Interreg CENTRAL EUROPE | Co-funded by the European Union

CE4CE

Annex 3 to Deliverable D3.1.2

Report on development of joint digital solutions to enable and accelerate circularity in public transport

Version 2

03 2026

Circular business planning tool for electrified public transport fleets and infrastructure at PKA Gdynia, Poland

DELIVERABLE D.3.1.2

Solutions O3.2 - Modules for predictive maintenance of infrastructure and rolling stock and O3.4 Circular business planning tool for electrified public transport fleets and infrastructure

Project index number and acronym	CE0100250 CE4CE
Lead partner	LVB – Leipzig Transport Company
Deliverable number and title	D3.1.2 – Report on development of joint digital solutions to enable and accelerate circularity in public transport
Responsible partner(s) (PP name and number)	Dominika Kowalkowska (PP2 – PKA), Agnieszka Szmelter-Jarosz, Marcin Wołek (PP3 – University of Gdansk)
Contributors	
Project website	https://www.interreg-central.eu/projects/ce4ce/
Delivery date	31.03.2026
Status	Public
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	Template preparation	1
PP8	UM	Danijel Hojski	Template preparation	1.1
PP1	LVB	Conrad Jentzsch	Template preparation	1.2
PP3	UG	Agnieszka Szmelter-Jarosz, Marcin Wołek	Document preparation	1.3
PP2	PKA	Dominika Kowalkowska	Review and document validation	2

Contents

List of figures

List of tables

1. Objectives

The primary aim of the document is to present the idea of *Circular business planning tool for electrified public transport fleets and infrastructure* that supports operators and public authorities in selecting relevant circularity KPIs, setting baselines and targets, and preparing investment or operational scenarios for e-bus or trolleybus or tram systems.

Public transport operators are well prepared to implement circular economy (CE) principles due to the specific characteristics of their operations, including diversified vehicle fleets and decentralized activities. Unlike exclusively rail-based systems, they offer greater adaptability (e.g., through lower dependence on track infrastructure) and stronger potential for pilot implementations. At the same time, they face challenges related to changing legal and regulatory requirements (including those concerning emissions), fleet maintenance, and real-time demand variability. Their CE initiatives should therefore take into account both technical optimization and responsibility for delivering public services, which are most often provided under direct award public service contracts (without competitive tendering).

It should be emphasized that the scale of solutions corresponding to CE principles that had been used for many years distinguished Polish public transport companies operating under the conditions of a shortage economy (euphemistically referred to as a centrally planned economy) and during the period of systemic transformation. This resulted from the permanent deficit of fuels, lubricants, spare parts, and limited financial resources, particularly for fleet renewal. Actions now classified as CE were not described in this way at the time, although they reflected an approach based on the intensive and comprehensive use of available resources. Examples include the conversion of used diesel buses into trolleybuses in Gdynia, or the comprehensive modernization of second-hand trams, including increasing low-floor accessibility, implemented by most Polish tram operators.

A case study of one of the partners in the CE4CE project implemented under the Interreg Programme in 2023-2026—PKA Gdynia Ltd.—provides a practical illustration of the possibilities for implementing CE measures at the level of a public transport operator in a medium-sized city.

In real-life electrification programmes, public transport authorities and operators often face a recurring issue: KPIs exist, but they are not organised into a coherent, repeatable system that can be consistently used for planning and later monitoring. Indicators frequently remain a “spreadsheet collection” assembled ad hoc - depending on the project, the reporting requirement, or the individual team responsible. They are also not maintained in a long run and not tailored tot he needs of the actors.

As a result, the same KPI label may be applied with different system boundaries, units, time horizons, or calculation approaches. This makes baseline definition and target-setting inconsistent, and it weakens the ability to compare progress over time or across stakeholders.

A second challenge is the gap between circular economy ambition and day-to-day planning practice for fleets and infrastructure. Circularity concepts (including “R-strategies”) are often understood at a general level, while planning decisions are highly practical and time-critical: which vehicles to procure, what charging infrastructure to deploy, how to define charging strategies, how to reduce energy losses, how to increase utilisation, and how to extend the service life of assets and components. Without a tool that translates circular objectives into concrete KPI choices and structured planning steps, circularity risks remaining a narrative rather than a measurable, operationalised planning discipline.

A third challenge concerns comparability of electrification pathways and investment scenarios. Even when multiple organisations pursue electrification, their contexts differ substantially: route profiles, climate conditions, energy prices and energy mix, grid constraints, charging concepts, and operational strategies. Without harmonised KPI definitions and a structured approach to selecting and configuring KPI sets, it becomes difficult to evaluate which scenarios are genuinely better - whether in terms of energy efficiency, resource use, lifecycle performance, operational resilience, or overall circularity outcomes. In practice, this leads to a situation where stakeholders lack a shared language for assessing alternatives and making decisions based on consistent evidence.

The scope of the solution covers electrified public transport systems understood as an integrated planning domain that combines fleet assets, enabling infrastructure, energy flows, and operational data. On the fleet side, this includes electrified vehicles used in public transport operations (e.g., battery-electric buses, trolleybuses, trams - depending on the local technology mix). On the infrastructure side, the scope includes the physical and operational enablers required for stable fleet operation: charging equipment and charging management concepts, power supply and connection constraints, depot-related infrastructure, and - where relevant - technology-specific supply systems (such as overhead line infrastructure).

