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CHALLENGES AND OPPORTUNITIES FOR ADVANCING ELECTRIC CARSHARING IN CENTRAL EUROPE

The Role of Infrastructure, Policy and Consumer Behavior in the Adoption of E-carsharing in Central Europe

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Abstract

Electric carsharing (e-carsharing) systems hold significant potential for promoting sustainable urban mobility in Central Europe, in this study particularly examined in Hungary, Slovakia, and Romania. Through a comparative analysis of carsharing models, charging infrastructure, and regulatory frameworks, this paper identifies key factors influencing the adoption of e-carsharing. The results demonstrate that while e-carsharing can substantially reduce carbon emissions and alleviate traffic congestion, its widespread implementation faces obstacles such as insufficient charging networks, limited governmental support, and consumer preferences for car ownership. In Central Europe, especially in the countries under examination, car ownership still holds great significance, which hinders the spread of e-carsharing services. Therefore, it is particularly important for e-carsharing services to be competitive, making government incentives necessary. Technological innovations like AI-based fleet management and Vehicle-to-Grid (V2G) systems are essential for improving operational efficiency and sustainability. Policy recommendations emphasize the need for robust government incentives, coherent energy policies, and targeted financial mechanisms to foster the growth and long-term viability of e-carsharing across the region.

Key words
Sharing economy, electromobility, carsharing, CEE, V2G, AI, Decision-makers

INTRODUCTION

Electric carsharing (e-carsharing) is becoming increasingly prominent in the evolution of sustainable transportation, combining the environmental advantages of electric vehicles with the flexibility inherent in shared mobility services. (Icaza et al., 2023; Rizopoulos et al., 2022; Sadhu et al., 2022; Venkatesh and Raslavičius, 2024; Yassine et al., 2024). E-carsharing allows users to access electric vehicles for short periods, avoiding the long-term financial commitments typically linked to vehicle ownership. (Amamra and Marco, 2019; Leal Filho et al., 2021; Ritter and Schanz, 2021). This model proves especially advantageous in urban environments, where traffic congestion, air pollution, and limited parking space pose daily challenges (Alanazi, 2023; Hassler et al., 2021; Manso-Burgos et al., 2021; Ravi and Aziz, 2022; Venkatesh and Raslavičius, 2024).

The aim of this study is to provide a detailed overview of the carsharing networks in Budapest, Bucharest, and Bratislava, with a particular focus on electric carsharing systems. The various infrastructural and regulatory challenges in these cities have a significant impact on the adoption and sustainability of e-carsharing services. Additionally, the study seeks to analyze the technological advancements in electric carsharing and their effects on user experience.

E-carsharing models are inherently tied to the rapid expansion of the sharing economy, with a primary focus on environmental sustainability (Galan and Zuñiga-Vicente, 2023). Leveraging innovative opportunities, providers can adopt emerging digital business models and essential sustainability tools (Briguglio and Formosa, 2023; Malakhatka et al., 2024; Ritter and Schanz, 2021; Y. Wang et al., 2024; Yassine et al., 2024). In recent years, a growing number of consumers and urban dwellers have embraced shared economy models that prioritize access over ownership (Han and Sun, 2024; Yang et al., 2024). Carsharing is particularly appealing to users who drive less frequently and wish to avoid the costs and responsibilities of vehicle ownership. Integrating electric vehicles into carsharing systems provides a pathway to decarbonize the transportation sector and enhance the efficiency of the whole transport system (Huang et al., 2020; Sarsia et al., 2023; Shaban et al., 2023; Venkatesan et al., 2024; Zhang et al., 2024a). E-carsharing systems offer major environmental benefits by reducing carbon emissions and local air pollution, contributing to sustainable urban transportation (Christensen et al., 2021; Luo et al., 2023; Sarsia et al., 2023). Moreover, e-carsharing fosters greater acceptance of electric vehicles by allowing users to experience the technology without the need for long-term commitment (Bohdanowicz et al., 2022; Hu and Han, 2023; Stanchev et al., 2023; Tiwari and Farag, 2022).

The integration of electric vehicles into the grid (Christensen et al., 2021; Huang et al., 2020; Neaimeh and Andersen, 2020; Pietracho et al., 2022; "Resilience

Enhancement of Urban Energy Systems via Coordinated Vehicle-to-grid Control Strategies," 2023) alongside load management, requires advancements in energy distribution systems, particularly for expanding urban charging networks (Ahmed et al., 2023; Lewicki et al., 2024; Zenhom et al., 2023; Zhang et al., 2024a). Integrating electric vehicles into the grid serves as a strategy to mitigate the extremities, the peaks and lows, of grid usage (Letha et al., 2023; Malya et al., 2021; Salehimehr et al., 2024; Srivastava et al., 2023).

The distinct economic, infrastructural, and social conditions of Central Europe profoundly influence the development and expansion of e-carsharing models (Y. Wang et al., 2024). The availability of electric vehicles, government incentives, the development of charging infrastructure, beside public awareness of environmental and financial benefits collectively shape the success of e-carsharing services (Bridi et al., 2024; Jaman et al., 2023). In this region, the adoption of electric vehicles may be impeded by income disparities, shortcomings in charging infrastructure, and insufficient user awareness regarding the advantages of electric mobility (Ritter and Schanz, 2021). Simultaneously, there is substantial growth potential for electric carsharing in Central Europe, particularly in metropolitan regions where transportation challenges and sustainability demands are more acute (Ma and Fang, 2022; Pan et al., 2023; Y. Wang et al., 2024). The expansion of electric carsharing and charging infrastructure presents new opportunities for building energy management systems (Brhane et al., 2024; Hossain et al., 2023; Jiang et al., 2023; Lewicki et al., 2024; Pedram et al., 2023). Electric vehicle charge control can not only contribute to building energy management systems but it also assists in balancing peak loads (Bhundar et al., 2023; Liu et al., 2023; Lu et al., 2023; Toniato et al., 2021). The sustainability of electric carsharing fundamentally depends on the efficiency of demand-side energy management (Bogdanova et al., 2023; Chen et al., 2024; Dorji et al., 2023; Mahani et al., 2023). As smart grids advance, the application of effective energy management techniques is becoming crucial (Venkatesan et al., 2024; Bakare et al., 2023; Muqbel et al., 2024; Esfandi et al., 2024; Kusznier, 2023; Ma et al., 2021; Mazhar et al., 2023).

