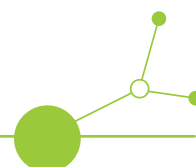
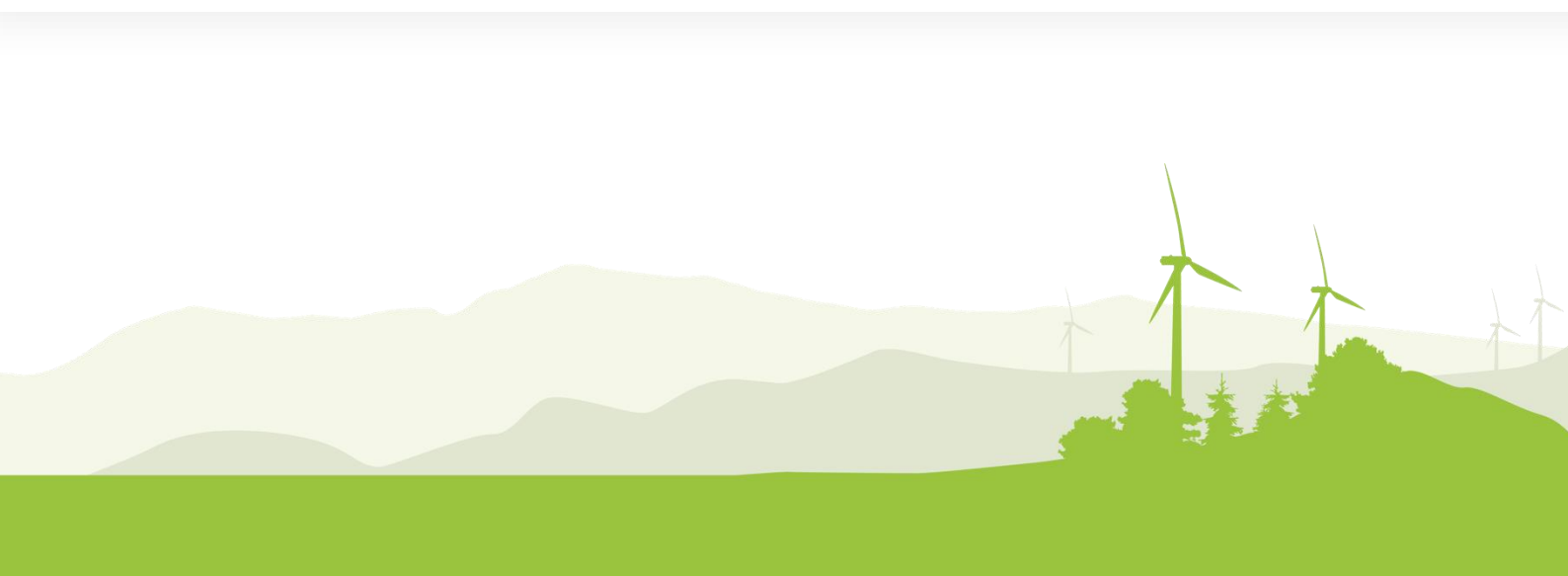


DELIVERABLE 2.3.1

Report on joint circular strategy development to preserve value and reduce waste of public transport vehicles/rolling stock



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List of abbreviations

Abbreviation	Full Term
AETE	AVOID-EXTEND-TRANSFORM-ENABLE
BIM	Building Information Modelling
CO2	Carbon Dioxide
CE4CE	Circular Economy for Central Europe
CEAP	Circular Economy Action Plan
EU	European Union
LCA	Lifecycle Assessment



PTO	Public Transport Operator
PTA	Public Transport Authorities
PTI	Public Transport Infrastructure

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Table 1: Analysis of key circular economy regulations and directives for rolling stock in the EU

Table 2: Non-exhaustive list of circular indicators for rolling stock



1. Introduction

1.1. Why circularity and the need for the CE4CE strategies?

The transport sector accounts for roughly one-fifth of the total EU emissions. While sectors like energy have reduced emissions since the 1990s, emissions from road transport continue to rise, reaching nearly 700 MtCO₂ as of 2023.¹ The challenge, however, EXTENDs beyond tailpipe emissions: the transport sector consumes vast resources, creating significant embedded emissions from activities like steel production for vehicles, gasoline refinement, lithium mining for batteries, and cement manufacturing for infrastructure. For instance, embedded GHG emissions can account for 50-60% of total lifecycle emissions in electric vehicle manufacturing, compared to just 10% for combustion engine cars.²

Emissions are symptomatic of a deeper issue—a linear economy built on a "take-use-throw" model that depletes finite resources and disregards ecological restoration, leading to critical ecosystem exhaustion. Addressing this requires a fundamental shift in how resources are designed, used, and consumed. A circular economy offers a cradle-to-cradle solution, tackling direct ecological impacts of transport activities while addressing the influence and effect in areas like construction, energy, and waste. By rethinking resource use, the circular economy seeks to address the systemic ecological and social impacts of the transport sector and beyond.

The CE4CE project pioneers this shift by transitioning from a linear model to a circular "AVOID-EXTEND-TRANSFORM-ENABLE" (AETE) approach, positioning public transport as a catalyst for transformation. Its initial phase developed the Circularity Compass³, establishing the AETE framework for understanding public transport activities within a life-cycle perspective, spanning three public transport pillars: Energy, Infrastructure, and Rolling Stock, with Governance as a cross-cutting pillar.

Building on this foundation, CE4CE is advancing **three strategies focused on Energy, Infrastructure, and Rolling Stock**. These strategies leverage the life-cycle approach of the Circularity Compass and adopt a common document structure to uncover the full ecological impacts of each area, exploring in detail their conditions, direct and embedded emissions, and sector-specific recommendations to advance a more circular approach. These strategies form the

¹ European Environment Agency. (2024). *Transport and mobility*.
<https://www.eea.europa.eu/en/analysis/indicators/greenhouse-gas-emissions-from-transport>

² Transport & Environment. (2024). *Cleaning up steel in cars: why and how*.
<https://www.transportenvironment.org/articles/cleaning-up-steel-in-cars-why-and-how>

³ Circular Economy for Public Transport. (n.d.). *Circularity Compass*. <https://circularity4publictransport.eu/circularity-compass/>



basis for localized action plans, offering concrete, time-bound measures and clearly defined responsibilities to make circularity a reality and drive the transition to net-zero public transport systems.

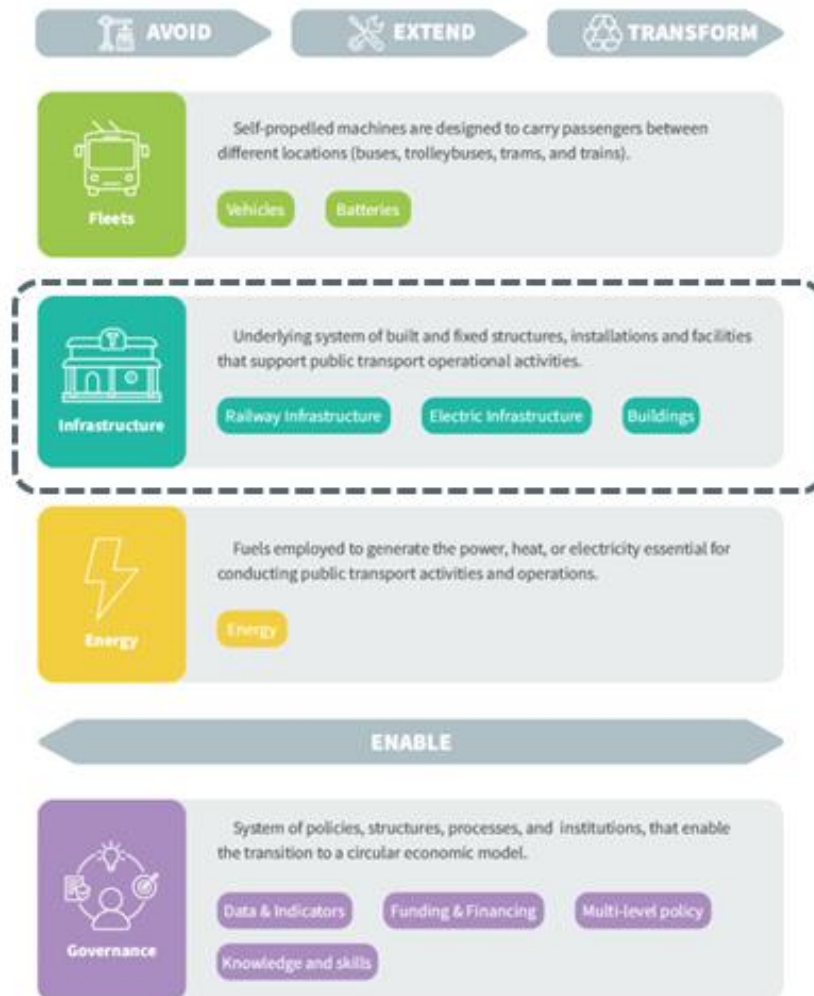


Figure 1. Visual summary of circularity compass life-cycle approach and public transport pillars. The frame highlights the focus of this strategy is on public transport infrastructure elements. Source: CE4CE

1.2. Why a circular economy approach in public transport rolling stock

Public Transport rolling stock is undergoing a deep transformation process, with a strong orientation towards decarbonisation thanks to the wide adoption of electrification technologies.

In this context, PTOs often struggle with the identification of a systemic approach for the transition, while the benefits of decarbonisation might be only partially exploited due to limited resources and lack of vision.



Furthermore, decarbonisation solutions, when not fine tuned within a long term strategy, might result in financially unsustainable investments.

The role of circularity has a twofold purpose:

- on one side, it is fundamental to ensure a minimisation of the negative external impacts generated by the material and energy intensive production, use and decommissioning of rolling stock;
- on the other side, a circular approach can generate returns in terms of resource efficiency through the extension of the lifespan of rolling stock, the rational planning of operations, maintenance and repair activities, the possibility of repurposing and reusing vehicles and especially key components (i.e. batteries).

By integrating circularity into planning and decision-making, stakeholders can enhance environmental performance, reduce waste, and support long-term value creation—ensuring that the process of renewal of fleets not only improves the quality of PT operations, but also aligns with broader environmental and sustainability objectives.

2. Conceptual and contextual basis

2.1. What is public transport rolling stock

In the railway industry, rolling stock refers to any railway vehicle that moves exclusively on rails or a tracked transport system. The term includes all powered (for example locomotives) and unpowered vehicles (for example passenger carriages or coaches and goods wagons etc.)⁴.

Following a broader approach, largely adopted in North America, rolling stock includes all “transit vehicles such as buses, vans, cars, railcars, locomotives, trolley cars and buses, and ferry boats, as well as vehicles used for support services”⁵.

For the purpose of the present strategy, developed for public transport, the perimeter of rolling stock will be defined taking into account buses, trolleybuses, trams, metro and light rail vehicles.

Furthermore, the focus of the proposed analysis identifies buses (and in particular e-buses), trolleybuses and trams as the core of the strategy.

⁴ Eurostat statistics explained: transport glossary https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Category:Transport_glossary

⁵ US Code of Federal Regulations (CFR) Title 49 Part 661.3 <https://www.ecfr.gov/current/title-49/subtitle-B/chapter-VI/part-661/section-661.3>



2.2. Defining public rolling stock for the CE4CE strategy

In the framework of the Circularity compass, the provisional definition of fleets (rolling stock) within the context of public transport systems pillar is: **Self-propelled machined designed to carry passengers between different locations** (buses, trolleybuses, trams, and trains). The circularity compass further breaks down the fleets pillar in two sub pillars:

Vehicles, with a specific focus - as mentioned - on e-buses and including buses, trolley buses and trams.

Batteries, as key component of electric and trolley buses, characterised by a different lifespan than the one of the vehicles, but also a potential extended life for stationary purposes.

Furthermore, in order to capture the whole circularity potential around the rolling stock topic, the functioning perimeter for the present strategy needs to be extended, according to the performed analysis, considering **Maintenance & Repair** as third sub pillar.

Under this category maintenance services, spare parts, tyres, cable and electronics, lubricants and coolants are included.

2.3. Introducing a life cycle approach in public transport rolling stock

A first and crucial step in advancing circularity in public transport rolling stock is adopting a life cycle perspective, in particular when designing procurement processes for fleet renewals. This is essential for understanding the full range of resource use and ecological impact, as well as for identifying where priorities should be set.

To achieve this, the strategy builds upon existing frameworks. On one hand, it is grounded in the **Circularity Compass AVOID-EXTEND-TRANSFORM-ENABLE framework⁶**, which, as part of the CE4CE project, has been tested, widely shared, and positively received by a large community of public transport stakeholders.

This framework intersects with **sustainability and performance evaluation methods** designed to capture the value of resource efficiency, environmental friendliness and circularity along the rolling stock chain. These evaluation methods represent also valid criteria for the integration of circularity elements in the rolling stock procurement procedures.

⁶ Circular Economy for Public Transport. (2024). *The Circularity Compass* (Version 2024.12.09).
<https://circularity4publictransport.eu/wp-content/uploads/2025/02/The-Circularity-Compass-2024.12.09.pdf>



A first approach to ensure that sustainability and circularity processes are adequately fulfilled by the rolling stock suppliers is represented by the **compliance analysis** with industrial standards (e.g. ISO).

The procurement process should include references to relevant ISO standards to ensure compliance with industry best practices. Examples of applicable ISO standards include:

- **ISO 14001**, provides a framework for organizations to design and implement an Environmental Management System (EMS), and continually improve their environmental performance. It outlines the requirements for a comprehensive EMS, including policy development, planning, implementation, monitoring, and continuous improvement.
- **ISO 14025**, establishes principles and procedures for developing Environmental Product Declarations (EPDs), presenting quantified environmental information on a product's life cycle, enabling comparisons between products fulfilling the same function.
- **ISO 14040**, a series of standards providing the principles and framework for conducting Life Cycle Assessment (LCA) studies. It establishes the foundation for conducting LCAs, including the definition of the goal and scope, the four phases of LCA (life cycle inventory, life cycle impact assessment, life cycle interpretation, and reporting), and the requirements for objectivity, consistency, and transparency.
- **ISO 14044**, provides detailed guidelines and requirements for conducting Life Cycle Assessments (LCAs), building upon the foundational principles outlined in ISO 14040 and providing practical guidance for each step of the LCA process.
- **ISO 22628** specifies a method for calculating the recyclability and recoverability rates of road vehicles. It defines how to determine the percentage of a vehicle's mass that can be potentially recycled, reused, or recovered, both by mass and in percentage. This standard helps vehicle manufacturers assess and improve the end-of-life performance of their vehicles, contributing to more sustainable design and manufacturing practices.

A second, and more direct approach to ensure that the procurement process valorises correctly the benefits of sustainable and circular practices is represented by the **life cycle assessment (LCA)** of the rolling stock. This can be required to the manufacturers, or elaborated by the procurer based on technical data provided by the manufacturers.

