doi: 10.46793/EEE24-1.22F

Originalni naučni rad

UDK 620.9:[629.33:621.33(497.11)

Unravelling the Serbian Energy Transition Puzzle: Driving an Electric Vehicle Result in Higher CO2 Emissions than Driving a Traditional Internal Combustion Engine Counterparty

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Abstract – This article delves into the intriguing paradox emerging in Serbia's transportation landscape, where electric vehicles (EVs) are projected to generate more carbon dioxide (CO2) emissions than internal combustion engine (ICE) until 2030. Driving an EV within Serbia over the upcoming five years is estimated to contribute to roughly 25% more CO2 emissions compared to ICE vehicles. The study unveils the underlying factors behind this paradox, including Serbia's energy mix dominated by lignite. By contrasting this with the European Union's cleaner energy sources, the article underscores the delayed CO2 emissions reduction from EVs in Serbia. Furthermore, it explores the carbon footprint associated with EV production and highlights the challenges posed by the country's energy infrastructure and vehicle fleet. The article concludes with insights into potential solutions, emphasizing the need for Serbia to accelerate its transition to renewables, aiming to align with 2030 targets, while parity with EU emissions levels is projected by 2040.

Index Terms – Energy, Sustainability, Carbon emissions, Electric vehicles

I Introduction

Electric vehicles are often seen as a promising solution to achieve sustainability and energy transition across industries, which have sparked many discussions regarding their efficiency in terms of decarbonisation, cost to produce and drive, and widespread use. Due to Serbia's unfavourable energy composition heavily reliant on lignite, driving electric vehicles over the next six years is estimated to contribute to CO_2 emissions approximately 25% more than driving internal combustion engine vehicles, necessitating the energy transition based on the accelerated shift towards renewable energy sources. Compared to the European Union residents and businesses usually experiencing reduced CO_2 emissions from driving electric vehicles after the second year of their use, Serbia's energy system is yet to attain parity with EU and achieve its emissions levels.

Therefore, the purpose of this article is to provide comprehensive insights into demystifying the Serbian energy transition puzzle rooted in the projection that electric vehicles (EVs) will produce higher carbon dioxide (CO_2) emissions than internal combustion engine (ICE) vehicles until 2030. This paper presents a synthesis of the most recent research on EVs, investigates energy production in Serbia, and reveals the potential for optimizing the utilization of EVs both domestically and globally. Further, the paper lays out proposed solutions for the energy transition and aims to integrate EVs seamlessly into Serbia's energy landscape.

II Literature Review

The comparison of CO_2 emissions from EVs and ICE vehicles, particularly in the context of proper energy mix and sustainable transportation, has garnered a lot of attention from researchers and experts worldwide. Numerous studies have addressed the complex interplay between vehicle technology, energy sources, and emissions reduction, shedding light on the factors influencing the Serbian energy transition puzzle and wider deployment of EVs [1].

The latest research provides a framework to assess EV emissions throughout their life cycle, considering energy sources and manufacturing procedures, and emphasizing the critical role of the energy mix in determining the overall environmental impact of EVs [2, 3]. The CO_2 emissions resulting from the production and operation of EVs are inextricably linked to the dynamic nature of energy transitions and the optimized energy mix [4, 5], particularly when considering factors such as spare parts production, energy generation, waste from roads, and others [5, 6]. Thus, promoting EVs as a sustainable transportation solution, without considering the total CO_2 emissions dispersed across different lifecycle phases, could obscure our vision, and potentially lead to misunderstandings regarding the importance of the energy mix [7]. Nevertheless, recent research on replacing ICE vehicles with EVs in the United States, Poland, and Brazil, has highlighted the promising future of EVs in terms of emission reduction [6, 8, 9], especially when reinforced by an energy transition and a shift towards renewable energy sources. Additionally, the benefits of energy transition have also been pointed out in the special reports published by the International Renewable Energy Agency and the Intergovernmental Panel on Climate Change – IPCC.

Concerning the specific instance of Serbia, recent studies have examined the CO_2 emissions consequences associated with adopting EVs in relation to the country's energy mix [10,11]. These studies underscore the requirement for a shift to more environmentally friendly energy sources to realize the emissions reduction potential of EVs in Serbia, even providing a timeline for when EVs could turn environmentally advantageous in the country. However, the necessity of transitioning from ICE vehicles to EVs has not been sufficiently acknowledged in Serbian legislation, a critical aspect for EVs to become a key player in the nation's energy and transportation sectors [12]. Consequently, both the energy transition and the deployment of EVs are gaining traction, as confirmed by official data from UNDP Serbia advocating the need for reducing CO_2 emissions. Several other authors, in addition to UNDP Serbia, have published research and case studies highlighting the urgency of long-term planning for carbon emissions reductions, which further underscores the pressing need for energy transition [14-16].

