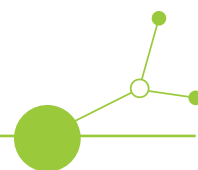


Deliverable D3.3.1

Report on pilot joint requirements,
preparation, implementation and evaluation

**Pilot action: Design for tram control units
within tram remanufacturing in Szeged,
Hungary**



Version 2
03 2026





DELIVERABLE D3.3.1

Pilot action Szeged, Hungary

Project index number and acronym	CE0100250 CE4CE
Lead partner	LP LVB
Deliverable number and title	D3.3.1 Report on pilot joint requirements, preparation, implementation and evaluation
Responsible partner(s) (PP name and number)	PP4 SZKT
Contributed person	Dr. Zoltán Ádám Németh, Gábor Jéga-Szabó
Project website	https://www.interreg-central.eu/projects/ce4ce/
Delivery date	31.03.2026
Status	Final
Dissemination level	Project

Authors and log change of the document

Partner No.	Partner Acronym	Name of the author	Action	Version
LP	Rupprecht Consult on behalf of LVB	Ana-Maria Baston	Starting version of the document drafted	0
PP7	UM	Danijel Hojski	Template design for reporting	0
PP4	SZKT	Dr. Zoltán Ádám Németh	Provided input and data	1
PP4	SZKT	Attila Náday	Provided input and data	1
PP4	SZKT	Gábor Jéga-Szabó	Provided input	2
PP4	SZKT	Attila Náday	Review and finalisation	2



Contents

1. Executive Summary	3
2. NUTS region(s) concerned by the pilot action (relevant NUTS level).....	3
3. Basic pilot concept	4
4. Key pilot development phases	6
5. Reparation and technical requirements	7
6. Implementation phase	8
7. Process evaluation	9
8. Testing and evaluation phase	10
9. Best practices	11
10. Risks and contingency approach	12
11. Pilot impact and sustainability	12
12. Transferability of the pilot action	13
13. Annexes.....	14
Annex 1: Door functions KT4D tram (separate annex)	14
Annex 2: Door functions T6A2 tram (separate annex).....	14



List of figures

Figure 1 KT4D ex-Potsdam tram from Szeged. Copyright: SZKT 5

Figure 2 T6A2-H tram from Szeged. Copyright: SZKT 5

Figure 3 Workshop with key stakeholders for planning the pilot action in Szeged, Hungary, 2024 8

Figure 4 Controlled test environment for internal testing 10

Figure 5 One of the 40 new door control units produced within the pilot action in Szeged 11

1. Executive Summary

The CE4CE project empowers circular economy system thinking for actors in public transport from Central European countries to reduce waste and create value along new life cycles of infrastructure and rolling stock. To achieve this, CE4CE jointly develops solutions that enhance knowledge and capacities for the sector, reduce barriers and costs, and initiate the development of new services and skilled jobs. Additionally, the project focuses on strategies and action plans that support policy development, learning, and exchange at both regional and transnational levels.

One of key aspects of CE4CE’s initiatives is the implementation of pilot actions that demonstrate and validate circular economy principles in public transport. By applying these principles in real-world settings, CE4CE aims to create new value chains, optimize resource efficiency, reduce costs, and foster innovation within the sector. These pilot initiatives serve as practical examples of how circular economy strategies can be integrated into public transport operations, ultimately contributing to a more sustainable and resource-efficient mobility system.

To achieve this, CE4CE pilots will test solutions that enhance knowledge and capacities for public transport stakeholders, address regulatory and financial barriers, and support the development of new services and job opportunities. The results of these pilots will contribute to shaping policies, guiding investments, and facilitating knowledge exchange at both regional and transnational levels.

Furthermore, CE4CE pilot actions will enable cooperation among key transport actors to co-develop and refine processes that integrate circular economy principles. This includes innovative procurement strategies, circular business models, extended life-cycle assessments, and cost-benefit methodologies.

2. NUTS region(s) concerned by the pilot action (relevant NUTS level)

Country (NUTS 0)	HU
Macroregion (NUTS 1)	HU3 - Great Plain and North
Region (NUTS 2)	HU33 - Southern Great Plain
Sub-region (NUTS 3)	HU333 - Csongrád-Csanád County



3. Basic pilot concept

The pilot action carried out by Szegedi Közlekedési Társaság (SZKT), the municipal transport operator of Szeged, Hungary, focused on the in-house development of a universal door opening and closing control unit for Tatra T6A2 and KT4D-ME trams. These original control units, manufactured between 1992 and 1997, are no longer in production and no spare parts are available on the market. At the time of the pilot, 99 such units were in active operation across 28 tram vehicles in Szeged. The failure of even a single unit can render a vehicle inoperable, creating a direct operational risk for the city's electric public transport network.