The LCA methodology can be used to assess the environmental impact of rolling stock across its entire lifespan, considering all processes involved from **the extraction of raw materials to the manufacturing (production phase), operations (use phase) and end-of-life (eol phase)**. The LCA exercise require knowledge and detailed data, as it develops through four methodological steps:



- Life cycle inventory, where data on flows between nature and the production system along the supply chain are collected (inputs as water, energy, raw materials, outputs towards air, water and land);
- Life cycle impact assessment, where indicators are selected and impacts are measured accordingly;
- Life cycle interpretation, the analysis of results, drawing of conclusions and recommendations for improving environmental performance;
- Reporting, documenting the LCA process to keep record of all the elements including assumptions, limitations, recommendations.

The third evaluation method useful to foster the adoption of circular strategies and practices is represented by the development of **Environmental Product Declarations (EPD)**. IT provides condensed, transparent and comparable information on the environmental impact of a product or service. The EPD is an independently verified document, compiled and reviewed by an independent certified body. By presenting the results of an LCA study in an EPD, manufacturers can provide clear and concise information to customers, and other stakeholders about the environmental impact of their products or services.

EPDs are based on LCA, verified by an independent third party, and based on a standardized format making it easier to compare the environmental performance of different products. Furthermore, EPDs provide clear and concise information about a product's environmental footprint.

The combination of the **Circularity Compass framework** and the one composed by the **phases (production, operations/use, end-of-life) at the basis of sustainability and performance evaluation methods** is summarised in the following paragraphs, where the potential circularity elements to be integrated in tendering procedures are described in more detail.

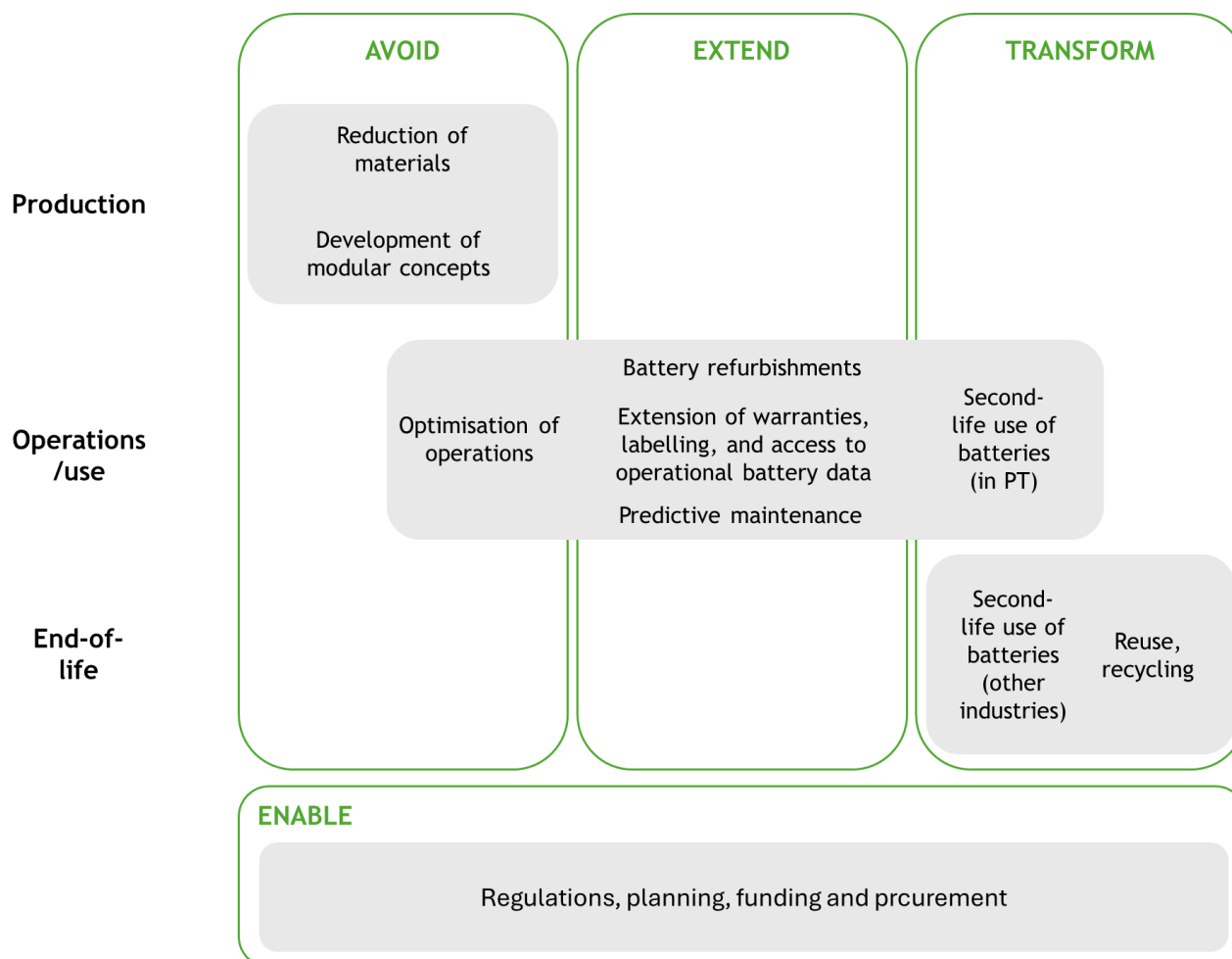


Figure 2. Circularity Compass framework for rolling stock adapted to production, operations/use, end-of-life phases

AVOID stage and rolling stock

The AVOID stage is in particular central to the planning and design of circular practices in the **production phase**, and refers to the strategic choices in raw and intermediate materials and energy sources to be provided to the process.

The **reduction of materials** used in the construction phase represents a practical example of actions that can be fostered by procurement practices and proven through a lifecycle assessment.

One relevant example is related to the reduction of materials in the construction phase: lightweight vehicles design decreases raw material consumption and manufacturing emissions, as well as emissions in the use phase. Studies on the use of advanced materials in automotive show that weight reduction can generate a 31 % decrease in body-in-white weight, and a 5,46 % reduction in global warming potential⁷.

⁷ Light Materials For Electric Vehicles (LEVIS) Project (2024) <https://cordis.europa.eu/article/id/455674-a-circular-approach-to-the-design-of-lightweight-electric-vehicles>



Another element to be considered, regarding the use phase, is related to the **optimisation of the operations** through the use of Route Planning Algorithms as well as Eco-Driving technologies and behaviours, to reduce energy consumption. The potential impact of these practices varies substantially from one context to another, depending on the characteristics of the service, the urban structure and road network

But the main contribution to the AVOID stage concerning rolling stock remains indeed focused on the construction phase: another important example is represented by the **development of modular components** for vehicles, reducing lifetime material demand, facilitating easier maintenance, repair, and replacement of parts.

EXTEND lifetime of rolling stock and components

The EXTEND stage is focusing in particular on the **use, or operational phase** of the rolling stock, but also to the **end-of-life** of their components, in particular batteries.

When it comes to the electrification of the fleets, the lifetime of vehicles and battery can be different, depending on the use of the rolling stock. **Battery refurbishments** extend the usable life of a vehicle (mainly bus or trolleybus) by seven to eight years, improving sustainability by generating relevant environmental as well as economic savings.

Furthermore, the life of batteries can be prolonged by **extension of warranties, labelling, and access to operational battery data**, in order to improve monitoring, optimisation of use and repair.

These three measures are strongly linked with the ENABLE approach, as the development of appropriate regulations is key to the integration of minimum requirements in procurement processes.

Predictive maintenance can increase the rolling stock lifespan, reducing the time for extraordinary interventions and consequent downtime of vehicles, and optimising the use of resources while performing maintenance operations.

Although mainly relevant to the TRANSFORM stage, **second-life use of batteries** can be considered also as an EXTEND practice in particular when applied to public transport depots or infrastructure to enable the integration of renewable energy sources (e.g. photovoltaic) or support the stability of the grid.



TRANSFORM assets beyond their lifespan

The TRANSFORM stage finds its main applications in the **end-of-life phase**, when rolling stock and its components are not suitable for the operations, and vehicles and components can be reused for different purposes or recycled.

Central to this process is the role of batteries: as main critical component in the decarbonisation and electrification of public transit, their reuse and recycling opportunity represent a game changer for the sustainability of electric fleets.

The lifespan of a battery, when reused in **stationary applications**, can be extended beyond the traditional utility in vehicles. This happens not only within the framework of public transport operations, but as the availability of batteries not anymore suitable for operations (typically after six to eight years, depending on the mileage) grows, options as their application in electricity grids, buildings and industry are becoming more relevant.

Recycling is the process of recovering raw materials as possible from batteries through a careful process that prevents fires and contamination. Batteries are composed by lithium, nickel, cobalt, copper, manganese. Fractions such as polymers, aluminium, copper, black mass can be sold as industrial raw materials or used for the production of new batteries. It has been estimated⁸ that the primary metal consumption for batteries can be reduced by 25% (lithium) to 55% (copper) in 2040, thanks to recycling, improving technologies and reusing of recycled materials.

Reusing and recycling are also relevant practices for other parts of the vehicles, such as steel chassis, glass windows, rims, cables, refrigerants, metal and plastic interior fittings (railings, chairs, buttons). Nowadays, the level of recyclability of these parts offered by bus manufacturers is extremely high, still a lot can be done in order to foster the adoption of these practice within the supply chain.

ENABLE circularity across different stages

The ENABLE approach can be considered cross cutting with respect to the **production, operations/use, end-of-life phases**, and comprises all those activities creating the conditions for circularity practices to be implemented, including regulations, planning, funding and procurement.

⁸ Institute for Sustainable Futures (2021), Reducing new mining for electric vehicle battery metals: responsible sourcing through demand reduction strategies and recycling <https://earthworks.org/wp-content/uploads/2021/09/UTS-EV-battery-metals-sourcing-20210419-FINAL.pdf>



These elements in particular, are relevant for the integration of circular practices upstream along the rolling stock supply chain, and therefore to the present strategy.

Policy measures can create the framework for the integration of circularity requirements into public procurement processes, by adapting to EU regulations and innovating.

Procurement can improve the impact of circularity not only by following regulatory prescriptions, but also innovating for example exploring the synergies between rolling stock, infrastructure and energy resources.

Under the methodological point of view, the implementation of **standardized LCA approaches**, and other evaluation models, can support the large adoption of circular approaches by PTOs and PTAs, in particular connected to investment strategies and procurement.

2.4. Regulatory framework

2.4.1. Introduction to the Circular Economy regulatory landscape in the EU

The regulatory landscape governing circular economy in public transport is characterised by a multi-tiered legal and policy framework, blending **binding legislations**, **strategic action plans**, and **supporting guidelines**. The enforceability of these instruments varies depending on their legal nature—whether they are **regulations**, **directives**, **decisions**, or **non-binding initiatives**—and on how they are implemented and monitored across Member States. This multilayered regulatory approach ensures that circular economy principles are embedded in EU legislation while allowing flexibility for Member States in implementation. At the core of this regulatory landscape is the European Green Deal⁹. It is EU's ambitious and overarching policy framework that aims to make Europe a climate-neutral continent by 2050 and to decouple growth from resource use and environmental degradation. It encompasses a broad spectrum of interconnected initiatives that address issues ranging from climate change to social fairness.

⁹ European Commission. (2020). *The European Green Deal*. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

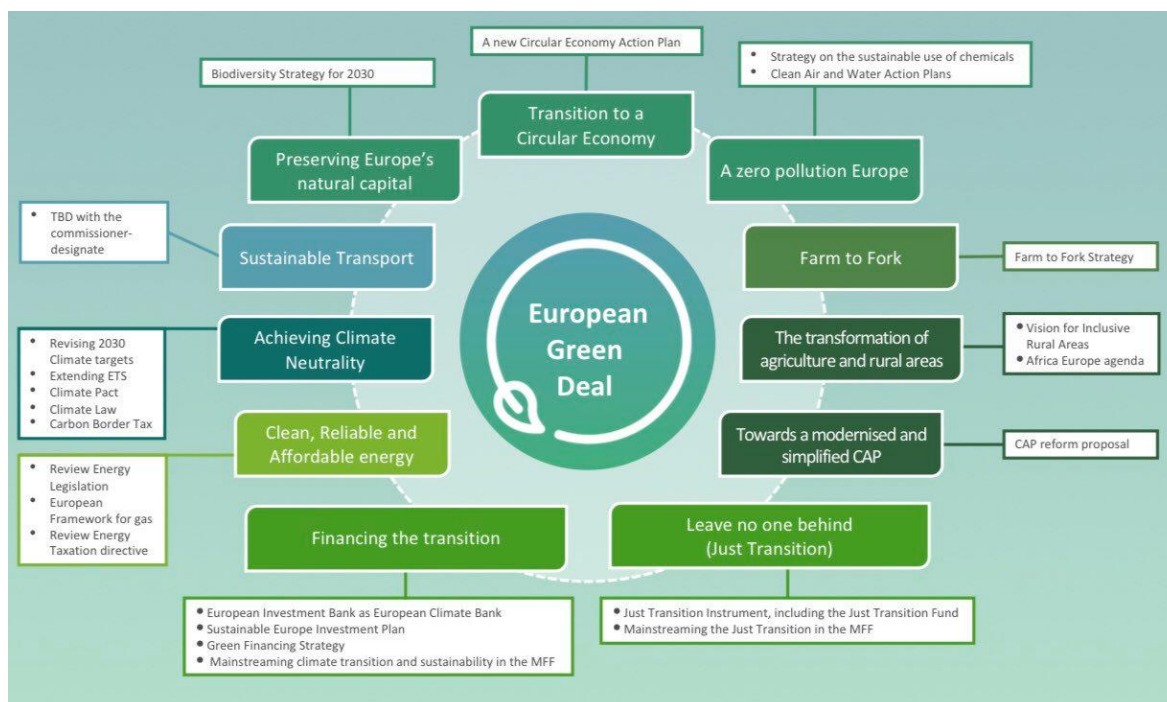


Figure 3. Framework of the European Green Deal. Source: The European Green Deal - European Commission

Supporting the Green Deal is the **Circular Economy Action Plan (CEAP)**, which provides a framework of measures to implement circularity in the European economy. Updated in 2020, the CEAP prioritizes sectors with significant environmental impact, such as transportation, and promotes design and production practices that extend product lifespans and facilitate circular use.

