ACTA TECHNICA JAURINENSIS
Vol. 16, No. 4, pp. 158-166, 2023
10.14513/actatechjaur.00713

The possibility of electrification in public transport bus services

Vince Kruchina*

Volánbusz Zrt, Üllői street 131, H-1091 Budapest, Hungary
*e-mail: vince.kruchina@volanbusz.hu

Submitted: 07/09/2023 Accepted: 17/10/2023 Published online: 18/10/2023

Abstract: From Shenzhen to Philadelphia and Izmir to Delhi, public bus operators around the world are increasingly using electric buses. Their choice is not only justified by support for the green transition or the reduction of background traffic noise: economic calculations regarding the entire life cycle cost also support the need for technological change. The article points out that the inclusion of electric vehicles in the service requires a complex approach and can bring a revolutionary change in our operation. The transport company can become a community service provider that occasionally provides balancing energy for energy supply systems (Vehicle-to-grid, i.e. V2G) or provides a virtual power plant service to the operators of photovoltaic power plants. The bus company can become a producer with independent network power generation capacity, which can sell the excess capacity it produces on the market to the owners of electric cars. The article presents the operating model that connects the transport, energy and battery industrial systems. Last but not least, batteries that have lost their capacity but are still usable can be resold for "storage" or other secondary purposes, even as uninterruptible power supplies. In order to implement the operation according to the model, Volánbusz Zrt. started building its data-driven ecosystem, which enables cost-optimized operation based on the data of an ever-growing electric bus fleet and the solutions of Industry 4.0 technology.

Keywords: electrification; electric bus; public transport; zero emissions; circular economy; Vehicle-to-grid; pilot project description

I. INTRODUCTION

"Thanks to advances in technology, in 2023 the introduction of electric buses in public transport is nowadays no longer an engineer's fantasy dreamed up on the drawing board, but an accomplished reality." [1]

From Shenzhen to Philadelphia and Izmir to Delhi, public bus operators around the world are increasingly using electric buses. Their choice is not only justified by support for the green transition or the reduction of background traffic noise: purely economic calculations also support the need for technological change. This is especially true where energy needs are extremely import-intensive. The energy crisis of recent years has pointed to the seemingly clichéd but all the more important conclusion that a country can be economically successful and stable if it is able to produce its own energy needs and transform its economic structure in such a way that its energy imports are as small as possible.

The revolution in battery technology emerging in the early 21st century is fundamentally transforming the manufacture of cars and buses. Electrification can significantly reduce the need for energy imports in countries which – like our own – have extremely limited fossil fuel resources, and it can also increase such countries' economic stability and independence.

Economic calculations and operational efficiency considerations play an increasingly important role in the rise of electric buses. This is confirmed by the results of tests and measurements carried out with scientific precision at Volánbusz Zrt.

II. THE RISE OF ELECTRIC BUSES IN PUBLIC TRANSPORT

The appearance of electric buses in transport goes back to the middle of the 19th century. Electric buses were first developed on an experimental basis in the late 1880s and early 1890s, and were in use in some cities as early as the late 1890s.

One of the early examples of electric buses was the British city of Brighton, where an electric bus line was put into operation in 1890. After that, they started experimenting with electric buses in other

