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Research Article

Energy sources as a function of electric vehicle emission: The case of Bosnia and Herzegovina

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ABSTRACT

This paper deals with the analysis of challenges and perspectives of the transition to electric vehicles as a sustainable solution for the transport sector in the context of global energy challenges and the need to reduce negative environmental impacts. With an emphasis on the energy situation in Bosnia and Herzegovina, the paper explores the possibilities of switching to electric vehicles (EVs) and analyses the effects of energy sources on CO_2 emissions. The paper highlights the motivation to switch to EVs, driven by the need to reduce greenhouse gas emissions and rely on renewable energy sources. After analysing relevant studies, it is concluded that smaller and lighter electric vehicles have lower CO_2 emissions and that the participation of renewable sources in electricity production reduces these emissions. The conducted analysis of the vehicle fleet specifies that the CO_2 emissions of electric vehicles are not zero and that they depend on the source of electricity. Furthermore, other factors, such as the production of batteries, also play an important role in the overall environmental impact. Although the motivation to switch to electric vehicles is emphasized to reduce greenhouse gas emissions and use renewable energy sources, it has been shown that the CO_2 emissions of electric vehicles (EVs) are not zero and significantly depend on the energy sources. Calculations performed on the vehicle fleet of the Federation of Bosnia and Herzegovina for the year 2021, using Copert as the tool, showed that vehicles driven by fossil fuels emit about 1.6 million tonnes of CO_2. In comparison, if all vehicles were replaced with electrical ones, the CO_2 emissions would be about 1.15 million tonnes. As for the required electricity to power EVs, it is calculated that the required amount would be about 1,539 GWh per year. This paper acknowledges the presence of emissions associated with battery production, storage, and disposal, as well as vehicles themselves. However, it does not delve into this issue in detail. Future research will aim to address this matter more thoroughly.

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INTRODUCTION

In today's world, we are encountering significant energy challenges that require sustainable solutions to minimize the adverse impact on the environment. The transition in the transport sector is one of the primary concerns, as it contributes to harmful gas emissions and air pollution. Therefore, shifting to electric vehicles (EVs) is crucial in achieving sustainable mobility and reducing environmental impact. This paper will discuss the energy challenges of transitioning to electric vehicles. We will focus on the global situation, specifically in the European Union and Bosnia and Herzegovina. We aim to explore this transition's advantages, challenges, and possibilities towards a more sustainable future. We

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hope to provide insight into this crucial step's current state and perspectives. The motivation to transition to electric vehicles stems from the growing awareness of climate change and the need to reduce emissions. Vehicles with engines that use fossil fuels by the nature of their operation emit exhaust gases that have a harmful effect on air quality and human health. The transition to EVs should make it possible to reduce dependence on fossil fuels, which would achieve a reduction in the emissions of CO_2 and other harmful substances from exhaust gases. However, the transition to EVs faces challenges. Adequate charging infrastructure is essential to ensure electric vehicles' practicality and reliability. Issues related to vehicle range and battery charging time and questions about the sustainability of battery production and waste management need to be addressed.

