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Comparison of Tender Criteria for Electric and Diesel Buses in Poland—Has the Ongoing Revolution in Urban Transport Been Overlooked?

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Abstract: The electrification of public transport is an overwhelming trend, representing the first step in the energy transition of the transport sector. The transport sector is characterized by the prevalence of public ownership and the significant influence of the public sector. Accordingly, tendering procedures are widely utilized to identify the most efficient bus delivery options. This paper compares, evaluates, and identifies the differences in criteria used in tenders for battery electric buses and diesel buses in Poland based on a deep bus market analysis supported by in-depth individual interviews. The article also attempts to determine whether the weight of the "vehicle price" criterion corresponds to the share of the vehicle price in its life cycle cost or total cost of ownership. The results indicate no significant difference in the tender criteria between battery electric buses and diesel buses. In the vast majority of cases, institutions that had previously developed diesel bus acquisition patterns transferred these patterns to tenders for battery electric bus purchases. Therefore, the criteria and their weights used in tenders do not consider the advantages and disadvantages of both technologies. Tendering procedures are adapted to local conditions and operational requirements. Electric buses often replace conventionally powered vehicles on existing routes and schedules. Thus, operational requirements are known. As a result, the necessary number of vehicles and the basic technical and operational parameters (e.g., selection of the optimal charging method and battery capacity) can be determined. In turn, the charging method will influence the total cost of ownership, with overnight charging favored for shorter assignments and opportunity charging favored for longer mileages.

Keywords: public transport; electromobility; tendering process; tender criteria; city buses

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1. Introduction

Climate change and the growing awareness of its consequences have become the starting point for formulating increasingly restrictive policies to initiate and accelerate the transformation of EU economies and societies. This transformation involves decarbonization, which means shifting away from fossil fuels [1,2]. This is occurring under challenging conditions, and in recent years, in an environment with significantly reduced predictability (e.g., COVID-19, the war in Ukraine).

Climate change is one of the biggest challenges of our times. Transport is a sector where emissions reduction is possible to a significant extent [3], but the results so far have not been satisfactory [4,5]. One of the main tools for the energy transition of the transport sector is its electrification. Not only would this increase energy efficiency and reduce emissions [6,7], but it would also have geopolitical benefits by reducing exposure to sudden changes in oil and gas prices caused by unforeseen events [8]. Currently, the transport sector manifests a strong dependence on fossil fuels [9], accounting for around 25% of energy-related greenhouse gas (GHG) emissions in the EU [10]. However, the share is even higher in a "well-to-tank" model, which considers the emissions required to produce and transport fuels [11]. The amount of GHG emissions associated with the electrification of public transport can be influenced by a variety of factors. In addition to a country's energy mix, two other critical variables must be considered when evaluating the environmental impact of electrifying transportation: the technology utilized in the production of traction batteries and the country of origin of those batteries. These factors have a major impact on the overall carbon footprint of electric public transportation systems and should be carefully evaluated when implementing such initiatives [12]. It is worth emphasizing that the estimation of emission costs should consider all phases of a vehicle's existence, including the production of raw materials, assembly and transport, operation, and recycling [13].

While electrification presents a viable option for public transportation in cities [14], it is important to note that a complete shift to electric vehicles may not significantly reduce emissions. It may, however, represent a first step in the energy transition of the transport sector and is an expression of the pro-environmental policy of local authorities, especially in countries with an unfavorable energy mix [15].

The rapid growth of sales of battery electric buses (BEBs) is gradually translating into an increase in their share of the total global fleet. In 2021, this amounted to 4%, representing around 670,000 vehicles [16]. Most new BEBs have been registered in China, but there is a noticeable increase in their importance in many EU countries. Depending on the adopted scenario, the number of BEBs worldwide will reach 3.05 to 4.35 million by 2030 [17].

Such a significant number of vehicles will be acquired primarily by public sector bodies. The tender is the primary instrument used to purchase vehicles in the public transport market. Consequently, it is essential to comprehend the criteria used for selecting electric vehicle fleets, which should include not only economic considerations but also technological and environmental factors. This paper provides a valuable contribution to the field of science by integrating legal and economic perspectives related to the development of electromobility in the public transport market. By examining the process of selecting these factors, the paper sheds light on important criteria that can impact the growth of electromobility in this sector. Therefore, the main purpose of this study was to compare and evaluate the criteria used in tenders for BEBs and diesel buses (DBs) in Poland. This was examined by answering the following three research questions:

RQ1: Do the criteria used in tendering for electric buses differ from those used in tendering for diesel buses?
RQ2: Do the criteria used in the tenders take into account the advantages and disadvantages of electric and diesel buses?
RQ3: Does the weight of the "vehicle price" criterion correspond to the share of the vehicle price in its life cycle cost or total cost of ownership?

The article is structured in the following sections to achieve the research objective. An overview of urban bus propulsion technologies follows this introduction. The progress of fleet electrification is then presented in Section 3 by comparing the characterization of the Polish urban bus market against the European one. Section 4 presents the research methods used in the data analysis, and Section 5 discusses the study's results. The paper concludes with some general recommendations.