A key principle of this scope definition is that energy acts as the common “system backbone” influencing costs, emissions, operational stability, and circularity performance simultaneously. Therefore, the tool also addresses the energy-related and operational datasets required to define and track KPIs in a meaningful way: energy consumption per vehicle-kilometre, charging efficiency and losses, availability and capacity of charging infrastructure, load profiles and constraints, the share of recuperated energy (where applicable), and indicators describing the system’s ability to maintain planned service levels while electrification increases.

In short, the tool does not treat fleet and infrastructure planning as separate topics. It frames them as one planning system, where KPI selection and configuration enable scenario comparison, baseline and target definition, and evidence-based monitoring of circular economy progress for electrified fleets and their supporting infrastructure.

In the PKA pilot context, the planning problem is closely linked to the upscaling of electrified services in the Western Bus Corridor in Gdynia, where scenarios for further electrification of bus or trolleybus services need to be prepared with evidence-based indicators.

Przedsiębiorstwo Komunikacji Autobusowej sp. z o.o. (hereafter: PKA) is one of three municipal operators providing public transport services in Gdynia and neighboring municipalities. The company was established on 1 June 1994 as a result of restructuring processes in Gdynia’s public transport system. The company operates from a single depot owned by the city, located in the northern part of Gdynia.

The company’s share capital amounts to PLN 30.547 million. It employs around 250 staff members and operates a fleet of more than 70 buses produced by Solaris, MAN, and Mercedes. The annual operational output is approximately 4 million vehicle-kilometers. Until 2022, only diesel-powered buses were in service. In 2022, the company introduced 24 electric Mercedes-Benz eCitaro buses, including 16 standard vehicles (with batteries of 193.5 kWh capacity) and 8 articulated buses (with batteries of 258 kWh capacity).

The vehicles are equipped with a modern preconditioning system, energy recuperation system, and innovative safety systems, including adaptive cruise control that warns about obstacles or automatically stops the bus in case of an immediate hazard. They also feature a 360° camera system providing the driver with a full view around the vehicle, an automatic fire detection and suppression system, modern air conditioning with active virus-neutralizing filters, a defibrillator, and an alcolock system. The buses use electric heating (without Webasto heaters) and are powered by two electric motors of 125 kW each, located at the wheel hubs.

An element of the fleet project was also the construction of charging infrastructure (twenty-four bus charging points at the bus depot, and seven pantograph fast-charging stations at five existing bus loops and terminal stops).

Continuing the electrification process, in 2024 PKA announced a tender for the purchase of eight additional articulated electric buses under the Green Public Transport programme.

In addition to fleet and infrastructure modernization, PKA is involved in international projects aimed at promoting sustainable public transport infrastructure. One such initiative is the “Partnership for Twin Transition to a Green Future.” Furthermore, PKA is a partner in projects co-financed by European Union funds, such as SPINE (Horizon 2020) and CE4CE (Interreg Central Europe). The company also actively engages with the local community through events such as the European Mobility Week, organizing educational activities for children.

Introducing the classic battery-electric buses increased the number of electric vehicles in the public transport fleet in Gdynia. Since 1943 the city operates trolleybuses with an extensive catenary network, expanding to the neighboring city of Sopot. Moreover, since 2015 the trolleybus system in Gdynia is being transformed into In-Motion Charging operational model with an increasing number of trolleybuses with batteries. The total number of electric vehicles in the public transport increased significantly. Therefore, the share of electric fleet in provision of the public transport supply in Gdynia increased to ca. 44% in 2023 (Fig. 1).

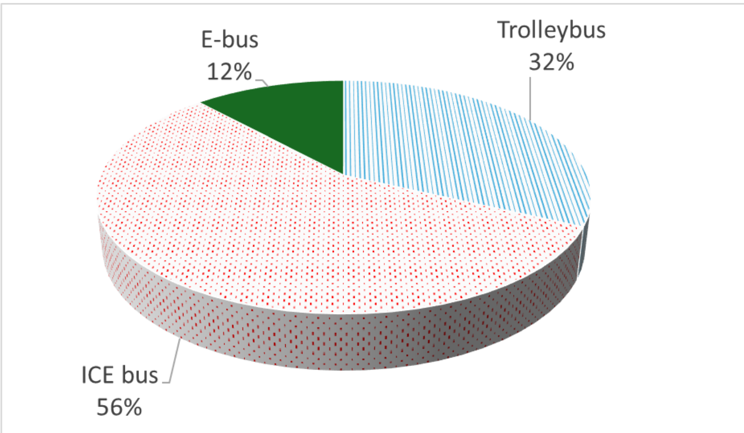

Figure 1 The structure of public transport in Gdynia in 2023 [%, calculation based on veh-kms]

As part of the CE4CE project, using the ARIS methodology, business processes at PKA were mapped and those processes were identified in which the company intends to implement circular economy (CE) principles as a priority.

The PKA pilot in CE4CE project explicitly aimed to prepare an assessment method to simulate circular electrification upscaling scenarios in order to optimise the delivery of charging infrastructure and vehicles, including aspects such as sharing resources, recapturing value from old batteries, and increasing the use of renewable energy sources.

However, the team developing the tool wanted to prepare it for broader context, also for tram and trolleybus systems. That is why the KPI list covers more areas than it should regarding the PKA Gdynia pilot scope. The digital twin prepared in the pilot action was very complex and revealed that it is impossible to prepare an unified approach to prepare the data and use it for simulations. In the case of every city the digital twin should be prepared from scratch. However, the unified approach can be used to prepare the goals to be achieved through the digital twin and therefore, this tool is proposed to wider public.

The tool operationalises circularity by translating CE4CE objectives and circular “R-strategies” into a KPI-based planning workflow (selection - baseline - target - monitoring), enabling lifetime extension, energy efficiency gains, and reduced resource consumption through better planning and prioritisation.

