# Total Cost of Ownership Analysis of Battery Electric Buses for Public Transport System in a Small to Midsize City

by

Hanhee Kim* and Niklas Hartmann

Hanhee Kim, Offenburg University of Applied Sciences, Offenburg, Germany, +49 781/205-4878, hanhee.kim@hs-offenburg.de
Niklas Hartmann, Offenburg University of Applied Sciences, Offenburg, Germany, +49 781/205-4645, niklas.hartmann@hs-offenburg.de

* Correspondence: Hanhee Kim M.Sc., Institute of Sustainable Energy Systems, Offenburg University of Applied Sciences, Badstr.24, 77652 Offenburg, Germany, +49 781/205-4878, hanhee.kim@hs-offenburg.de

## Abstract

The sharp rise in electricity and oil prices due to the war in Ukraine has caused fluctuations in the results of the previous study about the economic analysis of electric buses. This paper shows how the increase in fuel prices affects the implementation of electric buses. This publication is constructing the Total Cost of Ownership (TCO) model in the small-mid-size city, Offenburg for the transition to electric buses. The future development of costs is estimated and a projection based on learning curves will be carried out. This study intends to introduce a new future prospect by presenting the latest data based on previous research. Through the new TCO result, the cost differences between the existing diesel bus and the electric bus are updated, and also the future prospects for the economic feasibility of the electric bus in a small and midsize city are presented.

## 1. Introduction

The deployment of battery-electric buses within the public transportation sector plays an essential role in decreasing the exhaust gas emissions of transportation [1]. The introduction of technologies has accelerated quickly in the last decade, driven by environmental requirements more than by commercial considerations. Moreover, with the subsidies from government funding, a lot of small and medium-size cities are increasingly committing to the electrification of their bus fleets [2]. However, opinions are divided over when the introduction of electric buses will be economically beneficial without government subsidies. One study predicts that the economic sustainability of electric buses achieves parity with their fossil fuel equivalent by 2030 when the indirect costs to human health and climate change are included [3]. One other study presents that cumulative break-even occurs somewhere between 2030 and 2037 depending on the rate of battery cost decline and diesel-bus purchase prices [4].

But at the same time, one other paper emphasizes that most European countries will likely not be able to replace conventional diesel buses with replacement buses by 2050 [5].

Clearly, there are currently various barriers to the widespread adoption of electric buses. A significant challenge is the relatively low energy density of batteries, which is directly related to a price issue [6]. But, the recent development in battery technology has increased the potential of electric buses to be a viable solution for public transport, even also with the economical approach. Therefore, it has sufficient effects as a means of public transportation when used in the small downtown routes where the operation distances are short [7]. Also, the operation range remains a challenge for electric vehicles but for electric public buses it may not be considered a problem if the operation of buses is well managed in terms of charging and route planning [6].

This paper shows how the results of the current economic analysis in 2022 have changed compared to the results of the previous study about the implementation of electric bus in the German small to medium size city, Offenburg. The purpose of TCO analysis is to find out how the increase in fuel prices due to the Ukraine war affects electric buses.

## 2. Methods

The TCO (Total Cost of Ownership) has been identified as one of the main decision factors for the viability of investment for all types of buses [3, 4]. TCO considers all expenses linked to owning and operating public buses and is used to calculate the cost experienced during the entire life cycle [4, 5].

Although TCO has been calculated based on operational data and values from the literature, there is still uncertainty in the estimation of TCO. As those buses have not been manufactured yet in large-volume series, it is difficult to estimate the related costs precisely. Additionally, because their production is not mature enough when compared to conventional public buses, it is hard to estimate the technological development of alternative buses in terms of costs [8]. Especially, differences in the taxation policies of the energy in different countries make the overall cost calculation quite difficult [8], but in this study, they are not considered.

The TCO analysis increases accuracy with the data set obtained from detailed literature research. In order to establish TCO models, first an analysis of the Offenburg bus line is required, which selects a suitable bus line to replace with electric buses. The analysis gives also good candidate places to put chargers along the bus line. The bus line analysis follows the results of the past study [9].

Moreover, the economics for the different systems is analyzed, by calculating the cost for investments and operation of the bus lines using the different analyzed charger systems. In this study, depot charging and pantograph charging methods are analysed. Based on the TCO results, conclusions are suggested on the strengths and weaknesses of the compared charging systems. The result is an indication of which direction the development is likely to go.