Electric carsharing systems are progressively incorporating advanced technologies, such as mobile applications and real-time data management, to enhance user experience and optimize service efficiency (Briguglio and Formosa, 2023; Malakhatka et al., 2024; Y. Wang et al., 2024). Optimizing user experience is essential for fostering the widespread adoption of e-carsharing, as intuitive platforms and streamlined rental processes contribute to positive user experiences and foster long-term loyalty (Ritter and Schanz, 2021; Yang et al., 2024).

The regulatory framework also plays a pivotal role in shaping the development of e-carsharing markets, as government incentives and support mechanisms can substantially influence the expansion of charging infrastructure and the enhancement of user awareness (Jaman et al., 2023; Rego et al., 2023; Yassine et al., 2024).

Challenges of Electric Carsharing Systems

Electric carsharing offers benefits in both environmental sustainability and economic efficiency, yet it faces several critical challenges that may impede its broader adoption (Huang et al., 2020). On the other hand, there are a lot of challenges that service providers and users may face in the Central European context (Ghatikar and Alam, 2023). The following section enquires into these challenges.

Challenges in the Adoption of Electric Carsharing Systems

Despite the substantial environmental and economic benefits associated with e-carsharing, several challenges persist that may impede its widespread adoption, particularly within the Central European region (Bohdanowicz et al., 2022; Coban et al., 2022). A primary challenge lies in the construction and expansion of the charging infrastructure necessary for electric vehicle operation (Alanazi, 2023; Holly et al., 2020; Horváth et al., 2023). Efficient operation of e-carsharing services requires not only a sufficient number and the strategic placement of charging stations but also a continuous supply of clean energy to minimize the environmental impact of charging (Alanazi, 2023; "High Power Density EV Integrated Fast Battery Chargers Based on the General Torque Cancelation Law for Three-Phase Motors," 2024; Pan et al., 2023; Reddy et al., 2023).

Inadequacies in charging infrastructure not only diminish the user experience but also escalate operational costs (Shipman et al., 2019). When users fail to park vehicles at designated charging points, providers may require two employees to relocate the vehicle: one to drive it to the charging station and another to transport the first employee back. This situation can result in substantial labor costs and operational inefficiencies for providers. Thus, it is in the long-term interest of service providers to establish extended charging points in urban areas, where additional services such as cleaning and vehicle inspections can be performed concurrently, optimizing operations (Dalyac et al., 2021).

Comparative Advantages of e-Carsharing Over Taxi Services

E-carsharing services provide numerous advantages over conventional taxi services, particularly with regard to flexibility and operational efficiency. Whereas taxi services entail a separate booking for each trip, e-carsharing enables users to drive a pre-booked vehicle at their convenience and pace, granting them more autonomy. Additionally, taxis frequently operate without passengers while waiting for new bookings, resulting in unnecessary fuel consumption and contributing to increased traffic congestion. In contrast, e-carsharing vehicles are utilized solely when required, facilitating more efficient energy use, particularly when vehicles are stationed at charging points during periods of inactivity. This inherent flexibility and cost-efficiency render e-carsharing services especially appealing for urban transportation solutions.

Regulatory Challenges and Energy Efficiency in e-Carsharing Systems

Regulatory frameworks are pivotal in advancing the sustainability and widespread adoption of electric carsharing systems. To ensure the broad accessibility of e-carsharing, it is imperative to implement a supportive regulatory framework that promotes the integration of renewable energy sources and facilitates the development of essential infrastructure (Sousa and Costa, 2022; Sousa-Dias et al., 2024; Yassine et al., 2024).

Government interventions, including tax incentives, financial subsidies, and regulatory measures supporting the establishment of electric charging infrastructure, are critical in fostering the proliferation of electric vehicles. Conversely, the lack of appropriate regulatory framework can impede the development and the expansion of charging infrastructure, consequently restricting the growth of e-carsharing services within urban areas (Annamraju and Nandiraju, 2019a; Mulder and Klein, 2024; Zhou et al., 2023).

It is crucial for governments and local authorities to formulate coherent and comprehensive energy policies that facilitate the integration of renewable energy sources into the electric charging infrastructure. This approach not only supports the provision of clean energy but also contributes to the reduction of urban air pollution (Ahmed et al., 2024; Alfaverh et al., 2023). The deployment of hybrid energy storage systems is equally critical, as these systems enhance energy efficiency, alleviate grid load, and minimize environmental impact (Hassan et al., 2024; Tahir et al., 2024).

Beyond adequate government support, collaboration between public utilities and private enterprises is equally imperative for the development of effective regulatory frameworks. This is the only way to ensure that e-carsharing systems develop sustainably and present an attractive alternative to traditional car usage for users (Demirci et al., 2024; Salkuti, 2023; Xu et al., 2022).

To ensure the future development and the widespread adoption of electric vehicles, regulatory frameworks must remain flexible and adaptable, accommodating technological advancements and evolving user needs. Therefore, governments must prioritize the creation of support and incentive systems to ensure that sustainability-promoting e-carsharing truly achieves its goals (Adeyinka et al., 2024; Alpízar-Castillo et al., 2022; Berkes and Keshav, 2024; Li et al., 2022; Payakkamas et al., 2023).

Territorial Analysis of Carsharing Services in Central Europe

Electric vehicles (EVs) produce zero local emissions, given that they operate without the combustion of fossil fuels (Xu et al., 2024). Consequently, e-carsharing systems can contribute to the reduction of urban air pollution, a critical factor linked to serious health issues in metropolitan areas (Yang et al., 2024). This study aims to provide an in-depth examination of carsharing services across three Central European countries—Hungary, Romania, and Slovakia—focusing specifically on mapping their current state and sustainability dimensions. The analysis seeks to present a comprehensive overview of the current state of carsharing systems in the region, while identifying future development trajectories and potential growth opportunities (Briguglio and Formosa, 2023; Horváth et al., 2023; Y. Wang et al., 2024). Sustainability initiatives, alongside technological and infrastructural innovations, play a crucial role, as these factors critically shape the future development of carsharing. The analysis accounts for local consumer habits and attitudes influencing demand for carsharing services, alongside region-specific challenges and opportunities within the framework of sustainable mobility (Briguglio and Formosa, 2023; Horváth et al., 2023).