The aim of the pilot was to develop a modern, parameterisable, and diagnosable replacement hardware unit using contemporary vehicle-industry components, supported by a custom diagnostic software solution, and certified by the relevant transport authority. By successfully completing this pilot, SZKT acquired the internal know-how required to manufacture these critical electronic components independently, reducing reliance on unavailable external sources and significantly extending the operational lifespan of the Tatra tram fleet.

The basic concept of the pilot is firmly rooted in circular economy principles. Rather than prematurely retiring 28 functional electric tram vehicles due to the unavailability of a single electronic component, SZKT invested in reverse-engineering and modernising that component to give the vehicles a new lease of life. This approach directly embodies the circular economy tenet of extending product lifecycles and maximising the use of existing assets. The trams themselves – zero-emission electric vehicles – represent significant embodied capital and environmental value. Replacing a small but critical electronic unit to keep them operational for additional decades is far more resource-efficient and environmentally sound than scrapping and replacing entire vehicles. The pilot integrated circular economy principles at multiple levels: at the component level by replacing an obsolete part with a modern, serviceable equivalent; at the vehicle level by extending the operational lifetime of 28 trams; and at the systemic level by building internal capacity for future spare part development, thereby reducing dependency on linear supply chains that have already failed.

The main activities carried out during the pilot included:

- a technical feasibility study and identification of spare part requirements;
- procurement of engineering design proposals from external development partners;
- clarification of regulatory approval requirements with the relevant transport authority and certification bodies;
- re-issuance of technical specifications and formal public procurement;
- development and delivery of prototype units;
- live testing of prototype units in a controlled environment within SZKT's technical department;
- certification of the units by an external auditor (TÜV);
- obtaining national regulatory approval for use in city traffic;
- manufacture of 40 units for initial fleet coverage;
- installation of units in the vehicles with the highest failure risk or where existing regulators had already failed.

Long-term performance monitoring was integrated into SZKT's regular maintenance log.

The pilot aligned directly with local, regional, and national policies on sustainable public transport. At the local level, it supports the E-mobility Concept of Szeged, approved by the city council in November 2023, which establishes the long-term operation and expansion of zero-emission electric public transport as a strategic priority. Extending the life of the existing Tatra tram fleet directly serves this goal by maintaining emission-free capacity without the need for new vehicle procurement. At the national and European level, the pilot is consistent with policies promoting circular economy practices in transport, resource efficiency, and the reduction of waste through lifecycle extension of existing infrastructure.



Figure 1 KT4D ex-Potsdam tram from Szeged. Copyright: SZKT



Figure 2 T6A2-H tram from Szeged. Copyright: SZKT



4. Key pilot development phases

Main milestones of the pilot project	Description	Duration of the stage	Calendar term	Responsible partner
Pilot Design	Technical assessment	1 month	06.2023-07.2023	SZKT
Stakeholders Engagement and joint development	Regulatory approval requirements clarified with transport authority and certifying bodies	18 months	06.2023-11.2024	SZKT
Feasibility Study and Preparation	In-house development confirmed as technically and financially feasible	1 month	06.2023-06.2023	SZKT
	Controlled test environment established; full technical documentation drafted	12 months	07.2023-06.2024	SZKT
Procurement Process(es)	Procurement conducted (Development partner selected for engineering, prototyping, and delivery)	2 months	06.2024-07.2024	SZKT
Pilot Implementation	Prototype units produced and delivered Functional testing performed in controlled environment	12 months	08.2024-07.2025	SZKT
Operational Launch	40 units manufactured	3 months	05.2025-07.2025	SZKT
Monitoring and Evaluation	KPI tracking initiated	Ongoing	02.2026-	SZKT
Reporting and Documentation	Press release	1 day	10.2025.	SZKT
	Report on project	1 month	02.2026-03.2026	SZKT



5. Reparation and technical requirements

Technical Requirements

The replacement door control unit was required to meet a stringent set of technical standards. As a safety-critical component governing passenger door operation on urban trams, the unit had to comply with applicable EU and Hungarian regulations for safety-critical electronic components in public transport vehicles. The unit was required to be fully parameterisable via modern computer-based diagnostic tools, enabling SZKT's maintenance engineers to configure and adjust operational parameters without specialist manufacturer support. It had to incorporate diagnostic output capability, allowing real-time and logged fault detection. Physical compatibility with the door mechanics of both Tatra T6A2 and KT4D-ME tram types was mandatory, as was full interoperability with existing wiring and control interfaces. The development made use of contemporary vehicle-industry-grade electronic components to ensure long-term availability of parts and compliance with environmental and electromagnetic compatibility standards. A controlled test environment was established within SZKT's technical department prior to prototype delivery, replicating the electrical and mechanical conditions of the tram door systems.

