SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2023
ORGANIZATION AND MANAGEMENT SERIES NO. 190

TOTAL COST OF OWNERSHIP OF FUEL CELL (FCEV) AND ELECTRIC (EV) BUSES IN DELIVERY OF PUBLIC TRANSPORTATION SERVICES ON THE EXAMPLE OF UPPER-SILESIAN AND ZAGLEBIE METROPOLIS

Tomasz SZULC[1*], Grzegorz KRAWCZYK[2]

[1] Silesian University of Technology, Department of Logistics; tomasz.szulc@polsl.pl,
ORCID: 0000-0003-4823-7667
[2] University of Economics in Katowice, grzegorz.krawczyk@ue.katowice.pl, ORCID: 0000-0002-4888-9043
* Correspondence author

Purpose: The purpose of the article is to determine and compare Total Cost of Ownership (TCO) metrics of buses operating in public transportation system depending on their powertrain. TCO is widely used method supporting decision making in purchases, taking into account all operational and extraordinary costs of delivery, operations, maintenance and liquidation of an asset in its lifecycle. It will provide answer to the question of sustainability of the business in the time horizon reflecting economic life on an asset, in this case – the vehicle.
Design/methodology/approach: Main methods used in the paper are critical literature review concerning TCO models and its application for rolling stock, case study research conducted in the Upper Silesian and Zagłębie Metropolis aimed at collection of financial data. Gathered figures were used to develop comparative calculations of TCO for electric (EV) and fuel cell (FCEV) buses.
Findings: In course of the research and analyses it was confirmed that the Total Cost of Ownership of the EV is significantly lower, comparing to FCEV, and only political decisions and significant public support of investments in FCEV buses may equalize TCO values for both types of powertrain. Sensitivity of TCO calculated against fuel and electricity prices is very low, and such depreciation of hydrogen fuel is very unlikely to take place.
Research limitations/implications: Data gathered for EVs are real life, as carriers have long term experience in their use, whereas the data for FCEVs comes primarily from test drives and road tests carried out by the suppliers and carriers.
Practical implications: Development of hydrogen technology still requires massive public financial support, otherwise the costs of bus operations with this type of powertrain is uncompetitive comparing to battery (EV) powertrain. Decarbonisation of the economy is then highly dependent on political priorities, since the businesses may not demonstrate sufficient interest in participation in this process, primarily due to higher costs and lack of attractive incentives.
Originality/value: Originality of this approach results from rather infrequent use of this method, comparing to other, i.e. NPV. Use of TCO may facilitate decision making process as it does not require differential approach, comparing to NPV, however, for comparing different possible choices, such comparison of values may be also applied.

Keywords: total cost of ownership, economic performance, public transportation, FCEV, EV.
Category of the paper: conceptual paper, case study.

1. Introduction

Delivery of high quality public services meeting the standards of smart and resilient cities requires outlay of funds, the source of which is primarily local or metropolitan government's budget. However, growing costs of rendering services meeting the preferences of their users, requires higher spending. Upper Silesian and Zagłębie Metropolis is a sound example of the public organization and territorial unit, whose annual spending on public transportation services exceeds 1 billion złoty, which is the equivalent of roughly 200 millions Euros (MFF, 2023). Income sources of the Metropolis are insufficient to cover these costs, so it is necessary to move some part of the on the users of public transport. The system is built on three pillars: users, the Metropolis and operators of public transport (carriers). It is the Metropolis' legal obligation to deliver the services uninterruptedly, with the use of operators possessing buses, tramways and trolleybuses. According to the EU level regulations (Regulation 1370/2007), operators are entitled to have covered all the operating costs of delivery of transportation services, excluding extraordinary revenues, so that their net profit does not exceed the level of so called reasonable profit, calculated as a fair rate of return on equity capital multiplied by the value of equity capital for given year. In case of reporting loss on transportation services, the operators are entitled to receive additional compensation of the value making it possible to reach reasonable net profit. In the opposite situation, operators are obliged to return excessive revenues to the Metropolis, so that their net profit is reasonable.