## 3. Literature Review

In the recent trend, the values that have changed significantly from the previous study [9] are fuel prices, and electricity prices and diesel prices have risen significantly. Figure 1 shows electricity price between 1998 and 2022 according to EEG surcharge. The prices shown represent the average of the available tariffs for electricity for the respective period. This represents prices charged to companies with an annual consumption of 160 MWh to 20 GWh [10].

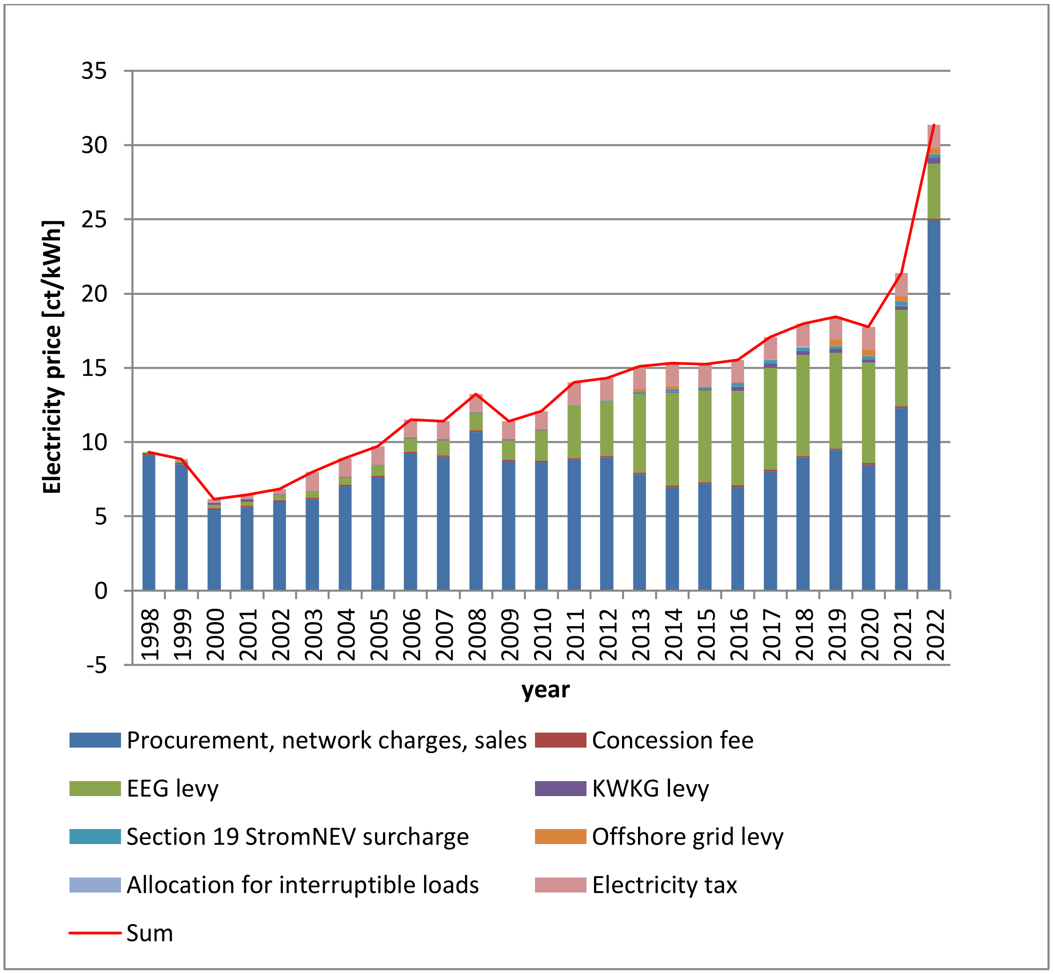


Figure 1. Average electricity prices between 1998 and 2022 in Germany, and 1 ct (cent) defined as 0.01 € [10, 11]

The electricity price in 2022 has risen by about 158%, from 19.83 ct/kWh (0.1983 €/kWh) predicted in the previous study [9] to 31.36 ct/kWh (0.1983 €/kWh). This appears to be because the price of procurement, network charges, and sales rose from the forecast value of 10 ct/kWh to 24.92 ct/kWh.