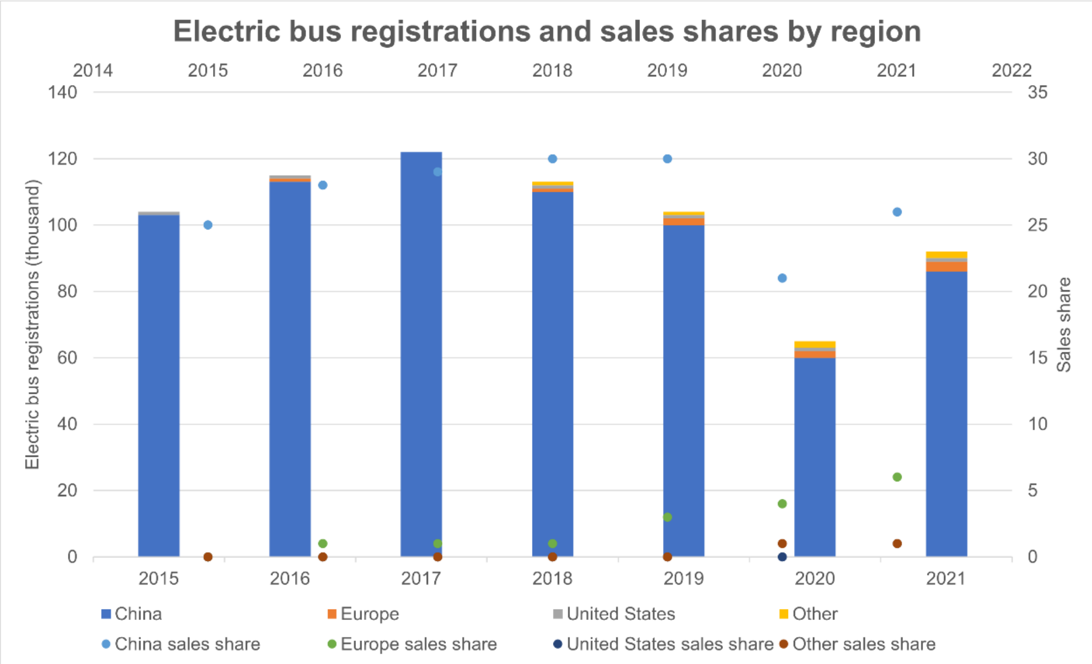

Figure 1. Electric bus registrations (dots) and share (bars) of total bus sales by region, 2015-2021 [3]

cities; for example, the first electric bus line in New York began operations in 1907.

The popularity of electric buses has fluctuated over the decades, and their adoption has been influenced by advances in technology, fluctuating oil prices and other factors. In recent decades, however, electric buses have become increasingly popular in urban public transport as a more environmentally friendly and sustainable transport option.

It is important to note that the technology and prevalence of electric buses may differ in each region and country, and their appearance over time also varies. The transport policies and development directions of the given cities and countries also play a role in the spread of electric buses.

Electric buses have been playing an increasingly important role in public transport in recent years, with their significance growing as cities and countries around the world seek more sustainable and environmentally friendly transportation options.

From the late 2010s to the early 2020s many cities in Europe, Asia, and North America have begun to make substantial investments in electric buses. Several major cities – such as London, New York, and Los Angeles – have announced plans to transition their entire bus fleets to electric vehicles over the coming years.

The upward trend in electric bus purchases is strengthening worldwide. **Fig. 1** shows the registration and sales share of electric buses by region in the period 2015–2021 [3]. In 2015, 103,000 electric buses were registered in China, and 25% of the buses sold there were electric. In 2021, the number of electric buses registered in the European Union increased to 3,000, and 6% of buses sold there were electric.

Analysing the latest data [4], it can be concluded that the registration of zero-emission buses in Europe increased from 1,400 in the first half of 2021 to approximately 2,600 in the first half of 2023. Moreover, their share of the total city bus registration is 22% in 2021, 30% in 2022, and – based on the first half of the year – 37.5% in 2023.

In the years 2022–23, the electrification of public transport in Hungary also started strongly, the decisive player in this being Volánbusz Zrt., which plays a significant role in regional and urban transport. [5, 6]

III. Global forces and trends determining the electrification of the transport industry

When making long-term development decisions related to transport enterprises, it is extremely important to take into account the global impacts and trends affecting the economy and technological processes. **Fig. 2** shows the trends and global impacts for 2023. For the development of vehicle fleets and the cost-effective, sustainable provision of transport services, the main economic and technology trends that public transport service providers must keep in mind are the applicability of circular economic models and the transformation – supported by data-driven decisions – needed to meet the demand for net zero operation of vehicle fleets. [2]

Figure 2. *Megatrends and global impacts for 2023*

IV. Reasons for deploying electric buses in vehicle fleets

The deployment of electric buses in public transport systems is driven by several compelling reasons, including environmental, economic and societal factors. Here are the main reasons to deploy electric buses.