III The Structure of Energy Production in Serbia

According to the official data, Serbia's energy system is characterized by a mix of various energy sources, with a notable presence of coal and lignite in the electricity generation [17, 18]. Key components of Serbia's energy system include [17]:

- Coal,
- Natural gas,
- Hydroelectric energy,
- Renewable energy and biofuels.

Historically, coal has been the primary energy source in Serbia, forming the bedrock of electricity and heat energy production. Notably, lignite, a type of brown coal, is abundant in the country and contributes significantly to power production [18]. Consequently, Serbia generates roughly 65-70% of its electricity primarily from low-calorific-value lignite in aged plants with suboptimal efficiency. This scenario results in considerably higher CO_2 emissions per MWh in Serbia than in most European countries [19, 20], as depicted in Figure 1. In addition, natural gas, which is mainly utilized for heating and industrial processes, also contributes to electricity generation, albeit to a lesser degree than coal and lignite, currently accounting to approximately 3-5% of Serbia's electricity production [18, 19].

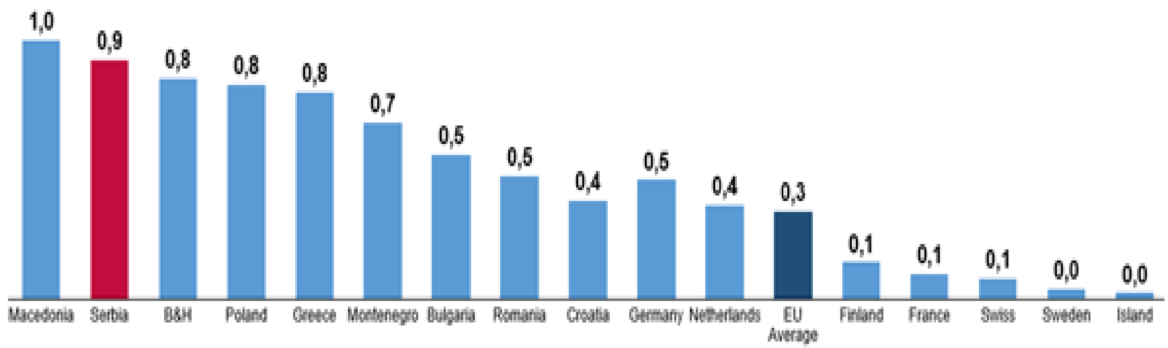

Figure 1. Emissions of tons of CO_2 per 1 MWh of electricity produced in 2019 [20]

Altogether, Serbia produces 0.9 tCO2/MWh [20], but this figure could potentially be even higher. A study conducted by the International Renewable Energy Agency estimates emissions of approximately 1.1 tCO2/MWh for electricity and heat production (see Figure 2) [21], necessitating new strategies for assembling the energy puzzle, predominantly based on renewable energy.

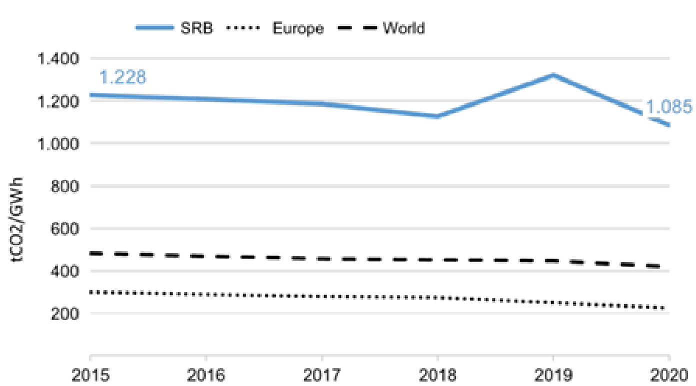

Figure 2. CO_2 emission factor for electricity and heat generation [21]

Serbia has been progressively increasing its utilization of renewable energy sources, including hydropower, wind power, and solar power [17-19]. Hydropower, being one of the oldest and most established renewable energy sources in the country, accounts for a significant portion of electricity production, contributing 25-30% to overall electricity generation. The combined contribution of wind and solar power to total electricity generation remains below 1% and can only exceed this benchmark when combined with biogas production [17,18]. Serbia has also demonstrated interest in nuclear energy and has contemplated the construction of nuclear power plants as a low-carbon energy source. To date, however, the country does not have operational nuclear power plants.

