital connections between modules, designed to ensure uniformity, compatibility, and stability across both hardware and software components. These attributes represent a crucial consideration in the selection of innovations. Economically, the adoption of standardized interfaces can significantly reduce integration and maintenance costs by enhancing interoperability and streamlining upgrade processes. From an ecological perspective, such interfaces facilitate reuse and interchangeability of components, thereby extending their operational lifespan and minimizing waste generation. This inherent flexibility contributes to reduced downtime and further cost savings in maintenance and integration. Consequently, logistics operations gain increased adaptability to evolving demands and technological advancements, while simultaneously achieving a reduction in environmental impacts through improved resource efficiency and enhanced circularity.

Configurability through combination

The ability to assemble standardized modules into various configurations enables the creation of variants tailored to specific operational tasks. This modular approach supports task-specific design adaptations, potentially reducing the overall number of vehicles required within a fleet. For instance, the installation of route-specific modules or adapting of the modules may eliminate the need for separate vehicles, resulting in lower total investment costs. Additionally, the reduction in deployed vehicles contributes to decreased energy consumption and labor input, enhancing both economic efficiency and environmental performance.

Independent module development

Enabling the design or improvement of modules independently from the overall vehicle architecture represents a strategic advantage in innovation development. Economically, this modular independence allows for accelerated and cost-efficient innovation cycles by focusing development activities on specific components rather than the entire system. From an environmental standpoint, it supports the integration of advanced, more sustainable technologies into targeted functional units, thus avoiding resource-intensive redesigns. A further dimension of this principle involves outsourcing module development to third-party providers. Such externally developed solutions can be retrofitted into existing products when required, enhancing system flexibility. This approach fosters technological diversity, encourages knowledge transfer, and contributes to the long-term adaptability and sustainability of the vehicle concept.

4.3 Sub-criteria of circularity

Circular economy principles aim to optimize the use of materials and energy through three overarching strategies: narrowing the loop, slowing the loop, and closing the loop. Each of these approaches is associated with certain R-strategies. The implementation of these strategies during the design and production phases ensures the optimization of resource efficiency. This is achieved by reducing consumption, extending product lifespans and recovering value at the end of the product's lifecycle. Consequently, this approach maximizes the potential for environmental and economic benefits.

4.3.1 Narrowing the loop

This aspect focuses on increasing production efficiency and reducing overall resource consumption by guiding both product creation and use through targeted R-strategies. The refuse approach eliminates harmful materials or products by substituting them with safer alternatives that provide the same function. Where full substitution is not feasible, the reduce approach minimizes the use of such materials, lowering their environmental and health impacts. The rethink approach encourages re-evaluating product design and broadening available variants to enable more sustainable choices from the outset.

Material selection

The composition of materials used in an innovation plays a critical role in determining the environmental and social impacts associated with their extraction, processing and use. Materials that require less intensive mining, avoid hazardous substances or come from responsibly managed sources reduce ecological degradation and energy consumption. By prioritizing such materials, the innovation supports circularity while minimizing the negative effects of raw material extraction on ecosystems and communities.

Material efficiency

The material selected for the innovation has a direct impact on the overall material efficiency, affecting both resource consumption and environmental performance. The adoption of lightweight construction methodologies has been demonstrated to reduce material consumption, thereby enhancing energy efficiency during operation. To a certain extent, the utilization of reduced material quantities in the production of goods results in a reduction in associated costs, as the demand for raw materials is decreased. However, this benefit can be mitigated or even eliminated, depending on the specific material and extent of lightweight construction employed. By optimizing material efficiency, the innovation supports circularity and contributes to both ecological and economic sustainability.

Energy efficiency

This criterion concerns the extent to which the selected materials and associated production processes contribute to reduced energy consumption during the manufacturing phase of an innovation. Different materials require varying levels of energy for extraction, refinement, and processing. The use of less energy-intensive materials has been shown to lower the carbon footprint and decrease overall resource demand. By prioritizing energy-efficient material choices, the innovation supports the principles of circularity and advances both environmental sustainability and economic efficiency.

4.3.2 Slowing the loop

This aspect aims to extend the product life. Strategies such as reuse involve the direct continued use of a product in its original form. In contrast, repair, refurbishment and remanufacturing focus on the restoration and reconstruction of products or components. Refurbishment enhances or updates products to meet current requirements, while remanufacturing involves rebuilding components to restore them to like-new condition. Repurposing refers to transforming components for a different function than originally intended. These strategies contribute to the circular economy by preserving product value, reducing the need for new resources and lowering environmental impacts over the product's life cycle.