1. Environmental Benefits

Electric buses produce zero tailpipe emissions, which helps mitigate climate change and reduce air pollution in urban areas through reduced greenhouse gas emissions. [7] They do not emit harmful pollutants like nitrogen oxides (NOx) and particulate matter (PM), leading to better air quality and public health outcomes.

These vehicles are quieter than their diesel or gasoline counterparts, reducing noise pollution in urban environments. However, the low noise levels produced by these vehicles, previously seen as an advantage, could pose a new risk to the safety of road users. [8] Due to their reduced noise output, quieter electric buses contribute to a more peaceful urban environment, especially in densely populated areas.

2. Societal factors

The public perception of electric buses that has developed is that they are a symbol of cities' commitment to sustainability and environmental responsibility, as a kind of shift to greener policies which can improve a city's image and appeal. An important health benefit is that cleaner air resulting from reduced emissions can lead to improved public health outcomes, including a decrease in respiratory and cardiovascular illnesses.

Investing in electric buses and related technologies can stimulate innovation and create opportunities for new industries and jobs.

It is important to note that the specific reasons for deploying electric buses can vary by region, depending on local priorities, policies, and the unique challenges faced by each city or transit agency. In addition to environmental and social aspects, factors of particular importance for large public transport companies operating in accordance with the legal and market economy rules of the European Union are economic sustainability, energy efficiency and the application of innovative technologies.

3. Compliance with Regulations

The pace of European transport systems' electrification is also sustained by the European Commission's development of a new package of proposals to reduce greenhouse gas emissions and introduce electric vehicles and other new technologies. Among other things, the decree sets specific dates for the phase-out of internal combustion engine vehicles. According to this, the sale of diesel and gasoline cars must be phased out by 2035, and all new cars must be emission-free. [9]

4. Energy Efficiency, Independence and Security

Electric buses are more energy-efficient than internal combustion engine (ICE) vehicles, leading to reduced energy consumption and operating costs. Due to their regenerative braking system they can recover energy during braking and deceleration, increasing overall energy efficiency.

Deploying electric buses reduces a city's dependency on fossil fuels, and by diversifying and using renewable energy sources, it greatly improves energy security.

5. Technological Advances

In addition to improving traffic safety, important cost-saving potential is offered by innovative functions used in electric buses, such as route optimization telematics, regenerative braking and integration with smart city systems. The charging infrastructure designed to operate electric bus fleets can also provide services for other electric vehicles, such as cars and trucks, providing a source of income to cover the costs of operation.

6. Cost Savings – Total Cost of Ownership

In addition to the aspects of sustainability and climate protection, electric buses must also compete with diesel buses in terms of total cost of ownership (TCO).