In order to predict the operating costs, generate different scenarios of revenues from public transportation services, taken into account the investment outlay on rolling stock or other necessary assets, it is needed to develop a method facilitating the aforementioned. Widely used discounted cash-flow methods (DCF) has a significant deficit. It always requires differential approach, comparing different investment options, resulting in different choices. The authors of the paper propose to use total cost of ownership approach (TCO) closely related to life-cycle costing. TCO uses similar positions of the financial forecasts, but may refer to single investment option. Its application enables decision makers to calculate all costs and investment outlay (incl. replacement expenditures), assign them to proper periods, depending on time horizon of calculations, as well as determine potential deficit or surplus generated by delivery of transportation services. This type of financial information will stabilize decisions of both operators and the Metropolis, as well as facilitate and support creation of fair tariff policy, which is one of the most sensitive factors, considered the passengers, final consumers of the services. In order to keep abreast to the latest technologies, more and more operators decide to replace their vehicles with direct ignition powertrain with electric ones or hydrogen-powered fuel-cell electric vehicles. The question of ability to generate reasonable profit by them, however, still remains unanswered. Similar dilemmas touch the financing of the whole system. Undoubtedly, it is necessary to determine future requirements of public co-financing of the services, as well as future tariffs, since the costs of use of public transportation must reflect its quality and must be competitive, comparing to private means of transport, mainly cars, the growing number of which deteriorates the condition of the environment and contributes to growth of traffic congestion.

2. Total Cost of Ownership concept – literature review

Total cost of ownership (TCO) is one of the methods of evaluating investments (Palmer, 2018; Rusich, 2015; Hurkens et al., 2006; Vora et al., 2017). This method takes into account not only the purchase, but also all other costs of maintaining and using a given resource. (Originally, the method was used to estimate the costs of purchasing and maintaining IT systems, but is currently used in the assessment of investments in various types of fixed assets (e.g. devices, machines) and services. The method has been used since 1990 and has gained recognition around the world (Korpi, Ala-Risku, 2008) due to its main advantages:

- indicates a precise result, which provides justification for the decision,
- covers the entire life cycle of a product or service,
- builds awareness of the costs of purchasing and using a given fixed asset,
- enables the presentation of results in an aggregated and individual manner.

The TCO method assumes taking into account all costs throughout the entire life cycle or the assumed analysis horizon. As a consequence, a person making a decision to purchase a product or service can compare values between variants. The main cost drivers include: operational cost, quality, logistics, technological advantage, supplier reliability and capability, maintenance, inventory cost, transaction cost, life cycle, initial price, customer-related, opportunity cost (Ferrin, Plank, 2002). The entity making the purchasing decision should determine which costs it considers to be the most important or significant in the process of acquiring, owning, using and subsequently selling a product or service (Ellram, 1995). Estimating so many values allows you to build awareness of the level of costs, but also to indicate potential areas for cost reduction. The wide range of variables included in the TCO model can also be seen as a disadvantage of this method. Forecasting the value of many variables over a period of, for example, several years increases the risk of making an estimation error. The limitations of using this method include the need to update calculations, especially during an extended decision-making process or variant investment implementation, due to changes in, among others, macroeconomic indicators, interest rates, exchange rates, etc.

The TCO method has been successfully applied to vehicle purchase decisions. Analyzes of vehicle maintenance costs are becoming more and more important due to the dynamic development of alternative drives. The subject of research is both passenger vehicles (Al-Alawi, Bradley, 2013) and public transport (Szumska, Pawełczyk, Jurecki, 2022). In recent years, many studies have been published on the comparison of TCO for vehicles with different drives. However, these results are most often regional in nature due to specific conditions (Falcao et al., 2017), e.g. technologies used (battery capacity), availability of charging/refueling infrastructure (limitations, e.g. in hydrogen refueling infrastructure and the availability of the power grid), the possibility of obtaining subsidies from public funds for the purchase of vehicles (Szulc, Krawczyk, Tchórzewski, 2021), and even cultural conditions (fear of change, education and training of employees) (Hurkens et al., 2006). The implementation of innovative drives causes many cost components to differ significantly, e.g. purchase costs, conditions related to refueling/charging infrastructure, unit cost of energy/fuel. There are also different forecasts regarding the costs of individual energy carriers, which is influenced by global policies aimed at, among others, to move away from fossil fuels (Palmer et al., 2018).

Due to its comprehensive approach to costs, the TCO method should be used more often in the public sector. The use of TCO may be one of the criteria for evaluating offers in tender procedures, including for the purchase of buses or public transport services (Jagiełło, Wołek, Bizon, 2023).