The core of the solution is a KPI catalogue structured by objective, planning level, circular R-strategy, and CE4CE area tags (infrastructure or energy or vehicle), including KPI definitions, units, example targets, and calculation notes (equations or variables). The online tool enables users to filter and select KPIs, create a KPI set for a planning case, and configure each KPI with baseline and target values, ownership, and data-source notes.

<u>**The introduction of the KPI catalogue-based online selection and configuration tool is considered successful if it demonstrably enables cities and operators to move from ad-hoc spreadsheet KPI handling to a repeatable, decision-ready planning workflow.**</u>

In practice, success means that stakeholders can:

a) select a relevant KPI set from the common CE4CE-aligned catalogue,

b) configure each KPI with a clearly defined scope, baseline, unit, data-source reference and ownership

c) define city-specific target levels and improvement pathways (recognising that each city starts from a different baseline and therefore sets different ambitions and timelines).

The tool should produce planning outputs that are usable in real governance and investment discussions - i.e., exported KPI packs are complete, traceable, and comparable across scenarios within a city - while also supporting transferability by keeping KPI definitions consistent across pilots and documenting local deviations transparently.

2. Target groups

The solution targets practical uptake by stakeholders who are responsible for defining, using, and maintaining **City or FUA-level KPI sets** for circular electrification planning.

Primary users include:

- municipal or metropolitan transport planning teams coordinating City or FUA strategies and reporting,
- public transport operator teams contributing operational and fleet-related inputs needed to quantify KPIs,
- energy and infrastructure specialists who provide the parameters and data required for energy- and charging-related KPIs.

These users use the tool to select a KPI set from the common catalogue and configure baselines, targets, ownership, and data readiness for their local context.

Secondary users include public transport authorities and funding bodies that require comparable KPI-based evidence across cities, as well as technology and service providers (fleet, charging, energy supply, monitoring or data platforms) who may contribute data interfaces or support KPI measurement. Research and consultancy actors can support interpretation and benchmarking, but the KPI definitions remain anchored in the common catalogue.

Wider beneficiaries are other cities and operators that want to replicate a structured, catalogue-based approach to circular electrification planning while maintaining local autonomy for target levels and improvement pathways.

2.1 Roles and RACI snapshot (aligned with city- or functional urban area - level KPI planning)

The pilot requires clear responsibility allocation to avoid "spreadsheet ownership ambiguity" and to ensure that KPI baselines and targets are credible:

- **City or PTA Planning and Strategy (R or A):** owns the KPI set selection for the City or FUA planning case, confirms scope boundaries (City or FUA vs local subsets), approves the final KPI pack for planning and reporting, and ensures targets reflect the city's ambition and timeframe.
- **Operator Planning or Asset Management (R or C):** provides fleet- and service-related inputs needed to quantify KPIs (e.g., vehicle-km, supply indicators, utilisation-relevant context), validates operational feasibility of targets, and supports interpretation of KPI results.
- **Energy or Sustainability (R or C):** owns energy-related KPI inputs and assumptions (e.g., energy consumption metrics, charging losses where measurable, renewable electricity share, energy sourcing rules), and supports consistent energy KPI definitions across planning cycles.
- **Infrastructure or Charging & Grid Interface (R or C):** validates infrastructure-related KPI assumptions and constraints (charging availability or capacity, charging efficiency where measurable, depot or charging readiness considerations) and supports realistic target setting for infrastructure KPIs.
- **IT or Data and Reporting (R):** confirms access to data sources for each KPI, documents data readiness (e.g., "easy or difficult"), defines export formats and reporting routines, and sets minimum data quality expectations (units, timestamps, update frequency).
- **External support partners (C, optional):** may support benchmarking, methodological guidance, or integration work where needed, but do not own KPI targets or definitions (which remain under City or PTA governance).

3. The solution concept

3.1 The test phase rationale

The pilot tested a structured approach to translate circular electrification objectives into a consistent variables framework that supports scenario-based decision-making. The context is the simulation of an electrified corridor ("e-corridor") and the analysis of energy flows on a digital twin to compare circular upscaling scenarios for electrified bus or trolleybus services.

A digital twin is a solution increasingly used in the design of infrastructure and public transport systems. It involves creating a digital representation of a specific physical asset, reflecting its structure, context, and behavior in relation to its real-world counterpart.

A practical example of the use of a digital twin in planning the development of public transport is the creation of an energy flow simulation for one of the transport corridors in Gdynia — the so-called "Western Corridor", which connects the city center with areas of intensive urban development. Spatial location of the Western Corridor is presented on the Fig. 2. below.