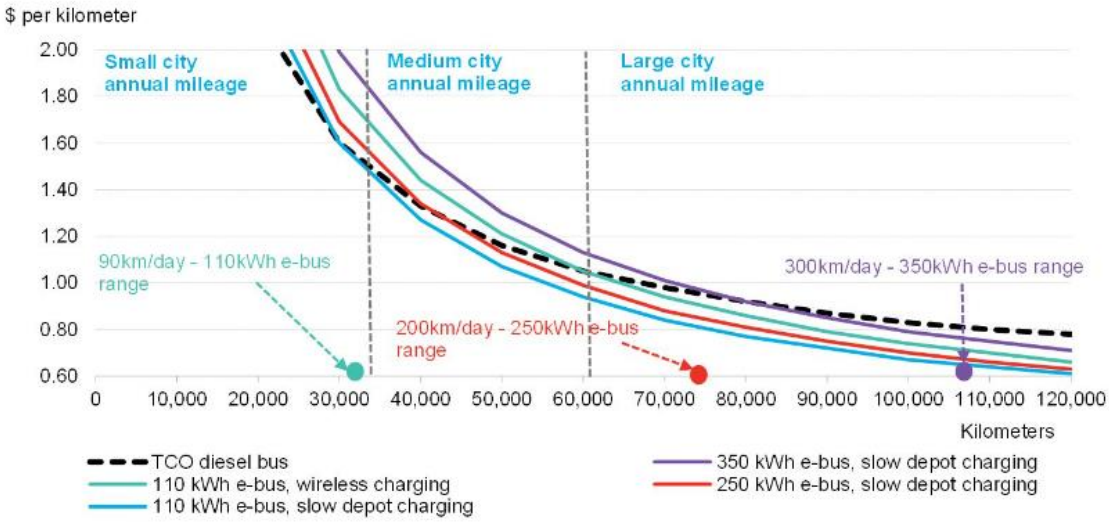

Figure 3. Comparison of e-bus and diesel bus TCOs in relation to annual mileage

Electric buses have fewer moving parts, require less maintenance, and have lower fuel costs compared to diesel or natural gas buses. All this contributes to lower operating costs.

Although the capital cost of electric buses may be higher, their lower operating and maintenance costs can result in long-term financial savings.

Fig. 3 illustrates that, assuming a given price of diesel and electricity, the TCO of an electric bus may be more favourable at higher daily mileage levels. As electric bus and traction battery manufacturing technologies advance, purchase prices may continue to fall, further improving TCO. [10]

In order to achieve optimal TCO in the electrification process of sustainable public transport, a continuous task is the comparative analysis of battery electric, hydrogen fuel cell and hybrid vehicles.

A cost-benefit analysis (CBA) was already carried out in the mid-2000s, which indicated that plug-in hybrid and electric city buses have the best potential to reduce energy consumption and emissions. But the most critical factors for improving the cost-efficiency of these alternative city bus configurations and reaching an appropriate TCO are the capital and energy storage system costs of city buses. [11]

In the electrification of city bus networks, the cost-effective location of the **charging infrastructure** and the battery sizing of fast-charging electric bus systems play an important role. By developing an optimization model, the TCO can be significantly improved. [12]

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A 2018 study concluded that H2FC buses meet operational and performance criteria and are environmentally friendly when using "green" hydrogen. This analysis also confirmed that the economic sustainability of buses in terms of affordability will be equal to their fossil fuel equivalents by 2030, when indirect costs related to human health and climate change are taken into account. [14]

A 2021 comparative TCO analysis of battery electric and hydrogen fuel cell buses for public transportation systems in small and medium-sized cities [15] shows that using short-range all-electric city buses with fast charging infrastructure will be the most economical option in 2030. The study compared the TCO of slow and fast-charging electric buses and hydrogen cell bus models with diesel buses.

The development directions determined on the basis of the experiences gained during the electrification of public transport in Poland in the 1990s–2020s show that the strategy of the national and regional authorities in Poland has focused mainly on electric buses and charging infrastructure, without a thorough analysis of the legality of their operation. It has paid insufficient regard to the energy balance in Poland, where fossil fuels are the main source of electricity production, and to the fact that the development of electric public transport and renewable energy sources should be combined to a greater extent. [16]

V. HOLISTIC MODEL INSTEAD OF SUBSYSTEM OPTIMA

There are quite a few arguments and counter-arguments for the use of electric buses in public transport, but the literature only deals with one or more subfields of the service-related factors, such as fuel consumption, charging infrastructure, battery capacity, vehicle range and investment cost. The purpose of this publication is to present a model with a holistic approach that examines the total lifetime cost of a larger electric bus fleet in a broader context. In the context of the model, it manages the possibility of connecting the systems of the energy industry, transport and battery industries, taking into account the requirements of a transport service provider. An essential part of this system is the circular battery value chain (**Fig. 4**) that links the transport and power sectors. [17]

Through data management and the disruptive tool system of Industry 4.0, the model coordinates the optimal way of procuring fuel with the use and storage of renewable energy sources in a circular economic process system. The data comes from the transport provider's real-time operation and traffic systems and, in connection with energy market information, optimizes the logistics processes in a predictive, prescriptive way. **Fig. 5** shows the logistic model of this data-driven management system.