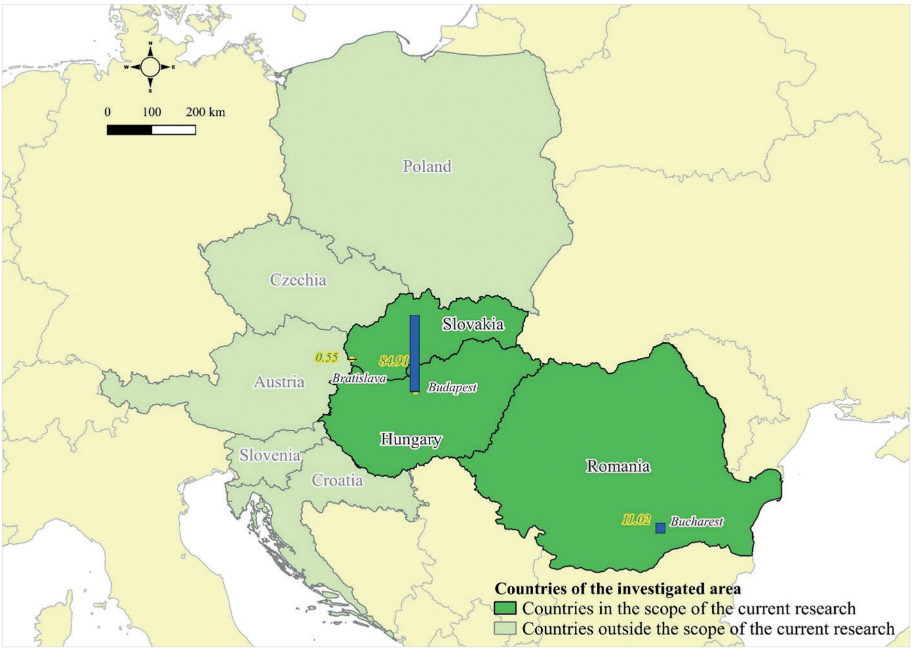

Fig. 1: The number of shared cars per 100,000 residents
Source: own editing according to ("Finally Here: MOL Limo Strengthens Fleet with Suzuki," 2024; "MOL Limo Car-Sharing Service," 2024; "MOL Limo Expands Fleet with Mercedes Vehicles," 2018)

There are significant differences in the development of carsharing markets between Western European and Central European countries. In Germany, where the carsharing market is the largest, there are 51 cars per 100,000 residents, in France there are 20 cars per 100,000 residents, and in the Netherlands, there are 40 shared cars per 100,000 residents. In contrast, Hungary has 14 cars, Romania has 1 car, and Slovakia has no cars available per 100,000 inhabitants ("INVERS GmbH (2024): INVERS Mobility Barometer. European Car Sharing," 2024; "The European Alternative Fuels Observatory provides comprehensive statistical data on all European Union member states," 2024). Besides the number of cars per 100,000 inhabitants, the countries involved in the current study are also lagging behind in other respects, as while there are car-sharing services available in several cities in Western European countries, in the countries we examined, such services can be found exclusively in the capital cities. Therefore, since car-sharing services can be utilized in urban transportation, this research will take a closer look at the car-sharing services in the capitals of the three examined countries. The number of shared cars per 100,000 residents is shown in Figure 1. It can be stated that among the three examined cities, Budapest stands out, as there are nearly 85 cars per 100,000 people, while in Bucharest, there are 11 cars, and in Bratislava, significantly fewer, with not a single car available per 100,000 residents. In Bratislava, there is only one micro-enterprise, which has a limited fleet, indicating that the opportunities for e-carsharing in Bratislava are underutilized. It cannot provide a viable alternative for urban transport unless there is an emergence of more providers and a larger fleet. At the same time, even in the case of Budapest, 85 shared cars per 100,000 residents prove to be quite inadequate. Overall, the figures show that all three examined cities require significant development in e-carsharing, which necessitates intervention from decision-makers and support for potential providers.

Comprehensive Overview of Budapest's Transportation Situation

Budapest, the capital of Hungary, with a population exceeding 1.75 million, has experienced substantial transformations in its public transportation system in recent years. The city's transportation network is traditionally centered around buses, trams, trolleybuses, and metro systems; however, carsharing services have been gaining increasing prominence. Sustainability considerations are obtaining priority, paralleling the increased adoption of electric vehicles and the integration of multimodal transportation options. Carsharing services, including GreenGo, MOL Limo, and Wigo, have been attaining firm foothold among the city's residents.

Growth of Carsharing Services in Budapest

In recent years, carsharing services have experienced significant growth in Budapest, in line with the city's commitment to promoting sustainable mobility. GreenGo, a carsharing provider exclusively offering electric vehicles, has steadily expanded its fleet since its launch in 2016 and currently it operates 470 fully electric vehicles across the city. In contrast, MOL Limo runs a mixed fleet, comprising both internal combustion engine (ICE) vehicles and electric cars. MOL Limo currently operates a fleet of 450 vehicles, 30% of which are electric, with the proportion of electric vehicles expected to increase in the coming years ("Finally Here: MOL Limo Strengthens Fleet with Suzuki," 2024; "MOL Limo Car-Sharing Service," 2024; "MOL Limo Expands Fleet with Mercedes Vehicles," 2018). Wigo, the most recent provider, manages a fleet of 500 vehicles, consisting of both internal combustion engine (ICE) and battery electric vehicles (BEV). A notable advantage of Wigo is its young fleet, with an average vehicle age of 18 months ("Introduction to Wigo," 2024).

The Expansion of Electric Vehicle Charging Networks and Infrastructure

The increasing adoption of electric vehicles poses new challenges for Budapest's urban infrastructure, particularly concerning the availability and density of charging stations. Many countries in the Central European region face comparable challenges, where regulatory gaps and underdeveloped infrastructure present significant obstacles (Horváth et al., 2023). According to EAFO data, in 2023 there were more than 731 public electric charging points in Budapest. The capacity of the charging infrastructure has experienced substantial growth in recent years, with charging stations providing an average power output of 22-50 kW. Nationally, the growth rate of charging infrastructure expanded by 15% between 2022 and 2023 ("The European Alternative Fuels Observatory provides comprehensive statistical data on all European Union member states," 2024), A total of 3,960 charging points were installed by Q3 2024, 21% of which are fast chargers. The most significant progress has been observed in Budapest ("MEKH Charging Points," 2024), particularly in the downtown areas where vehicle usage is the highest. In the future, the number of charging points is projected to continue increasing, with expanded coverage anticipated in suburban areas.