The war in Ukraine, which has lifted natural gas and coal prices, is the main driver of this increase. The price increase trend is also exacerbated by low nuclear power production in France: State-owned Electricite de France SA recently cut its 2022 nuclear output guidance to less than 300 terawatts hour, down more than 30% from what it produced a decade ago. [12]

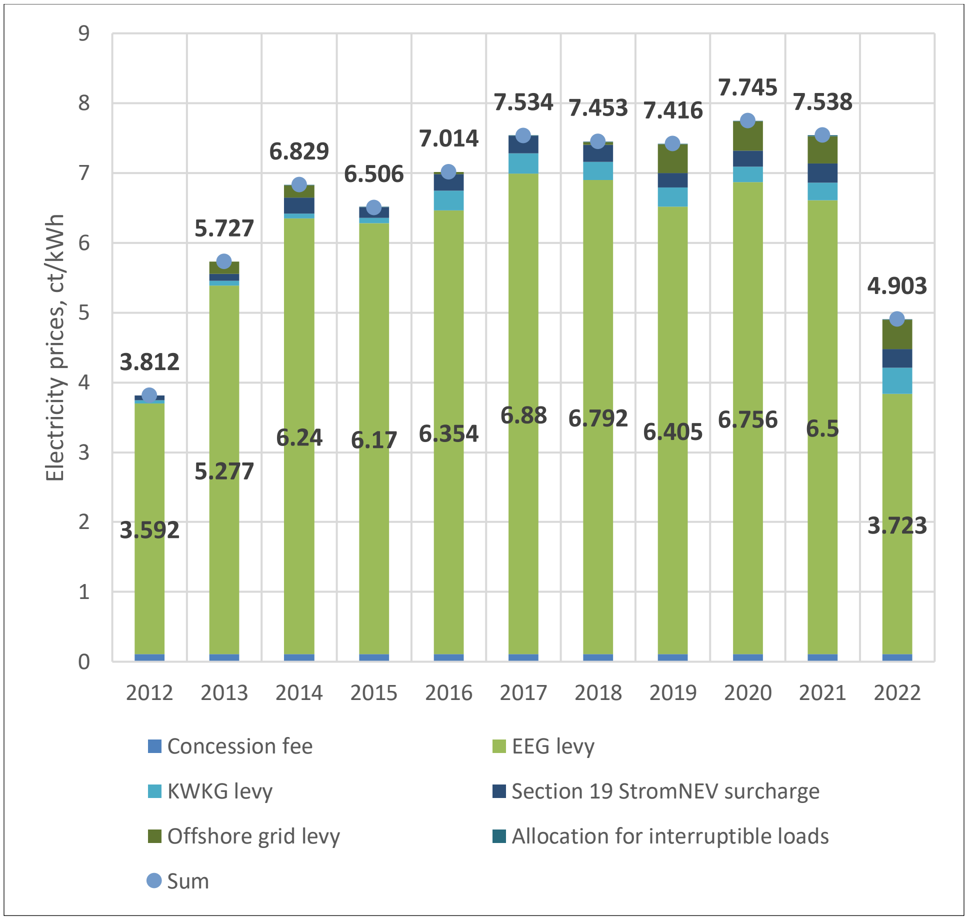


Figure 2. Average electricity prices for taxes and duties in industry in ct/kWh (without electricity tax), annual consumption 160,000 to 20 million kWh, medium-voltage, and 1 ct (cent) defined as 0.01 € [10]

However, from 2022 first of July, the EEG charge on electricity rates will no longer apply. With the EEG surcharge cut to 0 euro, decrease of electricity prices is expected. The EEW surcharge (EEW-Umlage) is a surcharge introduced through the Renewable Energy Sources Act in 2000 whose goal was to finance the promotion of wind and solar systems through household and business electricity rates. The most recent green electricity price was 3.723 cents per kilowatt-hour. It was slated to cease in early 2023, but the federal government has advanced this phase by half a year in light of rapidly rising energy costs. [13]