Research carried out in China [1] considered the influence of the vehicle category, the origin of the source of electricity used to charge electric vehicle batteries, and the technology used to produce batteries for electric vehicles on Carbon emissions. The results indicate that smaller and lighter vehicles have lower CO_2 emissions than larger and heavier ones. Also, the CO_2 emissions of electric vehicles depend on the share of energy sources in electricity production. These findings highlight the importance of optimising battery technology, battery manufacturing materials and vehicle energy efficiency to reduce CO_2 emissions in electric mobility. A similar study was conducted in Poland [2], where CO_2 emissions were also analysed from vehicles using fossil fuels and EVs. It has been concluded that introducing EVs in regions that rely on non-renewable sources of electricity, like coal, leads to higher CO_2 emissions than in regions that use renewable energy sources for electricity production. The usage of renewable energy sources does not contribute to additional CO_2 emissions. The use of batteries for EVs and their impact on the environment is shown in the example given in the research [3], where it is stated that the production and application of batteries also significantly impact the environment. In particular, the materials used in batteries are harmful to human health and the environment. The research focused on two types of batteries: $LiFePO_4$ batteries and $Li(NiCoMn)O_2$. The results show that $LiFePO_4$ batteries are more environmentally friendly in the production phase, while $Li(NiCoMn)O_2$ batteries are more environmentally friendly in the exploitation phase. Despite this, from a life cycle perspective, $LiFePO_4$ batteries are generally more environmentally friendly than $Li(NiCoMn)O_2$ batteries. Another research assesses various methods of recycling waste lithium-ion batteries, employing a multi-criteria decision-making approach. The study concludes that direct recycling exhibits advantages, particularly in environmental impact and technical, economic, and social aspects, despite its reliance on specific cathode materials [4]. Direct recycling aims to recover the cathode material without any chemical change in the structure of the recovered material and to produce new batteries by renewing them. The study [5] delves into diverse battery technologies for electric vehicles (EVs) and hybrid electric vehicles (HEVs). It highlights their benefits and drawbacks, focusing on aspects like energy density, costs, efficiency, and temperature range. The conclusion underscores the significance of EVs and HEVs in reducing noise, fossil fuel consumption, and environmental pollution in transport. However, it emphasizes the importance of advancing battery technology, which is crucial in determining vehicle range and performance, and acknowledges the high cost of batteries as a key challenge. The studies mentioned above [1–5] agree that EVs can have a lower pollution level than the vehicles using fossil fuels but that the source of electricity largely influences this. According to these studies, pollution reduction is achieved only when the sources of electricity are decarbonised. In the study given in [6], the authors consider that recent studies that have questioned whether driving EVs emit less greenhouse gases or whether we should wait for further decarbonization of electricity have several shortcomings. According to them, proper calculations show that EVs already emit less than half of the greenhouse gases than those using fossil fuels. Speculating on a future where production and driving are done using renewable energy results in at least ten times fewer emissions than vehicles using fossil fuels. This study lists six biggest mistakes in studies that claim EVs have greenhouse gas emissions similar to vehicles using fossil fuels. However, one gets the impression that the researchers in the study mentioned above [6] focused on geographical areas where significant progress has already been made in the decarbonization of electricity, which means that they relied on electrical grids with a high share of renewable energy sources. It is important to note that it cannot be concluded that this study considered areas where coal is still the dominant source of electricity. For this reason, the results of this study should be taken with a certain amount of caution. It is important to note that findings cannot be applied to regions or countries where coal is still intensively used to generate electricity. More research and analysis are necessary for a complete understanding of the impact of EVs on greenhouse gas emissions in all contexts. Research in the study [7] examined EV emissions across leading G20 countries, focusing on their electricity generation sources. France and Canada are highlighted as environmentally friendly due to their reliance on low-emission energy sources like nuclear and hydropower. In contrast, nations like Saudi Arabia and South Africa exhibited higher emissions owing to their reliance on oil and coal. The research emphasized the significance of cleaner energy sources to curb vehicle emissions without delving into specific pollutants. Research [8] focuses on analysing the economic aspects of electric roads compared to battery-powered EVs, particularly investigating their ability to reduce costs and CO_2 emissions. By exploring various scenarios involving electric roads and vehicles, the study confirms that implementing electric roads can significantly decrease costs, lower CO_2 emissions, and reduce the reliance on large batteries in EVs. The conclusions emphasize the potential of electric roads to create an unlimited range for EVs, contributing to reducing emissions and costs in road transport and positioning them as a pivotal element for sustainable transportation electrification. Similar research conducted in Türkiye [9] focused on analysing the daily electricity demand in transportation by implementing electric roads. The aim was to explore the variation in daily electricity demand in transportation on eight busiest roads connecting seven major cities in Türkiye and to estimate the impact of electric roads on CO_2 emissions in the road transport sector. The study's results highlight a significant increase of 3.7% in the daily electricity demand on the observed roads with complete electrification of existing traffic. However, if all roads in the country were converted into electric roads with full vehicle conversion, that increase would rise by as much as 100%. Furthermore, applying electric roads on high-traffic routes could reduce CO_2 emissions from the road transport sector by an impressive 18.8 million tons. This research lays the groundwork for further assessments of the sustainability and practicality of developing electric roads in Türkiye. It emphasizes the potential of electric roads to reduce CO_2 emissions but also underscores the complexity of challenges associated with developing electromobility on highways. It sets guidelines for future research and evaluations of the justification for implementing this technology in Türkiye transportation. Similar research to ones in [8, 9] can be found in [10].

The increase in the number of EVs will affect the emissions and the load on the power grid. The research [11] focused on the impact of EVs on the power grid and the required infrastructure for charging stations. Analyses revealed significant loads on transformers and lines during vehicle charging, emphasizing the need for long-term solutions due to the expected increase in EVs. Similar research was conducted in [12], concluding that EVs are a significant addition to the power grid, necessitating comprehensive research into their impact. By modelling EV charging behaviour and validating it with real data, the study establishes a foundation for analysing grid sufficiency, network quality, and how EVs as a new load will affect them. Research in [13] investigates the adverse effects of electric vehicle charging stations on the power grid. It proposes integrating solar power plants to mitigate these impacts, enhancing grid efficiency and quality. Careful planning of this integration is crucial in supporting sustainable energy practices.

Taking into consideration the existing literature review, this paper contributes to the field in the following areas: (I) Analysis of the impact of different energy sources in Bosnia and Herzegovina on CO_2 emissions from EVs, providing localized insights into the influence of energy sources on CO_2 emissions from EVs. (II) Identifying factors influencing CO_2 emissions from EVs, specifically highlighting the significance of energy sources in reducing CO_2 emissions in electromobility. (III) Analysis of energy consumption and CO_2 emissions from EVs in the Federation of Bosnia and Herzegovina and Sarajevo, ensuring a localized understanding of the impact of EVs on energy and CO_2 emissions in the domestic context. Additionally, the contributions made in this paper can be extended to other regions with diverse energy sources, offering a framework for evaluating the influence of varied energy mix on CO_2 emissions from EVs.

