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MONITORING THE ENERGY TRANSITION OF BUS PUBLIC TRANSPORT COMPANIES: A PROCESS-ORIENTED APPROACH

Summary. The study aims to identify principal processes involved in the electrification of bus transport and to develop key performance indicators (KPIs) that can effectively measure and optimize these processes within a public transport operator's framework. The study employed a case study approach, involving a systematic analysis of the processes within a selected bus transport operator that operates both conventional and electric buses in regular service. The analysis was conducted using the ARIS software. On this basis, key KPIs were assigned to monitor the individual main processes involved in transitioning the fleet to electromobility. The findings reveal that the transition to electromobility involves a comprehensive governance model that connects sustainability objectives with measurable operational outputs. Key identified subprocesses include Fleet Development, Continuous Improvement of Processes, Developing Charging Infrastructure, and Production and Storage of Energy from Renewable Energy Sources. Each subprocess is supported by specific key performance indicators (KPIs). These indicators facilitate data-driven decision-making and continuous performance monitoring, thereby enhancing the organization's capacity for

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innovation and adaptation in public transport services. Additionally, it emphasizes the importance of continuous monitoring and adaptation in response to evolving technology and shifting public expectations, providing a framework that can guide other transportation operators in their efforts to electrify. The insights gained from this case study offer valuable perspectives for city authorities and stakeholders involved in public transport management and policy-making.

Keywords: public transport, electromobility, energy transition, business process management

1. INTRODUCTION

Currently, in the member states of the European Union, a transition is underway from diesel-powered buses to electric buses. Figure 1 presents the market shares of various types of city buses in EU countries as of 2023. The data indicate that fleet policies vary significantly across member states. In some countries, such as Norway and Slovenia, new fleet investments are now exclusively directed towards electric buses. In contrast, in countries such as Estonia, Hungary, and the Czech Republic, diesel buses still dominate the domestic city bus markets. In Poland, the share of electric bus purchases is in line with the EU-27 average. The data also show that both in Poland and across other EU countries, hydrogen buses, which in many cases serve as an alternative to electric buses, continue to represent only a marginal share of the market.

The electrification of bus transport is a multifaceted process that impacts various aspects of public transport operators' operations [34,37]. Differences between diesel and electric buses occur throughout their entire life cycle [16,46]. This means that, from the perspective of a transport company, there are differences in the process of purchasing electric buses, their operation, servicing, and the disposal of the vehicles and their components after their service life has ended [1,27].

To optimize the entire process of bus transport electrification, it is essential to identify all key elements of this process. Only after identifying the components of the electrification process (both investment-related and, above all, operational) is it possible to measure them and, consequently, determine whether the processes carried out in a particular transport company are optimal or require corrective actions. In most cases, the transport company also serves as the operator of public transport services in urbanized areas (urban or suburban).

Moreover, the electrification of bus fleets not only leads to changes in existing processes of public transport companies that previously operated diesel buses, but also results in the emergence of entirely new processes. In these cases, their identification and measurement are particularly important due to the lack of knowledge and experience regarding optimal operating conditions, which could previously be acquired through the operation of diesel buses.

The process of electrifying urban bus fleets involves various stakeholders [28,45], pursuing diverse goals through the electrification of city buses. These entities differ not only in the goals they aim to achieve through bus electrification but also in the scale of their operations and impact (local, regional, national, international). In general terms, it can be stated that, both at the European and national levels, the primary goal of implementing electric buses is the reduction of global emissions of harmful substances and greenhouse gases, especially CO₂ [13,31]. From the perspective of public authorities, the goal of electrifying the bus fleet is to enhance the quality of life for city residents (e.g., by reducing noise pollution, improving travel comfort, and mitigating the negative health impacts of emissions on residents) [20,25,40]. At the level of transport companies, the goal of electrifying existing fleets should be

the optimization of total and operational costs related to vehicle mileage and passenger transport, without compromising service reliability [2,5,17]. However, trade-offs may occur, and it is necessary to find ways to align the actions of individual stakeholders to achieve a synergy effect in the bus transport electrification process. Nevertheless, the leading actor in this process – bearing the most significant risk throughout the entire life cycle of an electric bus (from acquisition to retirement, i.e., the "acquire-to-retire" process) – is the public transport operator.