The Growth of Multimodal Transportation Options in Budapest

In Budapest, in addition to vehicle-sharing services, electric scooters and bicycles are assuming an increasingly significant role in urban transportation. The incorporation of electric scooters into urban transportation offers several advantages, particularly in addressing short-distance and rapid transit requirements. Electric scooters operate with zero emissions, thereby contributing to the enhancement of urban air quality (Pan et al., 2023). Their compact and easily maneuverable design makes them particularly advantageous in congested urban areas and regions facing parking challenges. Moreover, electric scooters contribute to alleviating traffic congestion, offering a sustainable alternative to car usage and thus enhancing both the efficiency and environmental sustainability of urban mobility (Venkatesh and Raslavičius, 2024).

Budapest is home to two prominent electric scooter-sharing providers. Lime, one of the largest operators, currently offers over 500 electric scooters, primarily in the central urban areas. The Lime service provides a fast and efficient transportation solution, particularly advantageous in densely populated city regions, where parking and mobility present significant challenges ("Introduction to Lime," 2024).

Tier is another major player in Budapest's electric scooter market. The company puts great emphasis on sustainability, with its scooters operating at zero emissions, thereby contributing to the reduction of environmental impact. The provider's electric scooters are primarily available in the city center, where they offer an effective alternative for short-distance transportation, addressing the growing demand for energy-efficient mobility solutions (Chou et al., 2023; "Introduction to Tier," 2024). However, in 2024, the Blinkee scooter-sharing service ceased operations in Budapest, leading to a marked reduction in the availability of electric scooters across the city ("Blinkee megszűnése," 2024). In the bicycle-sharing domain, MOL Bubi is a leading service provider. Since its launch in 2014, its fleet has steadily grown and now consists of 2,460 bicycles available for rent at 211 stations throughout the city ("Introduction to MOL Bubi," 2024; "MOL Bubi: Budapest's Greenest Public Transport Solution," 2024). In recent years, MOL Bubi has implemented significant upgrades, focused on modernizing its fleet and expanding its services. Future plans include the introduction of electric bicycles, which are anticipated to further increase the user base and enhance the system's attractiveness.

Sustainability and Strategic Future Directions In Budapest's Transportation Policy

Sustainability and environmental protection are anticipated to assume an increasingly fundamentalrole in Budapest's transportation policy moving forward at present. However, low-emission zones (LEZ) have not yet been implemented, nor have congestion charges been introduced, despite both measures being integral components of the city's long-term plans. The primary objective of these initiatives is to contribute to the reduction of carbon dioxide emissions and mitigate transportation-related challenges. Promoting vehicle-sharing services and reassessing parking regulations could also be pivotal to advancing sustainable urban mobility, potentially enhancing the appeal of public transportation while simultaneously reducing road congestion.

All three companies reported negative financial outcomes for the year 2023, albeit to varying extents. MOL Limitless Mobility Kft. experienced a comparatively smaller financial deficit, whereas WAMO and GreenGo Car Europe Zrt. faced more serious challenges, largely attributed to geopolitical and market dynamics. These outcomes underscore the precarious and uncertain economic landscape surrounding services focused on sustainable urban mobility ("Green Car Europe Zrt. Audited Annual Report," 2023; "Mol Limitless Mobility Kft. Company Data," 2023; "Wigo (Wallis Autómegosztó Zrt.) Annual Report," 2023).

In terms of workforce size, WAMO is the largest employer among the three, whereas GreenGo Car Europe Zrt. and MOL Limitless Mobility Kft. operate with comparatively smaller labor forces. This distribution of labor indicates that the various car-sharing providers adopt different approaches to organizing and developing their operations ("Green Car Europe Zrt. Audited Annual Report," 2023; "Mol Limitless Mobility Kft. Company Data," 2023; "Wigo (Wallis Autómegosztó Zrt.) Annual Report," 2023).

All three companies are confronted with challenges, including elevated costs, geopolitical risks, and market volatility. However, they strive to maintain and expand their activities through continuous improvements, aligning well with Budapest's transportation policy objectives. Vehicle-sharing services can not only render urban transportation more sustainable but also contribute to the enhancement of transportation infrastructure and urban quality of life. Moving forward, the synergy between transportation policy advancements and electric vehicle-sharing services is poised to play a central role in realizing Budapest's sustainability objectives.

The Evolution and Future Trajectory of Slovakia's Car-Sharing Market

In recent years, Slovakia's car-sharing market, particularly in Bratislava, has experienced significant transformation, which earlier studies did not foresee. The initially optimistic scenarios for the proliferation of car-sharing and its anticipated impacts on urban transportation. However, the COVID-19 pandemic unexpectedly disrupted these projections, leading to significant economic challenges for the sector. At present, only one microenterprise, ShareCar, operates in Bratislava's car-sharing market, offering a mere four electric vehicles ("Introduction to Sharecar.sk," 2024). This limited capacity is insufficient to address the city's mobility needs and clearly illustrates that the considerable potential within the market remains untapped (Roblek et al., 2021; Stahl, 2021). In Slovakia, the charging infrastructure for electric vehicles (EVs) is undergoing continuous expansion; however, the distribution of charging points remains insufficient for widespread adoption. According to EAFO data, as of Q3 2024, there are a total of 2,699 charging points in the country, with 31% being fast chargers. Given the city's automotive traffic, the number of charging stations in Bratislava calls for further development, rendering the expansion of charging infrastructure in the city critically important for advancing sustainable transportation. Increasing and optimizing the available charging points is essential (Dalyac et al., 2021), ensuring that users can easily access charging options, thereby supporting the proliferation of electric vehicles and the development of car-sharing services ("EAFO Number of Charging Points in Slovakia," 2024; Shipman et al., 2019). According to Statista, the annual growth rate (CAGR) of the car-sharing market in Slovakia is 11.82%, and revenues are expected to reach €12 million by 2028, while the number of users could approach 92,000. These figures indicate that the opportunities within the sector are immense; nevertheless, the current situation does not reflect this potential ("Slovakia Car-Sharing Report," 2024). To promote sustainable transportation, it is essential to develop the transport infrastructure alongside the implementation of appropriate car-sharing services and the establishment of electric charging stations, which would enable the wider use of zero-emission vehicles (Roblek et al., 2021; Stahl, 2021). According to a research by the Wuppertal Institute, the role of car-sharing becomes crucial for improving the sustainability of urban transportation, and optimizing existing models is necessary to enhance the efficiency of urban mobility (Rudolph et al., 2021).