2. Polish Electric Bus Market against the Background of the European Union Market

In 2021, 9% of passenger transport on land and 55.7% of all public transport journeys in the European Union were made by city buses, suburban buses, and coaches [18], which equals 487.5 billion passenger kilometers and 32.1 billion passenger journeys. In Poland alone, public transport carried 2.5 billion passengers in 2021 (66 trips per capita) [19]. As research shows, one of the main factors influencing the willingness to use public transport and city buses by city dwellers is travel comfort (the other most frequently indicated factors are: city size, car ownership, income, public transport fares, public transport service frequency, travel time, population density, and trip distance) [20–23]. The above findings demonstrate that cities should strive to provide transport services with modern vehicles. Research conducted in Poland indicates that passengers more favorably assess new buses than older vehicles mainly because of travel comfort [24]. Research has also shown that the higher comfort of traveling in new vehicles reduces the perceived travel time by passengers [24]. The age of buses is an important factor not only for passengers but also for operators. Empirical data shows that maintenance costs increase with the increase in technical wear, mileage, and age of a bus [25–28]. This is because the cost and labor consumption of repairs and risk of failure increase, impacting a vehicle's technical readiness level. Therefore rolling stock investments are important for the urban transport system performance. Investments aimed not only at reducing the average age of the city bus fleet, but also at changing the technology to low or zero-emission technology, generate additional economic, social, and environmental challenges and benefits.

Due to the EU climate policy and subsequent EU targets for zero-emission mobility by 2050, zero-emission buses (ZEBs) accounted for 23% of new urban buses registered in the EU in 2021 [29]. BEBs currently have the highest share of all alternative city buses in the EU. The leaders in this respect are Finland (78% sales share), the Netherlands (59%), and Denmark (46%) [30]. Despite the ongoing revolution in how city buses are powered, some EU members had little to no deployment of BEBs in 2021. The above applies to Greece, Portugal, and Ireland, each with a share of ZEBs below 1%. Natural gas buses (NGBs) (especially in Sweden, France, and Spain) and hybrid buses (HEBs) (especially in Belgium, Spain, and Germany) have also been gaining in popularity. From 2016 to 2021, the share of gas buses in the EU fleet was higher than that of zero-emission buses, although the difference decreased annually. It is worth emphasizing that the Netherlands is the only country in the EU to have a significant share of hydrogen fuel cell buses (HFCB), which represented 11% of total buses sold in 2021 [30].

In 2020, there were 684,285 buses on EU roads. Almost half of these operated in Poland, France, and Italy [31]. Poland has the largest fleet of buses among all EU countries, amounting to approximately 125,000 vehicles. Differences in the structure of the European and Polish city bus markets are shown in Figure 1. In 2021, Solaris was the largest supplier of city buses to Polish cities for the nineteenth time in a row. The vast majority of city buses purchased in Poland are manufactured in domestic factories. During the analysis period of this research, 11 companies operated in the Polish BEBs market.

The data presented below also show that the concentration of the European city bus market is moderate to high. The value of the four-firm concentration ratio (CR4 index), amounting to 61, serves as evidence of the above. A market where the CR4 index value exceeds 60 is defined as a tight oligopoly [32,33]. The city bus market in Poland is even more concentrated, and its CR4 index amounts to 89. The very high concentration of the Polish city bus market is also indicated by its Herfindahl–Hirschman Index (HHI) value, which exceeds 3300. Such a high concentration of the market supply entails certain consequences. One is the number of rolling stock manufacturers who submit their offers to announced tenders. Only two producers participated in most of the tenders in the years analyzed here. This arose from the early stage of development of the BEBs market, including the limited production capacity of particular manufacturers. For this reason, a wide range of stakeholders (11 cities and civil society organizations from 11 countries) have written to the European Commission urging lawmakers to include a sales target for zero-emission urban buses in the forthcoming proposal on CO_2 standards for new heavy-duty vehicles. According to the signatories, "without action at the EU level, demand for zero-emission urban buses will not be matched by supply" [34]. Moreover, "constrained by a lack of availability or prices that are too high due to insufficient zero-emission bus supply, cities will be forced to keep buying combustion engine buses" [34].