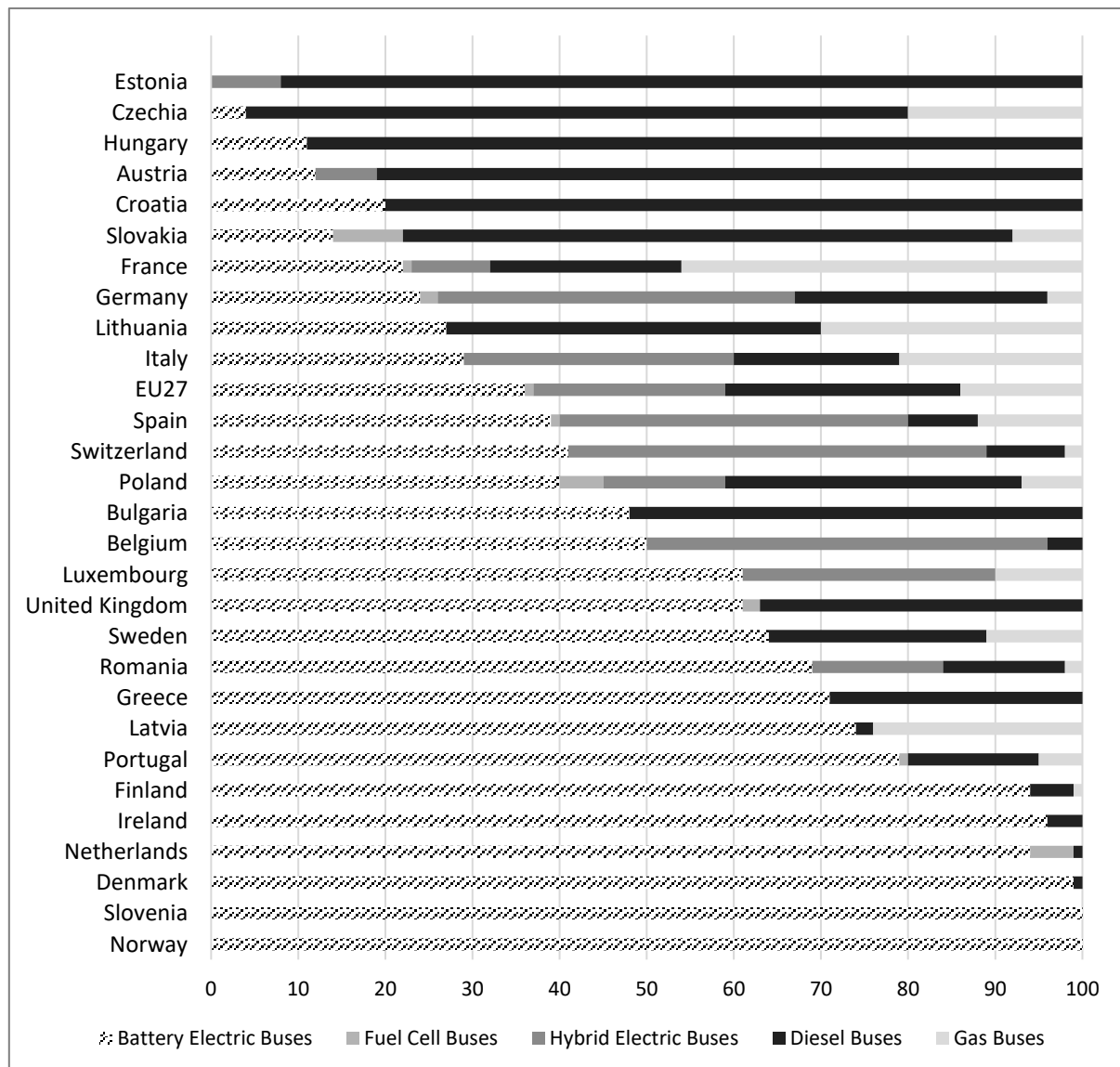


Fig. 1. Market Shares of Different Powertrains of Urban Buses in EU Countries in 2023

Source: [24]

Recognizing the conditions above influencing the transition process of transport companies from diesel to electric buses, this article answers the following research questions:

RQ1: What new processes emerge in a public transport operator as a result of fleet electrification?

RQ2: Through which Key Performance Indicators (KPIs) can the individual components of the electrification process in a public transport operator be measured for optimization?

Answering these research questions has enabled the achievement of the article's main goal, which is to diagnose the processes related to the electrification of electric buses in public transport companies and to propose methods for their measurement, improvement, and optimization using a set of proprietary KPIs. It is worth noting, however, that most of these KPIs will also apply to private and public-private fleet owners and operators investing in electric buses. Therefore, the primary outcome of this paper – the set of KPIs and process maps – will be useful for all operators, regardless of their ownership nature.

2. LITERATURE REVIEW

Every organization, including a public transportation service provider, consists of four main elements [22]:

- People,
- Processes,
- Control mechanisms,
- Structure.

Processes, therefore, serve as the cornerstone for the efficient functioning of a transportation company. Process mapping can be conducted across various operational domains within the company. The objectives of process mapping in businesses serve the achievement of numerous goals, including [3,7,14,19]:

- establishing quality standards by enhancing the repeatability and comparability of individual activities,
- analyzing the current situation, providing a foundation for subsequent changes,
- facilitating problem-solving by comprehending the constituent elements,
- mitigating losses and uncertainties through the identification of problematic areas or bottlenecks in specific processes,
- cultivating knowledge and awareness, thereby attributing responsibility to individual employees for the execution of specific actions,
- standardizing work procedures to boost productivity,
- facilitating employee rotation by improving efficiency and the seamless transfer of knowledge regarding identified elements of a given process,
- enhancing the clarity of processes through graphical representation for all stakeholders,
- identifying dependencies between components of processes and the achieved outcomes,
- recognizing the impact of changes in individual elements of processes on other interconnected elements,
- fostering discussions among employees and between employees and supervisors regarding potential enhancements to specific components of processes,
- providing precise guidance for individual employees on where to focus their efforts,
- indicating the role of individual employees and the impact of their work within a broader context,
- enabling the implementation of a system for measuring and evaluating the effectiveness of entire processes or their constituent parts.

Maximizing cost efficiency in each component of the process is possible after measuring the initial implementation level of each aspect. To achieve this, bus carriers can utilize Key Performance Indicators (KPIs). KPIs, as defined, enable the reduction of unnecessary resource wastage, increase and improve operational efficiency, productivity and profitability as well as control over whether the actions taken by the company bring it closer to achieving the intended results and strategic goals [4,8,21,26,39].