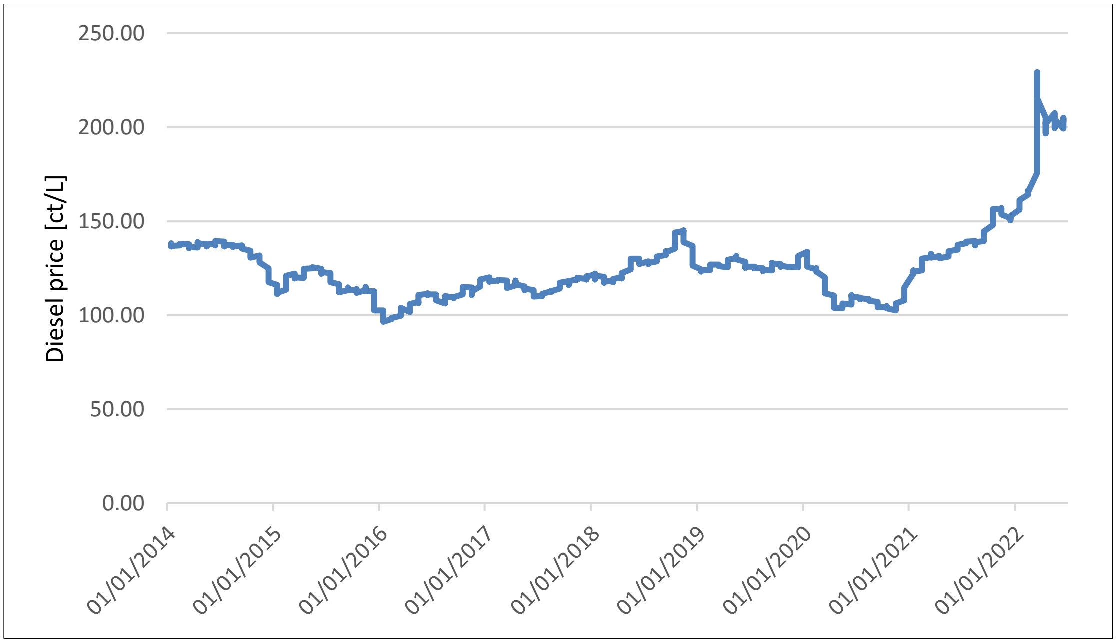

Figure 3. Diesel prices changes between 2014 and 2022 in Germany [14]

Like the price of electricity, the price of diesel has risen significantly. Based on 2022 June 28, a liter of diesel costs an average of 202.7 euro cents in Germany. The war in Ukraine and the associated uncertainties about the stable supply of crude oil and natural gas are currently driving oil prices, which then led to significant price jumps and new all-time highs. The highs of August 2012 and November 2021 were also exceeded. [14]
The increase in energy prices affects the price competitiveness of electric buses against diesel buses. This study shows how electricity and diesel prices in 2022 make a difference to the TCO values of electric buses.

## 4. Economic Parameters

With bus line analysis, an approach was presented to analyze the costs and benefits of electric bus fleet operation concerning different charging scenarios.

- Depot charing scenario: 5 depot charging station is placed for 11 electric buses.
- Pantograph charging scenario: 1 pantograph charging stations are considered for 11 electric buses.

The analysis is focused on minimizing the total cost of ownership (TCO). The bus size, route duration and energy consumption are constant for both charging methods.

### 4.1. Depot charging bus

Table 1 presents the CAPEX parameters for the bus procurement for overnight charging bus type as well as OPEX parameters, the electricity cost and maintenance & operational costs for bus and charger respectively. Compared to the previous study [9], the increase in electricity prices is noteworthy and has a significant impact on the results.

**Table 1.** Economical parameters for the depot charging scenario [9, 10]

| Parameter | Value | Unit |
|---|---|---|
| Vehicle cost | 300,000 | € |
| Battery cost | 667 | €/kWh |
| Depot charging station cost | 28,500 | € |
| Grid connection & Planning & Transformer cost | 15,500 | € |
| Electricity cost in 2020 | 0.181 | €/kWh |
| Electricity cost in 2022 | 0.298 | €/kWh |
| Maintenance & Operation cost (Bus) | 0.11 | €/km |
| Maintenance & Operation cost (Charger) | 0.14 | €/kWh |
| Interest rate | 5 | % |

## 4.2. Pantograph charging bus

The time and distance to reach the destination and return to the station are different for each line but all city buses pass through the Offenburg central station, which is with proper rescheduling, a single charging station can handle all 11 buses running on routes S1-5, S7, and S9.
The battery pack of the bus produced by each manufacturer has a certain capacity, and in the case of the pantograph model, it is approximately 90 kWh which was employed in this study.