The most comprehensive identification of cost drivers which may be applied for TCO calculations are provided by Ferrin and Planck.

They proposed the following groups of costs:

- operations costs,
- quality costs,
- logistics costs,
- costs of technological advantage,
- maintenance costs,
- inventory costs,
- customer-related costs,
- life cycle costs,
- miscellaneous costs (Ferrin, Planck, 2002).

Topal and Nakir proposed a comprehensive approach of Zero-Emissions Bus Purchase and Operation Model provided in the figure (Figure 1.)

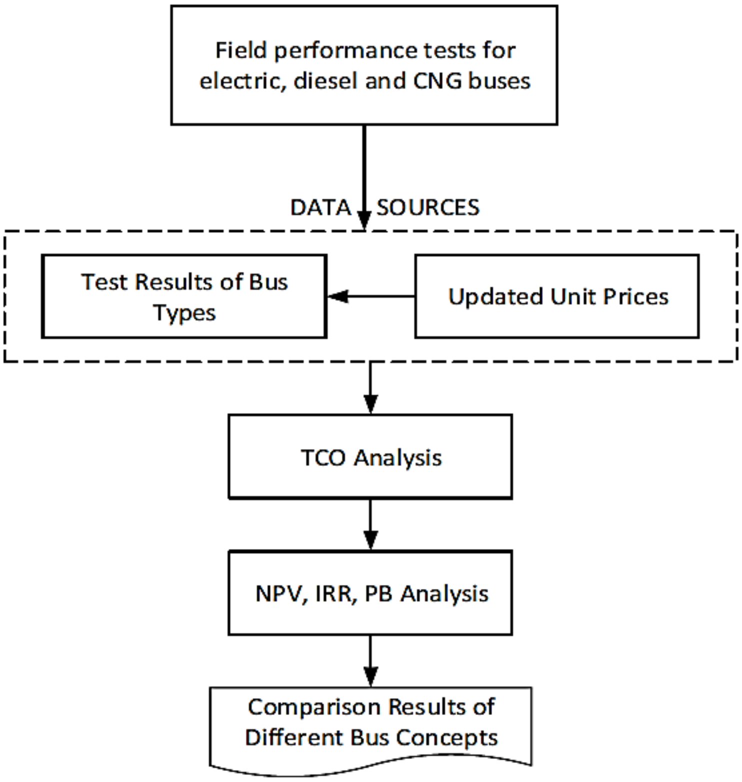

Figure 1. Zero Emissions Bus Purchase and Operation Model flowchart.

Source: Topal, Nakir, 2018, p. 4.

TCO analysis is performed in the third stage of the proposed model. The proposed TCO method takes into account the bus purchases and operational investment costs depends on the variables of transportation operators. The cost components considered in this model are the following:

Maintenance and Operating costs

- Preventive maintenance costs,
- Vehicle body cost,
- Engine renewal costs,
- Damage & repair payments costs,
- Material cost,
- Cost of emergency response team,
- General administrative management costs,
- Depot's energy costs (electricity, water, natural gas for heating),
- Traffic insurance and vehicle inspection expenses costs,
- Taxes.

Fuels

It should be underlined that no personnel related costs are included in this model. However direct and indirect labour costs are explicitly listed by Ferrin and Planck.

The authors of the paper decided to use the most universal approach to calculate respective TCOs, using the following formula:

$$TCO = I_0 + \sum_{t=0}^{n} \frac{POC + PRC}{(1 + r_d)^n} \tag{1}$$

where:
POC – period operating costs,
PRC – period replacement costs (where applicable),
I_0 – initial investment outlay,
r_d – discounting rate.

3. Total Cost of Ownership of EV and FCEV buses – case study

Calculations of TCO for both investment options are based on average operating costs reported by the public transportation operators (carriers) commissioned by Upper Silesian and Zagłębie Metropolis. All of them are presented as unit costs referred to kilometer of operational work. Detailed analytics is provided in the (Table 1). To reflect their forecasted annual change, there was applied the nominal growth rate published by the Ministry of Finance in October 2023 (Guidelines, 2023). Operational costs were divided into 3 groups: EV specific, FCEV specific and common for both types of powertrain, including costs of functioning of the depot.