In the literature on the subject, various characteristics of well-formulated and effective KPIs are discussed. The most important ones include [6]:

- KPIs serve as general performance indicators, focusing on critical aspects of outputs or outcomes,
- a limited and manageable number of KPIs should be maintained for regular use,
- excessive and overly complex KPIs can consume time and resources,
- the systematic use of KPIs is essential, as their value is derived from consistent application across various projects,
- data collection should be kept as simple as possible,
- KPIs should be designed for use on every project,
- effective performance measurement requires widespread acceptance, understanding, and ownership of measures or indicators throughout the organization,
- KPIs may need to evolve, with a likelihood of changes and refinements to the set of KPIs over time.

On the other hand, it is advised that for a set of KPIs to fulfil its purpose, it should avoid [9]:

- consisting of too many KPIs,
- leading to the necessity of collecting an excessive amount of data,
- comprising too few KPIs,
- including KPIs not aligned with the company's goals,
- referring to too short a time horizon,
- measuring the values of individual KPIs too frequently or too infrequently.

Therefore, to propose an optimal number of KPIs, it is necessary to identify indicators that measure the most critical processes within the company. In this way, the crucial aspects of their life cycle within a company will be measured to determine the necessary changes for future purchases, operation, maintenance, and other related activities. This approach enables the coverage of all crucial aspects of managing the fleet and electrification of transport, not only for the operating company itself, but also for other stakeholders.

3. METHOD

3.1. Case study selection

To accurately capture the specific processes resulting from the electrification of the bus fleet, a public transport operator from Poland, PKA Gdynia sp. z o.o., was selected for analysis.

The public transport system in Gdynia consists of two subsystems, i.e., railway (managed by the regional authorities) and urban, managed by the municipal government and represented by the Public Transport Authority. Buses (including electric, diesel and CNG) and trolleybuses supply urban transport [43].

PKA Gdynia sp. z o.o. is one out of three municipal operators of public transport in Gdynia (Poland). The company operates a single depot with technical facilities, a fueling station, and chargers for overnight charging of its electric buses.

PKA has a fleet of 89 vehicles, including 24 electric buses. The average age of the buses was 9 years (as of 2023). Each year, PKA buses cover approximately 4 million vehicle-kilometers. The operational speed of the buses in urban traffic was 16.3 km/h [29].

In 2022, the company implemented 24 electric buses along with charging infrastructure (24 charging stations at the PKA depot and 7 fast-charging pantograph stations located at 5 existing bus loops and terminal stops). The electric fleet comprises 16 standard 12-meter buses with NMC batteries of 193.5 kWh capacity and 8 articulated 18-meter buses with NMC batteries of 258 kWh capacity, each equipped with a maximum charging power of 300 kW.

The introduction of electric buses, which account for approximately 40% of operational work, poses a significant challenge to maintaining the continuity of reliable transport operations under strict qualitative supervision of the public transport authority.

3.2. Method

The methodological approach in this study was divided into two separate paths, which helped to answer the research questions posed in the introductory part:

- mapping the processes of the selected company [41],
- preparing a comprehensive list of KPIs that may be used to monitor the company's performance in specific processes related to fleet electrification [30].

Then, when both elements were ready, they were merged into one, assigning the KPIs to the processes. Firstly, mapping the processes helped in understanding the differences between processes carried out in bus fleet operations and those related to electrification, and also in adjusting the measurements of the processes and their performance in the case of electrification of the fleet. Secondly, longlisting the KPIs and validation with experts helped propose the basic KPIs – reliable, usable, and relevant for the business- to shortlist them later for the company chosen as a case study.

3.2.1. Mapping the processes

One of the established methodologies for implementing corporate governance through the design and optimization of enterprise architecture is the ARIS House methodology, which is grounded in the EPC (Event-driven Process Chain) notation. This comprehensive conceptual framework is specifically designed to optimize business processes and facilitate the integration of information systems within an organization as well as at its interfaces with external partners. ARIS House provides a structured approach to business process management (BPM) by bridging the gap between business process modeling and IT application deployment [32]. It encompasses the entire life cycle of business processes – from design and implementation to optimization and reengineering – thus offering an end-to-end solution for process governance.

This approach proves particularly beneficial for enterprises seeking to enhance their process-oriented software concepts and improve workflow-based applications. Key components of the ARIS House framework include:

- process engineering and planning: The ARIS House methodology integrates layers of process engineering, planning, and control that are essential for the effective design and

governance of business processes. These elements ensure that processes are aligned with organizational objectives and are continuously subject to improvement [32];

- workflow control: The framework incorporates workflow control mechanisms that are integrated with IT systems, organizational units, database elements, and products. This integration facilitates seamless transitions from business process reengineering to continuous process improvement, which is critical for maintaining operational efficiency [33];
- function mapping: ARIS House also supports functional mapping, ensuring that IT systems meet both current and anticipated requirements. This capability contributes to the enhancement of existing information systems and streamlines the implementation of new, IT-based solutions [38].

Although ARIS House offers a robust framework for business process management, its adaptability to diverse organizational contexts is a critical factor for success. The practical implementation of this methodology depends mainly on an organization's ability to integrate it with existing systems and processes. Furthermore, ARIS House must be continuously updated to reflect evolving business needs, technological advancements, and emerging process requirements, particularly in relation to ESG (Environmental, Social, and Governance) strategies, sustainable development, and the circular economy (CE).

A core element of the ARIS House methodology is the EPC notation, originally developed for modeling business processes. In the context of public sector organizations and circular economy initiatives, EPC can play a significant role in designing and managing circular strategies. By visually representing workflows, decision points, and stakeholder interactions, EPC facilitates the integration of corporate governance principles with circular economy, ESG, and sustainability reporting.