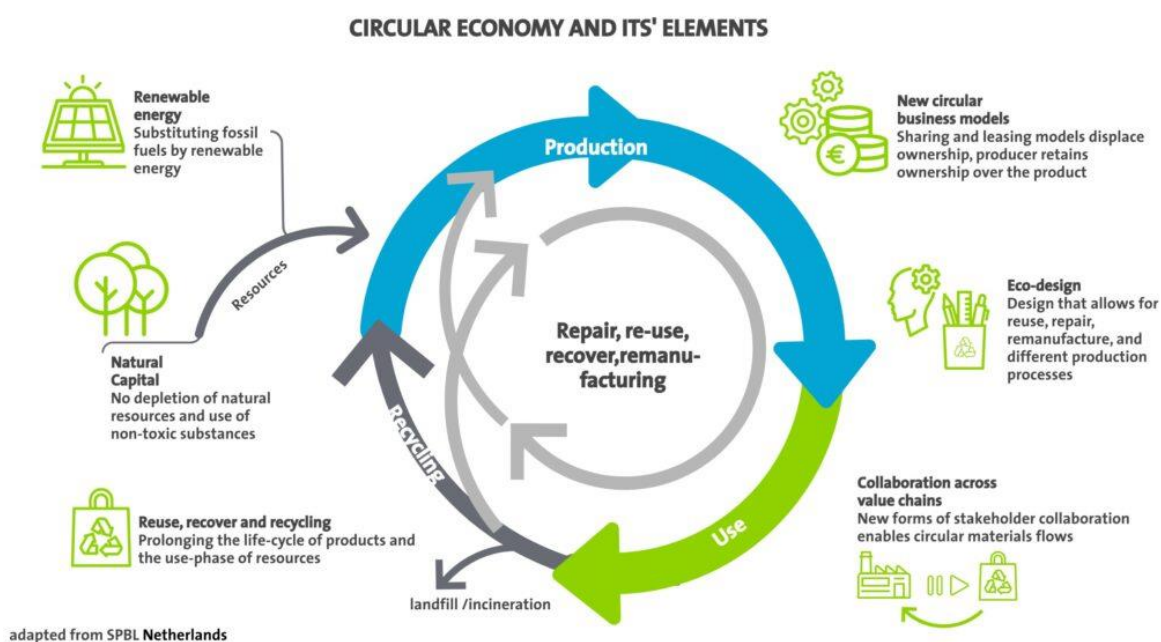


Figure 4. Circular Economy Action Plan and associated domains of influence Source: The Circular Economy Action Plan and its external Dimension.



The cornerstone of the action plan is to design and promote sustainable products that are durable, repairable, reusable, recyclable, and energy- and resource-efficient. The relevant product value chains which the action plan focusses on are: ‘Batteries and vehicles’ and ‘Construction and Buildings’ - both of which have direct implications on the public transport stakeholders. Public procurement, representing about 14% of the EU GDP ([Special report 28/2023: Public procurement in the EU](#)), will be leveraged to drive demand for sustainable products through mandatory green public procurement criteria and reporting. This would have a significant impact on the public transport stakeholders such as city authorities and PTAs who are heavily involved in procurement, especially of vehicles and associated components.

The above strategies are not legally binding. Rather, they serve as high-level frameworks that guide and shape legislative development. They also influence **funding allocations** (e.g., Horizon Europe, Cohesion Policy Funds, Just Transition Mechanism), by acting blueprints that steer EU financial resources toward sustainability and circularity. Hence, these strategic instruments translate high-level policy goals into concrete investments. For public transport stakeholders, this means that aligning projects with circular economy and climate objectives is increasingly essential to access EU funding, fostering innovation and infrastructure modernization that support Europe's green and just transition ambitions. The core enforceable elements of the EU's circular economy strategy are contained in **regulations** and **directives**. A few good examples are the **Waste Framework Directive (2008/98/EC)** which sets binding waste management targets and principles, the **Eco-design Directive (2009/125/EC)** that enforces design standards on products and raw materials, and the **New battery regulation ((2023/1542/EC)** that progressively introduces obligations for manufacturers, importers and distributors. They set binding targets and outcomes but leave Member States discretion over the means of implementation. All these policy instruments aggregate together in implementing circularity within different aspects and at several scales in the domain of public transport infrastructure.

Finally, we have the non-binding soft laws such as guidelines and standards. For e.g., the Green Public Procurement (GPP)¹⁰ criteria or the Digital Products Passport (DPP)¹¹ - While these tools are not legally enforceable, they **ENABLE** compliance with mandatory legislation and help stakeholders—particularly public authorities and industries—align with EU environmental expectations.

¹⁰ European Commission. (n.d.). *Green public procurement*. https://green-forum.ec.europa.eu/green-public-procurement_en

¹¹ European Commission. (2022, March 30). *Proposal for a regulation of the European Parliament and of the Council establishing a framework for setting ecodesign requirements for sustainable products and repealing Directive 2009/125/EC (COM(2022) 142 final)*. <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022PC0142>



2.4.2. Analysis of key circular economy regulations and directives in the EU

The following table gives a list of the major circular economy related policies and regulatory frameworks that are relevant from the public transport rolling stock perspective in Europe.

Table 1: Analysis of key circular economy regulations and directives in the EU

Policy name	Focus	Policy description	Policy targets	PT stakeholders affected/involved	Impact assessment on PT stakeholders
EU circular Economy Action Plan (2020) ¹²	Accelerate the transition to a circular economy in Europe	Promotes sustainable product design, circular processes, and waste reduction. It targets stakeholders from six key value chains and sectors those are: Electronics and ICT, Batteries and Vehicles, Packaging, Plastics, Textiles, and construction and buildings	Double the circular material use rate in the next decade Reduce waste by 50% in major sectors such as construction and demolition by 2030 Achieve a recycling rate of 70% for municipal waste by 2030	PTOs, PTAs, public authorities and waste management sectors, battery and vehicle manufacturers	The plan encourages the design of vehicles for easier disassembly, reuse, and recycling of materials, parts, and components, and sets requirements for minimum percentages of recycled content, including recycled end-of-life vehicles (ELVs), to be used in the production of new vehicles. The plan also promotes the identification of sustainability and transparency requirements for batteries taking account of, for instance, the carbon footprint of battery manufacturing, ethical sourcing of raw materials and security of supply, and facilitating reuse, repurposing and recycling.
Ecodesign for Sustainable Products Regulation (ESPR) ¹³	Sustainable and circular product design standards	To improve the sustainability of products placed on the EU market by improving their circularity, energy performance,	Varying targets to increase recycling and repairability in various sectors associated with public transport infrastructure such as	PTOs, PTAs, Vehicle and component manufacturers, Vehicle repairs and maintenance garages.	The stakeholders need to undertake the following steps: Manufacturers - Design vehicles to meet ESPR guidelines - i.e. durable, modular, and repair-friendly.

¹² European Commission. (n.d.). *Circular economy action plan*. https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en

European Commission. (2020, March 11). *A new Circular Economy Action Plan: For a cleaner and more competitive Europe* (COM(2020) 98 final). https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_1&format=PDF

¹³ European Commission. (2024). *Ecodesign for sustainable products regulation*. https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/ecodesign-sustainable-products-regulation_en

Policy name	Focus	Policy description	Policy targets	PT stakeholders affected/involved	Impact assessment on PT stakeholders
		recyclability and durability.	iron & steel, aluminium etc.		PTOs - Direct impacts in fleet management and procurement processes - i.e., prioritize EPSR compliant vehicles and equipment. Might incur higher upfront costs, but could achieve long-term savings through extended lifespan, re-use and recycling opportunities. PTAs - Revise tendering criteria to incorporate EPSR compliance, aligning purchasing decisions with sustainability and circularity goals Digital Products Passport - provide comprehensive information about each product's origin, materials, environmental impact, and disposal recommendations. Provide transparency across supply-chain. PTAs and PTOs need to utilise DPP info in procurement, life-cycle management and end-of-life stages of vehicles and buildings.
New battery regulation (2023)¹⁴	Promote a circular economy, reduce environmental impact, and	Defines mandatory requirements for all batteries placed on the EU market covering	Progressively introduce obligations such as Digital Battery Passport,	PTOs, PTAs, battery manufacturers, importers and distributors	PTOs and PTAs will benefit from the implementation of the regulation in terms of increased quality, environmental friendliness and

¹⁴ Regulation (EU) 2023/1542 of the European Parliament and of the Council of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC (Text with EEA relevance) <https://eur-lex.europa.eu/eli/reg/2023/1542/oj/eng>



Policy name	Focus	Policy description	Policy targets	PT stakeholders affected/involved	Impact assessment on PT stakeholders
	strengthen the EU's internal market for batteries	sustainability and safety, labelling, marking and information, due diligence, waste battery management, battery passport, green public procurement. Specifies obligations of the manufacturer, importer and distributor, also establishes conformity assessment procedure and market surveillance requirements.	Recycling Requirements, Carbon Footprint Declaration, Recycled Content, Removability and Replaceability Requirements, etc.		circularity of the products. They will reduce their carbon footprint, reduce the diagnostic, maintenance and repair costs, and increase the options for extension of the life of batteries thanks to a better labelling and modularity. Battery manufacturers, importers and distributors will be obliged to adopt circularity strategies and practices, and improve the transparency of information on products.
End-of-life vehicles Regulation (proposal, 2023)¹⁵	Prevent and limit waste from end-of-life vehicles and their components; improve the environmental performance of all economic	Amend the existing regulation to improve circular design, ensure that at least 25% of plastic used to build a vehicle comes from recycling, recover more and better-quality raw materials, extend	12.8 million tons less CO2 emitted 3.8 million more ELVs collected and treated in the EU 350 tons of rare earth materials collected	PTOs, PTAs, Vehicle manufacturers	PTOs and PTAs will reduce their carbon footprint, diagnostic, maintenance and repair costs. Vehicle manufacturers will increase their responsibilities and active role in the circularity process.

¹⁵ End-of-life vehicles Regulation - Protect the environment, reduce raw materials use, boost EU industry (n. a.) https://environment.ec.europa.eu/topics/waste-and-recycling/end-life-vehicles_en

Policy name	Focus	Policy description	Policy targets	PT stakeholders affected/involved	Impact assessment on PT stakeholders
	operators involved in the life-cycle of vehicles	responsibilities of manufacturers, extend to different vehicle categories including buses	for reuse and recycling 5.4 million tons of materials recycled at higher quality or re-used 22,000 new jobs will be created in the EU Lower prices for second-hand parts and components		
Clean Industrial Deal¹⁶	To turn decarbonisation into a driver of growth for European industries	To enhance the EU's manufacturing capacity for net-zero technologies, support a resilient green supply chain. It simplifies permitting processes, sets clear targets for strategic technologies (e.g., batteries, renewable energy, carbon capture), and establishes "Net-Zero Industry Academies" to reskill the workforce. The Act also emphasizes	Increase circular material use to 24% by 2030, from 11.8% today.	PTOs, PTAs, Municipal bodies, vehicle manufacturers.	Increased funding - €100 billion in public and private investment through mechanisms like the Industrial Decarbonisation Bank, InvestEU, and the Innovation Fund. Public procurement - Inclusion of non-price criteria focusing on sustainability, circular economy principles, and EU content requirements. Additional procurement regulations for PTAs, but beneficial in longer run. Voluntary Low-Carbon Product Labelling - this will help PTAs identify and preferentially use materials with lower carbon footprints.

¹⁶ European Commission. (2025, February 26). *Clean Industrial Deal*. https://commission.europa.eu/topics/eu-competitiveness/clean-industrial-deal_en

Policy name	Focus	Policy description	Policy targets	PT stakeholders affected/involved	Impact assessment on PT stakeholders
		circularity and resource efficiency, mandating the reuse, repair, and recycling of industrial components and materials.			Trans-Regional Circularity Hubs and Recycling Initiatives - to pool and process recyclable materials and components. Can improve the availability and quality of secondary raw materials for vehicle parts and infrastructure components.
Green Public Procurement¹⁷	Public procurement for better environment	A voluntary policy instrument whereby public authorities seek to procure goods, services and works with a reduced environmental impact throughout their life cycle.	Varying targets on procurement in different sectors associated with public transport.	PTOs, PTAs, Vehicle and component manufacturers	PTAs - procure vehicles that comply with latest emission norms such as Euro VI or alternative fuel (electric, hybrid, biofuels etc.) - 100% compliance by 2025 PTOs - Monitoring of emissions + documentation and verification of the same - E.g. emission certificates, Independent 3rd party verification of retrofitted emission systems on vehicles. Mandatory technology requirements - Traffic information and route optimization systems must be embedded in vehicles, TPMS (Tyre Pressure Monitoring Systems) and low rolling resistance tyres must be included in all vehicles.

¹⁷ European Commission. (n.d.). *Green public procurement*. https://green-forum.ec.europa.eu/green-public-procurement_en

Policy name	Focus	Policy description	Policy targets	PT stakeholders affected/involved	Impact assessment on PT stakeholders
Corporate Sustainability Reporting Directive (CSRD) ¹⁸	Improve corporate transparency in sustainability	Requires large and publicly listed companies in the EU to disclose detailed, standardized information about their sustainability practices, including environmental impacts, social responsibilities, and governance structures (i.e. ESG practices)	Applies to all large companies (over 250 employees, €40 million turnover, or €20 million balance sheet total) and all companies listed on EU regulated markets (except micro-enterprises)	Public Transport Operators (PTOs), Subcontract suppliers, City/Municipal authorities	PTOs will be mandated to do the following: Double materiality assessment: Assess and disclose sustainability-related information from environmental + social perspective and financial perspective. Adherence to European Sustainability Reporting Standards (ESRS) regulation - report on resource inflows (e.g., fuel, materials) and outflows (e.g., emissions, waste) Supply chain transparency - report on environmental impact across supply chain. Stakeholder Engagement - establish regular communication channels, such as surveys or community meetings, to gather feedback on sustainability initiatives. Digital Reporting Formats - Reports must be prepared in a digital, machine-readable format, adhering to the European Single Electronic Format (ESEF).

¹⁸ European Commission. (n.d.). *Corporate sustainability reporting*. https://finance.ec.europa.eu/capital-markets-union-and-financial-markets/company-reporting-and-auditing/company-reporting/corporate-sustainability-reporting_en

Policy name	Focus	Policy description	Policy targets	PT stakeholders affected/involved	Impact assessment on PT stakeholders
Revised Clean Vehicles Directive (2019) ¹⁹	Promote clean mobility solutions in public procurement tenders	Defines national targets for procuring clean vehicles, defined as a minimum percentage of clean vehicles in the aggregate public procurement across a Member State	Applies to public administrations and other bodies issuing public tenders. Targets are variable depending on the Country and on the vehicle category (light-duty, heavy duty)	PTOs, PTAs	PTAs and PTOs - procure vehicles that comply with definition of “clean vehicle”: hydrogen, battery electric (including plug-in hybrids), natural gas (both CNG and LNG, including biomethane), liquid biofuels, synthetic and paraffinic fuels, LPG (according to the Alternative Fuels Infrastructure Directive 2014/95) NB for buses, half of the target to be fulfilled by procuring zero-emission buses.

In summary, the diverse range of circular economy policies analysed highlights a comprehensive approach within Europe to foster circularity and sustainability across various sectors. Each policy targets specific areas, from vehicle design and construction to end of life or disposal. Public transport stakeholders stand to experience significant impacts, both in operational practices and environmental outcomes. Collectively, these policies not only promote resource efficiency and waste reduction but also pave the way for a more resilient public transport system, aligning with circularity goals. These initiatives underscores the importance of continued collaboration among policymakers, industry, and public transport entities to maximize the benefits for Europe's transition to a circular economy.

¹⁹ Directive (EU) 2019/1161 of the European Parliament and of the Council of 20 June 2019 amending Directive 2009/33/EC on the promotion of clean and energy-efficient road transport vehicles (Text with EEA relevance.) <https://eur-lex.europa.eu/eli/dir/2019/1161/oj/eng>

3. Status Quo analysis

This section provides an overview on the state of the art of circularity as perceived by a selected range of experts and relevant stakeholders engaged in the analysis of current practices, gaps and needs in order to increase the implementation of circularity approaches, principles, and solutions in public transport.