Table 1.
Unit operating costs in current prices

Analytics of operating costs per km (current prices)	Unit	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Growth rate of costs on non-consumer markets	%		12,00	6,60	4,10	3,10	2,50	2,50	2,50	2,50	2,50
EV											
External services and outsourcing	PLN/km	0,960	1,075	1,146	1,193	1,230	1,261	1,292	1,325	1,358	1,392
Taxes and fees	PLN/km	0,090	0,101	0,107	0,112	0,115	0,118	0,121	0,124	0,127	0,130
Wages (incl. costs management and administrative cost)	PLN/km	2,577	2,886	3,077	3,203	3,302	3,385	3,469	3,556	3,645	3,736
Social security and other HR costs	PLN/km	0,634	0,710	0,757	0,788	0,813	0,833	0,854	0,875	0,897	0,920
Other costs	PLN/km	0,146	0,164	0,174	0,182	0,187	0,192	0,197	0,202	0,207	0,212
FCEV											
External services and outsourcing	PLN/km	0,860	0,963	1,027	1,069	1,102	1,130	1,158	1,187	1,216	1,247
Taxes and fees	PLN/km	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Wages (incl. costs management and administrative cost)	PLN/km	2,577	2,886	3,077	3,203	3,302	3,385	3,469	3,556	3,645	3,736
Social security and other HR costs	PLN/km	0,634	0,710	0,757	0,788	0,813	0,833	0,854	0,875	0,897	0,920

Cont. table 1.

Other costs	PLN/ km	0,200	0,224	0,239	0,249	0,256	0,263	0,269	0,276	0,283	0,290
Depot costs of materials, additional fuels and energy											
Oils and lubricants	PLN/ km	0,018	0,020	0,021	0,022	0,023	0,023	0,024	0,025	0,025	0,026
Depot energy costs	PLN/ km	0,014	0,015	0,016	0,017	0,017	0,018	0,018	0,019	0,019	0,020
Other use of materials and energy	PLN/ km	0,359	0,402	0,429	0,446	0,460	0,471	0,483	0,495	0,508	0,520
Natural gas (heating)	PLN/ km	0,018	0,020	0,021	0,022	0,023	0,023	0,024	0,025	0,025	0,026
Tyres	PLN/ km	0,025	0,028	0,030	0,031	0,032	0,033	0,033	0,034	0,035	0,036
Water and wastewater	PLN/ km	0,004	0,004	0,005	0,005	0,005	0,005	0,005	0,005	0,005	0,005

Source: own elaboration based on financial reports and forecasts provided by the carriers.

In order to compare periodically the aforementioned values and finally aggregate them to calculate the ultimate value of TCO, it is necessary to determine the interest rate which will be used to find the present values of respective items as for year 2023. According to the rules of financial engineering, definition of the discount rate is the duty of the owners of capital engaged in the business. To determine the overall rate covering both equity capital and liabilities, excluding non-interest bearing current liabilities, weighted average cost of capital is used. Since the operators deliver public service, the authors of the paper decided to choose the minimum acceptable rate of return, which bears no risk. For the EU market it is the rate of return of German national bonds and for year 2023 it is 2,6% (Eurostat). Operating unit costs in constant prices are presented in the table (Table 2).

Table 2.
Unit operating costs in constant prices

Analytics of operating costs per km (constant prices)	Unit	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
EV											
External services and outsourcing	PLN/ km	0,960	1,048	1,089	1,105	1,110	1,109	1,108	1,107	1,106	1,105
Taxes and fees	PLN/ km	0,090	0,098	0,102	0,104	0,104	0,104	0,104	0,104	0,104	0,104
Wages (incl. costs management and administrative cost)	PLN/ km	2,577	2,813	2,923	2,965	2,980	2,977	2,974	2,971	2,968	2,965
Social security and other HR costs	PLN/ km	0,634	0,692	0,719	0,730	0,734	0,733	0,732	0,731	0,731	0,730
Other costs	PLN/ km	0,146	0,159	0,166	0,168	0,169	0,169	0,169	0,168	0,168	0,168
FCEV											
External services and outsourcing	PLN/ km	0,860	0,939	0,975	0,990	0,994	0,994	0,993	0,992	0,991	0,990
Taxes and fees	PLN/ km	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Wages (incl. costs management and administrative cost)	PLN/ km	2,577	2,813	2,923	2,965	2,980	2,977	2,974	2,971	2,968	2,965
Social security and other HR costs	PLN/ km	0,634	0,692	0,719	0,730	0,734	0,733	0,732	0,731	0,731	0,730
Other costs	PLN/ km	0,200	0,218	0,227	0,230	0,231	0,231	0,231	0,231	0,230	0,230

Cont. table 2.