Social Requirements

The pilot addressed a direct public service reliability concern. The unavailability of spare door control units posed a risk of vehicle withdrawals from service, which would have reduced tram capacity and negatively impacted the reliability of public transport for residents of Szeged. Stakeholder engagement focused primarily on internal actors – SZKT's engineering and maintenance teams – to ensure the new units were operationally accepted and that staff were adequately trained. The involvement of the tram maintenance department from the design phase ensured that practical usability and maintenance accessibility were built into the product from the outset.

Environmental Requirements

The pilot was inherently aligned with environmental objectives. By extending the operational life of 28 zero-emission electric trams, the project avoided the environmental costs associated with vehicle disposal and replacement. The use of vehicle-industry-grade components ensured compliance with RoHS and relevant environmental standards for electronic equipment. The pilot contributed to the goals of the E-mobility Concept of Szeged by sustaining the operational capacity of the city's electric tram fleet.

Economic Requirements

The pilot required a clearly defined budget covering engineering design, prototyping, testing infrastructure, certification fees, and the manufacture of 40 units for initial deployment. Economic feasibility was confirmed during the preparation phase, with the investment cost significantly lower than the alternative of replacing entire tram vehicles or withdrawing them from service.



6. Implementation phase

The implementation of the pilot was organised in a phased and structured manner, beginning with the preparation of detailed technical requirements and concluding with the installation of certified units in operational tram vehicles.

The procurement process was conducted in accordance with Hungarian public procurement legislation, which applies to SZKT as a publicly owned transport operator. A formal tender was issued following the clarification of regulatory approval requirements with the transport authority, as this information was necessary to define the full scope of work required from the development partner. Initial market engagement involved requesting offers from pre-identified companies to establish the technical feasibility and cost range before launching the formal procurement. The final procurement was open and competitive.

The relevant regulatory framework included Hungarian national regulations governing the approval of safety-critical components in urban rail vehicles, as well as applicable EU directives on electromagnetic compatibility and electronic component safety. The approval process required external certification by TÜV, which conducted an independent technical assessment of the prototype units prior to regulatory approval being granted by the national transport authority for use in city traffic.

Key stakeholders involved in the procurement and implementation process included SZKT's engineering and procurement teams, the selected development partner, the transport authority responsible for regulatory approval, and TÜV as the independent external certifier. SZKT's tram maintenance department played an active role during the testing and installation phases.



Figure 3 Workshop with key stakeholders for planning the pilot action in Szeged, Hungary, 2024



7. Process evaluation

The overall implementation of the pilot progressed in line with the planned phased approach, though one significant adjustment was required during the early stages. The initial expectation was that the regulatory approval process for the replacement units would follow a clearly defined and well-documented pathway. In practice, however, the precise requirements for approving a safety-critical replacement electronic component – one not covered by any existing type approval – were not immediately clear. SZKT had to proactively engage with the relevant approving institutes to clarify what testing and documentation was required before certification could be sought. This added time to the preparation phase but ultimately provided SZKT with valuable regulatory knowledge that is now retained as institutional expertise.

As a result of this clarification process, the initial round of offers received from development companies had to be revisited. Updated technical specifications incorporating the full approval requirements were issued, and offers were re-requested before the formal procurement was launched. This adjustment ensured that the procurement was conducted with full knowledge of the regulatory scope, avoiding potential delays or cost overruns at the certification stage.

The development, prototyping, and testing phases proceeded as planned once the procurement was concluded. The controlled test environment established within SZKT's technical department proved effective in validating the prototype units prior to external certification. TÜV certification was successfully obtained, followed by national regulatory approval. The manufacture of 40 units and their installation in the highest-risk vehicles was completed within the pilot delivery period.