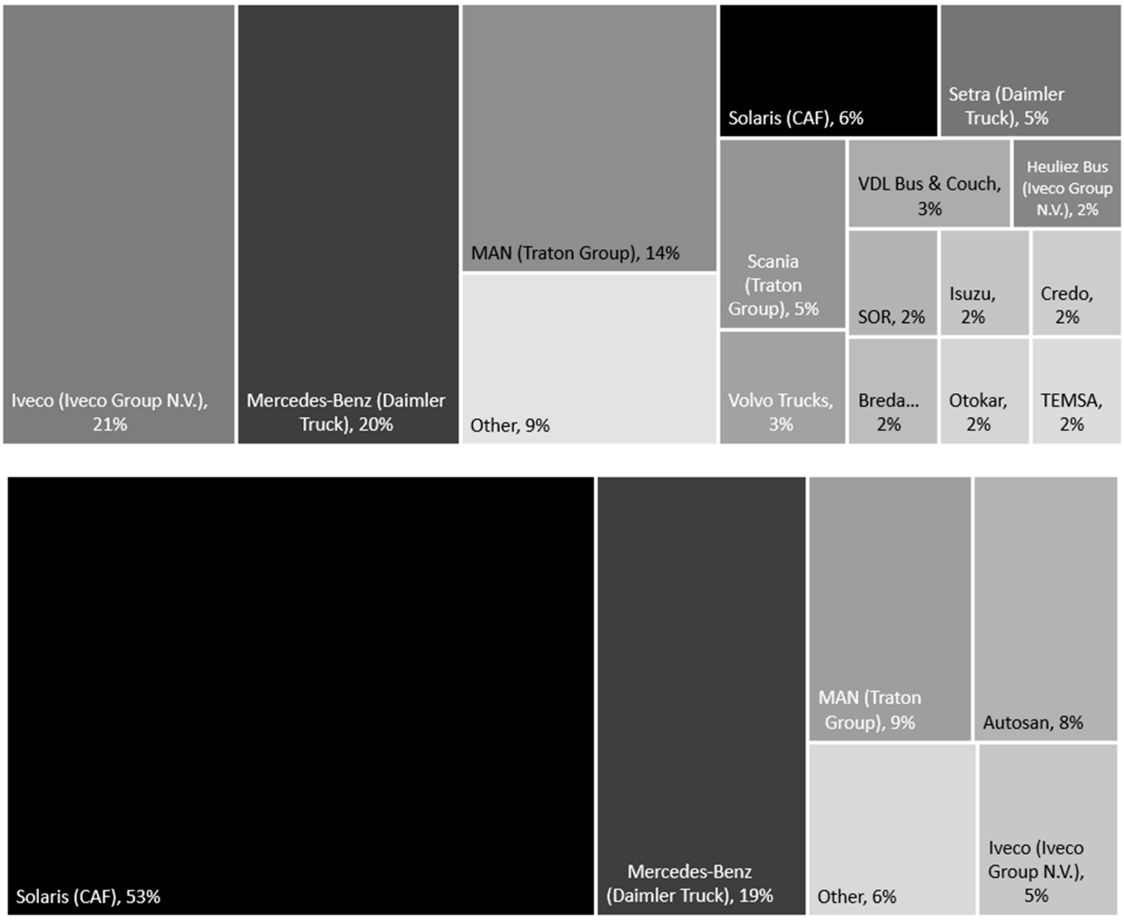

Figure 1. Market share of city bus sales by manufacturer in Europe (**upper part**) and Poland (**lower part**) in 2021. Source: Own elaboration based on [30,35].

In 2015, Jaworzno was the first city in Poland to introduce BEBs (Solaris Urbino 12 Electric) into regular operation. Since then, the number of BEBs and other alternative buses operated in Poland has steadily grown. However, the data presented in Table 1 shows that from 2016 to 2022, significantly more DBs (meeting Euro 6 standards) were purchased in Poland than all other types of city buses. In the analyzed period, the share of purchased new buses powered by compressed natural gas (CNG) or liquefied petroleum gas (LPG) also increased. Thus, in 2021, gas-powered buses accounted for one-quarter of newly purchased city buses in Poland. It is worth emphasizing that when the share of BEBs began to grow in Poland, the share of hybrid buses began to decrease. This means that electric and hybrid buses are perceived as substitutive technologies, with only BEBs being defined as zero-emission vehicles by the Polish Act on Electromobility and Alternative Fuel [36]. Non-refundable EU and national funds were the factors influencing the high dynamics of the increase in the purchase of BEBs.

Table 1. The number of new city buses purchased in Poland.

	2016	2017	2018	2019	2020	2021	I-III 2022	Total
Diesel	683	606	828	745	308	205	213	3588
BEB	6	63	63	54	198	213	115	712
CNG/LNG	19	12	54	182	165	150	60	642
HEB	17	85	200	51	31	11	34	429
HFCB	0	0	0	0	0	0	2	2
Total	725	766	1145	1032	702	579	424	5373

Source: Own elaboration based on [37–42].

Figure 2 shows the significant change in the share of particular types of city buses in the purchase of new vehicles in Poland in 2016 and 2021. The data shows that 2021 was the first year in which more new BEBs were purchased in Poland than DBs.

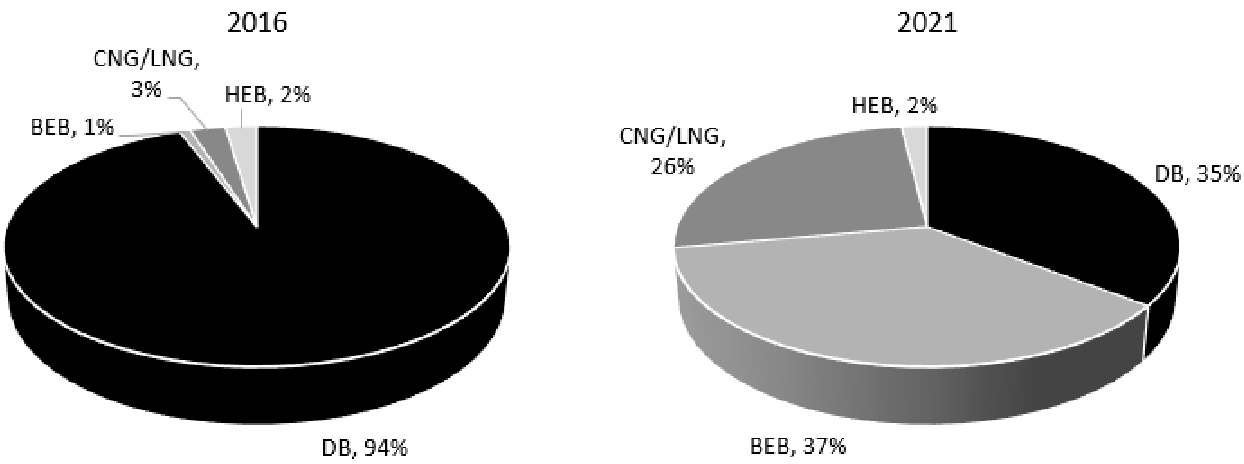

Figure 2. Share of particular types of city buses among new city buses purchased in Poland in 2016 and 2021. Source: Own elaboration based on [37,40,41].