**Table 2.** Economical parameters for the pantograph charging scenario [9]

| Parameter | Value | Unit |
|---|---|---|
| Vehicle cost | 330,000 | € |
| Battery cost | 1,200 | €/kWh |
| Pantograph charging station cost | 457,000 | € |
| Coupling system & Transformer cost | 58,500 | € |
| Maintenance & Operation cost (Charger) | 5,000 | €/year |

The most main parameters that affect the price of the pantograph charging scenario are the same as the depot charging one. However, the price of the opportunity charging bus is slightly increased by the charging component. In the pantograph charging, the prices of batteries are located in approximately twice that of depot charging method, which is due to the difference in battery capacity. [9]

## 4.3. Diesel charging bus

To compare the TCO with the electric bus, cost-effective parameters of the diesel bus are also researched. As one of OPEX parameters, the average price of a diesel bus defines 250,000 €. An important parameter in CAPEX on diesel buses is the diesel price. The diesel market price in Germany for 2020 was 1.24 €/L. In 2022, the diesel price increases as 2.02 €/L.

**Table 3.** Economical parameters for the pantograph charging scenario [9, 14]

| Parameter | Value | Unit |
|---|---|---|
| Vehicle cost | 250,000 | € |
| Diesel cost in 2020 | 1.24 | €/L |

| | | |
|---|---|---|
| Diesel cost in 2022 | 2.02 | €/L |
| Vehicle efficiency | 0.3904 | L/km |
| Maintenance & Operation cost | 0.25 | €/km |

## 5. Results

Figure 4 shows the TCO results calculated in 2020 based on the investigated parameters and the TCO in 2022 calculated using the updated energy price variables.

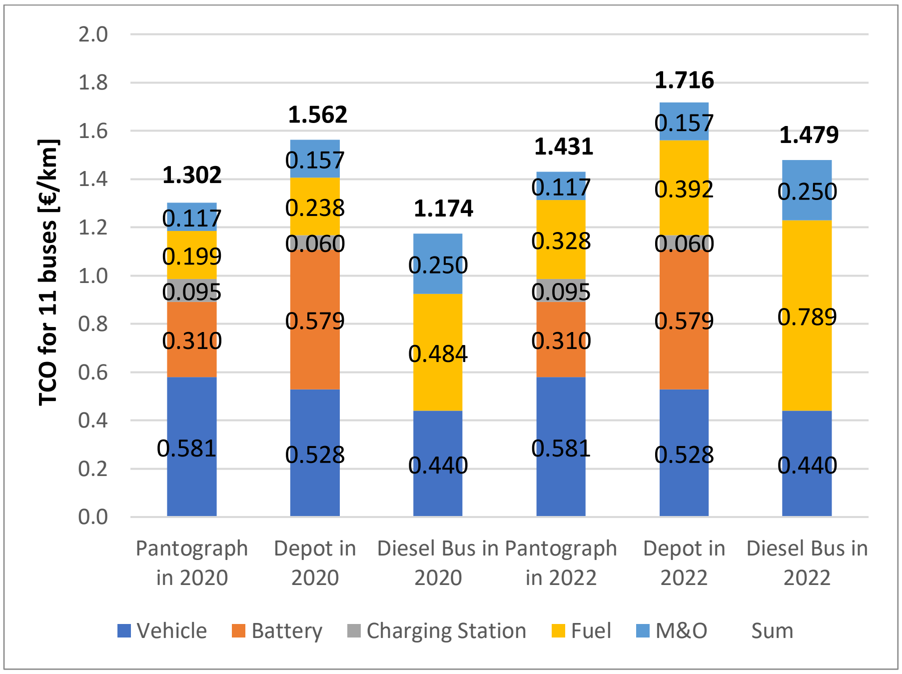


Figure 4. TCO results of battery electric bus with two charging methods and diesel bus in 2020 and 2022

In Figure 4, the pantograph bus scenario is more cost-effective than the depot bus in both 2020 and 2022. The main reason for this result is that it requires smaller battery capacities that have lower prices, although the pantograph bus price is higher than the depot charging bus due to the characteristics of opportunity charging. Additionally, it is possible to cover the route with less electricity, resulting in lower TCO.

In 2022, the biggest change is that the result of electric buses using the pantograph charging method is even slightly lower than the TCO results of diesel buses. Although the results of both the diesel and electric bus scenarios increased due to the increase in energy price, the TCO value of the pantograph charging bus increased by 0.129 €/km, which is relatively small compared to the diesel bus scenario, which increased from 1.174 €/km to 1.479 €/km by 0.305 €/km.

Instead, it seems that the overall increase in energy prices will positively affect the introduction of electric buses. Depot charging's price competitiveness is still insufficient compared to pantograph charging, but compared to the 0.388 €/km difference between the diesel bus and the diesel bus in 2020, the price difference with the diesel bus is decreasing with only 0.237 €/km difference in 2022.