The paper is structured as follows: in Chapter 1, an introduction to the motivation of the research, an overview of current research, and the contribution of this paper to the existing literature are given. Chapter 2 analyses the state of energy sources in 2021. For electricity production in the world, the EU and Bosnia and Herzegovina. The share of different energy sources in electricity production is analysed, and trends and plans for the future are presented. Also, the difference in the use of renewable energy sources between the EU, where significant progress is being made, and Bosnia and Herzegovina, where a dominant share of non-renewable sources is still present, is highlighted. In Chapter 3, an analysis of passenger vehicles in the Federation of BiH and taxi vehicles in Sarajevo for the year 2021 was conducted. Based on these data, the emissions of passenger and taxi vehicles were calculated with special emphasis on CO_2. After that, a hypothetical replacement of the aforementioned vehicles with electric ones was carried out. Finally, the required amount of electricity was calculated and the CO_2 emission analysis of EVs was performed, considering Bosnia and Herzegovina's energy mix. Finally, in Chapter 4, concluding considerations are presented, limitations of this research are highlighted, and recommendations for future research are given. It is important to note that the analysis of energy sources and the calculation of emissions were carried out based on data from 2021 because we had a database of vehicles from the Federation of Bosnia and Herzegovina for 2021 at our disposal.

The Current State and Perspectives of Energy Sources in the World, the European Union and Bosnia and Herzegovina

This chapter will analyse the current state and perspectives of energy sources worldwide in the European Union and Bosnia and Herzegovina. The goal is to provide more specific information about the share of different sources of electricity, trends, and plans for the future.

Current State of Energy Sources

According to available data for 2021 [14], fossil fuels have the largest share of global electricity production, accounting for about 61.4% of total production. Coal is still a dominant source in many parts of the world, although its share is gradually decreasing due to the faster growth of renewable energy sources.

Renewable energy sources, such as solar, wind, and hydropower, have significantly increased their share and currently account for around 25.1% of the total electricity production in the world. Solar energy has greatly increased in the last decade, with the continuous decline in solar panel prices and incentive policies. Nuclear power is also seeing strong growth, especially in Europe and China. Nuclear energy accounts for about 9.8% of the global electricity production. Nuclear power plants are a significant energy source in some countries, such as France and Japan, but they face challenges and issues of safety and nuclear waste management. Figure 1 shows the share of individual sources of electricity in the total world production for the year 2021 [14].