3. Review of TCO and LCCA Analysis of Electric and Diesel Buses

The total cost of ownership (TCO) is defined as "a purchasing tool and philosophy which is aimed at understanding the true cost of buying a particular good or service from a particular supplier" [43] or "the sum of all significant costs associated with an asset over its lifecycle, to support the asset-related decision-making for lifecycle management" [44]. It follows from these definitions that the result of TCO analysis is the total discounted cost of owning, operating, and maintaining an asset over a limited period. The analysis is, thus, used to compare competing investments and evaluate the most profitable alternative.

According to the above definitions, the final TCO result is influenced by three groups of variables:

- All costs of ownership.
- The period in which these costs occur.
- The discount rate.

The costs typically included in the TCO and life cycle cost analysis (LCCA) of city buses are:

- Vehicle cost—The vehicle cost includes the vehicle purchase cost, most often minus the residual value. In the case of BEBs, this category also includes the purchase cost of the first traction battery.
- Financing cost—Financing costs include interest payment costs.
- Fuel or electricity costs—Fuel or electricity costs are proportional to the price of the fuel and efficiency, the fuel and electricity efficiency of the vehicles, and the driving distance.
- Insurance—Insurance costs cover both liability and vehicle repair or replacement.
- Maintenance and repair—Maintenance includes the cost of scheduled and unscheduled vehicle repairs and fixes made while under the vehicle warranty.
- Taxes fees—Taxes and fees costs include all costs related to national and local taxes and fees imposed by, for example, local governments.
- Labor—Labor costs include wages and benefits for drivers. These costs also include the additional working time of drivers related to charging or refueling vehicles.

It has been revealed [45] that in the vast majority of cases, the TCO and LCCA evaluations of city buses have typically overlooked the external costs associated with their operation, such as the GHG. This is primarily because such expenses are not directly borne by the owners of the rolling stock. From a societal perspective, the reduction of external costs associated with public transportation is often regarded as the primary justification for transitioning to electric vehicles. Therefore, it is imperative to include external costs as a crucial component of cost-benefit analysis (CBA) and life cycle assessment (LCA) evaluations. These analyses play a crucial role in determining whether to replace diesel buses with electric ones. Once the decision to purchase electric buses has been made, TCO and LCCA analyses are sufficient to select the most suitable vehicle.

In the literature on this subject, the concept of TCO is strictly related to the concept of LCCA, and authors often do not make a clear differentiation between the two analyses [44,46]. Since both answer a similar question, they share similar disadvantages, which include [47]:

- Some lifecycle costs/costs of ownership may not be obvious.
- Benefits are not included.
- Some costs vary greatly over time.
- Relies heavily on estimation.

The literature on the subject also raises the following objections regarding the use of TCO and LCCA analyses to compare the costs of DBs and BEBs [48–51]:

- Some of the analyses do not take into account the need to operate a larger fleet of BEBs than DBs (due to the limited range of vehicles).
- Analyses often neglect service frequency, capacity, and range.
- Analyses ignore the costs associated with the fact that the placement and characteristics of charging infrastructure need to be harmonized with the planned bus fleet and schedule. This includes geographical placement, available power, number of outlets, and charging technology.

Table 2 summarizes the averaged global TCO and LCCA results for DBs and BEBs. The data show clear differences between the individual cost shares for both city bus technologies. The size of the differences in the comparison of DBs and BEBs is most affected by: the difference in vehicle prices, energy efficiency, liquid fuel prices, and electricity prices. The situation in domestic markets largely determines all of the above factors. For this reason, Table 3 presents the averaged results of the TCO and LCCA analyses performed in Polish conditions.

Table 2. Averaged global total cost of ownership and life cycle cost analysis results for electric and diesel buses (n = 23).

	Vehicle Costs [%]		Fuel or Electricity Costs [%]		Maintenance and Repair Costs [%]	
	Diesel	Electric	Diesel	Electric	Diesel	Electric
Average	28.5	47.5	39.9	12.6	20.2	14.7
Median	29.4	45.7	41.2	9.7	17.7	12.4
Min	9.4	16.3	12.2	3.4	6.4	4.1
Max	45.1	79.0	62.2	28.8	36.4	38.7

Source: own elaboration based on: [10,45,52–72].

Table 3. Averaged total cost of ownership and life cycle cost analysis results for electric and diesel buses in Polish conditions (n = 4).

	Vehicle Costs [%]		Fuel or Electricity Costs [%]		Maintenance and Repair Costs [%]	
	Diesel	Electric	Diesel	Electric	Diesel	Electric
Average	26.4	48.9	53.0	16.5	16.2	9.3

Source: own elaboration based on [52,53,67,68].