It's noteworthy that Serbia also imports a portion of its electricity from neighbouring countries to satisfy its energy needs and exports the surplus electricity generated, thereby maintaining the sustainability of the Serbian energy sector.

IV CO_2 Emissions of Electric Vehicles vs. Fossil Fuel Vehicles

For several decades, ICE vehicles have formed the foundation of global transportation, substantially contributing to the convenience and mobility of contemporary societies. However, the rise of ICE vehicles has sparked significant environmental concerns, particularly pertaining to their CO_2 emissions and the subsequent impact on climate change. Contemporary trends lean towards replacing ICE vehicles with EVs, but since the production and operation of both EVs and ICE vehicles result in CO_2 emissions, there's a genuine need to evaluate these in the context of sustainability and overall lifecycle emissions reduction.

Early research conducted by the Argonne National Laboratory in Chicago, renowned for its pioneering models in this area and affiliated with the US Department of Energy, reveals that manufacturing an average EV results in roughly 8.1 metric tons of CO_2 emissions, whereas the production of ICE vehicles entails emitting around 5.5 metric tons of CO_2, ICE vehicle production entails approximately 5.5 metric tons of CO2 emissions, underscoring the difference in emissions associated with distinct vehicle propulsion technologies [11, 22]. Thus, the production of an average EV generates around 2.6t CO_2 emissions more than production of an average ICE vehicle. This discrepancy primarily stems from the heightened emissions necessitated by the mining and processing of lithium and other ores crucial for producing electric vehicle batteries, along with the battery size and technology used in manufacturing. Additionally, while conventional ICE vehicle production has been in existence for an extended period, EVs production represents somewhat novel and promising technology set to revolutionize not only transportation but also society in general. Numerous authors recommend greater investment in EV technology and its key components, particularly batteries, and suggest that under certain conditions, EVs are substantially more efficient and counteract carbon emission more than ICE vehicles [23].

Concerning the driving phase of EVs or ICE vehicles, differing perspectives exist favouring one or the other in terms of CO_2 emissions and overall efficiency. The CO_2 emissions related to ICE vehicles stem from the combustion of fossil fuels, namely gasoline and diesel. Despite improvements in engine efficiency and emission control technologies, ICE vehicles continue to be a significant source of human-induced CO_2 emissions, thereby adding to global greenhouse gases (GHGs) accumulation. These emissions are influenced by various factors, such as engine design, vehicle weight, driving patterns, and fuel quality. While modern ICE vehicles are equipped with emissions control systems to mitigate pollutant releases, these measures often fall short in substantially reducing CO_2 output. Furthermore, the efficiency gains attained by the automotive industry in recent years have been partially nullified by the growing demand for larger, more powerful vehicles, underlining the intricate interaction between technology advancements, consumer preferences, and environmental objectives.

On the other hand, EVs are revolutionizing the industry and shifting the focus to sustainability ingrained in every facet of transportation paradigms [24]. The prevailing belief is that EVs emit no greenhouse gases, which is typically underscored as their primary advantage in reducing CO_2 emissions and positively affecting climate change. Consequently, EVs are viewed as the future of transportation and a cornerstone of the green transition. However, the flip side presents the challenge of electricity production necessary to charge EVs, which is not always environmentally friendly, posing a hurdle that many countries, including Serbia, find hard to overcome. Charging EVs typically involves multiple processes such as mining, ore processing, electricity generation, storage, and transmission, all of which result in sizeable GHG emissions [24]. Therefore, the total emissions derived from driving EVs are more complex to understand than initially perceived, and the reduction of CO_2 emissions from EVs hinges on the electricity generation mix, which differs across countries [7, 24]. According to recent studies, Serbia is among European nations with the highest proportion of fossil fuels in electricity generation, making the dream of transport electrification less feasible without a proper energy transition [24]. If we look at the average emissions data, prevalent ICE vehicles in Serbia, such as Volkswagen Golf, Skoda Fabia, and Skoda Octavia, produce between 110 to 134 gCO_2/km and, given the country's average consumption rate of ~0.17 kWh per 1 km drive and 0.9t/MWh CO_2 emissions, driving EVs in Serbia generates in average of ~150 gCO2 / km [25]. This factor implies that using EVs causes around 20 gCO_2/km more emissions than using prevalent ICE vehicles in Serbia. As such, the unique Serbian energy puzzle impacts the EV driving landscape, differentiating the country from EU nations where EVs, due to lower carbon intensity of their energy mix, have lower CO_2 emissions after just the second year of usage [2,7,24].