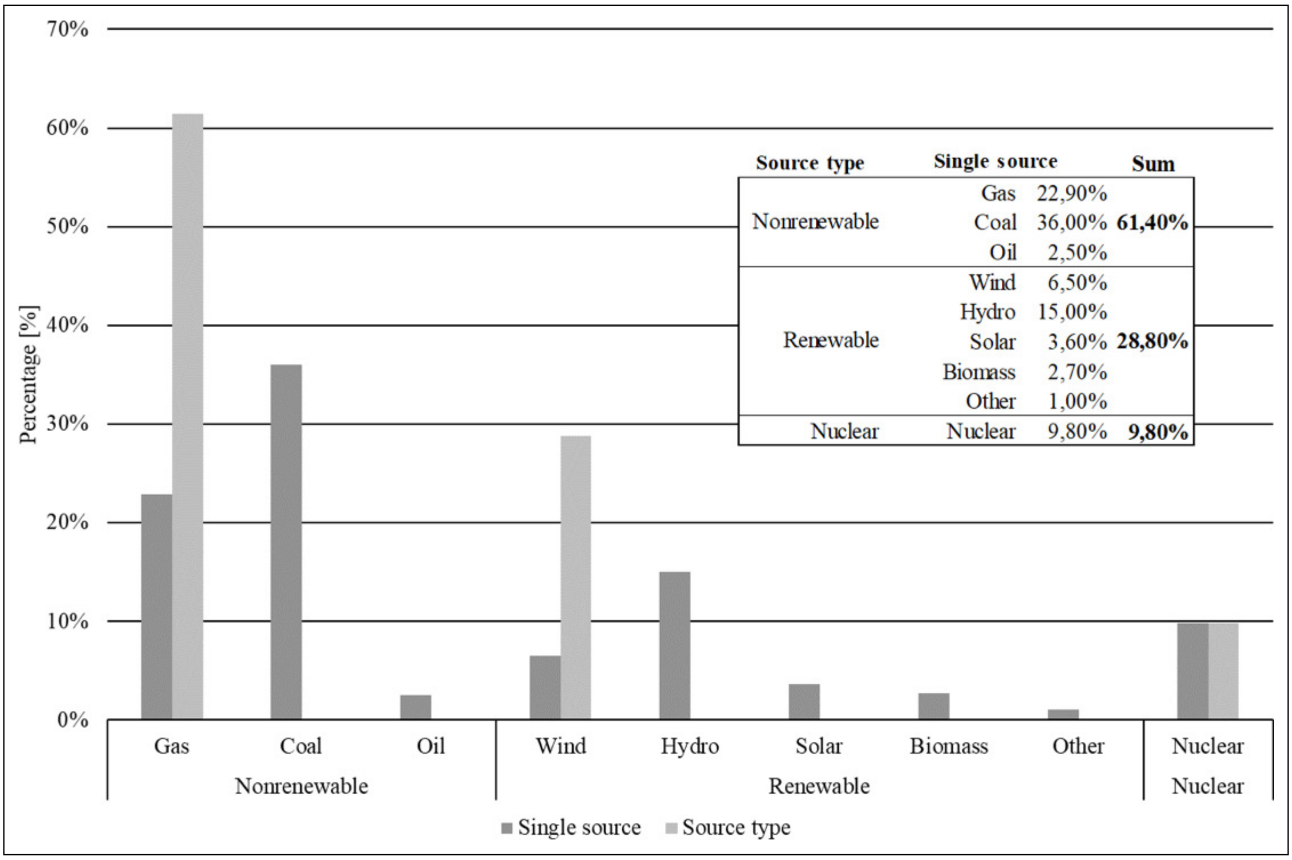

Figure 1. The share of individual sources of electricity in the total production in the world for the year 2021 [14].

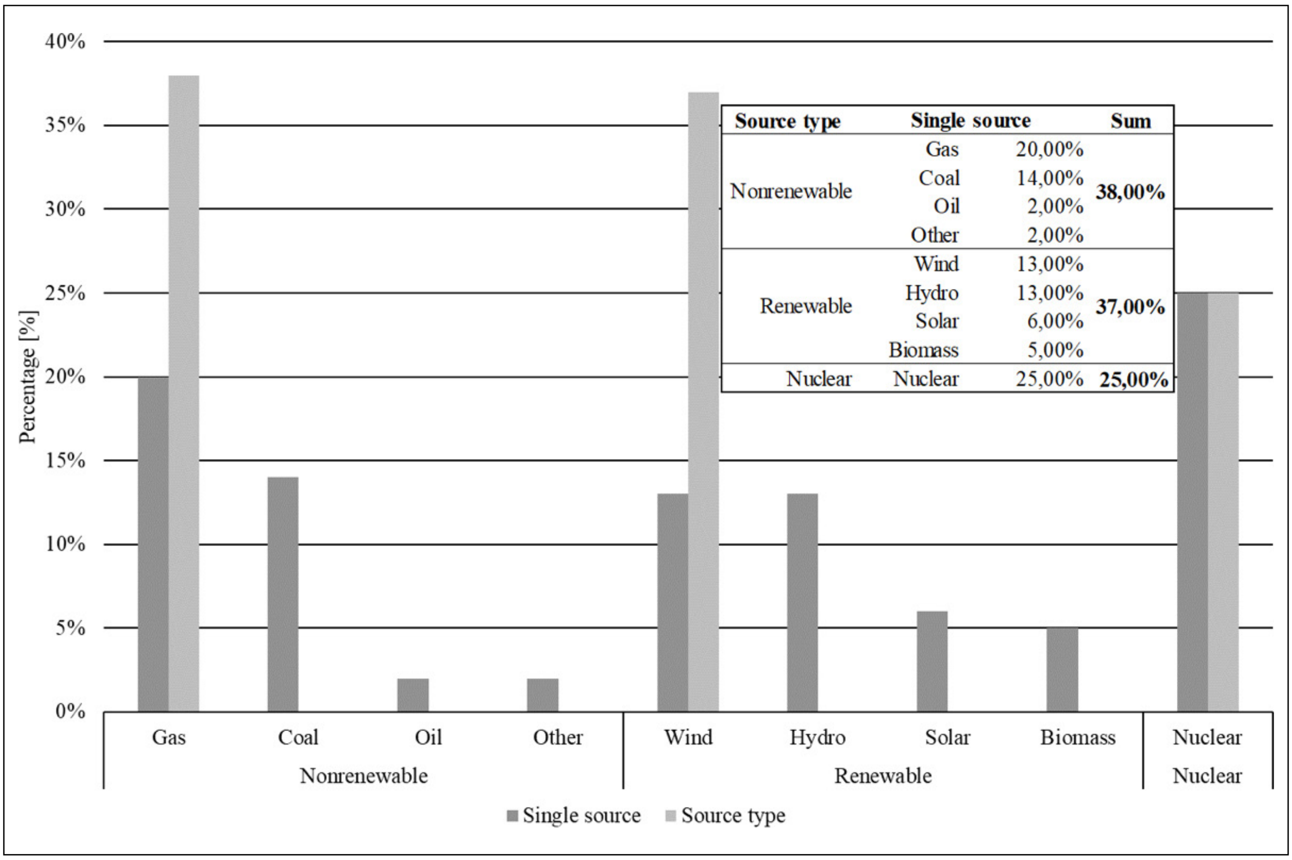

Figure 2. The participation of individual sources of electricity in the total production in the European Union for the year 2021 [15].