Depot costs of materials, additional fuels and energy											
Oils and lubricants	PLN/km	0,018	0,019	0,020	0,020	0,021	0,021	0,020	0,020	0,020	0,020
Depot energy costs	PLN/km	0,014	0,015	0,015	0,016	0,016	0,016	0,016	0,016	0,016	0,016
Other use of materials and energy	PLN/km	0,359	0,392	0,407	0,413	0,415	0,415	0,414	0,414	0,413	0,413
Natural gas (heating)	PLN/km	0,018	0,020	0,020	0,021	0,021	0,021	0,021	0,021	0,021	0,021
Tyres	PLN/km	0,025	0,027	0,028	0,029	0,029	0,029	0,029	0,029	0,029	0,029
Water and wastewater	PLN/km	0,004	0,004	0,004	0,004	0,004	0,004	0,004	0,004	0,004	0,004

Source: own elaboration.

One of the most important factors affecting TCO is consumption and cost of energy. According to the experience of the carriers, average consumption of energy for EV buses equals 120 kWh per 100 kilometers. Deviations are minor and depend basically on the shape of terrain and weather conditions of operations. For FCEV buses, according to significantly shorter experience and test drives provided by their suppliers, average consumption of hydrogen equals 6 kg per 100 kilometers. It may be observed that net energy demand for FCEVs is significantly higher as the energy density for hydrogen is ca. 33kWh/kg. In order to compare the costs of consumption it was calculated that typical vehicle's annual operational work in the transportation network of the Metropolis is about 75 000 km.

Considering the costs of hydrogen fuel and electricity, there was provided a forecast of their future costs in current and constant prices. Initial values of prices of 1kg of H_2 and electricity were provided by the carriers. These are the real prices offered by the suppliers of these media in 2023 and are subject to indexation by the nominal average growth rate of costs on non-consumer markets. The forecast is provided in the table below (Table 3).

Table 3.

Forecast of prices of electricity and hydrogen

Fuels and Energy (current prices)	Unit	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Hydrogen	PLN/kg	51,600	57,792	61,606	64,132	66,120	67,773	69,468	71,204	72,984	74,809
Electricity	PLN/kWh	0,750	0,840	0,895	0,932	0,961	0,985	1,010	1,035	1,061	1,087

Source: own elaboration.

Given the aforementioned data, annual cost of consumption of direct fuels and electricity in current and constant prices was provided in the table (Table 4).

Table 4.

Forecast of annual cost of hydrogen fuel and electricity in current and constant prices

Cost	Unit	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
(current prices)											
Hydrogen	PLN	309 600	346 752	369 638	384 793	396 721	406 639	416 805	427 226	437 906	448 854
Electricity	PLN	67 500	75 600	80 590	83 894	86 494	88 657	90 873	93 145	95 474	97 861
(constant prices)											
Hydrogen	PLN	309600	337965	351141	356275	358011	357662	357313	356965	356617	356270
Electricity	PLN	67500	73684	76557	77676	78055	77979	77903	77827	77751	77675

Source: own elaboration.

One of the factors affecting the ultimate value of TCO is the investment outlay, as it takes place mainly in the first periods of analysis. In this case it takes place in the first year. As it was reported by the operators who completed their tender procedures for deliveries of both types of vehicles, the prices of EV bus equals roughly 2 250 000 PLN net, and FCEV bus appropriately 3 750 000 PLN net. According to the experience in operating EVs, after 7 years of exploitation it is required to modernize the bus by replacing the battery due to loss of capacity and decline of its range without additional intra-day charging. Average cost of modernization stands for 40% of the value of a new vehicle. This fact was covered in the study and the value of this modernization in current and constant price was included in the calculations.