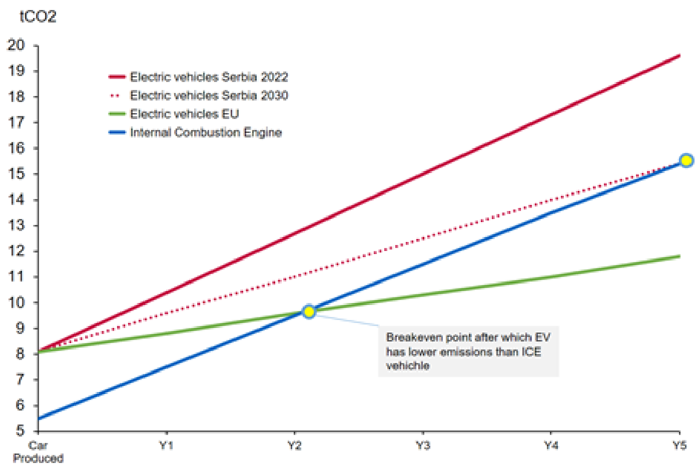

Figure 3. CO_2 emissions vs. Years of Driving

Despite the relatively low CO_2 emissions from the ICE vehicles predominantly used in Serbia, a pressing need exists for sustainable transportation solutions and an urgent transition towards low-carbon alternatives such as EVs, plug-in hybrids, hydrogen-powered vehicles, etc.

V EV Charging Infrastructure and the Vehicle Landscape in Serbia

Long journeys with EVs pose a challenge in Serbia, necessitating careful planning for the expansion of EV charging networks across the country. The current paucity and occasional unreliability of EV charging stations intensifies the dilemma for wider EV deployment and consumer interest, leaving drivers uncertain about whether to switch to EVs and act responsibly or stick with ICE vehicles for convenience. Consider this scenario: with only 20% battery charge remaining, a stop for charging on the highway is necessary. However, one may encounter a situation where one charging station is out of order, and another is occupied by an EV, resulting in an unexpected wait time of at least 30 minutes. A more dire situation arises when a non-operational charger disrupts the plan, leaving the EV stranded far from the nearest working station. As such, the density and reliability of charging infrastructure, which are presently inadequate, need to be addressed through legislative measures and practical initiatives to bolster the EV landscape in Serbia.

A noteworthy effort to address this challenge is Serbia's adoption of the Law on Energy of the Republic of Serbia, which establishes rules for charging infrastructure and providers [12]. This is in alignment with the European Union's plans to install EV chargers every 60km on all Class I roads (highways) before 2026, setting an encouraging timeline for substantial charging infrastructure expansion and the achievement of agreed upon sustainable development goals [12,26]. Serbia aspires to set up charging facilities not only at gas stations but also at nearly 20 highway rest areas and toll booths, positioning the country on par with the European Union and the United States in similar pursuits. Additionally, private energy companies, led by Naftna Industrija Serbije a.d. Novi Sad, play a significant role in expanding charging infrastructure as addressed in their sustainable development strategies [26-28]. It is also worth noting that besides Naftna Industrija Serbije a.d. Novi Sad, several other petroleum giants, along with private investors and entrepreneurs, are entering the EV charging arena [26].

Nevertheless, prevalent challenges with charging infrastructure persist. While recent legal provisions in Serbia are commendable, additional regulatory strides are essential to facilitate the economical charging of EVs. The existing legislation lacks the necessary framework for electric energy transactions pertaining to EV charging. This development is not only favorable for enhancing EV adoption but is also critical for maintaining revenue from tolls for foreign vehicles traversing Serbia. In contrast to the scarcity of EVs in Serbia's vehicular landscape, Western Europe's more prominent EV penetration and cleaner energy mix have prompted a substantial proportion of new vehicle registrations - 13.9% in 2023, with EVs commanding a 14.6% market share [29]. Meanwhile, EVs account for less than 1% of the total vehicles registered in Serbia [30].