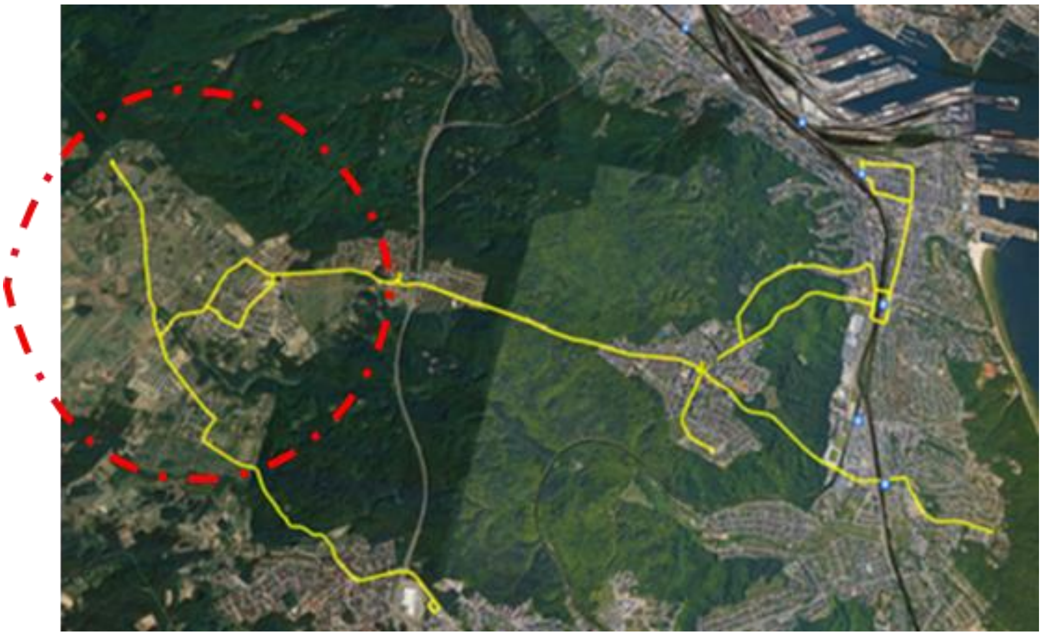

Figure 2 Location of the Western Corridor in Gdynia

The analysis has not taken into account a "Witomino Ringroad", one of the major road development investments improving the traffic conditions between Chwarzno-Wiczlino district and city centre. At the stage of the simulation development, the project was in pre-investment stage.

Based on dedicated software and real data obtained from public transport operators (such as the scale of operational work on specific routes, route alignment and topography, electricity consumption, parameters of existing infrastructure, etc.), a simulation of further electrification of public transport supply was conducted, identifying the most energy-efficient solutions.

Two currently operating public transport subsystems were included in the simulation: IMC trolleybuses (In-Motion Charging trolleybuses equipped with relatively small batteries that nevertheless allow operation for several dozen kilometers without overhead wires) and electric buses charged overnight and additionally recharged during the day at terminal loops.

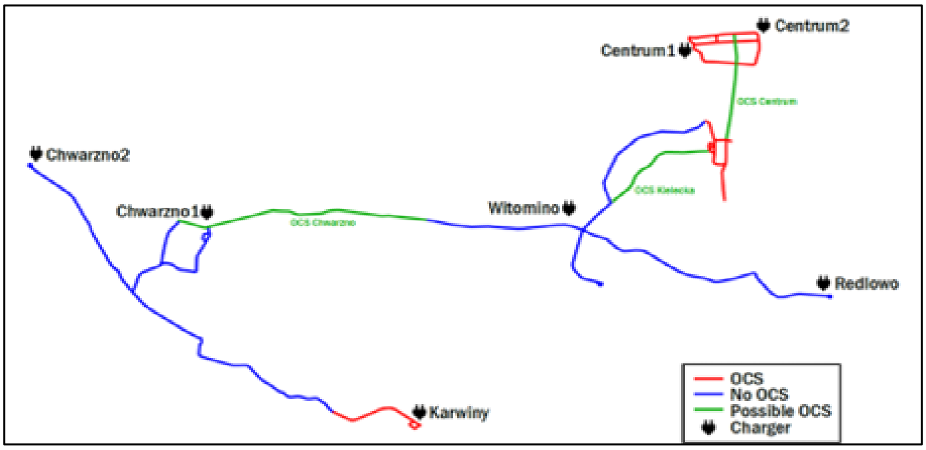

Figure 3 Potential scenarios for the Western Corridor development [OCS – Overhead Charging System]

The simulation also allowed the modeling of peak-hour conditions (including congestion) and the validation of the theoretical model with operational data obtained from an electric vehicle operating in the analyzed corridor. Simulations using digital twins can serve as a basis for investment scenarios, enabling numerous detailed simulations that help eliminate the least favorable options. The growing importance of digital twins also implies an increasing role for specialized technology companies in the transport planning process.

3.2 The solution’s description

The solution is an online KPI selection and configuration tool that replaces ad hoc spreadsheet handling with a guided workflow. Users start from the KPI catalogue and filter KPIs by objective, planning level, circular R-strategy, and system area (infrastructure or energy or vehicle). They then build a KPI set for a specific planning case (e.g., in Gdynia it was Western Bus Corridor electrification) and configure each KPI with baseline and target values, units, ownership, and data source notes. KPI set can serve as reference point and also support for digital twin implementation.

3.3 The importance of solution

The tool creates traceability between circular economy intentions and planning practice: it ensures that each KPI used in planning is explicitly linked to a circular objective and has a documented method and unit, making scenario comparisons and reporting more consistent. In addition, it provides a structured place to document data sources and limitations, which is critical in the pilot context where data collection involves multiple systems and validation steps.

3.4 Typical use cases

KPI set creation for corridor electrification scenarios. A planner selects “electrification upscaling” objectives and filters KPIs relevant to fleet, energy, and infrastructure, then exports a KPI set for a scenario workshop.

Baseline and target setting for energy-flow indicators. Energy and planning staff configure energy consumption KPIs and charging-related KPIs with baseline values and targets to support corridor simulation interpretation (digital twin outputs vs operational goals).

Data readiness and ownership mapping. The team assigns data owners and notes data sources for each KPI, explicitly capturing constraints (e.g., split across multiple supplier platforms and invoices) to avoid hidden assumptions later in the scenario process.

4. The solution development

4.1 Technical and functional requirements

Functionally, the tool must:

- store and display the KPI catalogue,
- provide strong filtering and search to build KPI sets,
- guide users through KPI configuration (baseline, target, unit confirmation, data source note, owner),
- export results for reporting and decision-making.