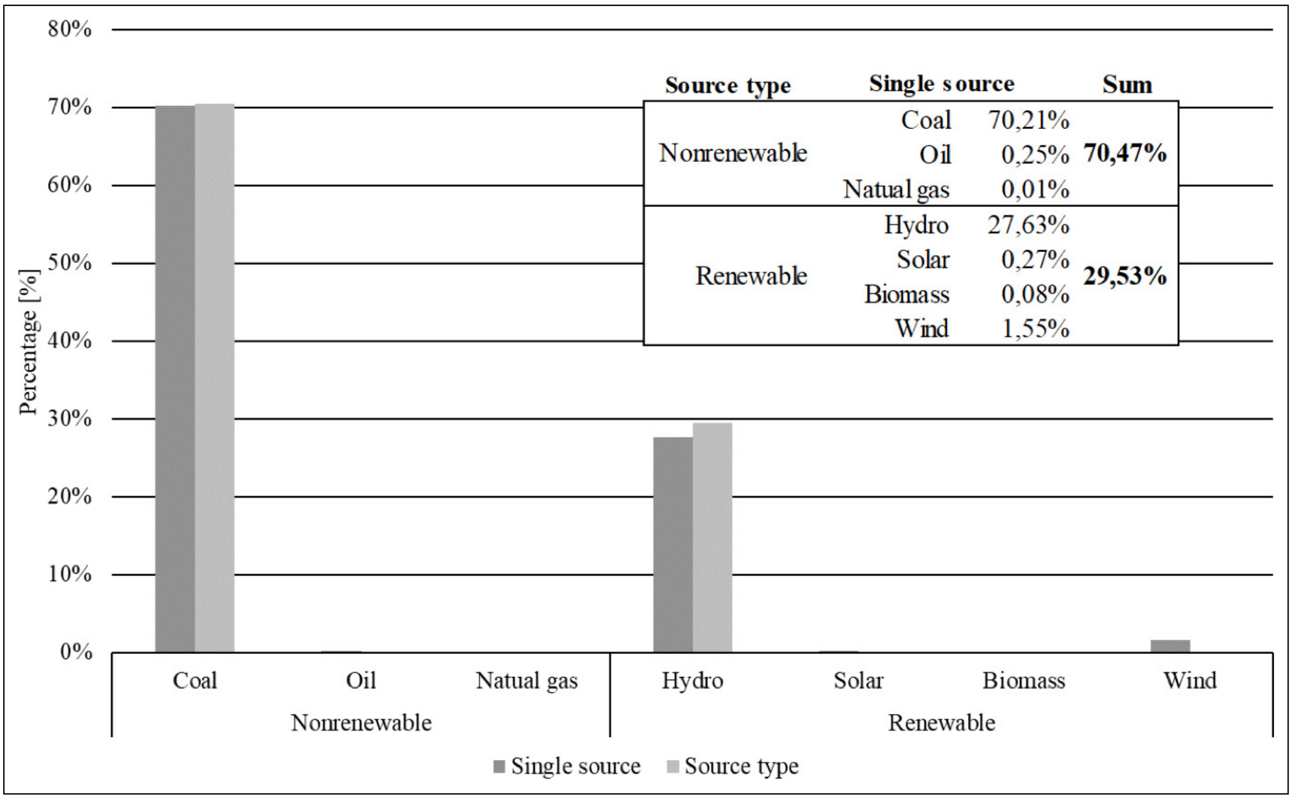

Figure 3. The participation of individual sources of electricity in the total production in Bosnia and Herzegovina for the year 2021 [16].

The European Union is one of the leading regions in the global transition towards sustainable electricity production. According to available data for 2021, the share of renewable energy sources in the total electricity production in the European Union was 38%, non-renewable 37% and nuclear 25% [6]. Countries such as Germany, Sweden, Denmark and Portugal are leading the way in using renewable energy sources, especially wind and solar. Germany is one of the world's leading producers of solar panels, while Denmark and Sweden have a significant share in electricity production with wind power. In the European Union, there is also a trend of gradual abandonment of nuclear energy in some countries, such as Germany.

Figure 2 shows the participation of individual sources of electricity in the total production in the European Union for the year 2021 [15].

According to data from the International Energy Agency for the year 2021, the energy sector in Bosnia and Herzegovina is characterised by a diversity of energy sources. Coal takes the largest share in electricity production and accounts for about 70% of the total production. Bosnia and Herzegovina has a significant potential for the development of hydropower, whose participation in the production of electricity amounts to about 27%. However, other renewable energy sources, such as solar and wind, are still limited. Solar energy accounts for only 0.27% of total production, while biomass and wind account for 1.63%. Figure 3 shows the participation of individual sources in the production of electricity in Bosnia and Herzegovina for the year 2021 [16].