Durability

This term refers to the capacity of an innovation to withstand wear, mechanical stress and environmental influences while maintaining its intended function over time. Enhanced durability of products leads to a reduction of the failure probability and therefor reduces the demand for replacement parts or entirely new products. This, in turn, results in a decrease in resource extraction, manufacturing energy use and waste generation in the context of sustainability. The integration of robust design, quality manufacturing and suitable material choices extend the product's service life, preserve value and strengthen both environmental and economic sustainability.

Design for high utilization

Design for high utilization prioritizes the optimization of operational utilization, ensuring that the innovation's capacity is utilized to its maximum potential over its entire lifecycle. High utilization has been demonstrated to reduce the total number of products necessary to deliver a given service, thereby decreasing resource extraction, manufacturing energy consumption and waste generation. The approach is characterized by adaptable design, shared-use concepts and efficient operational planning, which collectively enhance value creation while supporting environmental and economic sustainability.

Design for refurbishment

This practice ensures that an innovation can undergo a planned, comprehensive restoration process after a defined period of use. This process often involves disassembly, replacement of multiple components and performance upgrades. The objective of this initiative is to refurbish the product, thereby restoring it to a state of equivalent quality to that of a new product, while extending its overall service life and postponing the necessity for new production. This approach has been demonstrated to reduce large-scale resource demand and waste while retaining economic value over a longer lifecycle.

Design for repair

This criterion focuses on the ability of the innovation to resume functionality in the event of unanticipated failure or damage, typically involving the targeted replacement or repair of specific components. The primary objective of this initiative is to implement rapid and cost-effective solutions that ensure the continued functionality of the product, thereby minimizing operational downtime. Facilitating access to critical components, along with the use of standardized and interchangeable parts, contributes to reduced material waste caused by premature disposal. In doing so, design for repair enhances operational resilience and supports both environmental and economic sustainability.

Upgradeability

Enabling incremental enhancement over time, upgradeability allows innovations to integrate new technologies, features, or performance improvements without necessitating full system replacement. This capability enables products to maintain relevance and efficiency in the face of evolving operational or regulatory environments, thereby mitigating the necessity for complete substitutions and the associated resource and energy expenditure. By facilitating modular upgrades, standardized interfaces and backward compatibility, design for updateability contributes to the long-term retention of value, environmental responsibility and economic sustainability.

Multi-life-cycle use

This criterion ensures that an innovation can be repeatedly deployed through successive life cycles, either in its original form or after undergoing reconditioning, refurbishment or repurposing. This approach has aims to maximise the overall value of the product, reducing the need for new production and minimising the environmental impact of material extraction and processing. By facilitating durability, adaptability and ease of restoration, multi-life-cycle use ensures sustainable economic returns while strengthening resource efficiency and circularity.

Adaptability to market and regulatory change

This approach ensures that an innovation can be modified or reconfigured to meet evolving customer demands, industry trends and compliance requirements without requiring complete replacement. This flexibility reduces the risk of obsolescence, decreases resource and energy use associated with new production and extends the product's functional relevance. The incorporation of modular architectures, standardized interfaces and scalable features has been demonstrated to enhance economic resilience while fostering environmental and social sustainability.

4.3.3 Closing the loop

This aspect aims to return resources. The recover and recycle strategies are utilised when a product is no longer suitable for direct use. Energy is recovered through incineration and materials are recycled. This supplies resources for new products and closes the loop. If the material is no longer suitable due to degraded property, this is referred to as downcycling.

Recyclability

Recyclability ensures that, at the end of its functional lifespan, an innovation can be effectively broken down into reusable materials, facilitating their reuse in the creation of new products. The selection of innovations that are easily separable, non-toxic and compatible with existing recycling processes is a strategy that has been demonstrated to minimize waste and reduce the need for virgin resource extraction. The integration of effective material recovery mechanisms within the design process fosters the recycling of materials, thereby promoting resource efficiency, environmental sustainability and the maximization of long-term economic value.

Design for disassembly

This criterion refers to the physical ability to take a product apart into its individual components or modules. It prioritizes ease of separation without damage, enabling repair, refurbishment or recycling and facilitating efficient material management. The focus is on product architecture and assembly techniques that allow effective end-of-life processing while enhancing both resource efficiency and operational feasibility.