Based on the data in Table 3, it can be concluded that in Polish conditions, the shares of individual cost categories are similar to the global results presented in Table 2. Thus, in Polish conditions, in the case of BEBs, the share of vehicle cost is almost 50% of TCO. At the same time, the share of electricity costs for BEBs is over three times lower than the share of diesel costs for DBs. In the case of BEBs, larger and more significant categories of costs do not fall within the scope of the three categories analyzed (vehicles, fuel or electricity, and maintenance/repair costs). These costs include, in particular, battery replacement costs. These costs arise because the life cycle of a BEB is longer than the life cycle of its traction battery. In the future, with the development of traction battery technology, this situation is expected to change. It is predicted that future battery technologies will allow the batteries to be used for the same duration as the BEBs (the service life of BEBs is estimated at 12–15 years [73,74]).

Summarizing the above considerations, in the case of DBs, fuel costs are the factor with the largest share in the TCO and LCCA analyses. When purchasing a DB, decision-makers should pay special attention to ensuring that the purchased vehicles have the lowest possible diesel fuel consumption per 1 vkm. On the other hand, from the point of view of total costs in the case of electric buses, the price of the vehicle and traction batteries is a much more critical factor than energy efficiency. The above indicates that depending on the type of city bus technologies, the price may be or may not the most important criterion that differentiates individual vehicles.

4. Methods and Data

The research methodology involved the analysis of secondary data extracted from tender documents from 2017 to 2020 to answer the research questions formulated in Section 1. In addition, in-depth interviews were conducted with the CEOs of four urban transport operators at different stages of the electric bus implementation process.

The analysis included data on 451 tenders for city buses that were submitted in Poland from 2017 to 2020. As a result of these tenders, a total of 3898 city buses were purchased, of which 2642 were DBs and 749 BEBs. The category of BEBs includes both overnight charging and opportunity charging vehicles, as well as trolleybuses. As a result of the largest tender for BEBs, which took place in the period under review, 130 Solaris Urbino Electric 18 (Mega Class) buses were purchased by the municipal operator MZA Warszawa (Warsaw, Poland). The largest tender for DBs from 2017 to 2020 was the tender organized by another municipal operator, MPK Wrocław. It was planned to be concluded with a purchase of 60 vehicles (40 Maxi Class vehicles and 20 Mega Class vehicles). Table 4 presents the essential characteristics of the tenders analyzed in this study. The number of buses ordered in tenders was higher than the number of buses purchased in Poland because the data concerned both resolved and canceled tenders.

Table 4. Characteristics of analyzed tenders for diesel and electric buses in Poland.

Year	Electric Buses			Diesel Buses		
	Number of Tenders	Number of Buses	The Average Number of Buses per Tender	Number of Tenders	Number of Buses	The Average Number of Buses per Tender
2020	24	194	8.1	21	131	6.2
2019	16	210	13.1	37	186	5.0
2018	24	148	6.2	133	1085	8.2
2017	21	197	9.4	147	1240	8.4

Source: Own elaboration based on primary data.

The in-depth interviews were directed at determining the reasons for selecting specific tender criteria, justifying the choice of the importance of price, and matching the criteria to the chosen operating model for e-buses (overnight, opportunity charging, mixed). Table 5 shows the basic characteristics of the municipal operators included in this study.

Table 5. Characteristics of companies whose leaders were interviewed [as of December 2022].

Operator	Total Number of Buses as of 31.12.2021	Total Number of Electric Buses	Share of Electric Buses	Date of the First Purchase of E-Buses	Date of the Latest/Expected e-Bus Delivery	Number of E-Buses Purchased in the Last Tender
MZA Warszawa sp. z o.o.	1385 *	160	12%	2015	2020	130
MZK Zielona Góra sp. z o.o.	86	43	50%	2019	2023	12 (18) **
PKA Gdynia sp. z o.o.	80	24	30%	2022	2022	24
GAiT sp. z o.o. (Gdańsk)	251	3 ***	1%	2022	2023	18 ****

* including subcontractors, ** in brackets number of buses with option, *** midibuses, **** ordered, to be delivered in 2023. Source: Own elaboration based on interviews and internal data of companies.

5. Results and Discussion

The structure of this section reflects the search for answers to the three research questions formulated in Section 1.

5.1. Do the Criteria Used in Tendering for Electric Buses Differ from Those Used in Tendering for Diesel Buses?

During the analyzed period in the Polish market, the most important factor in evaluating offers for purchasing BEBs and DBs was the price, according to Table 6. The presented data reveal that the selection criteria for BEBs and DBs were highly similar in Poland. Notably, the weight of the price criterion in tenders for BEBs differed only slightly by 1.4% from tenders for DBs. Moreover, tenders for both types of buses in Poland used a comparable number of non-price criteria. In most cases, the contracting authorities used two non-price criteria and the price criterion to select the best offer.

Table 6. The importance of the price criterion in tenders for electric and diesel city buses in Poland from 2017 to 2020.