Based on the data presented, it can be concluded that in the European Union in 2021, significant participation of renewable energy sources in electricity production is noticeable, while in Bosnia and Herzegovina, non-renewable sources still prevail. These data indicate a global transition towards sustainable electricity production, especially in the European Union, where significant progress is made in using renewable energy sources. However, in Bosnia and Herzegovina, there is a need for further development of renewable energy sources to reduce the share of non-renewable sources and greenhouse gas emissions. In the future, further plans and initiatives are expected to improve the energy sector in the world, Europe and Bosnia and Herzegovina to increase the share of renewable energy sources and reduce greenhouse gas pollution.

Plans for Electricity Decarbonisation

Plans and goals in the world and Europe aim to reduce greenhouse gas emissions by transitioning to renewable energy sources for electricity production. This transition aims to combat climate change and create a sustainable energy sector.

There is a growing awareness of the importance of transitioning to renewable energy sources to reduce dependence on fossil fuels and greenhouse gas emissions. Many countries have adopted ambitious plans and targets for electricity decarbonisation. These plans include increasing the share of renewable energy sources, such as solar, wind, hydro, geothermal, and tidal energy.

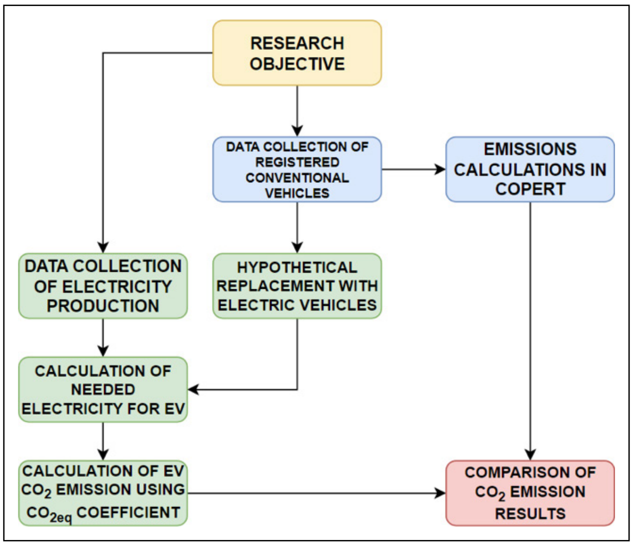

Figure 4. Methodology flowchart.

In Europe, the European Union is a leader in this area. One of the critical plans is the European Green Deal, which aims to achieve climate neutrality by 2050 [17]. As part of that plan, the European Union has set targets to reduce greenhouse gas emissions by at least 55% by 2030. This includes the goal for renewable energy sources to make up at least 32% of energy consumption in Europe by 2030.

Bosnia and Herzegovina also has the potential to develop renewable energy sources and reduce greenhouse gas emissions in the electricity sector. Plans for decarbonisation in Bosnia and Herzegovina include increasing the share of renewable energy sources, mainly hydropower, solar, and wind power plants. These plans aim to reduce dependence on fossil fuels, such as coal, and create a sustainable and clean energy sector.

To achieve these plans, it is crucial to invest in the infrastructure for renewable energy sources, encourage research and development of new technologies, and adopt incentive policies and measures to support the transition to renewable energy sources.

It is important to point out that Bosnia and Herzegovina has adopted the Framework Energy Strategy of Bosnia and Herzegovina until 2035 [18], which aims to increase the share of renewable energy sources and improve energy efficiency. To achieve these goals, further development of renewable energy sources in the country is expected.

All these measures aim to create a sustainable energy sector that will contribute to reducing greenhouse gas emissions, promoting environmental protection, and fighting against climate change.

To show the impact of the current situation in Bosnia and Herzegovina from the point of view of the source of electricity, modelling and comparison of the emissions of vehicles using fossil fuels and EVs will be carried out below.

Table 1. Vehicle fleet in the Federation of Bosnia and Herzegovina for 2021 [20]

Vehicle category	Quantity	Share
Motorcycles	9,669	1.45%
Passenger vehicles	576,450	86.65%
Busses	2,645	0.40%
Trucks, vans and lorries	54,694	8.22%
Trailers	17,793	2.67%
Tractors	2,854	0.43%
Others	1,120	0.17%
Total	665,225	100%

Electric Vehicles' Impact on Energy and CO_2 in Bosnia and Herzegovina

To analyse the impact of the introduction of electric vehicles on energy consumption and CO_2 emissions in the current conditions of electricity production in Bosnia and Herzegovina, an analysis of vehicles registered in the Federation of Bosnia and Herzegovina (FBiH) and Sarajevo will be conducted, with a particular emphasis on passenger vehicles. Also, the vehicle fleet in Sarajevo will be analysed. Still, only taxi vehicles will be singled out for the calculation to gain insight into their impact on electricity consumption and CO_2 emissions.