Circular documentation

This approach ensures that comprehensive information about a product, including material composition, component specifications, assembly methods, maintenance requirements and end-of-life handling is systematically collected, updated and easily accessible. Accurate documentation enables users and recyclers to perform repairs, refurbishments, disassembly and material recovery in an efficient and safe manner. By ensuring comprehensive traceability and transparency, circular documentation mitigates errors, prevents resource losses, reduces environmental impacts and fosters long-term economic value throughout the product's lifecycle.

Recovery-oriented end-of-life strategy

A recovery-oriented end-of-life strategy prioritizes the reintegration of materials and components into the value chain once a product has reached the end of its functional lifespan. This approach prioritizes recycling, remanufacturing and energy recovery over disposal. It integrates recovery planning into the design and operational phases. This reduces reliance on virgin resources, minimizes environmental impacts and enhances long-term economic and resource sustainability.

4.4 Sub-criteria of user acceptance

The criterion of user acceptance can fundamentally be subdivided into six central aspects: fundamental factors, functional factors, social influence, ease of use, enjoyment and safety. These attributes enable a systematic examination and evaluation of how new vehicle concepts are accepted by the key stakeholders.

4.4.1 Fundamental factors

Regulatory compliance

Regulatory compliance assesses whether an innovation meets all relevant legal, safety and environmental requirements necessary for market approval and operational use. This includes, for example, type approvals, environmental regulations, workplace guidelines or data protection requirements. A high level of compliance is essential for building trust in the technology and reduces legal risks. Innovations without evident regulatory barriers tend to achieve higher acceptance.

Investment and operating costs

This criterion assesses the economic viability of an innovation throughout its entire lifecycle. High functional acceptance is only achieved if the total costs including acquisition, maintenance, energy consumption, repairs and training are justified in relation to the benefits provided. Successful innovations demonstrate a clear economic forecast and achieve cost savings compared to the status quo without compromising functionality.

Return on invest

Return on Investment (ROI) evaluates how quickly and sustainably the introduction of an innovation pays off. An innovation is considered functionally accepted if it generates a positive net effect within an economically reasonable timeframe. Savings, such as energy, personnel and time, as well as potential additional revenues, for example through image gains or new services, play a role in this assessment. Success factors include short payback periods and a positive ROI over the entire lifecycle. A clear ROI signals that the innovation not only works but is also economically viable.

Eligibility for funding

This criterion assesses whether and to what extent an innovation qualifies for public funding programs. Although indirect, it is a crucial success factor. Good eligibility reduces market entry barriers for customers, improves financing conditions and signals regulatory alignment. Evaluation can include compatibility with programs for CO_2 reduction, innovation promotion or digitalization, as well as existing certifications and legal standards. Successful concepts meet common funding criteria and enable rapid funding applications for customers.

4.4.2 Functional factors

Usefulness

The criterion of usefulness evaluates the functional added value that an innovation generates for its target group within a specific application context. High usefulness is present when the innovation contributes to increased efficiency, process simplification, error reduction or the alleviation of physical and cognitive burdens. The assessment focuses on the extent to which the vehicle addresses real-world application problems, such as time savings, reduction of physical strain or support in complex tasks. Equally important is whether the innovation is perceived by users as helpful and appropriate across various usage scenarios. A high degree of usefulness is a key predictor of the functional acceptance of an innovation and significantly contributes to its long-term integration into operational processes. Thus, usefulness represents not only a functional but also a strategic criterion for the successful implementation of technical innovations.

Compatibility

Compatibility describes the extent to which an innovation can be seamlessly integrated into existing structures and processes. High compatibility not only reduces implementation costs and technical integration efforts but also positively influences acceptance during rollout, the time horizon for deployment and organizational transformation processes. The evaluation focuses on whether the innovation is compatible with existing infrastructure such as warehouse logistics, loading stations or workshop standards. It also considers compatibility with IT systems, planning software and safety regulations. Additionally, structural alignment with the organizational culture and operational objectives of potential users should be taken into account. Success factors include low integration effort and the use of established standards.