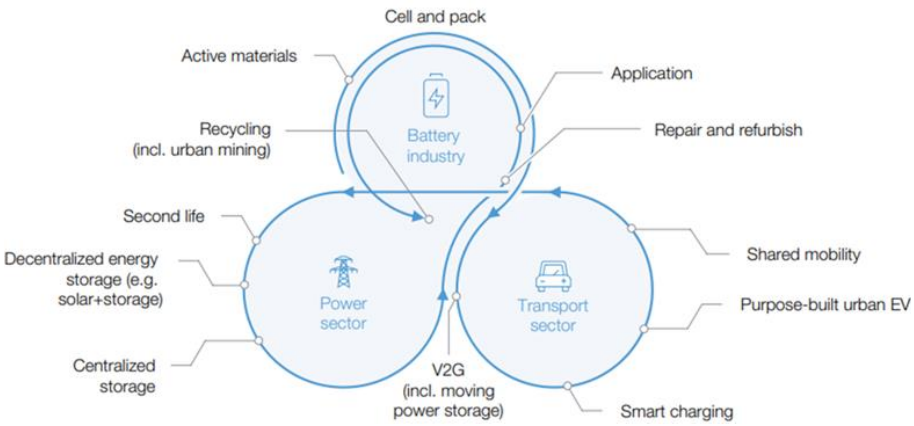

Figure 4. *Circular battery value chain that links the transport and power sectors [17]*

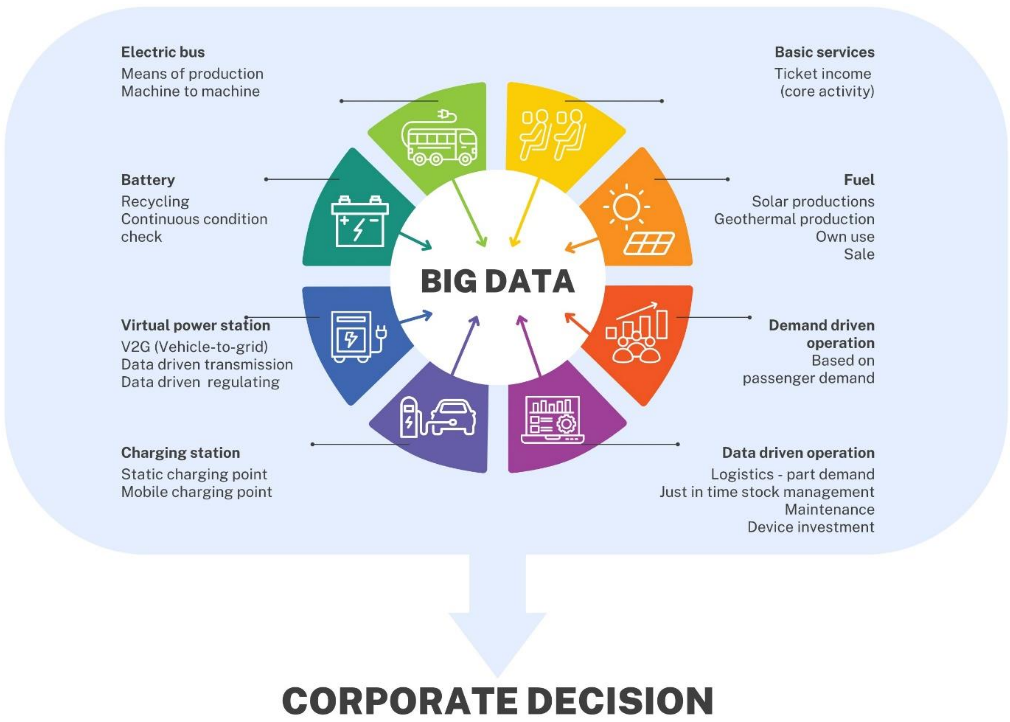

Figure 5. *The logic diagram of the data-driven company management system at Volánbusz Zrt [5]*