EPC, as a semi-formal, flowchart-based notation, is especially effective in representing logical sequences involving decisions, tasks, and events. It is widely employed in enterprise architecture and enables the modeling, analysis, and optimization of resource loops, reverse logistics, product life cycle extensions, and stakeholder collaborations [23]. Through its transparent and auditable structure, EPC contributes to enhanced corporate governance by supporting accountability, monitoring, and control mechanisms.

3.2.2. Develop a set of KPIs

The methodology chosen for this part consisted of four main steps: desk research, an expert workshop, and validation by an external expert [35]. Then, the last step was merged with the mapping process, which involved amending KPIs to fit the specific context and data management needs of the company. Each step was designed to ensure that the selected KPIs are not only relevant and measurable but also aligned with the organization's strategic objectives. The whole process has been conducted within the CE4CE Central Europe Interreg project.

Step 1: Desk Research: The initial phase involved comprehensive desk research aimed at gathering relevant information about the company, its industry, and best practices in KPI formulation [36]. This step involved a thorough review of existing literature, including academic articles, industry reports, project deliverables from EU-funded projects (TRIMIS and CORDIS databases), and case studies that discuss KPI frameworks and their application in similar organizations.

Key elements of the desk research included industry benchmarking and reviewing existing KPIs. The findings from the desk research served as a foundational knowledge base that formed the subsequent steps in the methodology.

Step 2: Expert Workshop: Following the desk research, an expert workshop was organized to facilitate collaborative discussions among key stakeholders within the company [47]. This workshop aimed to leverage the collective expertise of participants to identify and refine potential KPIs. Within the workshop, the group of 16 experts was divided into three groups based on their professional experience and knowledge, each focusing on reviewing and assessing KPIs for energy management, fleet management, and infrastructure management. Diversity of experts (public transport operators, public transport authorities, international transport organizations) ensured that multiple perspectives were considered in the KPI development process.

Through group discussions, participants discussed whether the KPIs proposed by desk research are essential and possible to implement in companies or cities. Each KPI was discussed in terms of its relevance, feasibility, and potential impact. Experts could add new KPIs, modify the existing ones and remove unnecessary ones [30].

The output of the expert workshop was a refined list of proposed KPIs, complete with initial definitions and descriptions of how each KPI would be measured.

Step 3: Validation by External Expert: To ensure the robustness and credibility of the proposed KPIs, a validation step was conducted involving an external expert in public transport performance. This person has served as the primary decision-maker in a public transport company in Poland for several years and has experience in the performance management of the analyzed PKA company. The validation process included [11]:

- review of proposed KPIs: The external expert reviewed the list of proposed KPIs, assessing them for clarity and relevance. Feedback was provided on each KPI, including suggestions for improvement or modification;
- feedback session: A feedback session was held with the internal team to discuss the expert's recommendations. This interactive session allowed for clarification of the expert's insights and facilitated further refinement of the KPIs;
- final adjustments: Based on the feedback received, final adjustments were made to the KPIs, ensuring they were both rigorous and tailored to the company's specific needs.

The final step involved adjusting the KPIs to align with the company's specific context, taking into account considerations for data management and analysis. This step ensured that the KPIs would be actionable and supported by reliable data sources.

The activities in this phase included:

- verification of KPIs: Each KPI was checked to see if it can reflect the unique operational context of the company. This included defining the data sources, calculation methods, and reporting frequency for each KPI;
- data management for KPIs: A data management strategy was developed to ensure that the necessary data would be available for KPI tracking. This included identifying data collection methods, data storage solutions, and responsibilities for data management;
- pilot testing: A pilot test of the KPIs was conducted to validate their effectiveness in real-world scenarios. This involved tracking the KPIs over a defined period and assessing their relevance and reliability. This was primarily achieved through discussions with PKA employees to confirm that specific KPIs could be calculated and implemented.

4. RESULTS AND DISCUSSION

4.1. What new processes emerge in a public transport operator as a result of fleet electrification?

The operational framework of the company under investigation comprises a structured integration of core and support processes that collectively support the delivery of efficient and sustainable public transportation services. These processes are categorized into two principal domains: basic processes, which directly pertain to the organization's primary service delivery functions, and support processes, which facilitate and sustain operational efficiency and strategic development.

Within the domain of fundamental processes, the transition towards sustainable transport is exemplified by the organization's emphasis on developing electromobility. This process reflects PKA's strategic orientation toward environmental sustainability and technological advancement, particularly through the gradual replacement of diesel-powered buses with electric alternatives. This transformation necessitates not only investment in electric vehicles but also infrastructural modifications and workforce adaptation.