Energy efficiency

Energy efficiency refers to an innovation's ability to utilize resources efficiently, particularly in terms of energy consumption, range and operational costs. Energy-efficient concepts not only reduce costs but also meet environmental requirements that are increasingly demanded by regulators and customers. Successful innovations demonstrate low consumption per transport output under real-world operating conditions. This can be achieved e.g. through optimized operational strategies as well as lighter and more efficient vehicles. High energy efficiency thus enhances both functional and social acceptance.

Reliability

Reliability measures the technical dependability of a vehicle innovation during regular operation. High reliability means that the system remains stable and available even under high loads, changing conditions or in the event of individual faults. This aspect is particularly critical, as failures have direct impacts on time windows, customer retention and operational costs. A high degree of reliability depends on a variety of technical and organizational factors. The technical robustness of a system ensures resistance against external influences and significantly contributes to the longevity of components. Optimised maintenance cycles and generally low maintenance requirements minimize unplanned downtime and reduce ongoing operating costs. The availability of spare parts and a widespread, structured service and workshop network ensure rapid restoration of operational capability in case of malfunctions. Equally important is a systematic approach to handling technical faults or errors, for example through integrated early diagnosis systems, fault tolerance mechanisms or adaptive system adjustments. Taken together, these features significantly enhance operational safety while minimizing resource use.

Scalability

Scalability measures an innovation's ability to be economically and functionally applicable across different deployment scenarios and company sizes. A scalable innovation can be used both in small pilot fleets and large fleet networks without incurring exponential costs or complexity. Evaluation criteria include modularity, platform concepts, adaptability to various markets and user groups, as well as requirements for infrastructure and personnel. High scalability increases market attractiveness and facilitates the broader implementation of successful pilot projects.

Flexibility

Flexibility describes the vehicle's adaptability to different requirements and conditions, such as operating locations, weather conditions, payload or operational processes. A high degree of flexibility increases the range of use and reduces the need for parallel system solutions. The evaluation includes factors such as variability in the operational spectrum and the ease of reconfiguring or adapting software and hardware to different scenarios. Innovations with high flexibility achieve higher utilization rates and are more future proof in changing market conditions.

Discomfort

Discomfort is a functional criterion that influences the quality of work and the physical and mental strain on vehicle users. Vehicles that are uncomfortable to operate, for example due to poor ergonomic design, difficult handling, or unintuitive controls, tend to be used less consistently and reliably over time. Unsuccessful designs increase health risks, accelerate fatigue, and decrease satisfaction in daily work, which in turn can increase employee turnover and absenteeism.

Accessibility

Accessibility describes the extent to which an innovation is fully accessible and operable for users with different physical, linguistic, cognitive and cultural abilities. In the logistics sector, which is characterised by high fluctuation, diverse employee groups and increasing internationalisation, accessible design is a key success factor for broad acceptance and safe use of technical systems. Successful innovations include double-handed operating concepts, linguistically easy-to-understand and multilingual user interfaces, instructions and voice output. Accessibility is therefore not only an instrument for social participation and the prevention of structural discrimination but is also gaining strategic relevance. It has a positive effect on staff retention, process reliability and the fulfilment of public procurement requirements.

4.4.3 Social influence

Image

The image criterion describes how positively a vehicle innovation is perceived in both public and corporate contexts. Especially in the current environment, factors such as environmental awareness and modern technologies influence a company's reputation and customer perception. An innovation with a strong, positive image can support market differentiation and is often easier to justify. A strong reputational gain signals social compatibility and reinforces the strategic legitimacy of the innovation. Key aspects of image impact relate to external perception, such as visible contributions to sustainability communicated to customers, partners and other stakeholders. In addition, acceptance among colleagues also plays a role. Positive reactions within the team, social norms and group dynamics can facilitate the adoption of new technologies. In this sense, a strong image also has an internal stabilizing effect within organizations and promotes willingness to actively participate in shaping change.

Identification

Identification describes the extent to which employees and other stakeholders can identify with the innovation or the underlying concept. A high level of identification strengthens motivation, acceptance and long-term engagement in working with new technologies. Successful innovations promote a sense of pride, spark curiosity and align with personal or organisational values.

Social responsibility

This criterion measures whether and to what extent an innovation contributes to achieving societal goals such as environmental protection, climate targets or social sustainability. Innovations that visibly and credibly demonstrate social responsibility through measures such as CO_2 reduction, low noise emissions or fair accessibility enhance their legitimacy in the public sphere. A strong contribution to social responsibility goes beyond purely functional benefits and strengthens long-term societal acceptance.