The current market environment indicates an urgent need for governmental intervention, with the involvement of financially robust companies potentially representing a strategic approach to revitalizing the sector through concerted efforts. Car-sharing in Bratislava remains in its early stages, but if the necessary infrastructure and services expand, future growth could emerge as a realistic possibility.

The Current State and Future Prospects of Romania's Car-Sharing Market

Based on Statista data for 2024, Romania's car-sharing market is projected to witness dynamic growth, with anticipated revenues of €9.9 million by 2028 and an estimated user base nearing 77,000. This trend highlights that car-sharing serves not only as an alternative mobility solution but also as a fundamental pillar of sustainable urban transportation ("Romania Car-Sharing Report 2024," n.d.).

EAFO data for Q3 2024 indicates that Romania hosts a total of 3,922 electric vehicle charging points, with 36% classified as fast chargers ("EAFO Number of Charging Points in Romania," 2024). The number of charging points in the country is continuously increasing, which is a positive sign for sustainable transportation. However, the proportion of fast chargers indicates that developing the charging infrastructure is particularly important for ensuring that users can conveniently and quickly access charging options. In Bucharest, the number of charging stations is still considered low in relation to the city's automotive traffic, which hinders the widespread use of electric vehicles and the proliferation of car-sharing services.

Enhancing the city's charging infrastructure and optimizing the distribution of charging points are critical to advancing sustainable transportation (Dalyac et al., 2021; Mulder and Klein, 2024). These steps could contribute to a greater adoption of zero-emission vehicles and enhance the user experience in urban transportation. Future challenges include changes in consumer behavior, increasing market competition, and establishing appropriate legal frameworks to support car-sharing initiatives (Alanazi, 2023). The integration of urban transportation policies, increasing social acceptance, and the introduction of technological innovations are essential for the Romanian car-sharing sector to truly harness its potential and contribute to the development of sustainable urban mobility (Sarsia et al., 2023; Zhang et al., 2024b).

The situation of car-sharing services in Bucharest has undergone significant transformation in recent years. The initially launched GetPony and Spark services were suspended due to the COVID-19 pandemic and funding difficulties, leaving Citylink as the sole representative of the car-sharing segment in the market, with approximately 250 passenger cars ("Case study – Car Sharing," 2024). Citylink focuses on the use of hybrids, thereby prioritizing sustainability in urban transportation. In addition to car-sharing, Citylink also offers bicycle solutions, having deployed a total of 350 bicycles on the streets of Bucharest ("350 Citylink bicycles on the streets of Bucharest," 2024). The service aims to promote sustainable transportation while reducing urban traffic and air pollution. Users can easily rent cars and bicycles through a mobile application, allowing them to access transportation options conveniently and adapt flexibly to their needs.

The current landscape presents both challenges and opportunities, as Bucharest's car-sharing market remains in an early stage of development. Citylink's operations and the services it offers contribute to the sustainability of urban mobility, but the emergence of additional market players is also necessary to make car-sharing services more widely available and attractive to users. When developing future car-sharing models, it is imperative to account for the increasing demand for sustainable transportation solutions.

Key Challenges Facing e-Carsharing Adoption in the Central European Market

Electric carsharing presents potentials within the Central European transportation market, as examined in Hungary, Slovakia, and Romania. Recent research underlines both the advantages and challenges inherent in e-carsharing models. The primary aim of the conclusions and recommendations is to assist policymakers, service providers, and users in the effective development and widespread adoption of e-carsharing systems (Alanazi, 2023; Almutairi et al., 2023; Borghetti et al., 2023; Icaza-Alvarez et al., 2023).

The expansion of e-carsharing systems across Central Europe, particularly in Hungary, Slovakia, and Romania, presents substantial opportunities for the development of sustainable transportation infrastructure. E-carsharing presents substantial economic benefits for both users and service providers (Demirci et al., 2023), such as the purchase price, depreciation, insurance premiums, fuel expenses, and maintenance or repair costs (Shipman et al., 2019). Through e-carsharing services, users pay solely when they require a vehicle, leading to significant cost savings for individuals who utilize cars infrequently (Al-Ghaili et al., 2022; Hassan et al., 2024).

The advantages of such systems encompass reducing air pollution and alleviating traffic congestion, while simultaneously enhancing the efficiency of urban mobility (Jiang et al., 2023; Venkatesh and Raslavičius, 2024; Yassine et al., 2024). The lower operating costs of electric vehicles (EVs)—including charging and maintenance expenses—also enhance the economic competitiveness of e-carsharing compared to internal combustion engine (ICE) vehicles (Alanazi, 2023; Y. Wang et al., 2024). Nevertheless, the establishment and maintenance of adequate charging infrastructure, particularly in urban and suburban areas, represent a fundamental challenge to the widespread adoption and long-term viability of e-carsharing systems (Horváth et al., 2023; Shipman et al., 2019; Wu et al., 2024).

Consumer behavior and attitudes are pivotal in shaping the acceptance of e-carsharing. Proper information and education for consumers are essential for making car-sharing a part of their daily lives. Understanding the heterogeneous demand for electric vehicles (EVs) and the diverse user preferences is also a critical factor in the development of car-sharing services (Briguglio and Formosa, 2023; Dorji et al., 2023; Yang et al., 2024). User behavior, such as charging habits and car usage preferences, fundamentally influences the efficiency and sustainability of car-sharing systems (Esfandi et al., 2024; Zhang et al., 2024a).

The integration of electric vehicles into smart grids enhances both energy efficiency and grid stability, particularly through Vehicle-to-Grid (V2G) technologies, allowing electric vehicles to act as energy sources (Darani et al., 2021; Mulder and Klein, 2024; Sora et al., 2024). The development of charging infrastructure should also consider energy storage solutions and smart charging technologies, which contribute to reducing grid load (Huang et al., 2020; Neaimeh and Andersen, 2020). Divergent regulatory environments, high initial investment costs, and shifts in consumer behavior may also present significant obstacles to the widespread adoption of e-carsharing (Giannelos et al., 2024; Jafari Kaleybar et al., 2024). Understanding consumer habits is fundamental to the success of electric car-sharing systems and to the conscious transition of drivers to the everyday use of car-sharing. It is particularly important to encourage car users towards shared vehicles while striving to minimize the temptation for public transport users to switch to car-sharing (Dorji et al., 2023; Yang et al., 2024). Consumers who decide between public transport and car usage may be particularly sensitive to promotional offers and educational programs that can steer them toward e-carsharing. Although the development of infrastructure requires high initial costs, smart grids and appropriate charging systems play a key role in the sustainable development of car-sharing.