3.1. Methodological approach

The reconstruction of the status quo has been carried out combining three interrelated approaches:

- **In-depth tests/interviews** guided by the circularity compass methodology (through the Circularity Compass self-assessment tool²⁰, 3 PTOs)

In this activity, engaged PTOs have been walked through the **structure and content of the circularity compass**, with a particular focus on the categories **vehicles, batteries and electric infrastructure**.

The most relevant aspects emerged through the scan of the compass components have been discussed in depth, in order to let emerge for each one a set of **challenges, experiences, solutions and recommendations** useful for the definition of the status quo and for the identification of possible good practices and tools to be further investigated.

- **A survey with lifecycle actors** (13 participants)

The survey engaged **supply chain operators**, in order to capture further insights on the **state of the art** as well as on the **positioning towards circularity**, highlighting the main **criticalities and opportunities**.

Stakeholders (suppliers) from rolling stock manufacturing, maintenance and spare parts, tyres and digital services, provided their contribution to the analysis, by answering the common survey and then discussing the results in a dedicated workshop.

The questionnaire for the survey has been structured in three sections, corresponding to the AVOID, EXTEND, TRANSFORM stages declined in specific categories of measures:

- **AVOID - refuse, reduce;**

²⁰ trolley:motion (2024). The Circularity compass self-assessment tool. <https://circularity4publictransport.eu/self-assessment-selection/>



- **EXTEND** - reuse, repair, refurbish, remanufacture;
- **TRANSFORM** - recycle, recover, dispose.

For each section, the questions focused on current **practices**, **criticalities/barriers**, **alternatives/good practices**, **objectives/actions** for the future.

- Two **workshops engaging international experts** in the debate

During the workshops, experts and stakeholders were engaged in discussions to define the possible elements of a common strategy to add and recapture value and optimise delivery of rolling stock along new life cycle value chains. The first step consisted in the discussion on **main challenges and opportunities** linked to the planning and implementation of circularity practices connected to rolling stock. The second one identified **factors and requirements** for circularity measures implementation, while the last one contributed to the creation of a **common vision and objectives** in order to move from the status quo towards a higher level of integration of circularity principles in public transport.

Although the approach was limited by the number and geographical scope of the stakeholders engaged, the status quo analysis identified a set of interesting challenges and described experiences in the field of circularity that represent the basis for the investigation on approaches, good practices and tools to advancing circularity in public transport rolling stock life cycle. The main findings are summarised in the following paragraphs.

3.2. AVOID stage

Analysis of the supply chain potential

A first aspect emerging from the analysis is represented by the supply chain potential. If the role of buses and battery manufacturers is clear and connected with the **technological development** of the vehicle manufacturing sector, on the other side part of the unexpressed potential lays in other sections of the chain.

In some cases, the **limits to circularity** are also related to the size of the supplier companies. Smaller suppliers do not have the **financial or innovation capacity** to invest and make their production more circular (from the installation of photovoltaic to the acquisition of electric duty vehicles, to the use of sustainable materials, etc.).

For other types of suppliers - e.g. paint producers - there can be a **trade-off** between the avoiding the use of harmful substances and the lifespan of the application, and therefore **between the AVOID and the EXTEND** approaches.



On the other side, some suppliers can be **focused on circular solutions**, and therefore adopt sustainable practices in their production methods. The production and use of **reconstructed tyres** for example, is an established practice that minimises the use of primary materials. In this field, the research is working to identify options to eliminate completely the use of harmful substances in the reconstruction process. However, one barrier to the large adoption of this particular solution is often represented by the **knowledge of new and reconstructed materials** by suppliers, the acceptance of the solution and general concerns about their durability and sometimes safety.

Research, and the design and implementation of **pilot activities** and **proof of concepts**, are fundamental in order to foster the adoption of circular innovative solutions developed by supply chain actors, based especially on the reuse of exhaust materials minimising the use of new ones.

Awareness on the demand side

Awareness (and acceptance) of new circular solutions has emerged in the analysis as a barrier to the successful implementation along the supply chain.

In some cases, the competitiveness of circular solutions is harmed by the availability of low price alternatives. This happens in the field of spare parts, where the combination between large availability and low costs of newly built components, lack of repair “culture” and knowledge, and low awareness of the benefits generated by avoiding the use of new parts (intensive use of raw materials, transport, waste). A life cycle assessment of all critical, energy and material intensive processes affecting not only the construction but also the operational phased of rolling stock lifespan would be important to correctly evaluate the impact of processes and benefits of circularity along the supply chain.

State of the art of LCA application and Ecodesign

LCA is there, but its adoption is still scattered although its range of application could be broadened. Circularity assessment has several linkages with company accounting practices (economic, sustainability, ESG), as it can highlight a broad range of internal and external benefits and savings.

Standardisation of assessment processes, labelling and especially a wider adoption of **sustainability and performance evaluation methods** in procurement should be accompanied by a cultural shift for the recognition of the value extracted through a strategic planning based on circularity, looking at a long period and inter-generational perspective.



From the supply side, important is the **progressive adoption of Ecodesign approaches**, to ensure not only that the final solution is compliant with sustainability and circularity paradigms, but also that the production process is optimised and cost effective.

3.3. EXTEND stage

Investment planning aligned with lifespan

The transmission towards zero emission fleets provides a great opportunity for the modernisation of public transport. At the same time, the system composed by vehicle, battery and infrastructure must be **fine tuned in the investment process**, in order to optimise the exploitation of the available resources over a longer period of time.

At the present stage, investments are not sufficiently aligned, case history is usually not enough reliable to build a comprehensive investment strategy on, and technological development is fast in developing new solutions to replace the current ones.

Planning according to the EXTEND principles, although the technological choices made in the recent past might not be cutting edge, and the lifecycle of the different components might not be aligned, is fundamental to **ensure long term sustainability to the ecological transition process**.

Revamping and overhaul of battery packs, upgrade of charging infrastructure, and to a certain extent also joint procurement and financing of vehicles and infrastructure are examples on how strategic planning can be successful. The level of complexity is raising as long as technologies overlap and different generations of solutions co-exist, a comprehensive approach is necessary to ensure the extension of lifespan of the fleet according to circularity objectives.

Research in recycled material performance

As already mentioned, the perception of quality of circular solutions is fundamental to foster their adoption.

From the planning point of view, setting criteria on percentages of recycled material used for some components of the supply chain can trigger the change in manufacturers. However, in different parts of the supply chain, different challenges arise around cost effectiveness and some time quality of the recycled materials used.

Research on recycled materials is fundamental in order to develop **high quality and scalable solutions**.



Raising awareness along the supply chain

As emerged from the analysis, there is a need for raising awareness on solutions supporting the extension of lifespan in the supply chain.

The transition from a linear to a circular model is particularly challenging for suppliers, as they have to adapt to the new approach raising quality standards, and especially allowing for repairability and eventually adapting their business model to the new needs.

Extending the lifespan of their products, and contributing to the extension of the one of the final or correlated product (e.g. the vehicle) represents a paradigm shift, and the generated value must be recognised in the process.

3.4. TRANSFORM stage

Product design

Another important topic emerged in the status quo analysis is related to the importance of product design in ensuring circularity in public transport.

Product design plays a pivotal role in enabling the transform stage of circularity, such as **remanufacturing, refurbishing, and recycling**, in roaming stock (e.g., vehicles, modular transport equipment) manufacturing. This stage in fact focuses on converting end-of-life products or components into new value-added forms, and well-considered product design is essential for this transformation to be efficient, cost-effective, and sustainable.

At the present stage, experiences of circular design in public transport are limited, and focused mainly on components such as interior furnishings, refurbishing seats, etc.

Innovative approaches to **circular product design** should focus in the future on the key components, such as powertrains and **batteries**, in order to allow their reuse in different contexts, extending their lifespan through alternative applications.

Design and development of modular concepts, together with actions fostering the rise of a “repair” culture within the companies, are expected to trigger circularity in public transport and spread it in those sectors where synergies can be found (in particular energy, and building).



Traceability of batteries

The status quo analysis highlighted the presence of practices for battery reuse, within and outside the public transport framework, mainly at test or pilot level. In many cases, the ownership of the battery at the end of life is not even clearly stated in the contracts. A systematic approach is needed-...

The traceability of batteries used in electric buses is advancing, but remains a work in progress as the industry seeks to enable efficient reuse and second-life applications. The core objective is to track the battery's history, usage, and condition throughout its lifecycle to facilitate safe and economically viable repurposing after its initial use in vehicles.

Modern electric buses are increasingly equipped with advanced **Battery Management Systems** (BMS) that collect real-time operational data, including charging cycles, temperature exposure, depth of discharge, and state of health. This data is crucial for assessing the battery's suitability for second-life applications. However, **additional analytics** and safety audits are necessary in order to ensure the reusability of the batteries and their components. As per today, the lack of universal standards for data sharing and traceability, which complicates the assessment and repurposing process across different manufacturers and regions.

3.5. ENABLE stage

Standardisation

One element emerged from all the methodological approaches applied for the analysis of the status quo is the need for standardisation of procedures and requirements related to the different stages of circularity and especially production and transformation.

Particularly important is the case of **batteries**, where standardisation is fundamental for **diagnosis, repairing, refurbishing**, transforming in order to exploit them further during their **second life**, and **recycling**.

But more in general, the standardisation of circular processes across all the stages (production, operations and end-of-life) is perceived as a necessary condition to create a valuable and **durable impact** with circularity practices.

Standards are also perceived as important, during the operation stage, to define **maintenance and refurbishing practices** connected to the EXTEND stage.



Enforcing EU regulations

Enforcing EU regulations, not only at national but also at local level, emerged in the discussion as a common need for implementing circularity measures in public transport.

In particular the regulation on batteries, as for other components, should be received and applied in order to improve the reliability and reduce risks for PTOs, in order to foster the broader application of new technologies.

Innovation in procurement

The status quo analysis highlighted how procurement seems to be one of the main fields where circularity principles in can be applied to the rolling stock category, in order to foster a consistent change along the whole supply chain.

Many circularity measures in fact, are perceived as beyond the competencies and responsibilities of PTOs, impacting on the production and on the end-of-life phases.

Green and circular procurement is the tool used by PTOs and PTAs to foster circularity along the supply chain, but there are challenges represented by the capacity of suppliers in generating benefits in a sustainable and competitive framework.

For this reason, it is very important that the experiences made become part of a strategic approach, where in many cases elements of innovation in procurement include the possibility of purchasing rolling-stock, infrastructure and energy in different combinations in order to create the conditions to extract value from the circularity process.

4. Approaches to advancing circularity in public transport rolling stock life cycle

As with the status quo analysis, this chapter follows the AETE framework, using the circularity principles measures diagram as a foundation.

When it comes to rolling stock, the procurement process is central to define the whole circularity strategy, as it sets the criteria under which circular principles can be applied to the purchase and maintenance along the supply chain:

- Upstream, considering design, materials and methods, strategic choices in terms of layout and size of components, and



- Downstream, taking into account extending and refurbishing, maintenance and spare parts, end of life and second life of components.

For this reason, the catalogue of circularity measures proposed for the strategy to add and recapture value and optimise the delivery of rolling stock, starts from the ENABLE approach, looking in particular at circularity approaches to procurement and tendering, and will be completed by a range of avoid, extend and transform complementary measures.

The AVOID approach is in fact depending on regulation and procurement practices fostering the reduction and reuse of materials, while the EXTEND relies on regulations on warranties, repair and extension of lifespan of rolling stock and their components.

Also the TRANSFORM approach, for which specific good practices will be presented, benefits by the presence of enabling measures focusing on modularity, responsibilities and traceability of vehicles and their components.

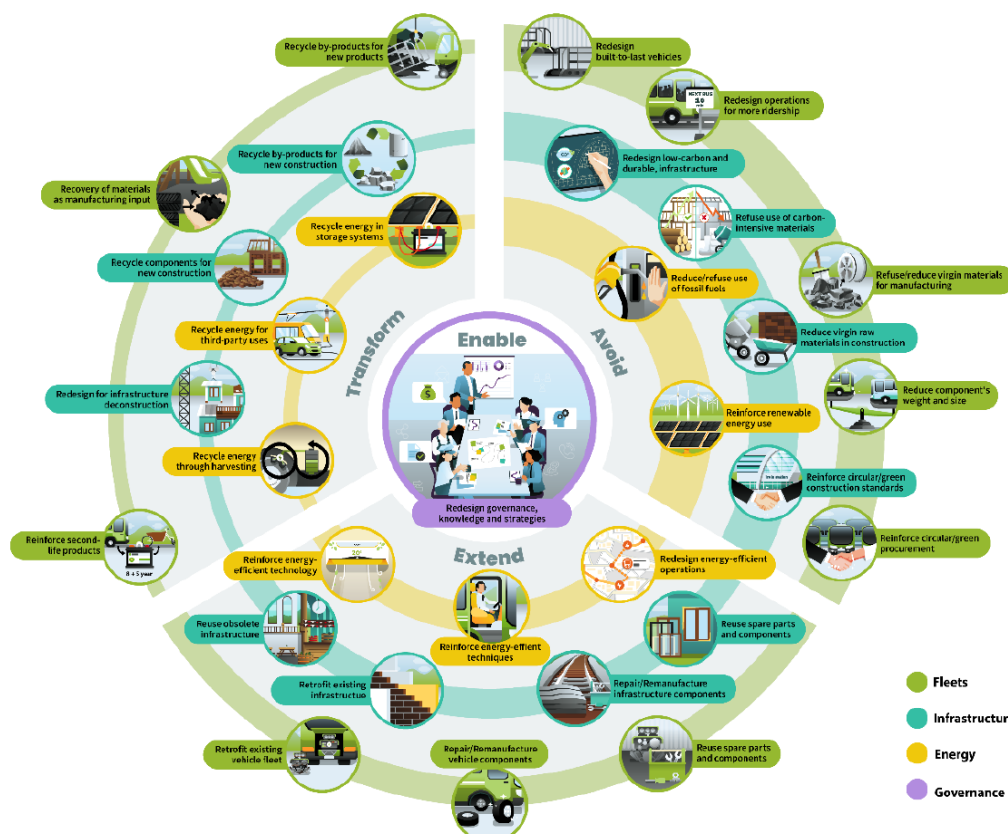


Figure 5 Circularity compass solutions diagram

The scope of this measures catalogue is represented by electric buses. The choice has been made on the basis of the current state of the art of the fleet decarbonisation process, where high investments are being put in place to convert existing fleets into electrics, while limited attention is given to the role of circularity in enhancing further the sustainability of the strategic choices,



generating value in terms of savings and potential revenues for PTOs and PTAs, and on the relevance that circularity can invest in geopolitical issues enabling a more durable exploitation of critical raw materials and components.

In general, it is worth to note that some measures may apply to different approaches; for clarity purposes, they have been assigned to the section where they are expected to generate the most relevant impact.

4.1. Approaches and solutions at the ENABLE stage

4.1.1. Circularity approaches to procurement and tendering

Extracting the benefits of circularity from the rolling stock production, operation and end-of-life phases, requires a paradigm shift in the assessment of the value generated in the procurement procedure.