4.4.4 Ease of use

Learnability

Learnability describes how quickly and easily users can understand and apply new functions and systems. A low entry barrier reduces training requirements and potential sources of error, especially in environments with frequently changing personnel. Innovations with high learnability can be introduced more rapidly and used more efficiently, which significantly increases functional acceptance.

Learning effort

This criterion describes how easily users can adopt new behaviours or operating methods from an emotional perspective. Even if an innovation is objectively learnable, it may still be perceived as overwhelming. Success is reflected when the learning curve is seen as positive, curiosity is sparked instead of frustration and the system feels intuitive. Low emotional learning effort is a key entry barrier, especially for digitalized or automated systems.

4.4.5 Enjoyment

Well-being

The well-being criterion measures how pleasant and stress-free the interaction with the innovation is experienced in everyday use. Emotional acceptance increases when users feel joy, ease or relief rather than uncertainty, overwhelm or discomfort. Successful innovations reduce strain, for example through intuitive interfaces, workload reduction or good ergonomics and promote a positive user experience. A high level of well-being is not only psychologically relevant but also a key driver for long-term use and user recommendation.

Hedonic motivation

Hedonic motivation describes whether and to what extent the innovation generates a positive impulse for change among users. It considers whether the innovation inspires, activates or releases new energy. Emotionally successful concepts create a sense of working with modern technology, contributing to something meaningful or developing new skills. This not only fosters acceptance of technological innovations but also positively influences job satisfaction, identification with the company and engagement in the change process.

4.4.6 Safety

Functional safety

The functional safety criterion assesses the protective effectiveness of technical and structural measures for drivers, the environment and cargo. High functional acceptance requires that the vehicle is safe to operate and that protective mechanisms function reliably in critical situations. An innovation is considered safety-accepted if it performs convincingly in tests and complies with relevant standards.

Trust

Trust evaluates how safe and reliable users subjectively perceive the new technology to be. Users must be confident that the technology functions dependably, that their data is protected and that they will not lose control in critical situations. Doubts about safety or concerns regarding surveillance can significantly hinder acceptance. To foster trust, the technology should be transparent, provide clear control options and address user concerns through training or informational materials. Clear and understandable error communication also contributes to building long-term trust. A high level of trust is a key prerequisite for emotional acceptance, especially in the case of disruptive technologies.

Perceived safety

While objective safety measures functional aspects, this criterion refers to the perceived level of safety when using the vehicle. Even if systems operate in accordance with standards, feelings of uncertainty, for example regarding automated functions, can hinder acceptance. A successful innovation conveys a sense of safety, control, clarity and predictability. Subjective safety is especially critical during transitional phases, such as the shift from conventional to automated systems.

Security

The security criterion evaluates how well a vehicle protects users, data, and operational processes from intentional threats, such as cyberattacks, unauthorized access or sabotage. High security acceptance requires that the vehicle's systems reliably prevent breaches and that sensitive information is safeguarded. Innovations are considered security-accepted if they demonstrate robust protection mechanisms, comply with relevant security standards, and maintain operational integrity even under targeted attacks. Clear communication about security measures and regular updates or patches further enhance user confidence and support long-term acceptance.

5. Assessment framework

After the derivation of the criteria, the final step consists of consolidating them into the comprehensive assessment framework. For this purpose, an assessment table is established that enables a structured evaluation and comparison of two concepts. Within WP3, this framework can be applied to the development of innovations in two distinct use cases.

First, it serves to compare the developed innovations with a state-of-the-art product. This makes it possible to verify whether the innovation generates value compared to existing alternatives and to identify aspects where further improvements are required to ensure the success of the product.

Second, the framework can be employed when two potential solutions emerge during the innovation development process. In such cases, the structured evaluation supports an objective decision on which option should be pursued further and where additional potential lies.

Overall, the framework is designed to guide the iterative development process toward optimal designs, thereby maximizing the potential impact of the project. An extract of the assessment table is provided in Table 2 (see below), while the complete version can be found in Annex 1.