The benefits of car-sharing include not only economic advantages but also environmental gains, as electric vehicles help decarbonize the transportation system (Alanazi et al., 2024; Boudmen et al., 2024; Sultan et al., 2022). At the same time, the transition to shared cars does not come with benefits in every regard and aspect. It should be noted that the use of shared cars has a spatial limitation, as the services usually only extend within the defined boundaries of a city. Therefore, for intercity travel, using public transportation is essential for traveling without car ownership, which is not necessarily a more environmentally friendly mode of travel either (Pařil and Viturka, 2020).

User Habits and Attitudes

Consumer attitudes and behaviors are fundamental in the adoption and proliferation of electric carsharing systems. The increasing popularity of e-carsharing is closely linked to rising environmental consciousness, which concurrently drives demand for electric vehicles (Anastasiadou and Gavanas, 2022; Pan et al., 2023; Shipman et al., 2019; Wu et al., 2024). Predominantly, consumers continue to favor personal vehicle ownership, perceiving it as a symbol of autonomy and convenience.

The COVID-19 Pandemic changed numerous aspects of our lives – and urban mobility was no exception. Residents had to completely change their lifestyle and travel habits, some of which changes persisted even after the pandemic. For instance, the 15-minute city concept was created, the essence of which is that locations for everyday tasks should be accessible within 15 minutes – such as the workplace, shopping centers, and public spaces. The concept of the 15-minute city also helps to uplift the underdeveloped areas of the city (Mocák et al., 2022). One important factor in this could be e-carsharing services, which enhance urban mobility.

E-carsharing presents substantial economic benefits for both users and service providers (Demirci et al., 2023), such as the purchase price, depreciation, insurance premiums, fuel expenses, and maintenance or repair costs (Shipman et al., 2019). Through e-carsharing services, users pay solely when they require a vehicle, leading to significant cost savings for individuals who utilize cars infrequently (Al-Ghaili et al., 2022; Hassan et al., 2024).

For service providers, the lower maintenance costs of electric vehicles, coupled with reduced fuel expenses, provide additional economic advantages. Electric vehicles possess fewer mechanical components compared to traditional internal combustion engine (ICE) vehicles, thereby reducing the likelihood of breakdowns and minimizing the need for repairs (Saha et al., 2022). Moreover, the charging costs of electric vehicles are generally lower than those associated with traditional fuels, particularly when renewable energy sources are used (Demirci et al., 2024; Jafari Kaleybar et al., 2024).

Enhancing consumer awareness and effectively demonstrating the benefits of e-carsharing are critical to its successful adoption. This requires the provision of reliable and easily accessible services, with a strong emphasis on optimizing user experience (Han and Sun, 2024; Ma and Fang, 2022; Yang et al., 2024). Vehicle availability and the simplicity of booking processes are fundamental to the proliferation of e-carsharing, as consumers seek convenient access to these services (Adnan et al., 2023; Chamberlain and Majeed, 2022; Luo et al., 2023).

Moreover, the flexible utilization of e-carsharing systems can incentivize consumers to rent vehicles outside peak periods, thereby alleviating urban traffic congestion. Dynamic pricing models and optimized vehicle utilization can not only reduce costs but also help mitigate the strain on transportation infrastructure (Singh et al., 2022; Venkatesh and Raslavičius, 2024; Wang and Zhou, 2023; Yao et al., 2023).

The successful implementation of future urban mobility solutions necessitates a thorough understanding of consumer habits and attitudes, as these factors critically influence the sustainability and diffusion of e-carsharing systems (Horváth et al., 2023; Jakimowicz, 2022). Electric carsharing is not only suitable for meeting individual mobility needs but also contributes to the transformation of urban transportation, which is essential for a sustainable future.

Flexible Tariffs and the Opportunities of Vehicle-To-Grid (V2G) Technology

The e-carsharing system presents a sustainable transportation alternative while simultaneously encountering emerging challenges and opportunities. To maintain system efficiency and sustainability, it is imperative for providers to implement flexible tariff structures that incentivize users to adopt conscious charging behaviors. Such tariff models enable providers to optimize fluctuations in electricity consumption by tailoring pricing mechanisms to vehicle charging patterns (Giordano et al., 2023; Gomes et al., 2020; Jiang et al., 2023; D. Li et al., 2023). For instance, strategic scheduling of charging periods—during off-peak times such as daytime or night-time—can mitigate grid load, thereby bolstering the stability of urban energy systems (Ahmed et al., 2023; Mądziel and Campisi, 2023; Sharida et al., 2024; Shipman et al., 2019; Venkatesan et al., 2024; Zahler et al., 2024).

The integration of Vehicle-to-Grid (V2G) technology represents a critical advancement for e-carsharing systems. This technology enables electric vehicles to transition from mere energy consumers to dynamic energy sources, capable of feeding electricity back into the grid, thus alleviating grid strain during peak demand periods (Ali et al., 2024; Bernal-Sancho et al., 2023; Coban et al., 2022; Giannelos et al., 2024; Rao and Venkateshwarlu, 2024). Electric vehicles can reverse-feed energy into the grid, not only mitigating peak loads but also facilitating the seamless integration of renewable energy sources into urban energy infrastructures (Arandhakar et al., 2022; Mojumder et al., 2022; Srivastava et al., 2023).

Introduction of Ai-Based Systems and Data-Driven Decision Making

Electric vehicle-sharing systems hold a pivotal role in advancing sustainable urban mobility. AI-driven systems are indispensable for optimizing energy consumption, facilitating real-time decision-making, and enhancing urban transportation efficiency. Leveraging these systems, the energy demands of vehicles can be precisely forecasted, enabling the optimization of charging cycles and more efficient utilization of urban infrastructure (Al-Chalabi and Banister, 2022; Benysek et al., 2022; Pai and Senjyu, 2022; Park et al., 2022; Strepparava et al., 2022). Smart charging systems provide solutions enabling vehicle charging during off-peak periods, thereby mitigating network overload and preventing unnecessary energy consumption spikes (El-Hendawi et al., 2022; Ghotge et al., 2022; Nepal et al., 2022).