One of the components of TCO approach is depreciation reflecting moral wear of assets. According to the accounting law, depreciation rate that must be applied to commercial vehicles incl. buses and coaches equals 10%. In the presented case for given time horizon the assets do not get fully depreciated, so for the last year of analysis there must be taken into account their residual value which is the net present value of non-depreciated part of the assets for last year of analysis. Residual value must be included in TCO calculations as a benefit, so it must be deducted from all identified costs. Depreciation, residual value in current and constant prices are provided in the table (Table 5).

Table 5.
Forecast of depreciation and residual value in current and constant prices

Item	Unit	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
(current prices)											
D(EV)	PLN	0	225000	225000	225000	225000	225000	225000	225000	225000	225000
D(FCEV)	PLN	0	375000	375000	375000	375000	375000	375000	375000	375000	375000
RV(EV)	PLN										219298,25
RV(FCEV)	PLN										365497,08
(constant prices)											
D(EV)	PLN	0	219298,25	213740,98	208324,54	203045,36	197899,96	192884,95	187997,03	183232,97	178589,64
D(FCEV)	PLN	0	365497,08	356234,97	347207,57	338408,94	329833,27	321474,92	313328,39	305388,29	297649,41
RV(EV)	PLN										174063,98
RV(FCEV)	PLN										290106,63

Source: own elaboration.

Having analyzed all the costs it was determined that:

- Present value (PV) of all operational costs incl. battery retrofitting for EVs, adjusted by residual value equals: 7 211 078,02 PLN net,
- Present value (PV) of all operational costs for FCEVs, adjusted by residual value equals: 10 172 013,73 PLN net.

The last element of the TCO calculation is inclusion in the calculations of the respective investment outlays.

The ultimate values of TCO for respective options are the following:

- TCO(EV) = 9 461 078,02 PLN net,
- TCO(FCEV) = 13 922 013,63 PLN net.

TCO per kilometer referred to respective years of analysis are presented in the graph (Figure 1). The first year of analysis was intentionally skipped, for the values include the investment outlay. It distorts the meaning of the numbers provided below. In the penultimate year of analysis there is a peak for EVs. It is the result of retrofitting of new batteries, which does not take place for FCEVs.