In general, the criteria integrated in a tendering procedure in order to achieve specific objectives such as, in our case, the enhancement of the level of circularity in rolling stock procurement, can be applied according to different patterns:

- Exclusion grounds
- Selection criteria
- Award criteria

These have to be modulated **taking into account** factors like the **level of maturity of the supply chain**, the **bargaining power** as a buyer, the **critical mass** of the procurement, and last but not least the **strategic relevance of circularity** towards specific technical characteristics, sometimes quality of the solution, and cost effectiveness

In general, in order to pursue circularity strategic objectives within the procurement process for rolling stock, it is useful to consider the following recommendations:

- **Adopt a long term and inter-generational perspective**

When defining the objectives of a fleet renewal plan within the energy transition and decarbonisation process, develop strategic long term approaches and indicators to forecast the expected impact.

- **Integrate environmental and circular performance in the economic assessment**

Use tools such as cost-benefit-analysis (CBA), and Life Cycle Assessment (LCA) to evaluate overall value generated by the procurement.



- **Embed circularity criteria in tender specifications**

Integrate specific and measurable circular design requirements into procurement documents—such as the use of secondary materials, modular construction, ease of repair, and end-of-life recoverability. Award higher scores to suppliers offering innovative circular solutions, including closed-loop models, resource efficiency improvements, and the use of material passports (esp. batteries).

- **Consider flexible and cooperative approaches to procurement**

Consider designing a procurement strategy embedding rolling stock, infrastructure and energy to identify innovative and efficient solutions developed through collaboration among actors and interdisciplinary approaches. Analyse different acquisition models (purchase, leasing, full service, bus-as-a-Service, etc.).

At the same time, adopt a collaborative approach with suppliers, by engaging them early in the procurement process and favour collaboration and aggregation.

- **Promote cross-authority and operator collaboration**

Encourage joint procurement, shared frameworks, and continuous knowledge exchange between public authorities, transport operators, and agencies. Coordinated action helps pool demand, reduce costs, improve supplier responsiveness, and accelerate circular innovation.

The following paragraphs summarise the main fields of applications identified for circularity criteria and approaches in the procurement and tendering process, enriched by the reference to examples, good practices and tools.

Pre-requirement: mission profile and technical specifications to enable zero emission buses

As the technological choices are influenced by the characteristics of the services and of the network, information on the field of operation of the rolling stock is useful for the supplier in order to design a compliant offer and in some cases suggest different technological options.

Tools, examples and good practices

[Tool] Checklist of technical specifications of the mission profile

The following technical specifications must be considered:

- Travel distance from terminus to depot



- Time spent in depot for recharging
- Average passenger capacity in % of maximum capacity
- Commercial network speed
- Slope (average and maximum)
- Frequency of trips (average and maximum)
- Service belt in hours (average and maximum)
- Length of timetable in km (average and maximum)
- Additional specifications to consider:
 - Charging type
 - Daily mileage
 - Estimated annual mileage
 - Average autonomy required (summer/winter)
 - Route and orography of the network
 - Average distance between stops
 - Annual climate profile

Source: Excerpt from standard tender specifications integrating circularity principles, Italy

General requirements on materials recyclability and reusability

The tendering procedure of new rolling stock can fix minimum requirements, evaluate alternatives according to a common scale, or attribute additional awarding points to the most innovative and sustainable solutions.

The design of circularity elements within the framework of a procurement process must identify exclusion grounds, selection and award criteria according to the importance given to circularity principles, taking into account the reachability of the thresholds and the technological and market maturity level of the solutions requested.



Tools, examples and good practices

[Example] Requirements on materials recyclability and reusability

“A specific score will be assigned to the fact that the vehicles are (a) reusable or recyclable for at least 85% of their weight; and b) reusable or recoverable for at least 95% of their weight (indication in the homologation certificate).”

[...]

“SEATS: The seats must be customizable in color and material, which must be of high quality, 100% recyclable, with seat and backrest, compliant with the standards: EN4554.2 (PC aluminum/steel); R118,02/03 (PA); R80UN/ECE., without padding (except for seats for which padding is required by law).”

Source: Excerpt from standard tender specifications integrating circularity principles, Italy

Requirements on coverings and materials

The textile and plastic industries appear to be one of the economic sectors most sensitive to the challenges of circular economy, with a broad experience in the recycling fields.

As those materials are widely used in the refurbishing of the vehicles, recycling criteria should always be integrated in the procurement process.

Tools, examples and good practices

[Example] Requirements on recycled materials for vehicle interiors

“The adoption of internal linings made of recycled fibre yarns with certifications such as the “Global Recycle Standard” (GRS) or “Remade in Italy” or “Plastica Seconda Vita” or equivalents, or made of bio-based polymers compliant with the technical regulation UNI-EN 16640:2017 and with certifications capable of guaranteeing that the origin of the bio-based raw material derives from recovery activities or is a by-product generated by other production processes, such as the “Global Recycle Standard” (GRS), the Remade in Italy certification or equivalent certifications based on the traceability of materials and mass balance issued by a conformity assessment body accredited in accordance with EU Regulation no. 765/2008 of the European Parliament and of the Council or by certificates that guarantee the environmental sustainability of the renewable raw materials used, i.e. that such raw materials, not consisting of biomass potentially destined for food use, do not originate from lands with high biodiversity and high carbon stocks, as defined by art. 29 of Directive (EU) no. 2018/2001, such as those recognized by the European Commission.”

[...]



The adoption of thermoplastic material made with recycled plastic in possession of certifications such as Plastica Seconda Vita, Remade in Italy, or equivalent certifications based on the traceability of materials and mass balance issued by a conformity assessment body accredited pursuant to Regulation (EU) no. 765/2008 of the European Parliament and of the Council, or are made of bio-based plastic compliant with the technical regulation UNI-EN 16640:2017 and have certifications that guarantee that the origin of the bio-based raw material derives from a recovery activity or is a by-product generated by other production processes, such as the Remade in Italy certification or equivalent certifications based on the traceability of materials and mass balance issued by a Conformity Assessment Body accredited pursuant to EU Regulation no. 765/2008 of the European Parliament and of the Council, or by certifications that guarantee the environmental sustainability of renewable raw materials, i.e. that such raw materials, not consisting of biomass potentially suitable for food use, do not originate from lands with high biodiversity and high carbon stocks, as defined by art. 29 of Directive (EU) no. 2018/2001, such as those of the European Commission.”

Source: Excerpt from standard tender specifications integrating circularity principles, Italy

Requirements on heating/cooling system

As vehicle heating and cooling systems play a role in climate change, impacting energy consumption and contributing to greenhouse gas emissions, specific requirements have to be set in the procurement documents, in order to guarantee the use of more advanced and environmentally friendly technologies.

Tools, examples and good practices

[Example] Requirements on heating/cooling system

“The vehicle must be equipped with an air conditioning system that uses an air refrigerant with a global warming potential (GWP) of less than 150. A declaration must be provided stating the following information:

- the type of refrigerant gas used for the air conditioning system;
- the relevant GWP (Annexes I and II of Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006);
- in the case of use of a mixture of refrigerant gases, the name of the individual refrigerant gases, the composition of the mixture of gases used with the GWP of the individual substances and the relative sum, the latter calculated as indicated in Annex IV of Regulation (EU) No 517/2014.”



Source: *Excerpt from standard tender specifications integrating circularity principles, Italy*

Energy recovery systems

Energy recovery systems in buses offer several benefits, including reduced fuel consumption, extended range, and decreased emissions. These systems, like regenerative braking, convert kinetic energy during braking into usable energy, which can be stored and used to power the bus or assist in propulsion.

When designing rolling stock and infrastructure, these systems can be embedded in vehicles or also in infrastructure (as in the case of supercapacitors, flywheels, etc.).

Tools, examples and good practices

[Example] Requirements on energy recovery systems

“The vehicle must be equipped of an electrodynamic slowdown braking system, with appreciable effectiveness at least up to a speed of 1.11 m/s (4 km/h) and such as to guarantee, at full load, a maximum deceleration value of 1.1 m/s².

The energy generated during braking will be recovered from the traction batteries, based on their acceptability characteristics.

The electric braking will be coordinated with the pneumatic braking system; furthermore, the concept of “braking prevalence” will be guaranteed to ensure safety conditions in the event that the starter and brake pedals are pressed simultaneously.

The design calculation of the maximum value of energy recovered during braking must be included in the technical offer.”

Source: *Excerpt from standard tender specifications integrating circularity principles, Italy*

Battery characteristics

When it comes to PT electric vehicles, the choice of the appropriate technology and operational solutions, together with the correct battery sizing, represents a strategic choice to be made in the planning phase.

Concerning procurement, two main elements must be specified in the documentation, in order to guarantee the responsiveness of the supply to circularity approach:



- performance criteria and durability, to ensure that the quality of the batteries is compliant with the requirements and suitable for operations according to the planning;
- the technical characteristics, data availability and compatibility of the battery management system (BMS) and other diagnostic tools; the reliability and availability of data are fundamental in order to monitor a range of key factors for the correct and efficient functioning of the electric rolling stock, including real consumption and state of health of the batteries.

Tools, examples and good practices

[Example] Battery characteristics

“The minimum guaranteed duration (number of cycles/kilometres/years) for the energy storage system must be indicated in the offer, based on the mission profiles indicated by the Customer. The battery performance that ensures the maintenance of the required mission profile must be guaranteed for the entire duration of the warranty offered by the manufacturer.

Therefore, the storage system is considered to be at the end of its useful life when the residual capacity falls below 80% (IEC 62660), or no longer compliant with the technical specifications, when the minimum performance required in terms of autonomy is not achieved.

The Customer can keep the batteries mounted even after the end of the warranty on the number of recharges, without having ensured the initial mission profile.

A decay curve of the capacity of the storage system must also be provided (based on the number of cycles and kilometres travelled) that provides evidence, through simulation, of the energy that can actually be stored with reference to the mission profile provided.

The Supplier shall provide a system that, once a limit threshold (SL) of the charge level (SOC) has been reached, signals this condition to the driver and progressively reduces the loads and power of the traction system in order to allow the vehicle to return to the depot or reach the rapid charging system (travel of at least 20 km) with the aim of maximising the battery life; this system shall be detailed in the technical offer (SL value, load exclusion logic, etc.).”

Source: *Excerpt from standard tender specifications integrating circularity principles, Italy*

Tools, examples and good practices

[Example] Battery Management System (BMS) characteristics



“The supplier must provide a BMS system for managing and monitoring the charging batteries, preferably integrated with the general and comprehensive diagnostic system of the vehicle.

The BMS system must be available on the cloud, with remote use, with the relevant licenses for the entire useful life of the bus and made available upon delivery of the vehicles to the depot.

The contracting station must be able to download the data locally via an interface with a PC equipped with a Windows operating system.

The vehicles supplied must therefore be equipped with either a specific approved modem dedicated to the transmission of diagnostic data or alternatively it is preferable that a single modem is provided as described in the following paragraph (“On-board systems”) that transmits both the diagnostic information including the batteries and the data of the on-board technological systems (AVM, SBE, etc.)

The characteristics of the BMS used must be indicated in detail.

The level of detail of the BMS and the information that will be made available will be positively assessed.”

Source: Excerpt from standard tender specifications integrating circularity principles, Italy

Tools, examples and good practices

[Tool] Draft criteria for procuring e-buses with durable batteries

Minimum durability requirements can be introduced in tendering documents. Minimum durability criteria for electric vehicle batteries (including those of e-busses) were developed by the United Nations Economic Commission for Europe (UNECE) in 2022.

The supplier shall ensure that the e-bus batteries' State of Certified Energy (SOCE) is in-line with the following minimum performance requirements or better:

Vehicle age/km	State of Certified Energy
From start of life to 6 years or 400,000 km, whichever comes first	80 %
Vehicles more than 6 years or 400,000 km, and up to whichever comes first of 10 years or 500,000 km	70 %

The supplier shall submit evidence of compliance through independent test protocols in line with verification methods and procedures set out in the United Nations Global Technical Regulation on In-vehicle Battery Durability for Electrified Vehicles.

Requirements can be adapted, and more ambitious criteria can be requested in tender documents and contracts, as technological advancements and increased competition in the industry are expected to improve lifetime and quality of the batteries further.



Source: TUMI E-Bus Mission (2023), Measures Catalogue for Improving the Circularity of Batteries Used in E-Buses https://transformative-mobility.org/wp-content/uploads/2023/06/eBusMission_Battery-Circularity-Measures-Catalogue.pdf

End of life of batteries

Although the circularity debate around batteries largely focuses on the possibility of extending their lifespan through stationary applications, PTOs must ensure that the purchased batteries generate, at the end of their life, minimal environmental impacts.

Furthermore, particularly in Europe, recycling of batteries represents a must for the competitiveness of the whole system, as the recovery of raw materials is crucial for the wide scale electrification of mobility.

For this reason, PTOs must ensure that manufacturers and importers are able to process the batteries at the end of their life, directly or by joining dedicated collection and recycle systems.

Tools, examples and good practices

[Example] Recycling of end-of life batteries

“Specific technical scores will be assigned if:

1) with regard to exhausted lithium batteries:

a) the manufacturer of the vehicles, or the manufacturer/importer of the traction battery, has entered into a contract with the collective or individual collection system under which all exhausted lithium batteries, used for the traction of electric vehicles, are intended both to be recovered and reassembled in storage packs for the storage of energy from renewable sources, and to the recovery of metals (lithium, cobalt, nickel and other heavy metals);

b) the manufacturer of the vehicles, or the manufacturer/importer of the traction battery has entered into a contract with the collective or individual collection system under which all exhausted lithium batteries, used for the traction of electric and hybrid vehicles, are intended to be recovered and reassembled in storage packs for the storage of energy from renewable sources;

c) the manufacturer of the vehicles, or the manufacturer/importer of the traction battery has entered into a contract with the collective or individual collection system under which a metal recovery process (lithium, cobalt, nickel and other heavy metals) is implemented on all spent lithium batteries used for the traction of electric and hybrid vehicles;



2) with regard to the metal recovery process of spent batteries: if the metal recovery process (lithium, cobalt, nickel and other heavy metals) implemented on spent lithium batteries used for the traction of electric and hybrid vehicles, a metal recovery process (lithium, cobalt, nickel and other heavy metals) is implemented;

3) with regard to more efficient and recoverable batteries: if the batteries used for the traction of electric and hybrid vehicles are made of more efficient and recoverable materials than lithium batteries.”

Source: Excerpt from standard tender specifications integrating circularity principles, Italy

4.1.2. Data standardisation for critical components

Ever since the circular economy concept emerged in the EU policy debate in the early to mid-2010s, there has been much discussion about the need to increase transparency across supply chains to accelerate the transition to a circular economy.

The Digital Product Passport is a tool that will electronically register, process and share product-related information amongst supply chain businesses, authorities. Batteries are the first product group for which the use of a DPP will be a legal requirement as of 2027 through the EU Batteries Regulation.

Tools, examples and good practices

[Tool] The DIN DKE SPEC 99100 on battery passport

The EU Battery Passport, mandated by the EU Battery Regulation, requires a QR code on every battery to link to a digital record containing detailed information. This data includes technical specifications, sustainability metrics, material composition, social responsibility, and recycling/reuse information.