Technically, the tool must support import or versioning of the KPI catalogue from file master (e.g. Excel), maintain stable KPI identifiers, and provide auditability (who selected or configured what, when). It should also allow optional integration points for simulation or digital-twin outputs and operational data sources over time, even if the MVP starts with manual input and export.

4.1.1 Technical requirements

The solution requires a web-based application architecture that can reliably store and present a structured KPI catalogue and support city-specific KPI planning instances. At minimum, the system must include:

- a persistent database for the KPI catalogue (imported from the file master) and for city-specific KPI sets (baseline or target configurations, ownership, data-source notes),
- role-based access control (admin or editor or viewer) to ensure accountability for KPI configuration and approvals,
- secure authentication and hosting aligned with the operator or city IT policies (including backups, audit logging, and basic cybersecurity controls),
- export capabilities to standard formats used in planning and reporting (e.g., Word or PDF).
- A reliable web platform (cloud or on-prem, depending on operator or city policy) with secure authentication, resilient availability, and backups.
- Explicit **data ownership and governance**: KPI catalogue stewardship (who maintains the master), city-level ownership (who approves baselines or targets), and clear rules for sharing or exporting KPI packs.
- **Stable KPI identifiers** linked to catalogue entries; controlled vocabularies for objectives, levels (City or FUA default), circular R-strategies, and area tags.
- Core metadata: scope boundary notes, units, timestamps for baseline or target, versioning of KPI plans, and **quality or readiness flags** (measured or estimated or missing; easy or difficult where applicable).
- Interfaces or exports to existing planning and reporting workflows.
- A user interface that supports fast KPI discovery and selection (filters and search), guided configuration (baseline or target or owner or source), and completeness validation.

- Clear “planning outputs”: printable or exportable KPI packs suitable for management, policy, and funding discussions.
- Basic trend handling is optional at MVP stage; where included, it should focus on baseline-to-target tracking and scenario comparability rather than real-time operational alerts.

4.1.2 Data-related requirements (catalogue, inputs, and governance)

The tool depends on a harmonised KPI catalogue with stable identifiers and metadata fields aligned with the Excel structure, including:

- CE4CE objective linkage, planning level (City or FUA as default), circular R-strategy mapping, and area tags (e.g., energy or infrastructure or vehicle),
- KPI definition, unit of measure, and calculation notes (equation or variables),
- optional implementation guidance fields such as priority (e.g., high or low) and data-readiness (e.g., easy or difficult), where available in Excel.

For each city or planning case, the tool must support configuration data including:

- baseline value and baseline year (and method or source),
- target value and target year and or improvement pathway definition,
- KPI owner (role or team), update frequency, and data source references,
- data readiness or data quality flags (measured or estimated or missing) to keep scenario outputs credible.

4.2 Regulatory and compliance considerations

This solution is not a safety-critical operational control system; therefore, vehicle certifications and hardware standards are not the primary concern. However, the tool must comply with:

- internal data governance requirements (data ownership, access rights, retention policy),
- GDPR and privacy rules where any datasets could contain personal information (typically avoided by design),
- cybersecurity and supplier or contractual requirements where data is sourced from third-party platforms.

4.3 Functional requirements for operators or cities

In what regards what users, for example operators or municipalities must be able to do, the minimum functional set includes:

- **Catalogue browsing and filtering**: filter KPIs by objective, level, circular R-strategy, area (energy or infrastructure or vehicle), and free-text search.
- **KPI set update**: create a KPI set for a city or planning case; select and save a “core set” and optionally an “extended set”.
- **KPI configuration workflow**: baseline or target entry, scope boundary confirmation (City or FUA vs local subset), ownership assignment, data-source documentation, readiness flags.
- **Review and completeness checks**: highlight missing baselines or targets or owners or sources; produce a “decision-ready” KPI pack.
- **Export and reporting**: export the configured KPI set into formats used in planning and deliverable reporting (e.g., annex-ready tables, CSV or Excel for internal use).
- **Versioning and auditability**: track catalogue versions and changes to local KPI plans (who changed what and when).

4.4 Operational use, performance and maintenance

Operationally, the tool is used as a planning workflow: stakeholders create a KPI set for a planning case, configure baselines and targets, document data sources and owners, and export the result as an input to scenario discussions and procurement or investment decisions. Over time, KPI sets can be revisited and updated as data availability improves (e.g., as simulation results or operational monitoring outputs mature).

Collectively, these KPIs build a part of the holistic governance model that connects strategic sustainability goals with measurable operational outputs. The application of these indicators facilitates data-driven decision-making, continuous performance monitoring, and iterative improvement. This framework not only supports the technical and infrastructural transition to electromobility but also embeds principles of safety, energy efficiency, and environmental stewardship into the organisational transformation process.

Selected Key Performance Indicators related to the electromobility processes at a company's level in the PKA Gdynia Sp. z o.o. in 2023 are presented in Table 1.

KPI	Unit	2023
Share of electric fleet	[%]	27%
Share of e-bus vehicle-km in the overall service supply	[%]	47%
Annual average mileage of e-bus	km	75 665
Average electric energy consumption	kWh/km	1,71
Average battery capacity	kWh	215
Number of chargers in the depot	unit	24
Number of chargers in the city	unit	7
Share of energy charged outside the depot	[%]	64

Table 1 KPIs related to the electromobility for the PKA Gdynia sp. z o. o. Source: own elaboration based on the PKA Gdynia sp. z o. o. data collected within the CE4CE Project

Due to the high upfront cost of electric buses, it is crucial to maintain high annual mileage, which, in the case under study, reaches values of up to 75,000 vehicle-kilometres per year. The share of energy charged outside the depot is an indicator specific to operators who operate electric buses in a mixed charging scheme (overnight charging at the depot and opportunity charging in the city).