To model the emission of polluting substances, the Copert program was used, which enables a detailed analysis of vehicle emissions based on vehicle characteristics and driving conditions. The methodology of emission calculations using the Copert program is given in the EMEP/EEA air pollutant emission inventory guidebook 2023 [19].

Given that the goal is to explore the impact of the transition to EVs, in further calculation, all vehicles in FBiH will be hypothetically replaced with EVs of appropriate characteristics and battery capacity. Then, using the data on electricity production in the FBiH, the CO_2 emissions resulting from that transition will be calculated. A similar calculation will be performed on the example of taxi vehicles in Sarajevo.

After that, the results obtained from the CO_2 emission analysis for conventional and electric vehicles will be compared. The flowchart of the research methodology is shown in Figure 4.

It is essential to note that although vehicles using fossil fuels also emit components such as CO, NO_x, HC, and soot particles in their exhaust gases, these components are not included in this analysis. This is due to their small presence in exhaust gases, which makes them local rather than global parameters. As technology advances, these components are increasingly removed from exhaust gases, highlighting CO_2 as a major global challenge and still the most critical factor. Even vehicle manufacturers, when describing the technical characteristics of their vehicles, emphasise only CO_2 as a crucial parameter.

Table 2. Emission standards by fuel type [20]

	Emission standard (ES)							
Fuel	**Conventional**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Euro 6**	**NO ES**
Gasoline	9,309	2,708	13,394	41,146	18,406	14,765	13,082	
Gasoline/LPG	741	399	1,285	5,497	2,938	1,610	631	
Diesel	31,608	9,475	20,983	151,778	109,344	83,025	44,264	
Diesel/CNG	0	0	0	3	3	3	0	
Electro								53
Total	41,658	12,582	35,662	198,424	130,691	99,403	57,977	53
Total M1 category				**576,450**				

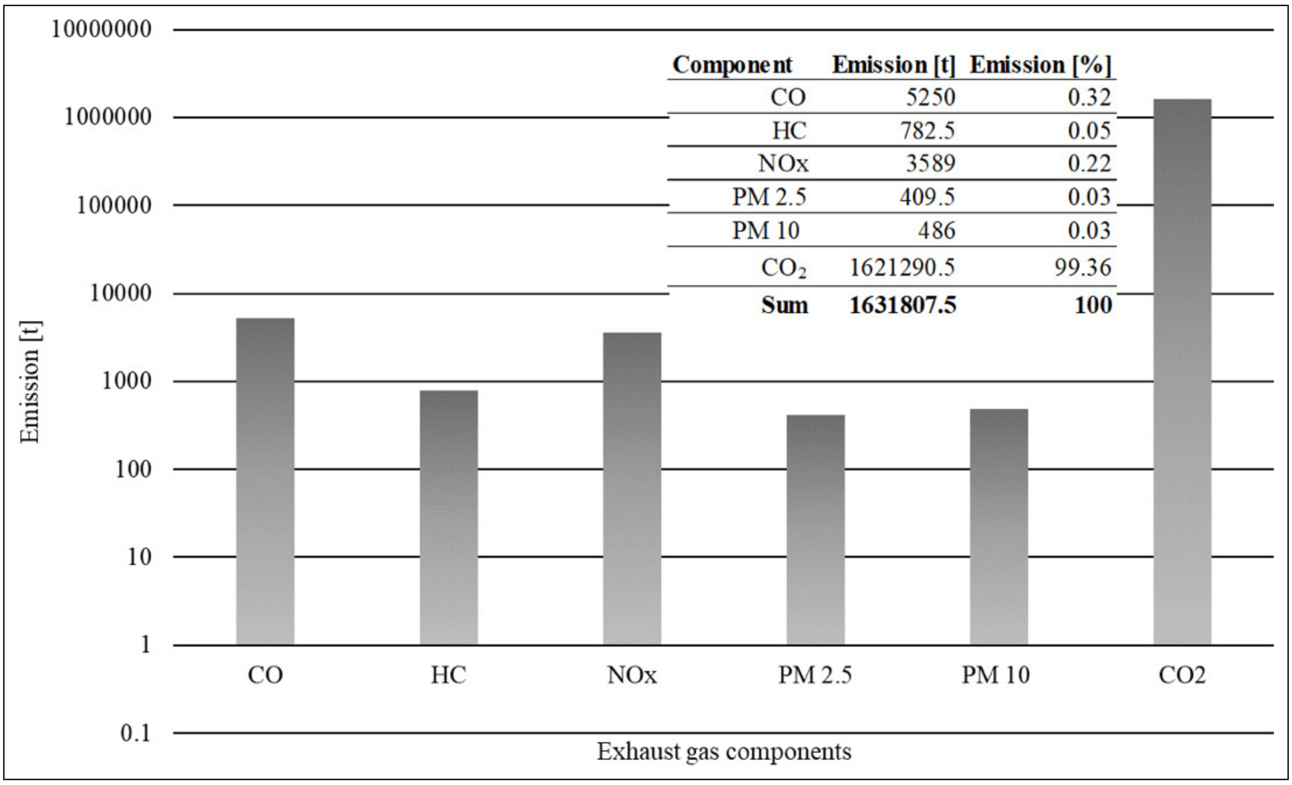

Figure 5. The results of exhaust gas emissions modelling of passenger vehicles in FBiH.