The DIN DKE SPEC 99100 - Requirements for Data Attributes of the Battery Passport - defines the data attributes that need to be included in the passport based on both requirements by the EU Battery Regulation, as well as voluntary additions. The

It focuses on several key areas:

- Technical specifications: Capacity, charge cycles, performance, and lifespan.
- Sustainability metrics: Carbon footprint along the supply chain, based on standardised calculation methods.
- Materials and resources: Data on material composition, particularly critical raw materials like lithium and cobalt.



- Social responsibility: Documentation of working conditions in raw material extraction and compliance with environmental and human rights standards.
- Recycling and reuse: Data on recyclability and traceability of components.

Source: <https://thebatterypass.eu/news/eu-battery-passport-increasing-data-availability-and-sustainability-with-a-new-standard/>

4.2. Approaches and solutions at the AVOID stage

4.2.1. Redesign operations for more energy-efficient solutions

The ongoing decarbonisation process in the public transport sector across Europe is oriented towards a large scale electrification of the sector.

However, to exploit the opportunities provided by this transition, and ensure its long term sustainability, mobility systems across EU need to be redesigned around the suitable technological options.

This **redesign process requires planning capacities, but also simulation tools** able to analyse and compare the effects of different technological solutions, and to identify the most effective service designs to combine energy efficiency and effectiveness of the transport system in fulfilling the needs of passengers.



Tools, examples and good practices

[Tool] Digital Twin E-corridor simulation tool in Gdynia



Figure 6 E-Bus in Gdynia

Source: circularity4publictransport.eu

An assessment method to simulate circular scenarios for electrification upscaling along an identified e-corridor in the city of Gdynia (the north of Poland), has been developed jointly and tested by Kruch Railway Innovations, University of Gdansk and PKA Gdynia (Gdynia bus and e-bus transport operator).

After mapping the processes and collecting data from electric buses and chargers the so called digital twin for the city of Gdynia has been modelled.

Based on simulation and by analysing real-life data (e.g. sensor data, energy consumption, charging performance, energy flows of a selected public transport corridor), various scenarios for further public transport electrification possible to be taken up in the city can be precisely developed.

The simulation is thus set up and can simulate different OCL (overhead contact line) settings, in-motion charging trolleybus (IMC), opportunity charging and overnight charging in all scenarios. Hence, the model conveniently allows to develop several scenarios for different options of the transport modes (IMC trolleybus, e-bus, mixed operations). Moreover, thanks to the model it is now also possible to optimally plan e.g. the most predestined location of e-bus chargers, photovoltaics infrastructure or to precisely determine the demand for electricity, anticipated energy consumption and its consequent costs. Thus, the model perfectly assists planning how and in what direction electric transport in Gdynia should be developed in the light of a circular economy, resources saving approach.

The simulation of circular scenarios for electrification in Gdynia also includes delivery optimisation of already existing fast-charging, trolleybus infrastructure in different parts of the city (e.g. by the possibility to analyse sharing the trolleybus grid for other electric public transport modes).

Source: https://circularity4publictransport.eu/best_practice/demonstration-on-how-to-prolong-the-lifespan-of-electric-public-transport-infrastructure-reutilizing-heavily-used-trolleybus-switches-in-szeged-hungary/

4.2.2. Reduce component's weight and size

In the bus industry, lightweight design is important to improve fuel efficiency, increase payload capacity, and generating lower operating costs and environmental impacts. When it comes to electric buses, the reduction of weight is fundamental in order to balance the impact of batteries.



Introducing lightweight materials by design is the most effective way of improving the efficiency of the rolling stock, and PTOs should foster the adoption of this innovative approach by their suppliers.

Looking at the battery of electric buses, the larger the capacity, the longer the distance a bus can cover without additional charging. A long use phase of e-buses significantly helps to avoid the production of new transport vehicles and is in line with the waste prevention concept that is given highest priority in the waste hierarchy. On the other hand, considering high-cost implications and increased weight, battery oversizing is to be avoided. Nevertheless, under sizing is also a risk, as undersized battery capacity may significantly impact the bus's functionality. Buses that cannot complete a full day of operation may require the purchase of back-up bus capacities, or even a full replacement.

Selecting the appropriate combination of battery size, fleet characteristics and charging infrastructure is the key success factor for the decarbonisation plans of PT fleets.

Tools, examples and good practices

[Good practice] Ebusco 3.0 - use of lightweight composite materials



Figure 7 Ebusco 3.0

Source: Ebusco

The Ebusco 3.0, 33% lighter than its predecessor, the Ebusco 2.2, started its operations in 2022 in The Netherlands.

Lightweight composite materials have been developed to keep the 3.0 18-meter's starting weight down to 14,500 kg (32,000 lbs). In combination with 350 and 500 kWh LFP battery packs, such a lightweight frame should give the new electric bus a range of 700 kilometres (435 miles), according to the company. The bus has a maximum capacity of 150 passengers.

Source: https://circularity4publictransport.eu/best_practice/demonstration-on-how-to-prolong-the-lifespan-of-electric-public-transport-infrastructure-reutilizing-heavily-used-trolleybus-switches-in-szeged-hungary/



Tools, examples and good practices

[Good practice] LEVIS project: a circular approach to the design of lightweight electric vehicles

Polymer-based composite materials and hybrid metal/composite components have long been explored to reduce weight in the automotive sector. Despite significant progress over the last two decades, their market adoption for structural elements remains limited, primarily to low-volume, high-end vehicles, with a few exceptions. Key barriers include high material and manufacturing costs, slow production rates and concerns over the reliability and robustness of these materials.

The Horizon 2020 LEVIS project focused on increasing the use of bio-based, recyclable and recycled materials, as well as creating new approaches for end-of-life product management. LEVIS also developed tools and methodologies to integrate eco-design practices and conducted environmental and cost life-cycle analyses.

The project team used innovative manufacturing methods to produce and validate four demo parts: a suspension control arm, a battery pack, a battery housing with integrated bus bar and a cross-car beam with a steering column carrier. These parts achieved a total weight reduction of around 30 % in all cases. The demonstrator manufacturing processes were successfully scaled up, with efforts concentrated on optimising parameters for resin transfer moulding, injection moulding, press forming and pultrusion techniques. Aluminium-composite joint configurations were analysed and optimised for the internal and side beams of the battery box, as well as for the steel-composite joint linking the steering column carrier group to the cross-car beam.

Sources: <https://greenvehicles-levis.eu/>

<https://cordis.europa.eu/article/id/455674-a-circular-approach-to-the-design-of-lightweight-electric-vehicles>

4.2.3. Reinforce circular/green procurement

Circular and green procurement, as already mentioned, must be supported through the adoption of a **long term and inter-generational perspective**, and by integrating environmental and circular performance in the economic assessment through **dedicated methodologies (e.g. LCA)**.

The procurement process must clearly identify the quality standards to be followed, and foster circular practices such as life extensions, modularity and repairability.

On the other side, quality standards are sometimes difficult to assess on paper, and **real life testing of alternative solutions** is in many cases a viable options to refine quality requirements as well as to collect information for the selection.



Tools, examples and good practices

[Good practice] Quality requirements for e-buses in the city of Leipzig

The City of Leipzig (Germany) works on a gradual transition of its bus fleet to battery electric buses. Buses are procured, owned and operated by the Leipziger Verkehrsbetriebe, which is a municipality-owned transport agency. In its tendering strategy, the Leipziger Verkehrsbetriebe require that suppliers must guarantee that the buses and their batteries achieve minimum performance requirements for ten years of constant operation. Instead of solely using indirect performance indicators (e.g., at least 80% of remaining battery capacity after a defined number of years), tender and contract specifications require that e-buses can - after ten years of constant operation under the given conditions in Leipzig - still cover a distance of 80 km with one battery charge. The 80 km are derived from typical operating conditions in Leipzig, which uses a combination of depot- and on-route charging. Further operating conditions in Leipzig are also specified in the tender documents, including information on terrain and prevailing temperature ranges. In case one or more supplied e-buses fail to meet this requirement, the supplier is contractually required to provide remedy such as a replacement of the battery.

Source: TUMI E-Bus Mission (2023), *Measures Catalogue for Improving the Circularity of Batteries Used in E-Buses* https://transformative-mobility.org/wp-content/uploads/2023/06/eBusMission_Battery-Circularity-Measures-Catalogue.pdf

Tools, examples and good practices

[Good practice] Testing of bus prototypes in India

In India, five large cities (Delhi, Calcutta, Surat, Bengaluru, and Hyderabad) joined forces in their efforts to procure electric buses. In this 'Grand Challenge', a total number of 5450 electric buses were procured through one tender process. While this large volume enabled a significant discount of unit prices, it also allowed to introduce further tendering requirements. Amongst others, the tendering process considered an interim stage in which the three best-rated supplier candidates were asked to provide prototypes for real-life testing. The results of this testing were used in the final selection of the supplier (Modi 2022).

A comparable large-scale follow-up tender for electric bus operation has been published in 2022 (6465 e-buses) and another one is planned for 2023 (~5000 e-buses) (Convergence 2022). Such demand bundling opens significant possibilities to request circular economy requirements including those described in all other recommended measures.

Source: TUMI E-Bus Mission (2023), *Measures Catalogue for Improving the Circularity of Batteries Used in E-Buses* https://transformative-mobility.org/wp-content/uploads/2023/06/eBusMission_Battery-Circularity-Measures-Catalogue.pdf



4.3. Approaches and solutions at the EXTEND stage

4.3.1. Retrofit existing vehicle fleet

In order to improve air quality in municipalities, it is crucial to renew the transport fleet with clean vehicles. Furthermore, the principles of the circular economy require the extension of product life. Therefore, vehicles that meet the clean vehicles or zero-emission vehicles requirements as a result of retrofitting should also be counted towards the achievement of the respective minimum procurement targets.

Retrofitting existing diesel buses with electric powertrains eliminates tailpipe emissions, and reduces Lifecycle carbon emissions, and represents a cost effective transition option. In recent years, multiple startups and innovative companies have emerged, offering tailored solutions to retrofit existing buses, trucks, and vans. Although the benefits of circularity by design are undoubtable, retrofitting is a complementary solutions to achieve a substantial decarbonisation of the existing fleets worldwide.

Tools, examples and good practices

[Good practice] Ankara - second-hand diesel public buses converted into electric vehicles



Figure 8 Retrofitted e-bus in Ankara

Source: <https://aim2flourish.com/>

Ankara Metropolitan Municipality has partnered with its subsidiary company BELKA A.Ş. to transform old diesel buses (from 2005) that have reached the end of their economic life into electric-powered buses.

In this innovation, the body, chassis, and axles are preserved in their original forms, with old power systems; instead of a diesel engine, transmission, and fuel system; electric motor, battery packs, and battery management systems by placing and it is mentioned that it will be transformed into a 100% electric bus. During the conversion, the original static and dynamic features of the vehicle were kept the same and the life of the vehicle was extended with additional changes and maintenance.

The goal of the project is to accelerate the process of transitioning to a more carbon- and environmentally friendly vehicle solution for public transportation that extends the life of buses in a circular manner. The project has converted 22 buses so far.

Source: <https://academic.oup.com/ijlct/article/doi/10.1093/ijlct/ctae049/7723583>

<https://aim2flourish.com/innovations/buses-that-come-alive-again-with-electricity-7>

Tools, examples and good practices

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Source: TUMI E-Bus Mission (2023), *Measures Catalogue for Improving the Circularity of Batteries Used in E-Buses* https://transformative-mobility.org/wp-content/uploads/2023/06/eBusMission_Battery-Circularity-Measures-Catalogue.pdf

Tools, examples and good practices

[Good practice] Paris - fleet life extension



Figure 9 RER B train

Source: <https://www.railwaypro.com/>

Alstom was selected to renovate up to 41 MI84 four-car trains in service on the Line B of the Paris RER network.

The four-car MI84 trainsets were assembled on the Alstom site of Valenciennes in the early 1980s and entered commercial service in 1985. The renovation aims to align the comfort levels of the MI84 trains with those of the MI79 trains renovated between 2010 and 2015, also in circulation on line B.

The refurbishment included an increase in seating capacity from 216 to 312 seats per car and internal changes like new floors, grab bars, LED lighting and CCTV camera installation. Air-conditioning was also added, the electronic equipment was replaced, and a new external livery was applied.

Source: <https://www.masstransitmag.com/rail/press-release/12302198/alstom-alstom-wins-contract-to-reno-vate-the-trains-of-the-rer-b>

4.4. Approaches and solutions at the TRANSFORM stage

4.4.1. Repurpose second-life batteries

Repurposing second-life batteries involves extending their utility beyond their initial application, for other energy storage needs. The repurposing process is complex and requires different phases:

- Testing and grading, to determine their remaining capacity and state of health (SOH)
- Disassembly and Refurbishing, preparing the modules for new applications;
- Combining modules to create larger storage units suitable for different purposes.

Second-life batteries can be used for example as stationary storage systems (BESS) for renewable energies, for grid support, and to power EV charging stations.



PTOs can plan the reuse of their own second-life batteries, typically at the depots for integration of renewable sources of in the network to support the dedicated grid.

Furthermore, second-life batteries can be used beyond the public transport domain: this requires collaborative approaches, standards and strategies to extend systematically the battery life and share the generated added value among the actors involved.

Tools, examples and good practices

[Good practice] Amsterdam - reusing car batteries for electricity storage



Figure 10 MEGA BATTERY

Source:

<https://www.johancruijffarena.nl/>

The Johan Cruijff Arena sports venue in Amsterdam has developed a renewable energy storage system that uses second-life electric vehicle batteries. Formed as part of a collaboration with businesses and partners, the innovative system enables electric vehicles to be used for a greater extent of their functional lives and provides a sustainable solution to energy storage.

Situated in the Netherlands' biggest multifunctional stadium, the 3 MW storage system provides more reliable, more efficient energy supply and consumption for the stadium, visitors, local residents and the Dutch energy grid.

The combination of Eaton's energy distribution system and the 148 Nissan LEAF batteries ensures not only that the energy storage system is more sustainable but also that it creates a circular economy for electric vehicle batteries.

The energy storage system plays a significant role in balancing the supply of and demand for energy in the Johan Cruijff Arena. The storage system has sufficient capacity to provide several thousand households with electricity. As a result of this capacity, the energy produced by the >4,200 solar panels on the Arena's roof can also be stored and used optimally.

The energy storage system provides backup power, reduces the use of diesel generators and eases the pressure on the energy grid by smoothing out the peaks that arise during such events as concerts.

Source: <https://www.johancruijffarena.nl/en/news/duurzaam/mega-batterij/>



Tools, examples and good practices

[Tool] Draft criteria for procuring e-buses with durable batteries

Companies taking overused and end-of-life vehicle batteries require information on their characteristics to take meaningful decisions on handling and management pathways, thereby helping to optimise end-of-life management. Battery-specific information can be provided by the producer in a way any third party can get easy access to it. This aspect has already been taken up by many fora and initiatives and is discussed under the keyword ‘battery passport’ (see European Battery Regulation, 2023).

While such labelling can be a useful tool to support end-of-life management, systems are not yet established in a uniform manner. Nevertheless, it can be required that producers of e-buses provide information on the batteries in an easily accessible manner.