Year	The Average Weight of the Price Criterion			The Average Weight of the Price Criterion Weighted by the Number of Buses in the Tender			The Average Number of Non-Price Criteria		
	Electric Buses [%]	Diesel Buses [%]	+/− [%]	Electric Buses [%]	Diesel Buses [%]	+/− [%]	Electric Buses [No.]	Diesel Buses [No.]	+/− [%]
2020	61.7	63.8	2.1	61.1	58.5	2.6	1.96	1.90	5.4
2019	61.7	61.9	0.3	76.7	59.5	17.3	2.13	1.97	15.2
2018	60.8	61.0	0.1	60.3	60.8	0.5	2.08	2.05	3.8
2017	65.1	62.1	3.0	62.5	61.2	1.3	2.38	2.20	18.4
Average	62.3	62.2	1.4	65.2	60.0	5.2	2.14	2.03	10.7

Source: Own elaboration.

Table 7 shows the importance of non-price criteria in tenders for BEBs and DBs from 2017 to 2020. The data shows that all significant non-price criteria had a high range value. In Polish conditions, individual entities ordering city buses used different strategies to select the most advantageous offer from rolling stock manufacturers. As in the case of the price criterion, the weight of non-price criteria used in tenders for DBs was very similar to those used in BEBs. The most significant non-price criterion in tenders was the “technical parameters” criterion. The “terms of warranty and service” criterion was nearly equally important when purchasing diesel and electric vehicles. Electric buses are at a much earlier stage of the product life cycle, which may result in a higher failure rate of components, especially traction batteries. The potentially higher failure rate of electric buses compared to conventional buses is indicated by numerous experiences from tests and actual operations described, among others, in [75–81].

Table 7. Importance of non-price criteria in tender procedures for electric and diesel buses from 2017 to 2020 [%].

Criterion	Bus Type	Measure					
		Minimum	Mean	Maximum	Range	Median	Dominant
Technical parameters	Diesel	2	29	48	46	30	40
	Electric	5	25	45	40	24	40
Terms of warranty and service	Diesel	3	13	40	37	10	10
	Electric	2	17	40	38	13	10
Fuel/energy consumption	Diesel	1	8	30	29	5	5
	Electric	3	9	17	14	10	5
Delivery date	Diesel	2	9	40	38	7	5
	Electric	5	10	40	35	5	5
Ecology	Diesel	1	3	5	4	3	5
	Electric	3	6	10	7	5	5
Other	Diesel	1	6	15	14	5	5
	Electric	5	8	10	5	8	8

Source: Own elaboration.

The low average weighting of the "ecology" criterion shows that, in the opinion of the contracting authorities, there were no significant differences in the levels of pollutants emitted by vehicles meeting specific standards (e.g., EURO 6) produced by individual manufacturers. In the case of DBs, the volume of pollutant emissions was very much correlated with the level of diesel consumption (which had a different criterion for bid selection). Similar conclusions have been reached in other studies [64,82], as authors found that "external costs are not entirely or only to a small extent taken into account as evaluation criteria in the bidding procedures for vehicle purchases".

The analysis not only included the weighting of individual criteria used in city bus tenders but also the objective factors that influenced the number of non-price criteria used in individual tenders (a number of non-price criteria in tendering, [NoC]). In order to investigate the factors influencing the number of criteria used in the tender process, we examined whether the size of the tender (understood as the number of vehicles to be procured, number of buses [NoB]), the type of vehicle being procured (differentiating between DB and BEB [Type]), and the year in which the tender was held (Year) were significant predictors. Statistical analysis revealed that the number of non-price criteria applied in the tender was significantly influenced by the number of buses being procured, but not by the year or type of vehicle. For more details, please refer to Table 8.

Table 8. Generalized linear model (GLM) results for a number of non-price criteria (NoC) in tendering.

	SS	df	MS	F	*p*
Intercept	636.8956	1	636.8956	668.9608	0.000000
NoB	8.7242	1	8.7242	9.1634	0.002646
Year	3.1274	3	1.0425	1.0949	0.351208
Type	0.0574	1	0.0574	0.0602	0.806259
Error	343.6963	361	0.9521		

Source: Own elaboration.

Although the number of buses had a statistically significant effect on the phenomenon under study, it poorly explained the changes in the adopted number of non-price parameters. This was due to the low degree of fit of the model ($R^2 = 0.04$, $F(5361) = 2.68$, $p = 0.02$)). Therefore, this shows that there are other factors involved, which are difficult to identify and have not been analyzed. These factors might have influenced the number of non-price parameters used in individual tenders. The in-depth analysis results also indicate that the weights attributed to the various non-price criteria depend on multiple factors, among which, the most common is order size and, to a lesser extent, the type of bus (electric or diesel). However, the proportion of explained variance by individual models was, in each case, at a relatively low level ($R^2 < 0.1$). With these caveats, it can be cautiously concluded that the type of bus had a statistically significant influence on the weighting of the criteria "technical parameters" and "warranty and service" (Table 9). Concerning the criterion "technical parameters," operators acquiring electric vehicles that used a new technology sought to minimize the technological risk and the likelihood of selecting a vehicle that did not fully meet the assumed technical requirements. Differences between tenders for DBs and BEBs regarding the warranty and service criterion manifested themselves, among other things, in the separation of the warranty periods for the vehicles and the batteries, which are still a high cost in the TCOs of electric buses. Operators also used the solution of extending the battery warranty period, which generally exceeded the vehicle warranty period. As BEBs are purchased using European and national non-refundable external funding sources, such a measure, despite affecting the higher price of the vehicle, allows operators to reduce the risks and their own costs associated with the subsequent vehicle operation. Based on the in-depth interviews, it can be concluded that operators are cautious about manufacturers' declarations regarding battery life. Operators are also aware that the TCO of an electric bus should assume at least one battery replacement during the life cycle of the electric bus [83]. Currently, some operators' tenders included the requirement that a new battery must be compatible with the current vehicle in the future and that replacing it will not result in additional costs due to the need to upgrade the bus.