VI. The role of Volánbusz Zrt. in the sustainability of domestic public transport

Volánbusz Zrt. is a key player in domestic road passenger transport. With its fleet of 5,247 intercity and 634 local and suburban buses, it transports 539.2 million passengers per year with a daily mileage of 1.2 million kilometres. With 17,755 employees, Volánbusz Zrt. is Hungary's 3rd largest employer.

Currently 95% of the vehicle fleet are diesel-powered buses. A smaller number of compressed natural gas (CNG) and liquefied natural gas (LNG) vehicles also operate, and the introduction of electric buses has also begun.

Fig. 6 shows the expected composition of the vehicle fleet of Volánbusz Zrt. According to the company's plans, the share of battery electric buses – which accounted for 0.9% of the fleet in 2023 – could reach 50% by 2032.

From 2024, Volánbusz Zrt. will gradually renew its bus fleet of local and intercity vehicles and replace most of its diesel buses with electric ones. By 2032, 50% of the fleet will be electric buses. **Fig. 5** shows the planned number of buses each year, according to propulsion system. We do not have any plans to increase the number of CNG buses, and the electric buses purchased will replace diesel buses.

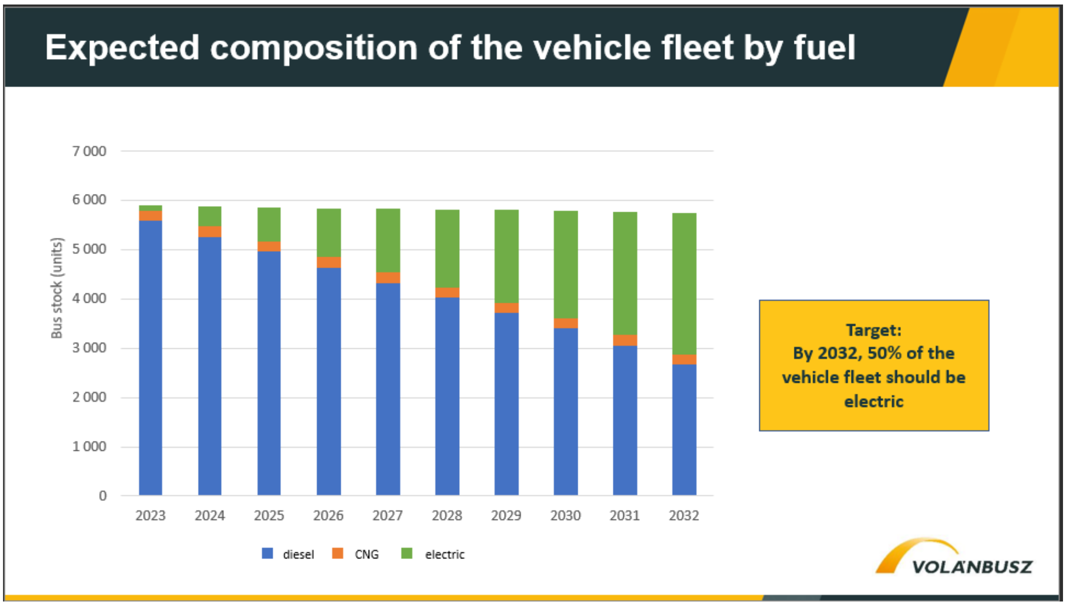

Figure 6. *Expected composition of the vehicle fleet of Volánbusz Zrt [6]*

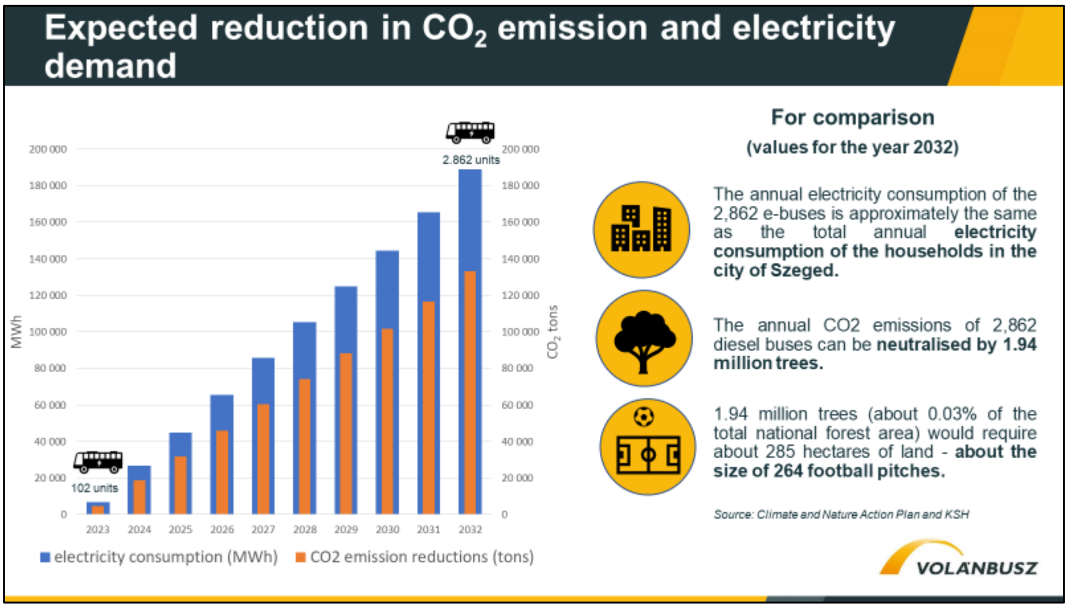

Figure 7. Expected reduction in CO_2 emissions and electricity demand [6]

The purchase of new buses will improve vehicle availability, resulting in a minimal reduction in the total number of buses in the fleet over the next 10 years (a reduction of almost 3% in the fleet by 2032).