Average energy consumption is one of the key indicators monitoring both the energy and cost efficiency of electric bus services. However, the values of this indicator should be monitored every month, taking into account the vehicle's heating method. In the case of the analysed company, heating and air conditioning are all-electric, so electricity consumption increases significantly during winter. This aspect should be taken into account when designing winter timetables.

4.5 Integration and transferability

Integration focuses on linking KPI configuration to existing PT systems and data sources over time (asset registers, fleet or energy monitoring platforms, simulation outputs). The pilot concept already highlights that data collection and validation require combining inputs from multiple systems and energy purchase records, which makes explicit documentation of data sources a critical transferability requirement.

Transferability to other cities or operators is straightforward if they can:

- adopt the KPI catalogue structure,
- map KPI variables to local data sources,
- establish ownership and routines for baseline or target updates.

5. Challenges and lessons learned

During the developing solution supporting the pilot actions, the main challenge was not the availability of KPIs as such, but the practical ability to **move from an Excel-based KPI catalogue to a repeatable, auditable planning workflow** that multiple stakeholders can use consistently. The pilot confirmed that the “hard part” of a circular business planning tool is governance and data discipline: establishing stable KPI definitions, aligning system boundaries, and ensuring that baselines and targets are traceable to real data sources rather than assumptions.

5.1 Technical barriers (data quality, robustness, refinement)

A recurring technical barrier was **data completeness, quality and comparability**, especially where KPI variables depend on multiple systems or are measured differently across vehicles, depots, or infrastructure assets. Even when data exists, it is often fragmented across operational platforms, supplier portals, energy invoices, depot logs, and manual spreadsheets. This fragmentation creates inconsistencies in units, timestamps, aggregation levels (vehicle vs line vs depot), and definitions (e.g., what exactly counts as “charging loss” or “availability”). As a result, early KPI baselines may need to be treated as preliminary, with clear metadata tags such as “measured”, “estimated”, or “partially available”, until robust pipelines are established.

A second technical barrier concerns the **robustness of the measurement chain**. Planning KPIs for electrified fleets (especially energy and utilisation indicators) depend on reliable telemetry. Where legacy meters, loggers, or indirect proxies are used, the analytics quality can be insufficient for confident baseline definition and trend tracking. This affects not only operational monitoring, but also scenario comparability, because baselines become sensitive to measurement artefacts rather than actual system performance.

Finally, a practical lesson learned is that “equations in the catalogue” are necessary but not sufficient. KPI definitions that appear clear in Excel still require iterative refinement when implemented in a tool: the workflow needs explicit handling of system boundaries, aggregation rules, missing data, and validation checks. In other words, the pilot highlighted that KPI implementation is as much about **data engineering and validation logic** as it is about the KPI formula itself.

5.2 Regulatory constraints and approval difficulties

The pilot also revealed regulatory and approval-related friction points, mainly connected to **data access and governance**. Even when data is technically available, access often depends on internal approvals, supplier agreements, and compliance requirements. In some contexts, detailed vehicle or infrastructure telemetry can be treated as sensitive from an operational, contractual, or cybersecurity perspective. This can slow down the transition from manual inputs to automated KPI updates and can limit the level of granularity that stakeholders are comfortable exposing across organisational boundaries.

Additionally, changes that affect operational procedures - such as introducing new reporting routines or data-sharing workflows - may require internal formalisation, which can be underestimated in pilot planning. The key lesson is that KPI-based planning tools should be designed so that they can start with **manual configuration and transparent data-source notes**, and then evolve to automated integrations once approvals and interfaces are in place.

5.2.1 Organisational challenges (roles, training, user acceptance)

On the organisational side, the most important challenge was ensuring that the tool is not perceived as "another reporting obligation", but as a practical planning instrument that reduces work and improves decision quality. User acceptance depends on clarity of ownership: each KPI needs a named owner (or owning function), a defined data source, and a realistic update frequency. Without these elements, KPI sets degrade into static lists that do not survive beyond the pilot.

Training needs were also non-trivial. Stakeholders often understand their own domain metrics, but a cross-domain planning tool forces alignment between planning, asset management, maintenance, operations, and energy management. The pilot confirmed that adoption improves when teams are trained not only on "how to click the tool", but also on **why KPI definitions, boundaries, and units must be standardised** for scenario comparability.

5.2.2 Mitigation strategies applied and effectiveness

To mitigate the above challenges, the pilot applied several practical strategies:

- **Metadata-first discipline:** Every selected KPI is configured with baseline, target, unit confirmation, data source note, and ownership. This reduced ambiguity and made limitations explicit early, rather than allowing them to remain hidden in spreadsheets.
- **Progressive data readiness:** KPIs were allowed to enter the plan even when data integration was not ready, but with clear readiness flags (e.g., measured or estimated or missing). This kept planning moving while still protecting credibility.
- **Incremental validation cycles:** KPI definitions and calculation notes were refined iteratively with domain owners, focusing first on a smaller "core set" of KPIs required for the pilot planning case and expanding only when data maturity allowed it.
- **Export-driven alignment:** Outputs were designed to match existing reporting and decision workflows (e.g., annex-style exports), improving acceptance because the tool produced something immediately usable.

Overall, these mitigations were effective in reducing confusion and improving comparability, but they also confirmed that long-term success depends on institutionalising governance: catalogue versioning, ownership, and routines for baseline or target review.