Table 9. Predictors for the set weights of individual non-price criteria.

Criterion	Predictors
Technical parameters	Year, Type
Terms of warranty and service	NoB, Type
Fuel/energy consumption	NoB
Delivery date	None
Ecology	NoB
Other	NoB

Source: Own elaboration.

It may be concluded from the above data that the criteria for tenders for BEBs and DBs in the Polish conditions during the analyzed period did not differ significantly. Therefore, it follows that the institutions that had previously developed patterns of behavior in the case of DBs purchases had, in the vast majority, transferred these patterns to tenders for BEBs purchases. For both BEBs and DBs tenders, there were outlier observations, such as single tenders in which the most important non-price criterion was the delivery time of the vehicle.

5.2. Do the Criteria Used in the Tenders Take into Account the Advantages and Disadvantages of Electric and Diesel Buses?

As outlined earlier in this article, the main advantages of DBs are the high range and flexibility of routes, the availability of refueling infrastructure, the low price of the vehicles, the increased passenger capacity, and the advanced stage of maturity of the technology. The disadvantages of DBs, on the other hand, are the high local emissions and noise and the high fuel price. For BEBs, their advantages include increased energy efficiency, lower electricity price relative to liquid fuels, no local emissions, and lower noise emissions. However, the current energy mix in Poland limits the ecological impact of BEB operation. Research even indicates that promoting the use of electric vehicles in regions where electricity is generated through the combustion of crude oil, hard coal, and lignite is counterproductive to the environment [84,85]. It is important to note that the electric buses being purchased today will remain in operation for at least 15 years. According to [85], economic analyses should adopt an ex-ante approach, which considers the future energy mix instead of the current one. By 2035, the share of conventional energy sources in Poland's electricity production is expected to decrease from 90% in 2018 to 40% [86]. This transition could significantly enhance the environmental benefits of BEBs in the future. The disadvantages of BEBs, on the other hand, include the high price of the vehicles (which in Polish conditions, is on average twice as high as that of DBs [67]), the high cost of infrastructure, the need to purchase additional traction batteries, and the use of technology that is still under development. Given the magnitude and diversity of differences in the advantages and disadvantages of the different types of city buses, it could be expected that the criteria used to select the best bid would reflect these differences. However, based on the analyses, it can be concluded that the criteria used and their weights in the tenders for DBs and BEBs are so convergent that the characteristics of the individual technologies are not taken into account. The assignment of convergent weights and criteria in the DBs and BEBs tenders does not consider the relevance of energy efficiency, which is a key cost driver in the case of DBs (Table 3). During the first tenders for electric buses, the knowledge of putting electric vehicles into service among operators and manufacturers was minimal. This risk was increased by an electric vehicle's much higher purchase price. In the Polish public transport market, municipal operators play a dominant role. Therefore, the primary measure to minimize the risk of purchasing electric vehicles is to entrust them with the preparation and implementation of the purchase. In countries with a different supply structure for the public transport market (e.g., Sweden and England), the involvement of public authorities in the first tenders for the purchase of electric buses can be seen as a measure to minimize the risk mentioned above [87].

In zero-emission vehicles, technological advances need to be considered due to the greater number of modern solutions and the short time for their implementation. The surveyed public transport operators indicated that heat pumps (introduced a few years ago) were such a revolutionary solution that it was reflected in the bid evaluation process. Nowadays, the heat pump is standard and will not be considered in future tendering procedures.

The basic elements of an electric bus that are closely linked are its configuration, electricity storage, and charging infrastructure [88]. Therefore, the choice of technical and operational model (opportunity charging, overnight charging, mixed) for the electric bus was preceded by an analysis of local conditions. Operators sought to precisely define boundary parameters, such as average speed (congestion, fewer stops, and stopping time, and in the case of longer stopping times, the use of electric heating was also factored in). In turn, the above influenced the choice of battery type and capacity affecting the LCCA/TCO of the vehicle. For example, a lithium-titanium-oxide battery (LTO), which is more expensive to purchase, is assumed to have a lifetime of 15 years [89] but is supposed to be replaced during the life cycle of an electric bus.

5.3. Does the Weight of the "Vehicle Price" Criterion Corresponds to the Share of the Vehicle Price in Their LCCA?

The data presented in this article shows that the share of the price criterion, which averaged 62% (Table 6), does not reflect the share of vehicle costs in TCO. This applies to both BEBs and DBs (Table 2). Thanks to the in-depth interviews, it is possible to partially explain the reasons for this. Firstly, operators purchasing electric buses co-financed from non-refundable sources (European and national funds) are subject to stringent formal requirements. The relatively small number of bidders taking part in tenders and their right to appeal against the tender results in the risk of their repetition and, consequently, prolongation of the process of purchasing rolling stock, which translates into a risk of missing the contract deadline. This is especially true given the additional time needed to produce the vehicles. The high share of price objectively facilitates the evaluation of bids and significantly reduces the risk of repeated tender procedures due to challenges to the marks awarded to non-price criteria.