Based on the concept presented above, the increase in the number of electric buses will be accompanied by an increase in electricity consumption and a reduction in CO_2 emissions as diesel buses are replaced. This is illustrated in **Fig. 7**.

VII. Technological change and re-evaluation of bus operators' classic role

Given the significant size of the fleet and the considerations outlined above, the question arises as to whether Volánbusz Zrt. could be more than simply a public transport operator. Taking into account today's technological advances and our company's vehicle operating practices, from the above figures it can be seen that with 1,000 electric buses and a battery capacity of 300 kWh per bus, the daily electricity demand of the total electric bus fleet would be 300 MWh. The scale of this could also revolutionise our operations: with this level of storage capacity, further business opportunities would open up. On the one hand, we could become a community service provider, intermittently supplying balancing power to the Hungarian electricity transmission system operator MAVIR (Vehicle-to-grid, or V2G) or a virtual power plant service for the operators of photovoltaic power plants. Our bus company could also become a stand-alone generator with independent generating capacity, which could sell its surplus capacity on the market – possibly also to the public. (There would be the potential to sell electricity to the owners of electric cars at charging stations set up at the more than sixty sites across the country belonging to Volánbusz Zrt.) Last but not least, there is a further business opportunity in the circular economy, with batteries with reduced but still usable capacity being resold as uninterruptible power sources for storage or other secondary uses. **Fig. 8** shows how Volánbusz Zrt. plans to implement this technology change.