5.2.3 Change management patterns

- **Early, continuous co-design** with Asset Management, Maintenance and Operations increases adoption and shortens learning cycles.
- **Secure the vehicle data path** (e.g., CAN or drivetrain signals) early; legacy meters or loggers may be insufficient for analytics-quality KPI baselines.
- **Contractually separate hardware or data capture from analytics services**; keep interfaces and IP clauses explicit to avoid lock-in and to protect future scalability.

6. Expected change

6.1 Expected results, long-term changes and benefits (KPI catalogue-based planning tool)

The solution is expected to generate long-term benefits by replacing fragmented, spreadsheet-based KPI handling with a structured, catalogue-driven planning workflow. Over time, this changes how electrification and circularity decisions are prepared: KPI sets become consistent, baselines and targets become traceable to defined data sources and owners, and scenario comparisons become more credible for management and funding decisions. The result is not a single operational “quick win”, but a sustained improvement in decision quality, governance, and the ability to steer electrification programmes towards circular outcomes.

6.1.1 Operational improvements and cost reductions

Operationally, the tool reduces repetitive manual effort spent on compiling KPI lists, aligning definitions, and rebuilding “one-off” reporting tables. Planning teams can assemble a decision-ready KPI pack faster, with fewer iterations and fewer misunderstandings between departments. In the medium term, improved KPI discipline supports more robust investment planning (e.g., sizing and prioritisation of charging infrastructure, energy procurement assumptions, fleet deployment strategies). This reduces the risk of costly rework, under or over-dimensioning, and inconsistent reporting - thereby lowering planning overhead and improving CAPEX or OPEX decisions.

6.1.2 Extended lifetime of assets and reduced need for replacements

While the tool does not directly perform maintenance actions, it enables the planning and governance conditions that support longer asset lifetimes. By tracking circularity-relevant KPIs consistently (e.g., utilisation, energy efficiency, infrastructure availability or efficiency, and other lifecycle-oriented indicators in the catalogue), organisations can prioritise measures that reduce unnecessary stress on assets, improve operational efficiency, and support life-extension strategies. Over time, better planning reduces premature replacements by aligning infrastructure capacity, charging strategies, and operational patterns with realistic lifecycle targets.

6.1.3 Environmental benefits (energy, materials, CO_2 savings)

Environmental benefits emerge through better-informed electrification upscaling and efficiency choices. With harmonised KPI definitions and city-specific targets, the tool supports measurable improvements such as reduced energy consumption per service output, improved charging efficiency (lower losses), increased renewable electricity share (where included in the KPI set), and better utilisation of electrified assets. These effects translate into lower CO_2 emissions and reduced material demand over the lifecycle, because efficient planning tends to reduce unnecessary infrastructure expansion and supports longer use of existing assets.

6.1.4 Changes for end-users, staff and passengers

For staff, the main change is a shift from “spreadsheet ownership” and ad hoc reporting to a clearer, role-based workflow with shared definitions, documented assumptions, and transparent responsibility for each KPI. This reduces friction between planning, operations, energy, and finance teams and creates a more credible basis for internal decisions and external reporting. For passengers and end-users, impacts are indirect but material: improved electrification planning supports more reliable service scaling, fewer disruptions related to infrastructure constraints, and a stronger pathway to cleaner transport outcomes. In the long term, better planning contributes to improved service quality and public trust, because investments are more clearly justified and monitored.

6.2 Before or After (reference pattern)

Before

KPIs maintained in static spreadsheets; definitions vary by team; baselines and targets are inconsistently documented; scenario comparisons rely on assumptions that are not transparent; planning and reporting cycles require repeated manual consolidation, with limited auditability and weak traceability to circular objectives.

After

A structured KPI catalogue and guided selection workflow produce consistent KPI sets linked to CE4CE objectives and circular strategies; baselines, targets, ownership, and data-source notes are systematically captured; scenario comparisons are supported by comparable KPI packs and documented assumptions; planning becomes more evidence-based, enabling more objective budgeting and better electrification upscaling decisions - including sustained focus on reducing energy per service output and improving circular performance over time.

7. Sustainability, transferability and replicability

7.1 Environmental and economic sustainability considerations

The solution supports environmental sustainability primarily by enabling **better planning decisions for electrified fleets and their supporting infrastructure**, using a consistent KPI framework rather than fragmented spreadsheets. By standardising how energy- and infrastructure-related indicators are selected, defined, and tracked, stakeholders can more reliably identify which scenario options reduce energy consumption per vehicle-kilometre, minimise charging losses, increase recuperation where applicable, and raise the share of renewable electricity in operations. In practice, the largest environmental value comes from making the “right” infrastructure and operational choices earlier - so that electrification upscaling is not only achieved, but achieved efficiently and with fewer avoidable resource and energy losses.

Economic sustainability is closely linked: when KPI baselines and targets are traceable and comparable, investment planning becomes less dependent on intuition and more dependent on evidence. The tool supports scenario evaluation in a way that helps reduce costly mistakes such as overbuilding charging capacity, selecting suboptimal charging strategies, or underestimating operational impacts that later translate into extra OPEX. Over time, consistent KPI tracking also strengthens lifecycle thinking, it makes it easier to justify actions that extend asset life (vehicles, batteries, infrastructure components), improve utilisation, and reduce total cost of ownership through more informed maintenance and renewal strategies.

7.2 Business model elements (CAPEX or OPEX implications, service models)

From a business-model perspective, the solution is lightweight in assets but meaningful in governance and services.