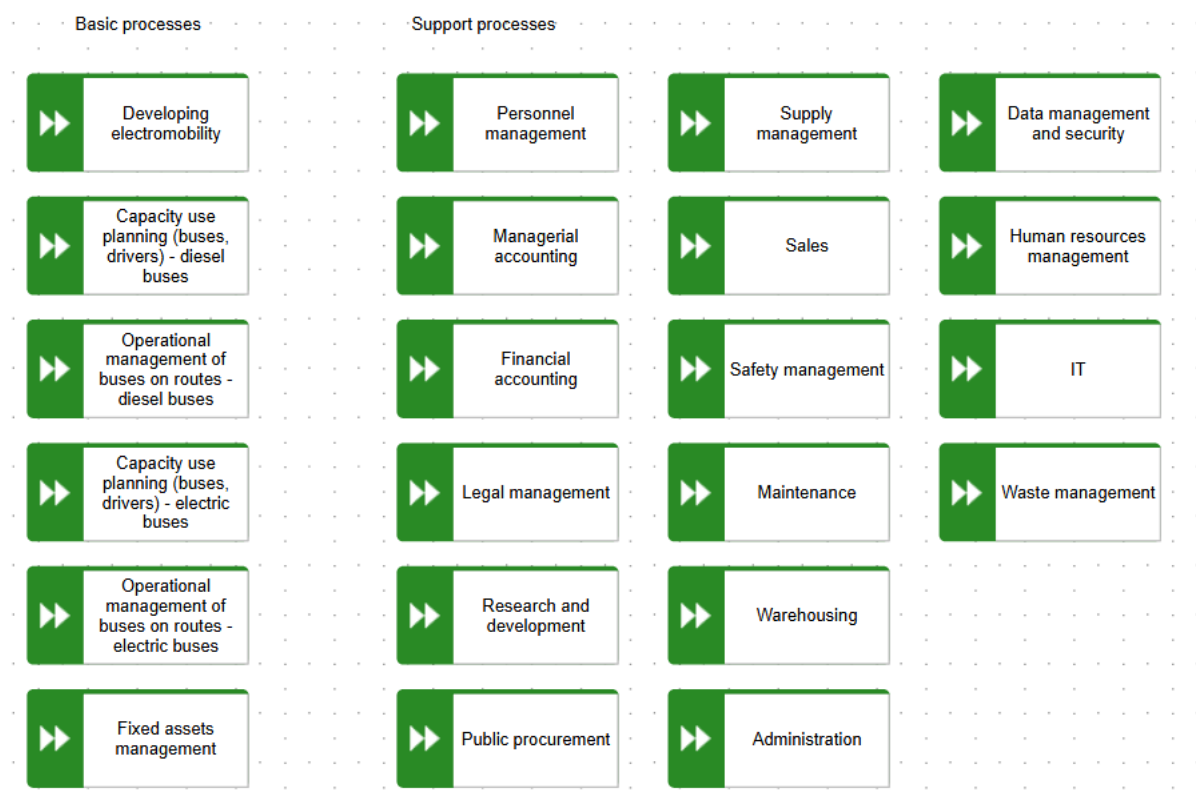


Fig. 2. Basic and support processes of the public transport bus operator (case study)
Source: own elaboration

Closely associated with this transformation are the capacity use planning processes for both diesel and electric fleets. These planning activities encompass the allocation and scheduling of buses and drivers, ensuring optimal utilization of operational resources. Effective planning is fundamental for maintaining service reliability and meeting fluctuating passenger demand.

The operational management of buses on routes constitutes another critical basic process. This involves the real-time oversight of fleet performance, route adherence, and incident response, thereby ensuring punctuality, safety, and service continuity for both diesel and electric vehicles. Additionally, fixed assets management plays a vital role in safeguarding the longevity and value of infrastructure assets, including vehicles, depots, and associated facilities. This function supports long-term capital planning and risk mitigation.

Complementing these core activities, the support processes provide essential services that underpin the operational backbone of PKA. Human resources and personnel management focus on workforce planning, recruitment, training, and compliance with labor regulations. Concurrently, managerial and financial accounting provide data-driven insights for internal decision-making and ensure adherence to external financial reporting standards.

Legal management and public procurement functions facilitate regulatory compliance and transparent acquisition of goods and services. Research and development further enhance the organization's capacity for innovation, supporting the adoption of technology and process improvements. Logistics-related processes, including supply management, warehousing, and maintenance, ensure the availability and operational readiness of critical inputs and assets.

Additional support functions such as sales, safety management, and administration ensure the organization remains responsive to stakeholder needs while maintaining service quality and regulatory adherence. Waste management is focused on tire management. Finally, information technology, data management, and security provide the digital infrastructure necessary for coordination, data integrity, and cybersecurity across the organization.

Collectively, these interrelated processes form a comprehensive operational model, positioning PKA as a forward-looking, efficient, and resilient provider of public transportation services.

To answer the first RQ, it was necessary to analyze the differences between managing diesel and electric buses. In a public transportation operator, the processes for managing fleets and drivers of electric and diesel buses differ significantly due to the distinct technical and operational requirements of each vehicle type. Diesel buses, as a long-established standard in public transportation, follow conventional scheduling, refueling, and maintenance routines, with predictable route planning and minimal infrastructure constraints. Driver deployment is typically straightforward, as refueling is quick and widely accessible, allowing for flexible route and shift planning. In contrast, managing an electric bus fleet requires a more complex and adaptive approach. Route planning must consider battery range, energy consumption profiles, and the availability and duration of charging cycles, which can directly influence the scheduling of both vehicles and drivers. Charging infrastructure within depots must be strategically managed, and vehicle rotation must align with recharging times to ensure optimal utilization. Additionally, drivers operating electric buses require specific training in energy-efficient driving techniques, regenerative braking, and battery management. These differences mean that electric bus operations demand closer integration between planning, IT systems, and energy management. Special software for smart overnight charging is also required to optimize operational costs while utilizing maximum capacity. Thus, although both types of fleets operate under the same public transport operator, the shift to electrification necessitates distinct strategies for scheduling, infrastructure planning, and workforce training to ensure reliable and efficient service delivery.

4.2. Through which Key Performance Indicators (KPIs) can the individual components of the electrification process in a public transport operator be measured for optimization?