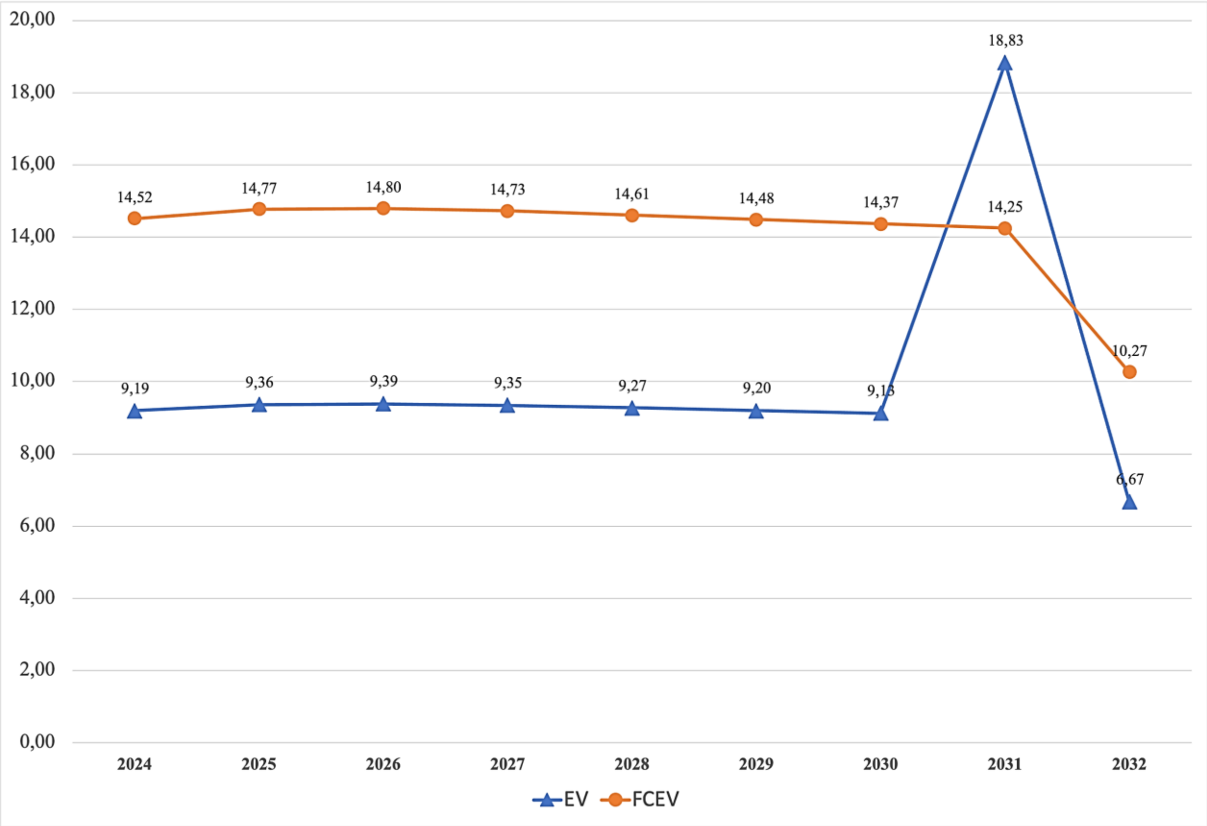

Figure 1. TCO per kilometer for EVs and FCEVs.

Source: own elaboration.

The first year of analysis was intentionally skipped, for the values include the investment outlay. It distorts the meaning of the numbers provided below. In the penultimate year of analysis there is a peak for EVs. It is the result of retrofitting of new batteries, which does not take place for FCEVs.

4. Sensitivity analysis, future research lines and conclusions

Critical factors affecting significant difference between these options are: investment outlay for new buses and costs of fuel and electricity. It should be also indicated that energy demand of EVs and FCEVs is significantly different. It was measured that EV bus needs 120 kWh to run 100 kms, whereas FCEV bus consuming 8 kgs of H_2, uses 264 kWh to run 100 kms.

Since the hydrogen technology for powertrain is rather immature, its cost of purchase is significantly higher than the mature technology used in EV buses.

Having calculated both TCO values, the authors decided to conduct the sensitivity analysis. In this approach there were indicated four variables which may affect TCO: investment outlay for FCEV and EV, and unit cost of fuel or electricity.

In the first scenario the independent variable was the unit price of hydrogen. In order to equalize TCO of EVs with TCO of FCEVs, the cost of H_2 fuel should have negative value, which is simply impossible.

In the second scenario the independent variable was the unit price of electricity. If TCO values for EVs and FCEVs are supposed to be the same, the cost of energy should increase from 0,75 PLN net to 5,14 PLN net. This scenario is also extremely unlikely and the result is rather ridiculous.

In the third scenario, the independent variable was the price of the FCEV bus. In such case the purchase cost of a new vehicle should not exceed 30% of its current price (approx. 1 150 000,00 PLN net). That is why investments in FCEV buses is strongly supported by the European Union, as it stays in line with its decarbonization policy. However, taking into account market game only (excl. EU grants), use of FCEVs becomes costly and uncompetitive, comparing to other sources of powertrain of the buses.

In the fourth scenario, the independent variable was the price of the EV bus. In such case the purchase cost of a new vehicle should increase almost twice to 4 450 000 PLN net, which also seems rather unlikely, since it does not reflect current market values.

Concluding, in order to get more and more comprehensive values of TCO, regardless of the type of vehicle, it is necessary to indicate or determine more specific costs, as proposed by Ferrin and Plank (Ferrin, Plank, 2002). Many of them are not calculated by the businesses, since they are not required for financial reporting. The same refers to environmental and social costs or benefits, as it was proposed by Moreira Falcão et al. and Rusich and Danielis (Moreira Falcão et al., 2017; Rusich, Danielis, 2015). Lack of legal obligation of their reporting results in practical lack of data do acquire from the businesses.

References

1. Al-Alawi, B.M., Bradley, T.H. (2013). Total cost of ownership, payback, and consumer preference modeling of plug-in hybrid electric vehicles. *Applied Energy, Vol. 103*, pp. 488-506, doi: 10.1016/j.apenergy.2012.10.009
2. Ellram, L.M. (1995). Total cost of ownership. An analysis approach for purchasing. *International Journal of Physical Distribution & Logistics Management, Vol. 25, Iss. 8*, pp. 4-23, doi: 10.1108/09600039510099928.