As of February 2024, Serbia's total EV population is approximately 2,700 vehicles, with an annual growth of almost 60%, and it also hosts 18,000 hybrid vehicles, with an annual growth rate of nearly 30% [30]. Notably, the number of EVs and hybrid vehicles is on the rise, influenced to some degree by the state granting owners similar incentives to purchase EVs or plug-in hybrid vehicles, including purchase incentives and reduced registration costs. However, there is currently just one EV charging station per 100,000 citizens, calling for immediate action to meet previously set goals regarding charging infrastructure accessibility [30]. Another distinct challenge arises from Serbia's purchasing power landscape. According to the Strategy on Traffic Safety of the Republic of Serbia, the average vehicle age fluctuates between 15 and 17 years each year, and import practices predominantly rely on sourcing used vehicles from EU countries [17, 31]. Thus, expecting the inevitable increase of EVs, the primary charging context should lean towards residential and commercial properties, mirroring trends in Europe and the United States, which could also be influenced by consumers' purchasing power and the lack of an initial investment to install a home charger. These findings underscore the pivotal role of state regulations in determining infrastructure priorities.

Furthermore, the inevitable degradation of older EV batteries, which results in reduced range throughout the battery lifetime, poses a dilemma concerning proper disposal, not only in Serbia but globally. The current state of battery recycling technology only exacerbates this issue, highlighting the importance of holistic solutions in correlation with the expansion of the EV market.

VI TRANSITIONING ENERGY PRODUCTION

The transition towards sustainable energy production is a complex and challenging endeavour, characterized by neither low cost nor swift implementation, neither low cost nor rapid implementation, much like other aspects of the energy transition. A crucial first step involves curbing the carbon dioxide (CO_2) emissions from Serbia's energy system. Given the constraints of resource availability, particularly the prevalence of domestically sourced lignite, and probable limitations in improving thermal capacity efficiency, a practical solution involves phasing out or reducing dependence on existing thermal facilities. The subsequent priority is the establishment of new power capacities derived from renewable sources such as wind, solar, and hydroelectric power. Clearly, Serbia is actively steering its energy trajectory towards these objectives and is striving to transform its energy system to generate cleaner energy and support a sustainable future for all. Thus, the Electric Power Industry of Serbia (EPS) has unveiled an ambitious roadmap through the "Go Green Road" initiative, strengthened by its partial integration into the official documentation of the Ministry of Energy. Government-led market premium allocations have resulted in the division of quotas, with 400MW allocated for wind energy and 12MW for solar energy.

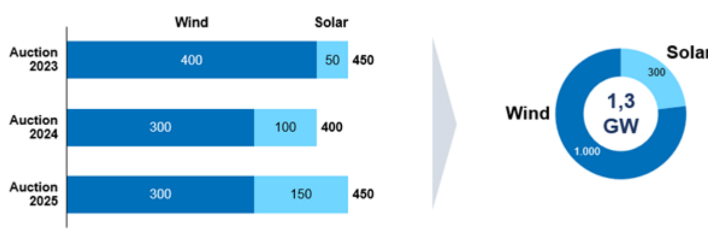

Figure 4. Quotas for RES auctions, MW

Additionally, the Serbian government's recent call for tender submissions for the construction of 1GW solar capacity, including 200MW battery storage, underscores the country's momentum. Notably, private businesses are also converging on solar and wind projects, highlighting the transition from aspirations to concrete projects. This shift towards sustainable energy isn't just strategic but is supported by detailed project designs. Projections indicate the overall expense of this transition, estimated at approximately €11 billion based on internal calculations, additionally factoring in construction costs and reinforcement of the transmission network. The ensuing challenge lies in synchronizing the energy system amidst increasing supply from wind and solar sources, necessitating system balance and enhanced transmission capabilities. The culmination of this renewable energy integration is expected to occur around 2030, with the addition of an extra 3GW of renewable capacity to Serbia's energy mix. This point is predicted to create a scenario where EVs become a prudent choice, gradually compensating for the CO_2 emissions difference vis-à-vis internal combustion engine vehicles.

Another aspect of the sustainable energy discourse is the technology of carbon capture, utilization, and storage (CCUS). By capturing CO_2 emissions from the chimneys of thermal power plants and storing them in geologically suitable reservoirs, the CO_2 emissions from electricity generation can be mitigated. Notably, CCUS technology is approaching feasibility in Europe, as evidenced by its near-profitability, driven by a carbon tax exceeding €90 per metric ton of CO_2. If Serbia were to implement a similar carbon tax regimen, dependent on the introduction of the Carbon Border Adjustment Mechanism (CBAM) and the Clean Development Mechanism (CDM), CCUS technology's prospects within the country appear promising [32].