The technological change outlined in this article and the re-evaluation of bus operators' classic role could be facilitated by synthesising the contributions of the major Hungarian-owned bus manufacturers present on the domestic market, battery manufacturers which have arrived more recently, and the professional and operational experience of Volánbusz Zrt. – which is unique in both domestic and international terms. Using these three pillars, in my view rapid changes in technology now make it possible to create a new operational structure – a new business model – for public transport bus services, while at the same time taking into account the specific geographical characteristics of our country (the potential for development of solar parks and geothermal power plant capacities, as well as a lack of fossil fuels). In this new structure the bus company can – in addition to its activities as a transport operator – perform energy trading and production tasks, and thus become a catalyst for the electric bus industry.

VIII. Conclusions

Global changes and emerging technological trends in the world, as well as the depletion of fossil energy sources, present new challenges – including for public transport companies. Around the world, operators of public transport bus services are

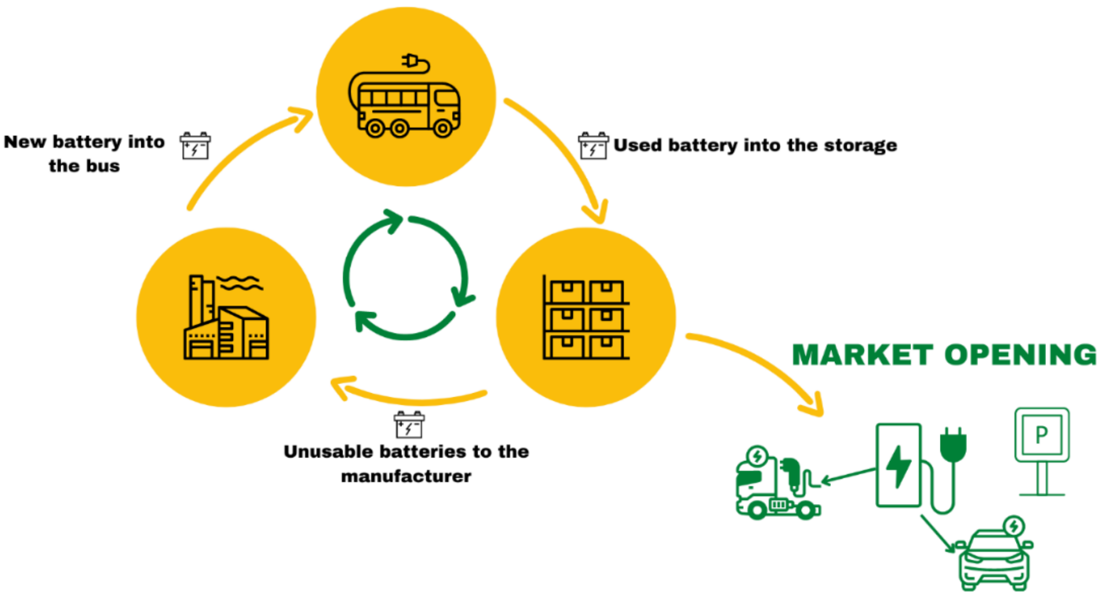

Figure 8. *The technology change model at Volánbusz Zrt [6]*

increasingly using electric buses. The revolution in battery technology is fundamentally transforming the manufacture of cars and buses. Electrification can significantly reduce the need for energy imports in countries which have extremely limited fossil fuel resources.

As confirmed by the tests and measurements carried out at Volánbusz Zrt., economic calculations and operational efficiency considerations play an increasingly important role in the adoption of electric buses. All this confirms the conclusion that technological transformation and reinterpretation of the classic role of the transport service provider are not merely possible, but urgent imperatives.

AUTHOR CONTRIBUTIONS

V. Kruchina: Conceptualization, Experiments, Theoretical analysis, Writing, Review and editing.

DISCLOSURE STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ORCID

V. Kruchina https://orcid.org/0009-0009-1220-2519

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