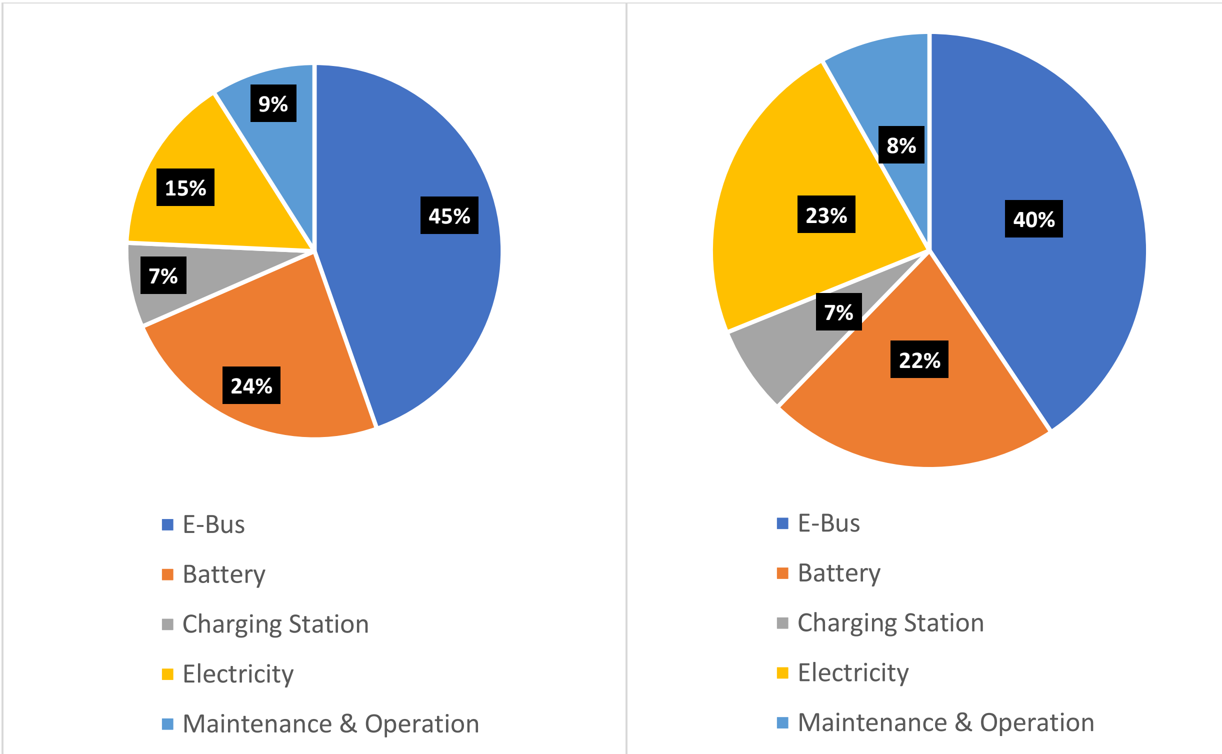


Figure 5. TCO results of battery electric bus with pantograph charging methods in 2020 and 2022

In 2022, as energy prices rise, the share of electricity prices in TCO will increase from 15% to 23%, which becomes a factor that lowers the proportion of other factors. In particular, the share of battery prices will drop from 24% to 22%, resulting in a higher percentage of electricity costs than battery prices. Therefore, energy cost becomes the second most important driving factor on total cost after bus cost in 2022.

## 6. Conclusions

The TCO models are used in finding economical solutions for a full emission-free bus introduction into the public transport system. In the study, the depot and pantograph charging electric bus TCO models were compared with the diesel bus model. The results indicate that the short-range fully electric bus scenario with shared opportunity charging infrastructure is the most economical solution in 2022.

The reason why the most economical model is changed from the diesel bus model in 2020 to the pantograph model in 2022 is because of the rising fuel prices due to the Ukraine war. In fact, compared to 2020, diesel prices rose by about 163% in 2022, which is very similar to the 164% increase in electricity prices. However, the vehicle efficiency of the diesel bus is 0.3904 L/km, while the fuel efficiency of the electric bus is 1.1 kWh/km. Therefore, if the price increase rate of diesel and electricity is similar, electric buses become more competitive in price than diesel buses. In addition, as the policy of reducing the EEW surcharge to zero euros is implemented, the difference will become even greater. These results are expected to have a positive impact on the introduction of electric buses.