3. Falcao, E.A.M., Teixeira, A.C.R., Sodre, J.R. (2017). Analysis of CO_2 emissions and techno-economic feasibility of an electric commercial. *Applied Energy, Vol. 193,* pp. 297-307, doi: 10.1016/j.apenergy.2017.02.050.
4. Ferrin, B.G., Plank, R.E. (2002). Total Cost of Ownership Models: An Exploratory Study, *Journal of Supply Chain Management, 38(3),* pp. 18-29, doi: DOI: 10.1111/j.1745-493X.2002.tb00132.x.
5. Hurkens, K., van der Valk, W., Wynstra, F. (2006). Total Cost of Ownership in the Services Sector: a case study. *Journal of Supply Chain Management, Vol. 42, Iss. 1,* pp. 27-37, doi: 10.1111/j.1745-493X.2006.04201004.x.
6. Jagiełło, A., Wołek, M., Bizon, W. (2023). Comparison of Tender Criteria for Electric and Diesel Buses in Poland—Has the Ongoing Revolution in Urban Transport Been Overlooked? *Energies, Vol. 16, Iss. 11,* doi: 10.3390/en16114280
7. Korpi, E., Ala-Risku, T., (2018). Life cycle coasting. A review of published case studies. *Managerial Auditing Journal, Vol. 23(3),* pp. 240-261, doi: 10.1108/02686900810857703.
8. Ministry of Finance (October 2023). *Guidelines for the use of uniform macroeconomic indicators as a basis for estimation of the financial effects of proposed laws*, https://www.gov.pl/web/finanse/wytyczne-sytuacja-makroekonomiczna, 11/2023.
9. Moreira Falcão, E.A., Rodrigues Teixeira, A.C., Sodré, J.R. (2017). Analysis of CO_2 emissions and techno-economic feasibility of an electric commercial vehicle. *Applied Energy, vol. 193,* pp. 297-307, doi: 10.1016/j.apenergy.2017.02.050
10. Palmer, K. et al. (2018). Total cost of ownership and market share for hybrid and electric vehicles in the UK, US and Japan. *Applied Energy, 209*, pp. 108-119, doi: 10.1016/j.apenergy.2017.10.089
11. Palmer, K., Tate J.A., Wadud Z., Nellthorp, J. (2018). Total cost of ownership and market share for hybrid and electric vehicles in the UK, US and Japan. *Applied Energy, Vol. 209,* pp. 108-119, doi: 10.1016/j.apenergy.2017.10.089.
12. Regulation (EC) No 1370/2007 of the European Parliament and of the Council of 23 October 2007 on public passenger transport services by rail and by road and repealing Council Regulations (EEC) Nos 1191/69 and 1107/70; OJ L 315, 3.12.2007, pp. 1-13, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32007R1370, 11/2023.
13. Resolution No. XLIX/359/2022 of the Assembly of the Upper Silesia and Zagłębie Metropolis of 16 December 2022 on adopting the Multiannual Financial Forecast for years 2023-2032, https://bip.metropoliagzm.pl/artykul/34656/129566/uchwala-nr-307-2022-zarzadu-gornoslasko-zaglebiowskiej-metropolii-z-dnia-15-listopada-2022-r-w-sprawie-projektu-wpf-2023-2032, 11/2023.
14. Rusich, A., Danielis, R. (2015). Total cost of ownership, social lifecycle cost and energy consumption of various automotive technologies in Italy. *Research in Transportation Economics,* doi:10.1016/j.retrec.2015.06.002

15. Szulc, T., Krawczyk G., Tchórzewski, S. (2021). Models of Delivery of Sustainable Public Transportation Services in Metropolitan Areas–Comparison of Conventional, Battery Powered and Hydrogen Fuel-Cell Drives. *Energies*, *Vol. 14, Iss. 22*, doi: 10.3390/en14227725
16. Topal, O., Nakir, I. (2018). Total Cost of Ownership Based Economic Analysis of Diesel, CNG and Electric Bus Concepts for the Public Transport in Istanbul City. *Energies, 11, 2369*, doi:10.3390/en11092369
17. Vora, A. et al. (2017). Design-space exploration of series plug-in hybrid electric vehicles for medium-duty truck applications in a total cost-of-ownership framework. *Applied Energy, vol. 202*, pp. 662-672, doi: 10.1016/j.apenergy.2017.05.090