Overall, the pilot met its core objectives: a functioning, certified replacement unit was developed and deployed, SZKT acquired the associated engineering and regulatory know-how, and the operational lifespan of the affected tram fleet was secured. The main learning from the process evaluation was the importance of early and direct engagement with regulatory bodies when developing safety-critical components for which no established approval pathway exists.



8. Testing and evaluation phase

The KPI's of our pilot project are long term, and can only be produced after years of operation, so it is still ongoing.

Category	Indicator	Unit
Operation	Vehicle types affected by critical components	pcs
Operation	Number of operated vehicles affected by critical components	pcs
Operation	Quantity of critical components procured (door controller)	pcs
Operation	Critical components with enhanced diagnostic capability (door controller)	pcs

Testing of the new door control units was carried out in two stages: first in the controlled test environment established within SZKT's technical department, and subsequently in live operational conditions following installation in tram vehicles.



Figure 4 Controlled test environment for internal testing



During the controlled testing phase, the prototype units were subjected to functional verification against the full technical specification. Parameters measured included door opening and closing response times, accuracy of parameter settings applied via the diagnostic software, fault detection sensitivity and response, compatibility with the electrical interfaces of both Tatra T6A2 and KT4D-ME tram types, and operational stability under simulated load conditions. The diagnostic software was tested for its ability to read, record, and display operational data in real time, and to allow parameter adjustment without hardware modification.

Following successful internal testing, the prototype units were submitted to TÜV for independent external certification testing. TÜV assessed the units against applicable safety and technical standards for safety-critical electronic components in urban rail applications. Certification was granted upon satisfactory completion of this process.

After installation in operational vehicles, long-term performance monitoring was integrated into SZKT's standard maintenance logging system. The primary KPI for the pilot was defined as the operational lifetime and reliability of the new units – specifically, whether they demonstrate reliability comparable to or exceeding that of the original units over an extended monitoring period. Secondary KPIs included the frequency of maintenance interventions required per unit, the incidence of door system faults attributable to the control unit, and the effectiveness of the diagnostic software in supporting fault identification and resolution. KPI data was collected through SZKT's existing maintenance log infrastructure, supplemented by diagnostic data outputs from the new software.



Figure 5 One of the 40 new door control units produced within the pilot action in Szeged

9. Best practices

Similar door reconstructions were made already, where SZKT project learned practices, but were different in safety level compliance methods:

1. - Budapest Transport Company (BKV): full tram door electronics modernisation project.
2. - National Railway (MÁV): passenger car door control units, but on high-level safety and compliance processes from railway regulation were adapted.



10. Risks and contingency approach

The primary technical risk identified at the outset of the pilot was the possibility that a modern replacement unit could not be developed to a standard sufficient to meet the regulatory requirements for a safety-critical component in urban tram operation. This risk was mitigated by engaging qualified external development partners with relevant experience, establishing a rigorous internal testing environment before external certification was sought, and maintaining close dialogue with the transport authority to ensure alignment with approval requirements throughout the development process.

A significant regulatory risk materialised early in the pilot: the approval pathway for a replacement electronic component of this type was not clearly defined in advance. SZKT addressed this by proactively engaging with the relevant approving institutes before committing to a final technical specification or launching procurement. This approach converted an initially open-ended regulatory risk into a managed and ultimately resolved process step.

Supply chain and delivery risk was present given the reliance on an external development partner for engineering and manufacturing. SZKT mitigated this by conducting a competitive procurement process and retaining the technical documentation and know-how internally, so that a different supplier could be engaged if necessary. The controlled test environment within SZKT's technical department also provided the capability to independently verify delivered units regardless of which supplier produced them.

In the event that a key stakeholder or development partner had withdrawn from the pilot, SZKT's contingency approach would have been to re-issue the procurement to an alternative supplier, using the technical specification and documentation already developed. Because SZKT retained full ownership of the technical requirements and test protocols, the withdrawal of a single partner would not have resulted in loss of the project's accumulated know-how. The early engagement with the transport authority also meant that the regulatory pathway was understood and documented independently of any specific supplier relationship. In the most serious contingency scenario – failure to achieve certification – SZKT would have continued to repair original units in-house on a case-by-case basis while pursuing an alternative development approach, supported by the knowledge gained during the pilot.

11. Pilot impact and sustainability

Impact and Benefits

The most immediate and tangible impact of the pilot was the elimination of an acute operational risk for Szeged's tram network. Prior to the pilot, the 99 door control units in service across 28 Tatra trams had no available replacement, meaning that each unit failure brought a vehicle closer to permanent withdrawal from service. The development and deployment of a certified replacement unit directly secured the continued operation of these vehicles, preserving tram capacity and service reliability for the residents of Szeged.