Individuals possessing residential solar panels and a compatible energy storage system represent an ideal group to adopt EVs, offering the privilege of lower emissions even within the initial kilometres of travel, and a notably reduced cost for charging their EV. Similarly, businesses advocating for environmentally conscious practices can also capitalize on this synergy between renewable energy and EVs. Enhancing this trajectory involves improving the energy utilization efficiency of EV batteries, currently estimated at around 0.17 kWh per kilometre. Nevertheless, it is crucial to acknowledge that advancements in the efficiency of internal combustion engines can also significantly reduce exhaust emissions, as demonstrated historically. In conclusion, the shift towards cleaner energy production remains a complex yet essential endeavour for Serbia, reliant on a symbiotic relationship between the deployment of renewable energy, emission mitigation, and sustainable transportation paradigms.

VII Conclusion

This study illuminates the intricate relationship between electric vehicles (EVs), carbon dioxide (CO2) emissions, and Serbia's distinct energy landscape. At the intersection of these three elements, the "Serbian energy transition puzzle" emerges and poses a challenge necessary to surmount in the coming years - despite all green initiatives, EVs are projected to emit more CO2 than ICE vehicles until 2030. This paradox, anchored in the country's unfavourable energy mix, emphasizes the crucial role of altering energy sources to attain environmental benefits and facilitate transportation electrification.

The importance of recognizing the transitional nature of adopting and driving EVs in Serbia, which could serve as a harbinger of more sustainable transportation and society in general. While the current energy mix impedes immediate emissions reductions, it also offers a key opportunity for learning from global best practices. Therefore, Serbia's delay in transitioning to EVs allows the country to bypass the challenges encountered by early adopters, enabling a smoother integration of cleaner technologies. A promising opportunity also lies in expanding the EV charging infrastructure and supporting the installation of EV chargers and the placement of solar panels at individual homes, thus creating a landscape that encourages EV use and facilitates the integration of EVs into everyday activities. Lastly, emerging technologies such as CCUS, hydrogen-powered vehicles, synthetic and biofuels, among others, also present potential solutions to mitigate emissions from both the energy and transportation sectors.

As Serbia aligns its trajectory towards sustainable transportation and renewable energy sources, governmental interventions, and further infrastructure development play key roles. Therefore, to harness the full potential of EVs, it is essential to introduce policies and practices that respect emerging energy and transportation needs, streamline the energy mix, and increase the availability of resources required to purchase, charge, and drive EVs. In conclusion, the future of EVs in Serbia is promising and will become more apparent as the benefits of the energy transition permeate into transportation, facilitating the use of EVs.

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Rešavanje zagonetke energetske tranzicije Srbije: Vožnja električnim vozilima dovodi do veće emisije CO_2 nego vožnja tradicionalnih vozila sa SUS motorom

Rezime - Ovaj se članak bavi veoma zanimljivim paradoksom koji se pojavljuje u sferi saobraćajnog prevoza u Srbiji, koji predviđa da će električna vozila proizvoditi više emisije ugljen-dioksida (CO_2) nego motor sa unutrašnjim sagorevanjem (SUS) do 2030. Procenjuje se da će vožnja električnim vozilima u Srbiji tokom predstojećih pet godina za približno 25% povećati emisiju CO_2 u poređenju sa vozilima pogonjenim SUS motorima. Ovo istraživanje otkriva osnovne faktore koji stoje iza ovog paradoksa, uključujući energetski miks Srbije kojim dominira lignit. Upoređujući ovo sa čistijim izvorima energije Evropske unije, članak naglašava odloženo smanjenje emisije CO_2 iz električnih vozila u Srbiji. Štaviše, istražuje karbonski otisak povezan sa proizvodnjom električnih vozila i naglašava izazove koje predstavljaju energetska infrastruktura i vozni park u zemlji. Članak se završava uvidom u potencijalna rešenja, naglašavajući potrebu da Srbija ubrza svoj prelazak na obnovljive izvore energije, sa ciljem da se uskladi sa ciljevima do 2030. godine, dok se paritet sa nivoima emisija u EU predviđa do 2040. godine.

Ključne reči - energija, održivost, emisije SO2, električna vozila