AI-powered fleet management systems optimize vehicle operations, enable intelligent route planning, and precisely forecast charging demands (Lam et al., 2022; Ouramdane et al., 2022). Intelligent fleet management enhances vehicle availability, reduces operational costs, and improves energy efficiency (Galan and Zuñiga-Vicente, 2023; Goh et al., 2022; Saad et al., 2022). AI-driven fleet management enables real-time vehicle tracking, facilitating rapid responses to emergent maintenance needs and system faults (Czarnecka et al., 2022; Minhas et al., 2022; Vilathgamuwa et al., 2022).

The integration of AI technologies in urban mobility not only enhances energy efficiency but also bolsters the reliability of transportation networks. Intelligent urban systems enable dynamic management of energy consumption, optimal route planning, and more effective utilization of renewable energy sources, thereby contributing to the development of sustainable urban transportation (Bohdanowicz et al., 2022; Khan and Masood, 2022; Sousa and Costa, 2022).

Recommendations for Decision-Makers

The effective advancement of electric carsharing systems in Central Europe necessitates strategic collaboration among policymakers, service providers, and end-users. This research aims to offer actionable recommendations for policymakers, recognizing their pivotal role in facilitating the widespread adoption of e-carsharing systems. While users may exhibit environmental consciousness, without robust government support, the economic feasibility of adopting these services remains compromised. Public policy objectives must be designed to incentivize car users to transition to e-carsharing systems, thereby reducing conventional vehicle reliance and advancing sustainable mobility.

Ensuring the long-term sustainability of electric carsharing necessitates the efficient integration of decentralized renewable energy sources (Adnan et al., 2023; Jafari Kaleybar et al., 2024; Luo et al., 2023; Mulder and Klein, 2024; Tomczewski et al., 2023; Z. Wang et al., 2024). The effective integration of these energy sources facilitates the development of sustainable transportation models (Chamberlain and Majeed, 2022; Korõtko et al., 2023; Lazović and Đurišić, 2023; Yao et al., 2023). These systems are confronted with growing uncertainties, particularly concerning renewable energy sources (Annamraju and Nandiraju, 2019a, 2019b; Fu et al., 2022). These challenges encompass market fluctuations and rapid technological advancements (Ahmed et al., 2024; Michalski et al., 2024)

Proactively steering drivers towards carsharing is paramount, especially through the targeted development of infrastructure. The deployment of smart grids and energy-efficient charging infrastructures is crucial for ensuring the system's effective functionality, supported by targeted educational initiatives and promotional incentives (Demirci et al., 2023; Dorji et al., 2023; Icaza-Alvarez et al., 2023; Tomczewski et al., 2023).

Optimizing the energy consumption of electric vehicles during connection enhances the efficiency of both residential and commercial energy management. Additionally, it contributes to reducing the carbon footprint of transportation, particularly when the electric energy is sourced from renewables such as solar, wind, or hydropower (Alfaverh et al., 2023; Boudmen et al., 2024; Hassan et al., 2024; Umoren et al., 2023), (Al-Ghaili et al., 2022; Kunatsa et al., 2024; Saha et al., 2022; Tahir et al., 2024). The integration of renewable energy sources further strengthens the sustainability of electric vehicles by mitigating greenhouse gas emissions (Abdelsattar et al., 2024; Alam et al., 2023; Sinha et al., 2023).

The successful realization of electric carsharing systems depends on policymakers and necessitates extensive infrastructure enhancement alongside political backing. Among the primary objectives is the expansion of the electric charging network, particularly in urban and suburban areas (Demirci et al., 2023; Dorji et al., 2023; Icaza-Alvarez et al., 2023; Tomczewski et al., 2023). The integration of smart grids and energy-efficient technologies, including Vehicle-to-Grid (V2G) systems, is vital for incorporating electric vehicles into the broader transportation ecosystem (Almutairi et al., 2023; W. Li et al., 2023; Yassine et al., 2024).

The role of policymakers is pivotal not only in facilitating infrastructure investments but also in streamlining and regulating the deployment of electric vehicles and charging stations (Horváth et al., 2023; Sousa-Dias et al., 2024). Moreover, it is essential to enact energy policy measures that incentivize the adoption of sustainable energy sources, fostering both the stability and efficiency of energy systems (Tantau et al., 2024; Liang et al., 2022; L. Wang et al., 2024; Reddy et al., 2023). Data-driven smart grids enhance the efficiency of energy utilization for electric vehicles and contribute to reducing grid load (Darwish et al., 2024; Esfandi et al., 2024; Muqbel et al., 2024; Venkatesan et al., 2024).

Financial incentives and subsidies, including green loans, tax exemptions, and governmental backing for renewable energy initiatives, could further accelerate the proliferation of electric car-sharing (Ahsan et al., 2023; Darani et al., 2021; Shipman et al., 2019). These measures would enhance the sustainability of urban mobility while simultaneously reducing reliance on conventional car usage (Demirci et al., 2024; Jafari Kaleybar et al., 2024; Jiang et al., 2023; Wu et al., 2024). To expedite infrastructure development, policymakers must ensure that providers have access to streamlined and efficient permitting administration processes for the installation of charging stations, particularly at strategic urban locations (Al-Ghaili et al., 2022; Annamraju and Nandiraju, 2019a; García et al., 2023; Hassan et al., 2024).

The smart city concept can positively influence the city from several aspects, including urban mobility. The establishment of a smart district has the potential to enhance the quality of life, thereby increasing its appeal. In the Czech Republic there is a smart city project, namely Špitálka, in Brno – the second biggest city of the country. This initiative aspires to mitigate mobility challenges by integrating housing units, social services, and shops within a single locale. Emphasizing sustainable mobility, the promotion of public transportation, as well as cycling and pedestrian pathways, is a critical element of urban revitalization. Through intelligent urban planning, reliance on private automobile travel is reduced through the establishment of essential facilities in proximity to residential areas. This strategy not only diminishes negative externalities such as environmental pollution but also decreases the time spent in transit (Neumannová, 2022). Overall, the smart city concept aims to enhance the efficiency and sustainability of transportation systems, thereby improving the quality of urban life. Therefore, government support for smart cities is essential, of which e-carsharing should be an important part.