This study is related to other small to midsize cities, as these generally have similar public bus lines and schedules. These public bus lines in small to midsize cities will increasingly obtain economic competitiveness with alternative powertrains compared with existing diesel buses. Research can continue to support this transformation by taking into account the complex relationships in public transport, and making alternative powertrain city bus a sustainable reality. Such a transformation necessitates changes in the value chain of public transport with considerations of new business models, new traffic system designs, and operations. Decisively, a bold decision of the city is needed to get started with this revolutionary change in public transport.

**Funding:** The paper [9] that became the basis for this study was funded by the Ministry of the Environment, Climate and Energy Economics in the State of Baden-Württemberg within the frame of the "H2-BUS Offenburg" project.

## References


1. Kunith, A.; Mendelevitch, R.; Goehlich, D. Electrification of a city bus network - An optimization model for cost-effective placing of charging infrastructure and battery sizing of fast charging electric bus systems, DIW Discussion Papers, No. 1577, 2016
2. Offer, G.J.; Howey, D.; Contestabile, M.; Clague, R.; Brandon, N.P. Comparative analysis of battery electric, hydrogen fuel cell and hybrid vehicles in a future sustainable road transport system. Energy Policy, 2010, vol. 38 (1), pp. 24–29
3. Lozanovski, A.; Whitehouse, N.; Ko, N.; Whitehouse, S. Sustainability Assessment of Fuel Cell Buses in Public Transport. Sustainability 2018, 10, 1480. https://doi.org/10.3390/su10051480
4. Quarles, N.; Kockelman, K.M.; Mohamed, M. Costs and Benefits of Electrifying and Automating Bus Transit Fleets. Sus-tainability 2020, 12, 3977. https://doi.org/10.3390/su12103977
5. Brdulak, A.; Chaberek, G.; Jagodziński, J. Development Forecasts for the Zero-Emission Bus Fleet in Servicing Public Transport in Chosen EU Member Countries. Energies 2020, 13, 4239. https://doi.org/10.3390/en13164239
6. Offer, G.J.; Howey, D.; Contestabile, M.; Clague, R.; Brandon, N.P. Comparative analysis of battery electric, hydrogen fuel cell and hybrid vehicles in a future sustainable road transport system. Energy Policy, 2010, vol. 38 (1), pp. 24–29
7. Choi, U.; Jeong, H.; Jeong, S. Commercial Operation of Ultra Low Floor Electric Bus for Seoul City Route", IEEE Vehicle Power and Propulsion Conference (VPPC), Seoul, Korea, October 2012
8. Lajunen, A. Energy consumption and cost-benefit analysis of hybrid and electric city buses, Transportation Research Part C. 2014, vol. 38, pp.1–15.
9. Kim, H.; Hartmann, N.; Zeller, M.; Luise, R.; Soylu, T. Comparative TCO Analysis of Battery Electric and Hydrogen Fuel Cell Buses for Public Transport System in Small to Midsize Cities. Energies 2021, 14, 4384. https://doi.org/10.3390/en14144384
10. BDEW, BDEW-Strompreisanalyse April 2022, https://www.bdew.de/service/daten-und-grafiken/bdew-strompreisanalyse/, accessed on 2022-07-07
11. BDEW, BDEW-Strompreisanalyse Januar 2020, https://www.bdew.de/media/documents/20200107_BDEW-Strompreisanalyse_Januar_2020.pdf, accessed on 2022-07-07

12. Blas, J.; Bigger Shocks Are Coming With Your Electricity Bills, 2022, https://www.bloomberg.com/opinion/articles/2022-05-23/electricity-prices-are-going-to-be-overwhelming-for-late-2022-and-all-of-2023#xj4y7vzkg, accessed on 2022-07-11
13. Göpfert, A.; Wird Strom jetzt wirklich billiger?, 2022. July. 01, https://www.tagesschau.de/wirtschaft/verbraucher/strompreis-eeg-umlage-verbraucher-101.html, accessed on 2022-07-11
14. Statisia, Durchschnittlicher Preis für Diesel-Kraftstoff in Deutschland vom 7. Januar 2014 bis zum 12. Juli 2022, 2022 July, https://de.statista.com/statistik/daten/studie/224105/umfrage/durchschnittlicher-preis-fuer-diesel-kraftstoff/, accessed on 2022-07-14