CAPEX implications are typically limited to:

- initial configuration or setup effort (catalogue import, system tailoring, user roles),
- optional integration work (interfaces to fleet monitoring, energy systems, asset registers),
- optional expansion modules (scenario simulation outputs integration, advanced analytics).

OPEX implications are primarily:

- ongoing catalogue governance (versioning, controlled updates, change log),
- KPI ownership routines (baseline or target review cycles, data readiness updates),
- platform operation (hosting, support, security updates),
- gradual data integration and quality improvement work.

A practical service model is often the most realistic starting point: a **subscription or managed service** that includes onboarding, KPI catalogue maintenance, and support for periodic planning or reporting cycles. For public transport contexts, a "tool and facilitation" package tends to increase success: the software alone does not replace the need for cross-functional alignment on KPI boundaries, ownership, and decision gates. As maturity increases, more automated data pipelines can reduce recurring manual effort, shifting OPEX from manual compilation to controlled monitoring and governance.

7.3 Replication pathways for other cities or operators

Replication is feasible because the core of the solution is a **structured KPI catalogue and a guided selection or configuration workflow**, not a highly bespoke technical system. The replication logic is modular:

- **Adopt the KPI catalogue structure** (Objectives, Level, Circular R-strategy, CE4CE area tags, definitions, units, calculation notes).
- **Create a local planning case** (city or operator or line) and select a subset of KPIs relevant to that context.
- **Map KPI variables to local data sources** (even if initially manual) and assign KPI owners.
- **Run at least one planning cycle** (baseline and target and export) and refine definitions or boundaries where local practices differ.
- **Scale gradually** by adding additional lines, depots, vehicle types, and infrastructure elements once the process stabilises.

Replication friction is reduced when the tool is standards-aligned (units, boundary definitions, reporting formats) and when its design is modular. A key lesson for transferability is to separate "master catalogue governance" from "local plan instances": other operators should not need to rewrite KPI definitions to use the tool; they should only need to configure baselines, targets, and data mappings.

7.4 Next steps planned within the decision making process

To move from pilot adoption to institutional uptake, the next steps should focus on decision-maker confidence in three areas: credibility, cost or benefit, and governance.

- **Policy alignment:** present how the KPI framework supports policy objectives (decarbonisation, energy efficiency, circularity) and produces auditable evidence for reporting and funding justification.
- **Management case:** demonstrate faster scenario preparation and clearer decision gates (e.g., what must be true in the KPIs before scaling electrification on additional lines).
- **Finance case:** quantify avoided costs and improved investment quality (reduced rework, fewer over or under-sizing risks, better lifecycle planning).
- **Governance package:** provide a clear operating model: catalogue versioning, KPI ownership, update cycles, and data-quality maturity targets. Decision makers rarely approve “a tool”; they approve a controlled process with accountable roles.

A strong next step is to run a decision-focused workshop using a real planning case: start from the KPI catalogue, select a KPI set, configure baselines or targets, generate an export, and use it to compare 2-3 scenarios. This produces a tangible output that policy or management or finance can evaluate directly.

7.4.1 Maturity path (self-assessment)

The pilot suggests a practical maturity pathway for organisations adopting KPI-based circular planning:

- **Reactive:** KPIs exist mainly as ad hoc reporting outputs (often spreadsheet-based); baselines and targets are inconsistent; data sources are unclear or manual.
- **Condition-based:** a stable KPI set is defined for a planning case; baselines are established and refreshed periodically; ownership and data-source notes exist; data quality is improving.
- **Predictive:** KPI trends are analysed proactively; scenario planning uses KPI-driven assumptions; early signals trigger reviews of infrastructure and operational strategies; partial automation of data feeds begins.
- **Optimised or Circular:** KPI governance is institutionalised; scenario planning and monitoring are continuous; lifecycle and circularity strategies (e.g., life extension, reuse, energy efficiency, resource optimisation) are demonstrably improving over time and embedded in decision gates.

The step-up criteria (to move from one level to the next) include data quality and uptime (reliability of KPI inputs), measurable KPI trend improvements (not just one-off reporting), process maturity (repeatable planning cycles, versioning, audit trail), and role competence (owners trained and accountable; cross-functional alignment).

8. Conclusions

The pilot-level solution successfully translated the CE4CE KPI catalogue from an Excel asset into a structured, repeatable planning workflow for electrified public transport fleets and infrastructure. Instead of ad hoc spreadsheet handling, stakeholders can now select a consistent KPI set linked to CE4CE objectives, planning levels, and circular “R-strategies”, and configure each KPI with baselines, targets, ownership, and data-source notes. This creates traceability from circular economy ambition to measurable planning outputs, strengthens scenario comparability, and improves the credibility of investment and operational decisions.

By operationalising KPI-based circular planning, the solution contributes directly to CE4CE project objectives by enabling evidence-based electrification upscaling, supporting harmonised circularity measurement, and providing a transferable approach that other cities and operators can replicate with limited local tailoring.

The tool is available publicly at: https://ce4ce.ug.edu.pl/

Roll-out recommendation

After validation, scale deliberately - starting with additional lines and fleet subsets, then expanding to new fleet types and infrastructure contexts once KPI ownership and data readiness are stable. Embed parametric planning so that investment scenarios (CAPEX or OPEX, energy assumptions, charging concepts) can be compared consistently using the same KPI framework. Institutionalise governance with an annual KPI and calculation-logic review, supported by training refreshers and clear role accountability, to keep definitions, data sources, and targets robust as the electrification programme evolves.

9. Annexes

Annex 1: Excel file as a reference base for the KPI online selector (separate annex)