The producer shall equip all battery packs with a well visible and accessible label / digital identifier (e.g., QR code) linked to a data website given information on at least the following battery characteristics:

- the battery chemistry (cathode and anode type)
- the manufacturer
- the date of manufacture
- the minimum, maximum and mean voltage
- the rated capacity

The website shall retain the information for at least 15 years from the date of manufacture and shall be made publicly accessible without any charge and registration procedure.

The labelling and information provided shall further be aligned with common industry formats for this purpose, including the size, design and placement of the labels, and the format of digital data provision. Information on further battery characteristics shall be additionally provided through the system in line with established practices and legal requirements.

Source: TUMI E-Bus Mission (2023), *Measures Catalogue for Improving the Circularity of Batteries Used in E-Buses* https://transformative-mobility.org/wp-content/uploads/2023/06/eBusMission_Battery-Circularity-Measures-Catalogue.pdf



Tools, examples and good practices

[Good practice] Used batteries to store energy for powering a fast-charger

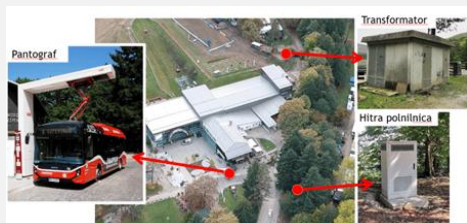


Figure 11 Battery storage and fast charging in Maribor

Source: circularity4publictransport.eu

Following the integration of the fast charger in 2022 and full electrification of bus line 6 in 2023, the Municipality of Maribor (MOM) aims to modernize public transport infrastructure at Vzpenjača station. The CE4CE project focuses on incorporating circular economy principles into public transport. As part of this initiative, the municipality is implementing a battery bank utilizing repurposed second-life batteries, powered by renewable energy sources (RES), to support the fast charger at Vzpenjača station.

This pilot demonstrates the strategic application of used batteries for storing (renewable) energy to power a fast charger. It serves as an example of how public transport can integrate circular economy principles by utilizing second-life batteries. The pilot also aims to highlight the cost-saving potential and energy efficiency improvements of such a system.

Source: https://circularity4publictransport.eu/best_practice/use-of-used-batteries-to-store-energy-for-powering-a-fast-charger/

4.4.2. Recycle materials for new manufacturing

Recycling and reusing components from electric buses is essential for creating a sustainable, circular manufacturing process.

When batteries can no longer be reused, advanced recycling methods can recover up to 95% of valuable materials (nickel, cobalt, lithium).

Electric motors contain valuable materials like copper and rare earth metals. New strategies are being developed to repair, remanufacture, and reuse motors, extending their lifespan and reducing the carbon footprint associated with raw material extraction.

Other mechanical components can be remanufactured. This involves collecting used parts, thoroughly cleaning and inspecting them, then rebuilding to original specifications. Remanufactured parts meet high quality standards and use significantly less energy than producing new parts, significantly lowering emissions and resource consumption.

Batteries are indeed the element with more strategic recycling potential, as the recovery of materials is crucial for the EU industry in terms of competitiveness and efficiency due to the lack of raw materials.



At the same time, bus recycling is an opportunity for reducing the overall impact of the public transport industry, as their construction is resource and energy intensive on a lifecycle perspective.

Tools, examples and good practices

[Good practice] Siemens Mireo regional train



Figure 12 Siemens Mireo

Source: <https://rollingstockworld.com/>

Siemens' regional train, Mireo, stands as a prime example of cutting-edge rolling stock, embodying key principles of energy efficiency, recyclability, flexibility and profitability. It is engineered for superior energy efficiency compared to other trains with a similar capacity, resulting in reduced greenhouse gas emissions. Its design incorporates lighter materials, optimised aerodynamics and innovative features such as the driver advisory system, all contributing to enhanced performance, cost savings and environmental sustainability.

With a recycling rate exceeding 95% and a focus on preventive service and smart maintenance, Mireo also ensures a prolonged lifespan of the asset and operational reliability. The train was successfully piloted in the outskirts of Munich and could expand its application to the rest of Bavaria and Europe.

Source: <https://www.mobility.siemens.com/global/en/portfolio/rolling-stock/commuter-and-regional-trains/mireo.html>

Tools, examples and good practices

[Good practice] Salzgitter - battery recycling pilot plant



Figure 13 Battery recycling

Source: media.vw.com/

Volkswagen Group Components has opened the group's first plant for recycling electric car batteries in Salzgitter, in Germany, and a pilot operation has started in the Lower Saxony city. Until now, used batteries have mostly been incinerated.

Volkswagen Group Components is using, for the first time, a mechanical process to drain and dismantle the batteries in their components so that they can be recovered here and returned to the production cycle.

The plant has been designed to initially recycle up to 3,600 battery systems per year during the pilot phase - this is the equivalent of approximately 1,500 tonnes. As the plant reaches capacity, the system can be



scaled up to handle larger quantities, and additional, larger plants could be built. If they produce cathodes exclusively from recycled material, Volkswagen will save more than one ton of CO₂ per vehicle.

Source: <https://knowledge-hub.circle-economy.com/article/12715?n=From-old-to-new-%E2%80%93-Battery-recycling-in-Salzgitter>

5. Monitoring and evaluating circular economy in PT Rolling stock

This section aims to provide a framework of indicators at the intersection of transport assets and the circular economy. Each strategy will include its own list of indicators, with potential overlapping. It represents a curated yet evolving list of indicators, continuously refined based on new insights and practical experience. The list is not intended to be a fixed set of indicators, but rather a catalyst in the initiation of cross value chain conversations. It acknowledges gaps and the need for further discussion, aiming to serve as a foundation for dialogue, refinement, and harmonization with stakeholders across different scales—from individual companies to government policies.

5.1. Importance and scope of circularity indicators for public transport

For the effective implementation of the circular economy in any sector—especially in public transport infrastructure—an indicator-based monitoring process is essential. Circularity indicators play a pivotal role, primarily for public transport operators, and secondarily for policymakers, city planners, and transport authorities. These indicators help assess how effectively public transport systems are closing resource loops, minimizing environmental impacts, and promoting reuse and recycling, all measured against a set of predefined criteria. Without a clear and consistent set of indicators, progress toward circular economy goals remains vague, and the impact becomes difficult to track, improve, and ultimately realize.

To the best of our knowledge, limited work has been done in proposing a comprehensive set of indicators specifically addressing the relationship between public transport and circularity. Circularity indicators differ from conventional ones by focusing on how well transport systems manage the entire lifecycle of materials—reducing resource consumption, extending asset lifespans, and increasing the reintroduction of materials into the economy. However, this does not mean starting from scratch. In fact, public transport operators and other stakeholders have a well-established practice of tracking indicators such as fuel consumption, asset lifespan, and material recycling rates. These indicators, in turn, act as circularity metrics, offering valuable insights into resource usage, extension, and recovery. The approach followed to develop this list is to build upon what stakeholders—particularly public transport operators—are already typically



tracking, and, where necessary, adjust or refine these metrics to better report on circularity. Although this is the "low-hanging fruit," the goal is not to remain there, but to raise ambition and broaden the scope. Therefore, we propose rating the indicators based on their scope:

- **Indicators within the PTO's scope of work:** These are indicators that PTOs are already tracking or have the agency to track, even if some effort or adjustment is required.
- **Indicators Outside of the PTO's Scope of Work:** Information related to these indicators is typically owned by and under the control of other public transport stakeholders, not PTOs. Although PTOs cannot track these themselves, they are essential for addressing the public transport life cycle value chain and truly assessing circularity. Therefore, we strongly encourage PTOs and other public transport authorities to initiate collaboration with partners and municipalities to obtain this crucial data.

In order to reflect the above rating, an indicator validation workshop was done with subject experts and partner PTOs. It was primarily done using the Miro Board platform (Figure 14). The participants were requested to rate the indicators based on their trackability and ease of implementation. PTO representatives categorised the indicators into the above-mentioned baskets - i.e., indicators within or outside the PTO's scope. The insights from the same has also been incorporated to further refine and clearly categorize the indicators within the AETE framework.

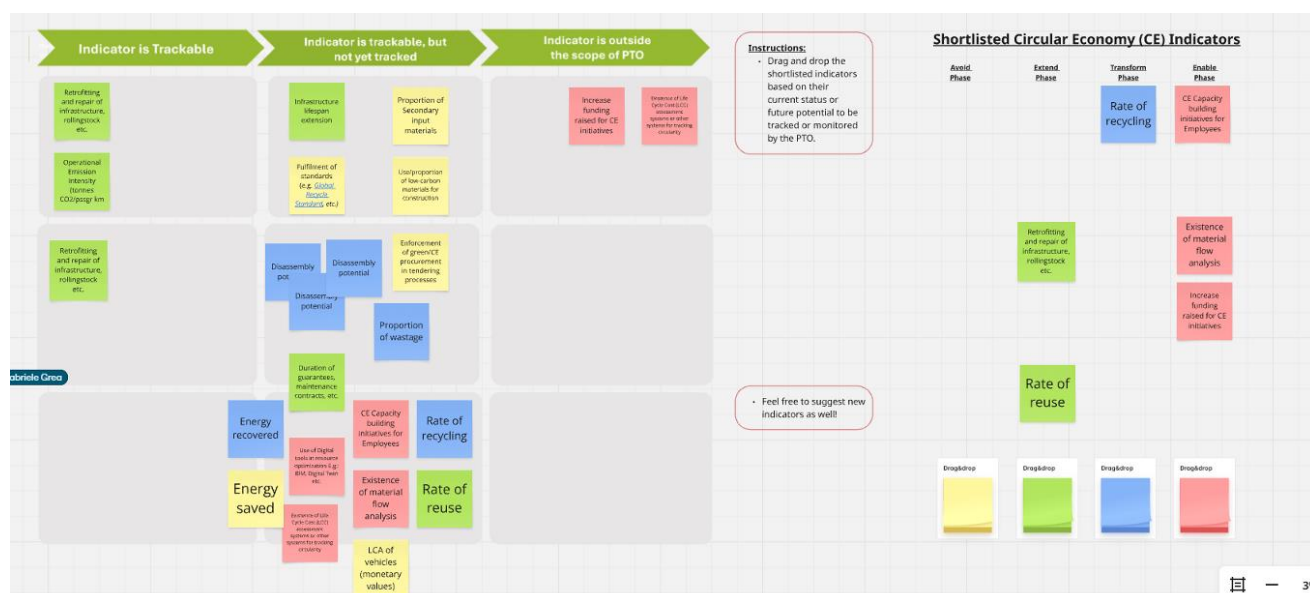


Figure 14 Miro Board excerpts from the 'Indicator validation workshop' with PTO representatives and subject experts on 17th April 2025.



5.2. Overview of current state of the debate and advancements in circular economy indicators

Numerous indicator frameworks to measure the implementation of circular economy exist in literature and practice. However, a lack of standardisation exists with respect to methodological and conceptual foundation for the same. This section gives an overview of the different circular economy indicator systems widely referred to.

A good starting point is the recent Bellagio Declaration, which was endorsed in December 2020 by the Heads of the Environment Protection Agency of Germany, France, Slovakia, Switzerland, the Netherlands, Austria, Italy and the European Environment Agency (EEA). According to ISPRA & EEA (2020), it is a set of principles on how to ensure that a monitoring of the transition to a circular economy captures all relevant aspects and involve all relevant parties.

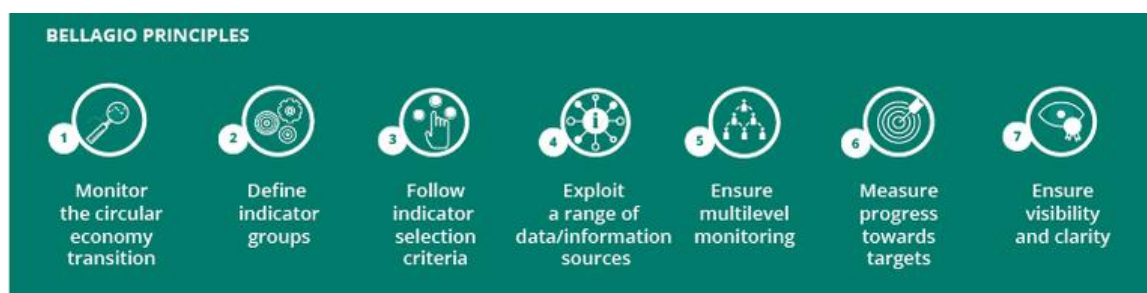


Figure 15 The 7 Bellagio Principles on Circular Economy indicators. Source: [bellagio-declaration.pdf](#)

Figure 15 describes the brief outline of the 7 Bellagio principles. Within the indicator development framework, it defines the following 4 indicator groups:

1. **Material and waste flow indicators:** To monitor changes throughout the material life cycle, including resource efficiency dimensions.
2. **Environmental footprint indicators:** To capture the impacts across the full life cycle of products and materials, ensuring that spill-over effects are assessed, and planetary boundaries are respected.
3. **Economic and social impact indicators:** These capture both positive and negative impacts that may occur during the structural changes of the circular economic transition.
4. **Policy, process, and behavior indicators:** These track the implementation of specific circular economy policy measures and initiatives.



Another popular indicator system is the European Circular Economy Monitoring Framework²¹, established by the European Commission and Eurostat to monitor progress towards a circular economy using available statistical data. The key components of this framework include:

1. **Material footprint:** Measuring the total amount of raw materials used.
2. **Consumption footprint:** Assessing the environmental impact of consumption.
3. **Circular material use rate:** Calculating the percentage of materials that are reused or recycled.
4. **Waste generation and decoupling:** Tracking the amount of waste generated and efforts to decouple economic growth from waste production

The next case in point is the Circularity Transition Indicators (CTI)²² framework by the World Business Council for Sustainable Development (WBCSD). It was developed in collaboration with 50+ companies and organizations and aims to make a credible assessment of a company's contribution to circularity. The CTI assess the material flow within the company at three key intervention points:

Inflow Assessment:

- **Renewable materials:** It evaluates the percentage of materials entering the system that are renewable, meaning they can be replenished naturally over time.
- **Non-virgin materials:** It also measures the proportion of non-virgin materials, which are materials that have been previously used and recycled, thus reducing the need for new raw materials.

Outflow Assessment:

- **Recoverability:** CTI assesses how easily materials can be recovered at the end of their life cycle. This includes evaluating the design of products to ensure they can be disassembled and their components reused or recycled.
- **Actual recovery:** It measures the actual percentage of materials that are successfully recovered and reintroduced into the production cycle, rather than being disposed of as waste.