Secondly, operators in Poland in the period under study were, in most cases purchasing electric buses for the first time. The higher share of the price (an objective criterion) reflected the desire to minimize the risk when purchasing the first electric buses. The experience of the operation of e-buses by other operators in Poland was small. The technological safeguard for the higher price share was the detailed requirements and criteria written in the description of the object of the contract (DOC). In the DOC, which served as a "filter" for potential bidders, the importance of other technical requirements was emphasized (e.g., a large number of seats, a detailed description of the characteristics of the vehicle, in particular, the minimum size of batteries or their functional capacity, or the bus heating system using only electricity). The most serious selection criterion for bids at the OPZ stage was quite often the range of the vehicle, which was aimed at eliminating bids that were less technologically advanced or not tested under specific operating conditions.

Thirdly, according to some operators, the lack of a standardized methodology and good experience in using LCCA in tendering procedures may result in the transfer of risk to the rolling stock supplier. In such a situation, the risk will be transferred to the value of the final bid.

By expecting a longer warranty for traction batteries than for buses themselves, contracting authorities attempt to incorporate LCCA analysis results into the decision-making process. Although this solution may be expensive (the battery warranty period ranged from 7 to 10 years in the companies studied in-depth), it shows a desire to minimize technological risks. In the Polish market, where most BEBs purchases are subsidized by non-refundable EU or national funds, the cost of an extended warranty is less of a burden for the operator. Indeed, LCCA is also reflected in detailed technical solutions, such as in the largest tender to date for the supply of 130 electric buses for MZA Warsaw, where vehicles were equipped with silicon carbide inverters. Although this solution raises the purchase cost, it results in electricity consumption savings and increased range with unchanged battery capacity [90].

To conclude the discussion, tendering procedures are adapted to local conditions and operational requirements. Electric buses often replace conventionally powered vehicles on existing routes and schedules. Thus, operational requirements such as route length and topography, the number of stops, frequency, and traffic conditions are known. As a result, the necessary number of vehicles and the basic technical and operational parameters (e.g., selection of the optimal charging method and battery capacity) can be determined. In turn, the charging method will influence the TCO, with overnight charging favored for shorter assignments and opportunity charging favored for longer mileages [91].

6. Conclusions

A key trend shaping the future of public transportation in Poland is the exponential growth of electric buses in the fleets of transit operators. The growth in the importance of ZEVs, including ZEBs, is stimulated by the policies of public authorities at various levels [92]. Public procurement is an important instrument of public intervention in the market mechanism [93]. In this sense, public procurement in urban transport can be considered not only as a legal instrument, but also as an economic tool for public intervention at the local level.

The highly dynamic changes in the public transport operators' environment are forcing them to constantly adapt to the new realities of urban transport systems. The era when DBs were the indispensable backbone of city bus fleets, while alternative technologies were primarily experimental or utilized only to a limited extent in specific conditions (e.g., trolleybuses with in-motion charging), is coming to an end [94].

Adapting new technologies on the scale of electromobility is generally a lengthy, costly, and phased process. Experience shows that the spread of intrinsic technological changes in transport has, on average, taken several decades. For example, the diffusion process of airbags took 25 years, automatic transmission 50 years, navigation systems 30 years, and hybrid vehicles were developed 30 years ago and continue to be used today [95]. The history of the implementation of battery electric vehicles dates back to the late nineteenth century.

However, their subsequent disappearance in favor of conventional vehicles means that the process of adapting the technology has begun anew, under new conditions. As BEVs are more expensive and technologically more complex than the above examples, under market conditions, their acceptance and market penetration would most likely require a more extended period [96]. In Polish conditions, however, implementing electric buses does not occur spontaneously under market conditions but manifests top-down planned climate and transport policy. This state of affairs results in the shortening of the process and other specific consequences, one of which is the lack of sufficient experience in the factors, which precludes the selection of the best offer in the tender process for electric vehicles. As the analysis presented in this article indicates, from 2017 to 2020, decision-makers used converging criteria and their weights when tendering for BEBs and DBs. They did not consider all the advantages and disadvantages of both technologies.

Further analyses are therefore needed, which will result in recommendations for decision-makers on the most optimal set of criteria for selecting the best rolling stock offer. There is also a need to provide an efficient flow of data and information on the actual operation of electric buses between different urban transport operators in the EU. This would allow the results of the TCO and LCCA analyses to be more detailed and realistic and the calculations to be more adapted to local and regional market conditions. This would be a factor in accelerating the electromobility transition while minimizing its costs and risks.

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Nomenclature

BEB	battery electric bus
CNG	compressed natural gas
CR4	four-firm concentration ratio
CBA	cost-benefit analysis
DB	diesel bus
DOC	description of the object of contract
EV	electric vehicle
GHG	greenhouse gas
GLM	generalized linear models
HEB	hybrid electric bus
HFCB	hydrogen fuel cell bus
HHI	Herfindahl–Hirschman Index
NoB	number of buses
NoC	number of non-price criteria in tendering
LCA	life cycle assessment
LCC	life cycle cost
LCCA	life cycle cost analysis

LNG	liquefied natural gas
LPG	liquefied petroleum gas
NGB	natural gas bus
OPZ	description of the object of contract
TCO	total cost of ownership
VKM	vehicle-kilometer
ZEB	zero-emission bus
ZEV	zero-emission vehicle

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