The task of public policy decision-makers is to enhance the sustainability of the transportation system through the integration of electric vehicles and the reduction of traditional car usage. This requires comprehensive support for charging infrastructure, the development of the regulatory environment, and the introduction of innovative technological solutions and incentives that will result in a sustainable mobility system in the long term (Ahmed et al., 2024; Naidu et al., 2024; Sun et al., 2020; Tahir et al., 2024; Xu et al., 2022).

Future Research Directions

Central European countries, including Hungary, Slovakia, and Romania, exhibit distinct economic, social, and infrastructural conditions, all of which shape the efficiency and adoption of e-carsharing systems (Abdi, 2022; Borghetti et al., 2023; Icaza et al., 2023). Existing studies and data frequently offer generalizations that do not fully capture the region's specific contexts. Consequently, further empirical research is required to examine the specific circumstances of individual countries and cities, considering local regulatory environments, charging infrastructure availability, economic incentives, and the evolution of public transportation habits and preferences (Briguglio and Formosa, 2023; Han and Sun, 2024). Examining the role of car ownership as a status symbol is particularly important, as it can represent a substantial barrier to the widespread adoption of e-carsharing systems. In Central European culture, car ownership carries significant prestige (Morton et al., 2016). Thus, a detailed analysis of consumer attitudes is essential, alongside strategies aimed at diminishing the importance of this status symbol and fostering openness to electric carsharing services (Dorji et al., 2023; Muqbel et al., 2024). Demand-side energy management systems are assuming increasing significance as smart grids become more widespread (Bakare et al., 2023; Esfandi et al., 2024; Wang et al., 2023). Moreover, public policy and regulatory frameworks oblige careful consideration, as they can profoundly influence the development of e-carsharing systems, particularly through localized incentives and regulations (Darani et al., 2021). The following research directions are likely to be critical for the continued development of the e-carsharing market (Zhang et al., 2024b).

Central Europe's distinct economic, infrastructural and social conditions exert a substantial influence on the development and dissemination of e-carsharing models. The proliferation of e-mobility in this region hinges primarily on government support, infrastructure development, and public attitudes (Alanazi, 2023; Lu et al., 2024; Zhang et al., 2024b). Analyzing public policies and regulatory frameworks is crucial, as regulations, tax incentives, and other policy measures across different countries and cities can substantially influence the effectiveness of electric car-sharing systems (Mulder and Klein, 2024).

Future research must be grounded in comprehensive data collection, encompassing the analysis of vehicle usage patterns, charging behaviors, service demands, and cost-effectiveness (Abdi, 2022; Ghatikar and Alam, 2023). This approach would empower decision-makers and providers to implement targeted strategies for the development and optimization of e-carsharing systems, aligning with the specific challenges and opportunities within the region. For instance, localized data analyses could assist in identifying neighbourhoods with the highest demand for expanding charging infrastructure or regions where car-sharing services could be most effectively implemented (Almutairi et al., 2023).

Moreover, it is essential to investigate the social impacts of e-carsharing systems, particularly with regard to ensuring equitable access for diverse social groups and their potential role in mitigating social inequalities (Singh et al., 2022).

Consumer attitudes and technological advancements are intrinsically connected to the future expansion of e-carsharing systems (Sun et al., 2020). In Central Europe, where car ownership traditionally carries high prestige, it is crucial to develop a deeper understanding of consumer behaviors and attitudes to facilitate the widespread acceptance and adoption of e-carsharing systems. Future research should focus on consumer behavior and preferences, particularly regarding the acceptance of electric vehicles and shared mobility services (Khan et al., 2024). The technological advancements and decreasing costs of electric vehicles significantly contribute to the future of sustainable mobility. The development of energy transfer technologies for electric vehicles promotes sustainability and cost reduction for fleet service providers (Rene and Fokui, 2024). Privacy issues and cybersecurity also require significant attention with the growth of e-carsharing systems, especially concerning the rise of AI and autonomous vehicles. This research provides recommendations for decision-makers, as they are the key participants in the success of e-mobility. Without adequate government support, e-carsharing services cannot be profitable, thus hindering providers from promoting the widespread adoption of e-mobility. For users, the economic viability holds equal importance alongside sustainability and environmental protection. Future research must concentrate on consumer behaviors and preferences, especially in relation to the acceptance of electric vehicles and shared mobility services.

CONCLUSIONS

Electric carsharing systems in Central Europe currently occupy a mixed and relatively minor role in advancing sustainable mobility, particularly in Hungary, Slovakia, and Romania. While e-carsharing systems offer substantial economic advantages, they also encounter numerous challenges in the region. The diffusion and acceptance of electric vehicles are shaped by diverse social, economic, and infrastructural factors specific to the area.

Infrastructure development plays a pivotal role in the success of electric car-sharing, particularly with respect to the expansion of charging networks and the integration of renewable energy sources. The study emphasizes that government regulation and support mechanisms are critical incentives for promoting market growth. An analysis of public policy and regulatory frameworks reveals how different approaches in various countries—such as state support and environmental regulations—directly influence the diffusion and effectiveness of e-carsharing services.

Consumer attitudes heavily influence the acceptance of electric car-sharing. In Central Europe, where car ownership traditionally functions as a status symbol, this perception presents a significant barrier to the widespread adoption of e-carsharing. Gaining a deeper understanding of consumer behaviors and attitudes is crucial for providers to formulate strategies that mitigate the prestige attached to car ownership and foster openness toward electric car-sharing.

The study also highlights the potential for incorporating AI-based systems and data-driven decision-making in electric car-sharing. Intelligent energy management and fleet optimization will be key to future progress, enhancing both efficiency and cost-effectiveness. The deployment of artificial intelligence can significantly contribute to the sustainability of electric vehicles, optimizing energy use and aligning services more effectively with consumer demands.

In conclusion, the development of electric carsharing in Central Europe is a complex, multi-dimensional process shaped by a variety of economic, social, and technological dynamics. The findings indicate an urgent need for future research focused on localized data collection and analysis, which would enable decision-makers and providers to effectively support the further expansion and sustainable evolution of e-carsharing systems. Successful integration will require an interdisciplinary approach that brings together technological innovation, changes in consumer behavior, and the management of regulatory and infrastructural challenges.

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