From an environmental perspective, the impact is significant. The 28 Tatra trams in question are zero-emission electric vehicles. Their continued operation avoids both the environmental cost of premature vehicle disposal – including the embodied energy and materials in each vehicle – and the potential need for replacement vehicles, which would carry their own production-related environmental footprint. Extending the operational life of each tram by a further decade or more through a targeted component replacement represents a highly resource-efficient outcome consistent with circular economy principles.



Socially, the pilot supports the continuity and reliability of electric public transport in Szeged, a key element of the city's sustainable mobility strategy. Reliable tram services reduce car dependency and contribute to improved urban air quality. The pilot also built internal technical capacity within SZKT, creating skilled employment in specialised tram electronics maintenance and development.

Economically, the pilot represents a cost-effective solution to what would otherwise have been an unresolvable spare parts problem. The cost of developing and certifying the replacement units – and manufacturing an initial batch of 40 – is substantially lower than the cost of replacing 28 tram vehicles.

Sustainability Beyond the Project Lifetime

The sustainability of the pilot's results is strong. SZKT now holds the complete technical documentation, design specifications, diagnostic software, and regulatory approval for the replacement unit. This means that future batches can be manufactured without repeating the development or certification process. The know-how is retained within SZKT's engineering team and embedded in its standard technical documentation and maintenance protocols.

The pilot has established a precedent and methodology for future in-house spare part development. SZKT identified this approach as a replicable model applicable to other obsolete electronic components in its fleet – including potential future applications to trolleybus door systems, which use similar technology. The documented process for regulatory engagement is particularly valuable, as it removes a key barrier that would otherwise slow future development initiatives. Regular training for SZKT engineers on the new system has been embedded in the outcome, ensuring that operational knowledge is distributed across the maintenance team rather than concentrated in a small number of individuals.

12. Transferability of the pilot action

The pilot action developed by SZKT has strong potential for transfer to other public transport operators across Hungary, Central and Eastern Europe, and beyond. The challenge it addressed – the obsolescence of original electronic components in ageing but otherwise serviceable tram fleets – is not unique to Szeged. Numerous cities across the region operate Tatra trams of the same or similar types (KT4D, T6A2 and related variants), produced in the same era, and face identical spare parts supply challenges. The door control unit developed by SZKT was designed as a universal replacement, meaning it is in principle adaptable to vehicles operated by other fleet owners with minimal modification.

Several elements of the pilot are directly transferable. The technical documentation and design specification for the replacement unit can serve as a reference for other operators seeking to develop equivalent components. The certification process experience and documentation templates accumulated by SZKT represent a significant body of knowledge that would reduce the regulatory burden for any operator attempting a similar development. The diagnostic software and tools developed as part of the pilot are usable across fleets, and SZKT has the capacity to share or license these to other operators.

The broader methodology – cataloguing critical spare parts, identifying use cases for in-house development, engaging regulatory bodies early, and building internal engineering capacity – is fully transferable as a strategic approach to fleet lifecycle management. This is particularly relevant for operators of trolleybuses, which use similar door system technologies and face comparable obsolescence challenges. SZKT's pilot provides a worked example of how this approach can be executed from concept through to certified deployment.



There is also a commercial transferability opportunity. SZKT could offer retrofit kits and associated expertise to other Hungarian and European operators, positioning itself as an innovation leader in public transport component development. This could create a modest revenue stream while simultaneously addressing a shared challenge across the sector.

Challenges in transferability are primarily regulatory. Each country has its own transport authority and approval processes for safety-critical components, and the certification obtained in Hungary does not automatically apply in other jurisdictions. Operators in other countries would need to engage their own national authorities, though SZKT's documentation and experience would substantially reduce the time and cost of doing so. Technical adaptation may also be required for vehicles with slightly different wiring configurations or door mechanics, though the universal design philosophy of the SZKT unit minimises this risk.

Language and institutional barriers may also need to be addressed when sharing documentation and know-how across borders, particularly with operators in countries where technical documentation standards differ. SZKT's participation in the broader Interreg project framework provides a natural channel for disseminating the pilot's outcomes to partner organisations and associated cities, many of which operate similar fleets and could benefit directly from the transferable elements of this pilot.

13. Annexes

[Annex 1: Door functions KT4D tram \(separate annex\)](#)

[Annex 2: Door functions T6A2 tram \(separate annex\)](#)