Main Criterion	Sub Criterion	Individual Criterion	Description Concept 1	Description Concept 2	Comparison of concept 1 and 2	Summary and recommended action
User acceptance	Functional factors	Usefulness				
		Compatibility				
		…				
		Summary User acceptance				
		Overall Summary				

Table 2. Extract from the Assessment table

The assessment table is structured in a way that facilitates both detailed evaluation and transparent comparison of the concepts. On the left-hand side, it provides an overview of the main, sub and individual criteria. For each individual criterion, separate columns are allocated to Concept 1 and Concept 2, which are to be filled with detailed descriptions of how the respective concept addresses the criterion. These entries may include strengths, weaknesses, and suggested improvements. Following this, a direct comparison between Concept 1 and Concept 2 is conducted for the given main criterion. The final column contains a synthesis of the findings together with a recommended course of action regarding the criterion.

Once all sub-criteria of a main criterion have been evaluated, a summary for the main criterion is provided. This includes a description of how both concepts perform with respect to the main criterion, followed by a comparison and a concluding recommendation. The same procedure is applied to all remaining main criteria.

At the end of the process, an overall synthesis is presented that integrates the results across all criteria. This final section describes and compares both concepts in terms of their overall performance and concludes with a comprehensive summary and final recommendation.

When fully completed, the document offers a clear and detailed overview of how the concepts perform in relation to sustainability, modularity, circularity, and user acceptance. Furthermore, it provides an accessible basis for identifying which concept is preferable and which actions should be pursued to further strengthen the selected innovation.

6. Conclusion and outlook

Deliverable 3.1 establishes a structured framework for the systematic development and evaluation of Shift2Zero innovations. Through a mythological approach that combines insights from literature, consortium experts, and user feedback collected in Work Package 2, the framework enables a comprehensive and evidence-based assessment of vehicle concepts.

The aim of the framework is to systematically compare two vehicle concepts or innovations in terms of the key success factors: sustainability, modularity, circularity, and user acceptance, highlighting their strengths and weaknesses in a structured manner. Based on these factors, 52 specific design criteria were derived, providing actionable guidelines that directly support the design and development process.

The developed framework is intended to be applied throughout the innovation process in Work Package 3, guiding iterative development and optimization. By allowing continuous assessment and comparison, the framework ensures that improvements are systematically identified and implemented, steering the project toward the most promising and impactful solutions. In this way, the framework not only supports objective decision-making but also fosters innovations that maximize long-term success.

7. Annex 1. Assessment table

Main Criterion	Sub Criterion	Individual Criterion	Description		Comparison of concept 1 and 2	Summary and recommended action
			Concept 1	Concept 2		
Sustainability	Economic sustainability	Acquisition costs				
		Operating costs				
		Maintenance costs				
		Personnel costs				
		End-of-life costs				
	Environmental sustainability	Production interrelations				
		Usage interrelations				
		End-of-life interrelations				
	Social sustainability	Safety standards for users				
		Origin of the product				
		Reputation of producer				
		Summary Sustainability				

Main Criterion	Sub Criterion	Individual Criterion	Description		Comparison of concept 1 and 2	Summary and recommended action
			Concept 1	Concept 2		
Modularity	-	Physical modularity Functional decoupling Standardized interfaces Configurability through combination Independent module development				
		Summary Modularity				

Main Criterion	Sub Criterion	Individual Criterion	Description		Comparison of concept 1 and 2	Summary and recommended action
			Concept 1	Concept 2		
Circularity	Narrowing the loop	Material selection				
		Material efficiency				
		Energy efficiency				
	Slowing the loop	Durability				
		Design for high utilization				
		Design for refurbishment				
		Design for repair				
		Upgradeability				
		Multi-life-cycle use				
		Adaptability to market and regulatory change				
	Closing the loop	Recyclability				
		Design for disassembly				
		Circular documentation				
		Recovery-oriented end-of-life strategy				
		Summary Circularity				

Main Criterion	Sub Criterion	Individual Criterion	Description		Comparison of concept 1 and 2	Summary and recommended action
			Concept 1	Concept 2		
User acceptance	Fundamental factors	Regulatory compliance				
		Investment and operating costs				
		Return on invest				
		Eligibility for funding				
	Functional factors	Usefulness				
		Compatibility				
		Energy efficiency				
		Reliability				
		Scalability				
		Flexibility				
		Discomfort				
		Accessibility				
	Social influence	Image				
		Identification				
		Social responsibility				
	Ease of use	Learning effort				
		Learnability				
	Ease of use	Learning effort				

		Learnability				
	Enjoyment	Well-being Motivation				
	Safety	Functional safety Perceived safety Trust Security				
		Summary Sustainability				

Overall Summary				