Due to the limited space available to present all the processes and KPIs in the research paper, some were selected to reflect the approach described in the methodology section. Some of the chosen KPIs were assigned to the processes on the most general level (see Figure 3). The life cycle of the battery and its subsequent use are among the most significant challenges for the development of electromobility. This issue has been addressed at the level of generic KPIs; however, due to volume constraints, it will not be discussed further in this article.

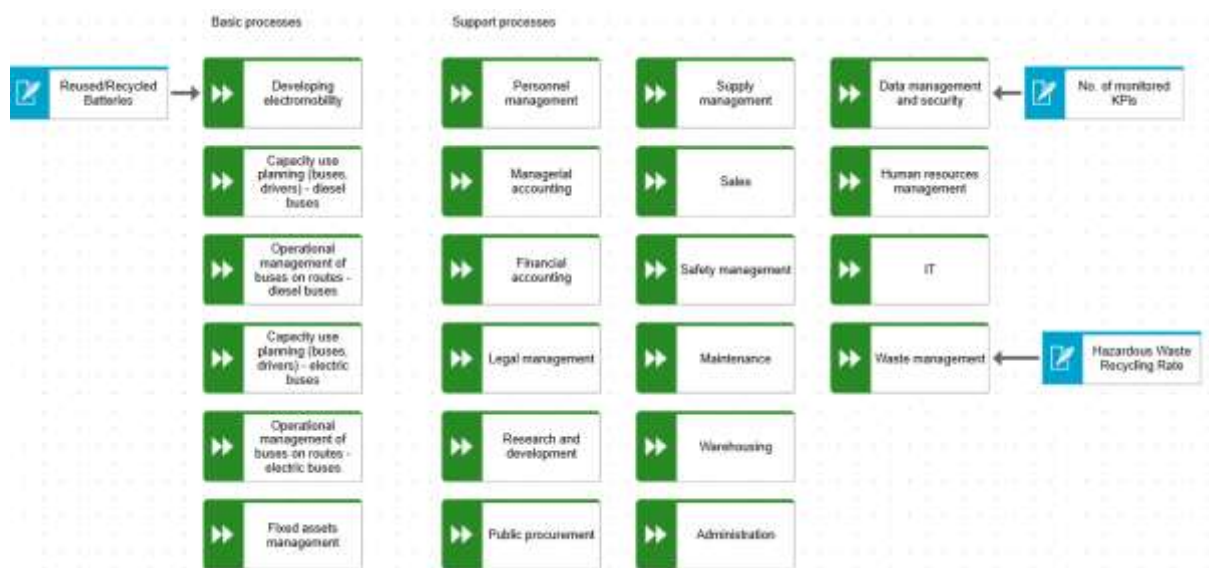


Fig. 3. Processes with KPIs assigned at a general level of the company
Source: own elaboration

In turn, the other ones were assigned to processes on a more specific level. For instance, in developing the electromobility process, the company has identified several subprocesses. Figure 4 illustrates a detailed decomposition of the process into its key subprocesses, each supported by specific Key Performance Indicators (KPIs) designed to measure the effectiveness and progress of implementation. This structured approach ensures that the transition toward electric public transportation is monitored across operational, infrastructural, and environmental dimensions.

The first identified subprocess is Fleet Development, which focuses on modernizing and electrifying the vehicle fleet. The corresponding KPIs are the "Share of Electric Fleet", which quantifies the proportion of electric vehicles within the total bus fleet, and "Share of Electric Buses in the Overall Supply", indicating the proportion of vehicle-kms performed with electric buses. These metrics reflect both investment in sustainable mobility and alignment with carbon reduction targets, as reflected by other KPIs assigned to other processes. Another KPI "Annual Average Mileage of Electric Bus" shows the efficiency of electric fleet performance. Various studies emphasize the need to increase the intensity of electric vehicle use to reduce average fixed costs [10,12,15,18,42,44].