²¹ European Commission. (n.d.). *Circular economy monitoring framework*. <https://ec.europa.eu/eurostat/web/circular-economy/monitoring-framework>

European Environment Agency. (n.d.). *Measuring Europe's circular economy*. <https://www.eea.europa.eu/en/topics/in-depth/circular-economy/measuring-europes-circular-economy>

²² World Business Council for Sustainable Development. (2025, March). *Circular Transition Indicators (CTI): Enabling solutions*. https://www.wbcsd.org/wp-content/uploads/2025/03/WBCSD_CTI_enabling_solutions.pdf

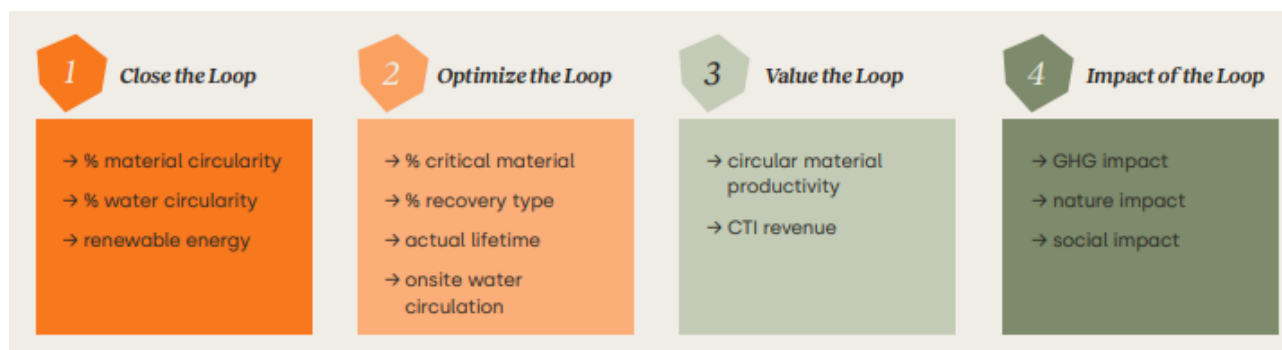


Figure 16: CTI indicators retrieved from CTI v4.0. Source: WBCSD_CTI_enabling_solutions.pdf

5.3. Evolving list of indicators for monitoring circularity in public transport

This section will present a non-exhaustive and evolving set of indicators that can be used to measure or assess the extent of implementation of circularity in the domain of public transport. In alignment with the circularity compass, the indicators have been classified into the following categories:

AVOID (Upfront stage): These are indicators that assess the strategies aiming to promote circularity by avoiding the use of primary or virgin materials, unsustainable materials etc. They focus on the proportion of secondary materials, carbon-neutral products, and durable materials, promoting the use of resources that have a lower environmental impact and longer lifespans.

EXTEND (Operational stage): These indicators focus on the performance and efficiency of the rolling stock during its operational phase. They include metrics such as energy consumption, operational waste reduction, and operational emission intensity, aiming to optimize resource use, reduce waste, and minimize the environmental footprint of the fleets.

TRANSFORM (end-of-life stage): These indicators assess circularity by looking into the actions or strategies done on components at the end of their lifecycle. They include metrics such as the rate of recycling, reuse, repurposing, and repair, emphasizing the importance of extending the life of materials and reducing waste through effective recovery and reuse strategies.

ENABLE: These indicators evaluate the efficiency and sustainability of processes and systems used in public transport rolling stock. They cover the use of life cycle assessment tools, and other practices that enhance resource efficiency and minimize environmental impact throughout the rolling stock's lifecycle.

It is important to note that the given categorization of circularity indicators is not set in stone. Different approaches can be used to classify and measure circularity in public transport infrastructure. The approach provided here is comprehensive and covers various aspects of



circularity, but other approaches could also be equally valid. This flexibility allows for the adaptation of indicators to specific contexts and objectives, ensuring that the assessment of circularity remains relevant and effective.

Table 2: Non-exhaustive list of circular indicators for PT Rolling Stock

Indicators Category	Indicator	Unit	Description	Measurement Methodology	Data Required	Significance of the Indicator	Scope of Implementation for PTOs
AVOID	Secondary Material Input Ratio	%	What percentage of input materials (by weight, volume etc.) are secondary /non-virgin materials sourced from end-of-life scrap of internal or external sources.	Calculate the weight or volume of secondary materials used in rolling stock divided by the total weight or volume of all materials used. This can be tracked through procurement records and verified by certifications or documentation from suppliers	Inventory of non-virgin or end of life materials available internally or Historic data on performance of components with non-virgin materials	Encourages the use of scrap materials, reducing the demand for virgin resources and minimizing environmental impact.	Within Scope of PTOs, and the indicator is trackable.
	Circular Economy procurement or tendering	% or scoring index	Inclusion and enforcement of green and circular economy principles within the procurement and tendering procedures.	Proportion of tenders in which CE-related criteria are included as mandatory requirements, or preferential conditions.	Information on procurement policies, guidelines, data on contractual clauses enforcing CE-related outcomes, interviews with procurement officers or auditors.	By enforcing CE principles at the procurement stage, PTOs can significantly influence supplier behaviour, drive demand for low-impact materials and technologies, and foster innovation across the value chain.	Within the scope of PTOs, and the indicator is trackable.



ENABLE	Life Cycle Cost (LCC) assessment	Qualitative index	Indicates whether Life Cycle Cost (LCC) assessment systems or other systems for tracking circularity are implemented in the infrastructure project.	Verify the presence of LCC assessment systems or other circularity tracking systems through project documentation, procurement records, and system implementation reports.		They are crucial for evaluating the total cost of ownership, including initial construction, operation, maintenance, and end-of-life disposal - which can help in furthering circularity in the system.	Within scope of PTOs, but difficult to implement or track. LCA is a complex process that requires specialised knowledge and skillsets.
	Circular Economy Competency Development	%	Capacity building initiatives such as workshops, online courses/webinars, industry collabs etc. for employees that can improve knowledge and awareness on circular economy.	Measure of the total number of CE focussed initiatives out of the total number of capacity building exercises carried out for employees in a fixed time period.	Information on training calendars, HR plans and strategies, Certification or partnerships with CE education providers, post-training assessments or feedback reports.	Competency development fosters organizational readiness, reduces resistance to change, and enhances innovation by embedding CE thinking across roles and departments.	Within the scope of PTOs, and the indicator is trackable.
EXTEND	Retrofitting and repair	% or scoring index	Proportion of maintenance activities that successfully.	Track the number of successful maintenance interventions divided by	Asset management plans and	Extending the life of rolling stock through	Within the scope of PTOs and the indicator is

			Extend the lifespan of rolling stock.	the total maintenance activities for predetermined unit of time OR Assessing financial investment in repair vs new procurement.	maintenance schedules, Records of repair, retrofitting, or refurbishment projects, Inventory of rolling stock and infrastructure upgrades, Interviews with maintenance and operations personnel.	targeted upgrades supports environmental sustainability, cost savings, and service continuity management.	already being tracked by several PTOs.
	Operational Emission Intensity	tonnes CO2e/passenger-km	Estimate of the greenhouse gas emissions per passenger-kilometre during operation.	Total GHG emissions generated, divided by the total passenger-kilometres of the vehicle. Operation done for defined reporting period.	Fuel consumption records, Emission factor values, Vehicle-kilometres or passenger-kilometres operated, fleet characteristics.	Helps in assessing the environmental impact and promoting low-emission technologies.	Within the scope of PTOs and the indicator is already being tracked by several PTOs.
	Shared Infrastructure Use	%	Extent to which physical infrastructure (e.g., stations, depots) is shared between different modes or services to reduce redundancy.	Calculate the proportion of infrastructure that is shared, based on either physical dimension (e.g., floor area), number of facilities, or functional capacity. Data can be	Infrastructure asset inventories, facility usage logs or schedules, inter-agency sharing	This strategy reduces the need for duplicative construction and maximizes asset utilization, it contributes to	Within the scope of PTOs and the indicator is already being tracked and implemented by several PTOs.

				obtained from infrastructure asset inventories, operational agreements, or facility management records.	agreements, interviews with infrastructure and operations managers.	lower material consumption, reduced land use, and improved cost efficiency. It also facilitates intermodal connectivity and supports more seamless passenger experiences.	
TRANSFORM	Material recycling rate	%	Refers to the ability to reclaim, recover, or repurpose materials and components at the end of their useful life.	Recycling Rate - Calculation of the percentage of materials (by weight, volume etc.) that are recycled compared to the total amount generated or used. ²³	Inventory of recyclable materials and their properties, Historic data on performance and condition of assets containing recycled components throughout lifecycle, Waste management logs or reports, facility-level waste sorting	Implementation and tracking of this indicator helps reduce environmental footprints, lower disposal costs, and meet regulatory compliance on waste diversion.	Within the scope of PTOs, and the indicator is trackable.

²³ Stipanovic, I., Skaric Palic, S., Rodik, D., Indacoechea Vega, I., Pascual Muñoz, P., Martin-Portugues Montoliu, C., Bartolomé Muñoz, C., & Tomar, R. (2024). *Holistic circularity framework* (Deliverable D1.1). CIRCUIT Project. https://www.circuitproject.eu/wp-content/uploads/2024/06/circuit_d1.1-holistic-circularity-framework_v6_final_ipk.pdf



				CE4CE	and disposal records, Contracts or service agreements with recycling vendors.		
Material reuse rate	%	Refers to the ability of an object or component to be used multiple times for various purposes without losing their function and without significant degradation in quality or performance. In essence, it involves EXTENDING the lifespan and utility of a resource beyond its initial intended use.	The percentage (by weight, volume etc.) of total materials used are reused at the end-of-life cycle	Inventory of reusable materials and their properties, asset recovery and refurbishment records. Historic data on performance and condition of assets containing recycled components throughout lifecycle.	Material reuse sits higher on the waste hierarchy than recycling, as it preserves more of the embedded energy and labor in products. Fostering reuse reduces demand for virgin materials, lowers lifecycle costs, and extends the utility of assets.	Within the scope of PTOs, and the indicator is trackable.	
Proportion of wastage	%	Refers to the materials & wastes going to landfilling, incineration or lost at the end of life cycle or during life cycle of a system/structure/element.	The percentage of materials (by weight, volume etc.) that go to waste or completely lost at end-of-life cycle.	Quantity of materials used. Properties of the materials, Waste disposal logs and contractor reports, Construction or	High wastage rates indicate inefficiencies in material use and highlight areas for improvement in resource management.	Within the scope of PTOs, and the indicator is trackable.	



				CE4CE	maintenance logs indicating surplus or rejected materials.		
Disassembly potential	Qualitative - Grades or scoring index	Level of capacity of a product/system/structure or built asset to be disassembled at the end of its useful life so that parts and components can be recycled, repurposed, or used in other ways to be diverted from the waste stream.	Assess the design and construction of rolling stock components based on criteria such as modularity, use of reversible connections, and the presence of disassembly instructions. Assign a score to each criterion and calculate an overall index value.		Data on modularity of the rolling stock,	Enables effective recovery of parts and materials, reducing the need for virgin resource extraction and minimizing waste at end-of-life. Contributes to sustainable decommissioning practices and lowers the total environmental footprint of infrastructure and assets.	Within the scope of PTOs, and the indicator is trackable.

The indicators presented in this chapter offer a structured yet adaptable framework for assessing the implementation of circular economy principles in public transport rolling stock. The indicators are also rated as per the current scope of implementation by PTOs or future potential to do the same. Within the circularity framework of AVOID-EXTEND-TRANSFORM-ENABLE, the indicators try to capture a wide range of lifecycle stages—from construction and operational phase to end-of-life recovery stage. These indicators provide practical entry points for public transport authorities and other stakeholders to monitor, evaluate, and enhance circularity within their systems. While not exhaustive, the set is designed to evolve alongside technological advancements, policy developments, and industry best practices.



Ultimately, the use of such indicators can guide more informed decision-making, support regulatory compliance, and foster innovation in the transition toward a more sustainable and circular public transport ecosystem.

6. Conclusions and Recommendations

This strategy examines public transport rolling stock through the lens of the AETE circularity framework, offering a life cycle approach that can drive transformative change in fleet renewal and management. It promotes a more holistic way of planning, using, maintaining, and decommissioning assets to reduce resource use, boost resilience, and respond to environmental, social, and economic challenges.

The strategy serves as a flexible foundation for developing CE4CE Action Plans and beyond, aiming to support wider adoption of circularity principles among European public transport organizations. In addition to specific recommendations in each section, this document outlines overarching conclusions to support the creation of localized, actionable plans.

Adopt a Life Cycle Approach in Planning, Construction, and Management

Public transport operators are called upon to move beyond isolated, piecemeal actions and fully embrace a life cycle, systemic perspective when managing public transport fleets. While individual efforts are valuable, real impact comes from coordinated actions across the entire life cycle, aligned within a circularity framework guided by clear priorities and steps. To prioritize effectively, decisions should be data/evidence-driven, considering a wide range of impacts—not just costs, energy use, or CO2 emissions—but all factors that contribute to significantly reducing natural resource consumption and ecological harm.

Even if not directly involved in every stage, public transport operators play a vital role as enablers by leading within their scope and influencing progress through procurement, collaboration with stakeholders, and advocacy where direct their action is limited.

Consolidate existing improvements in the operational stage

There are promising initiatives underway to extend the lifecycle of assets while maintaining strong performance. Public transport operators are encouraged to continue and accelerate this good work. Ongoing initiatives focus in particular on the extension of the lifespan of batteries, but also of the electric buses through refurbishments and overhauls. Vehicles are expected to become more durable also through the application of predictive maintenance approaches, and to the extension of a repair culture across PTOs but also along the supply chain. Additionally, there is growing ambition to increase the use of recycled materials within the vehicles and batteries production supply chains.



Prioritize “AVOID” and “TRANSFORM” Stages via Circular Procurement

Although circularity efforts in the operational phase are advancing, the “AVOID” and “TRANSFORM” stages still need greater attention. “AVOID” is especially critical as it has the highest ecological leverage and sets the course for later stages. “TRANSFORM” focuses on reducing waste and demand for scarce resources—key drivers of biodiversity loss.

Public transport authorities may not directly control these phases, but they wield powerful influence through procurement. When operators demand low carbon, recycled, or modular assets, industry responds. Circular procurement is a proven tool to reshape markets—especially when aligned with instruments like the EU Green Public Procurement Regulation and strengthened through early dialogue with industry. Setting clear requirements and shared goals from the start will accelerate adoption of circular practices in manufacturing, and end-of-life.

Advocate for transformative policy measures to break linear models

Last but not least, real circularity cannot be achieved without ambitious policies that promote innovative approaches and create a level playing field, which are essential to overcoming the structural barriers maintaining the linear model. While some progress has been made through existing regulations, more work is needed. Current policy discussions that are moving in the right direction, revolve around including strengthening green public procurement with concrete incentives to prioritize assets with better life-cycle environmental performance over price, regulations that opt out waste by making recycling and recovery standard practices, and clear, harmonized guidelines for establishing an EU-wide second-hand market for transport parts and assets. These measures would help pave the way for national and local public authorities to implement and enforce policies tailored to their specific local contexts.

Foster Cross-Sector Collaboration

Circularity in PTI cannot succeed without collaboration—across departments, organizations, and industries. For instance, the lifespan of rail and cableway systems is often compromised by the lack of spare parts, many of which are obsolete or difficult to repair. Public transport operators must work together to consolidate needs and engage local manufacturers who can benefit from economies of scale and provide long-term solutions. Likewise, rolling stock designed for disassembly and material recovery will only become standard if public transport funders and managers actively demand it from the manufacturing sector. This is not merely a technical issue—it’s an institutional challenge that requires trust, commitment, and aligned intent among all stakeholders.