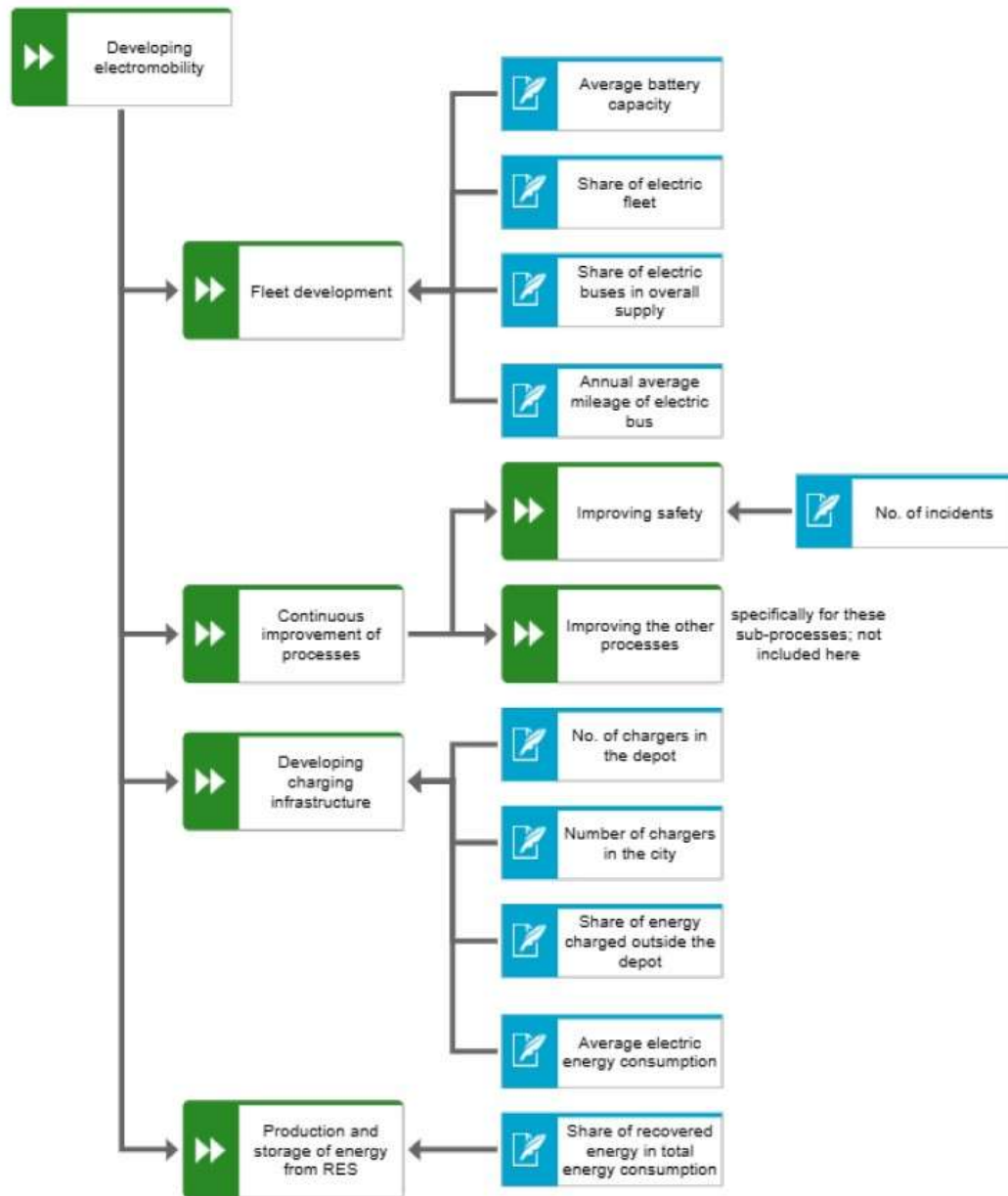


Fig. 4. KPIs assigned to the subprocesses of developing electromobility
Source. own elaboration

The second subprocess, Continuous Improvement of Processes, emphasizes ongoing efforts to refine operations, particularly in terms of safety and performance. This subprocess is bifurcated into two focus areas: Improving Safety, which is monitored through the "Number of Incidents" KPI, and Improving Other Processes, for which process-specific KPIs are noted but not included in the diagram. The inclusion of safety as a dedicated improvement domain highlights the critical importance of operational risk reduction in electromobility, particularly in the context of fire protection.

The third subprocess, Developing Charging Infrastructure, addresses the physical infrastructure necessary to support the deployment of electric vehicles. The relevant KPIs are the "Number of Chargers in the Depot" and "Number of Chargers in the City", which reflect

infrastructural readiness and the charging capacity required to maintain service continuity. Moreover, they also reflect specific models for electric vehicle charging, such as overnight charging or mixed charging.

The fourth subprocess, Production and Storage of Energy from Renewable Energy Sources (RES), integrates sustainability and energy efficiency considerations into the electromobility strategy. It is measured by the KPI “Share of Recovered Energy in Total Energy Consumption”, indicating the degree to which energy efficiency and renewable integration are achieved within depot and operational systems.

Collectively, these subprocesses and KPIs represent a 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 organizational transformation process.

Selected indicator values were calculated for the period 2021-2024, with the implementation of electric buses in the second half of 2022.

Tab. 1

Selected Key Performance Indicators related to the electromobility processes at
a company's level in the PKA Gdynia sp. zo.o.

KPI	Unit	2021	2022	2023	2024
Share of electric fleet	[%]	0	13%*	27%	27%
Share of e-bus vehicle-km in the overall service supply	[%]	0	23%	47%	47%
Annual average mileage of e-bus	km	0	39 076*	75 665	74 464
Average electric energy consumption	kWh/km	0	1,56**	1,71	1,69
Average battery capacity	kWh	0	215	215	215
Number of chargers in the depot	unit	0	24	24	24
Number of chargers in the city	unit	0	5	7	7
Share of energy charged outside the depot	[%]	0	62	64	68

*Average for the whole year, ** lower average value due to operations limited only to the second half of 2022

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-kilometers 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 analyzed 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. Figure 5 shows the average monthly electricity consumption values for the period 2023-2024.

The highest variation between average monthly energy consumption values was as high as 1.13 kWh/vehicle-kilometer. This difference highlights the specificity of winter operations and poses a challenge for fleet development with a high proportion of electric vehicles.

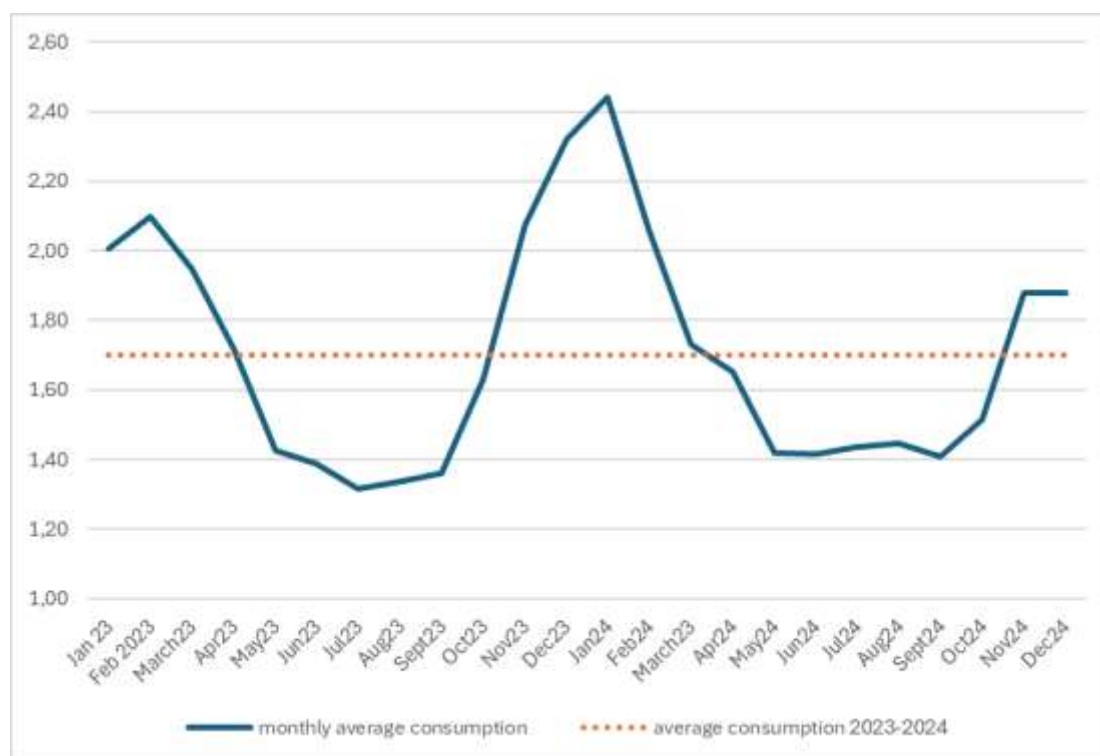


Fig. 5. Energy consumption [kWh/vehicle-km] per month and per annum in 2023-2024 of electric buses of the PKA Gdynia sp. z o.o.

Source. own elaboration

5. CONCLUSIONS

In the context of a transportation company offering urban transport services, its internal processes should facilitate the delivery of services in both quantity and quality, tailored to the expectations and preferences of passengers, all while maintaining economic efficiency. Moreover, service standards must meet the requirements of the public contract concluded with the public authority, which serves as the basis for granting subsidies for unprofitable urban transport services. On one hand, the unique nature of operating in the public urban transport sector means that the economic efficiency of individual carriers is crucial. This stems from the fact that, in principle, urban transport systems are unable to cover their operational costs with ticket revenues alone.

On the other hand, urban transport, as a public utility service, aims to provide universally accessible transport services to meet the ongoing and uninterrupted transportation needs of the community in a given area. Urban transport services do not have a commercial nature; hence, their primary goal is not the maximization of economic efficiency and profits for owners. This applies to both the transportation company itself and the processes occurring within it.

The transition to electromobility introduces a range of new processes within public transport operators, fundamentally reshaping how organizations manage their operations. The integration of electric buses into the fleet requires not only technological adaptation but also a comprehensive reorganization of management structures and workflows. Traditional approaches to fleet management, maintenance, and scheduling must be revised to accommodate the specific characteristics of electric vehicles, such as limited range, charging requirements, and energy consumption patterns. As a result, new operational and strategic processes emerge – particularly in areas like charging infrastructure management, energy planning, and driver training – which necessitate the definition and implementation of dedicated Key Performance Indicators (KPIs).

To ensure effective control and continuous improvement of these new processes, transport operators must adopt KPIs tailored to electromobility. In the context of charging infrastructure, relevant KPIs include the number of available charging stations, charger utilization rate, average charging time, and energy source mix (e.g., share of renewable energy). For fleet management, appropriate indicators involve the share of electric vehicles in the total fleet, average operational range, battery efficiency, energy consumption per kilometer, and downtime due to charging or maintenance. By redefining performance measurement to reflect these changes, operators can more effectively monitor efficiency, support informed strategic decisions, and ensure a successful and sustainable transition to electric public transport.

The electrification of public road transport in European cities is a widespread phenomenon. For public road transport operators, this means implementing new technology and, consequently, redefining processes related to transport planning, fleet and infrastructure maintenance, and logistics. Key Performance Indicators (KPIs) are used to accurately monitor the processes involved in transitioning the fleet to electromobility. The electrification of the fleet requires the creation and use of new KPIs, some of which can be used not only for company management but also for evaluating their management by the owners (city authorities).

The set of fundamental indicators proposed in this article was developed as part of the CE4CE (Circular Economy for Central Europe) project, which is being carried out under the Interreg Central Europe program. Due to volume limitations, this is not a complete set of indicators that covers all the processes identified in the company. It focuses on core indicators that are (or can be) commonly used by other operators with different scales of operation. In addition, the specifics of the company analyzed (size, location, market share, existing technology), the timing of the implementation of the first electric vehicles, and the characteristics of the lines served influenced the selection of indicators.

Limitations of the present study mainly concerned the accuracy of the part of the data related to electricity consumption for traction and non-traction purposes (heating, air conditioning). In winter (and in the warm summer months), the share of electricity used for heating or air conditioning can be higher than for traction. This is an issue that requires in-depth monitoring to optimally balance the objectives of maintaining thermal comfort for passengers with those of maintaining an adequate level of reliability and operational efficiency.

Some limitations are also due to the method chosen, i.e., case study analysis. However, the benefits of being able to focus accurately on a company that has recently introduced electric buses into service outweighed this.

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