Modelling of Passenger Vehicle Emissions in the Federation of Bosnia and Herzegovina

To provide an insight into the state of the vehicle fleet in the Federation of Bosnia and Herzegovina, the database [20] of technical inspections of vehicles for the year 2021 was used. The Federal Ministry of Transport and Communications obtained the database officially, and the data set did not use any personal data of vehicle owners, only the technical characteristics of the vehicles. Table 1 shows the condition of the vehicle fleet in the Federation of Bosnia and Herzegovina for 2021 [20].

Table 2 provides an overview of the passenger vehicles' emission standards according to the type of fuel [20].

The Copert program was used to calculate the emissions of passenger motor vehicles from Table 1. Detailed data on the number of vehicles according to eco characteristics, type, and engine volume was determined from the database of vehicle technical inspections for 2021 [20]. Data for the fuel consumed in 2021 were obtained based on data from the Federal Ministry of Trade for 2021 [21], while climatological data were taken from the Meteorological Yearbook for 2021 published by the Federal Hydrometeorological Institute [22].

Figure 5 shows the results of the modelling of exhaust gas emissions of passenger vehicles using fossil fuels.

The components of exhaust gases from Figure 5 are given in tons and displayed on a logarithmic scale. The reason for this is the largest CO_2 emission, which is significantly higher than other components of exhaust gases, typically considered polluting. The ratio of polluting components (CO, HC, NO_x, PM) to the amount of CO_2 is expected because these components occupy a very small percentage of exhaust gases in modern vehicles using fossil fuels.

Table 3. Electric vehicles that would replace the fleet in the Federation of Bosnia and Herzegovina

Vehicle class	Curb mass [kg]	Battery capacity [kWh]	Range [km]	Consumption of the el. energy [kWh/100 km]	Number of vehicles	Average annual mileage [km/yr]	El. energy consumption [kWh]	CO_2eq emission [t]
A	<1,100	17.7	151	11.67	202,347	20,000	472,277,898	354,208
B	1,101–1,500	24.4	177	13.71	256,063	20,000	702,124,746	526,594
C	1,501–1,750	42.1	281	14.98	86,234	20,000	258,357,064	193,768
D	≥1,751	59.9	357	16.77	31,753	20,000	106,499,562	79,875
				Total	**576,397**		**1,539,259,270**	**1,154,444**

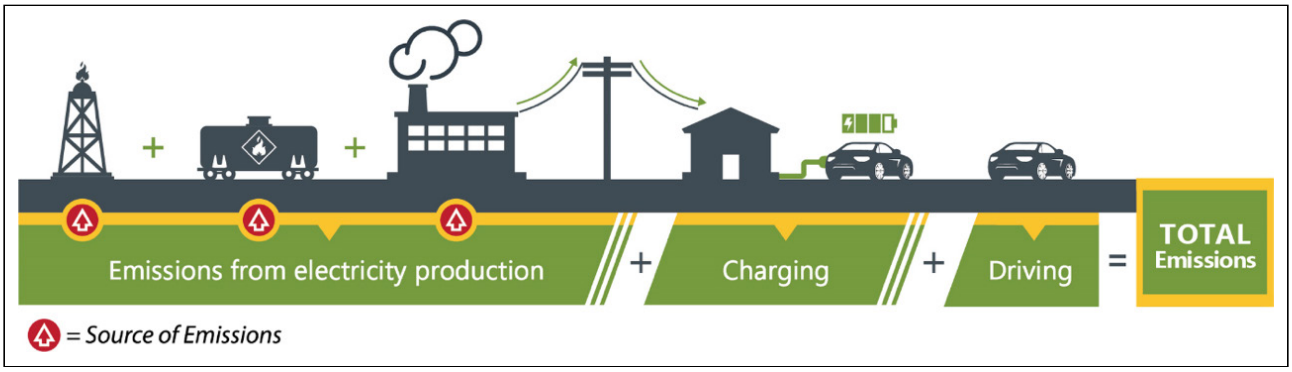

Figure 6. The emission mechanism of EVs due to the source of electricity [24].

To compare the exhaust gas emissions of conventional passenger vehicles given in Table 1 with EVs, a hypothetical assumption is made that the complete fleet of passenger vehicles from Table 1 is replaced with EVs of similar characteristics. Table 3 shows the proposal to replace the fleet with EVs. EVs are divided into four groups based on the weight of the empty vehicle, according to recommendations from [1].

Table 3 also shows the calculation of the required electricity based on data on the number of vehicles and characteristics of electricity consumption. By multiplying the number of vehicles by the electricity consumption per vehicle and the average annual mileage, the total electricity consumption for certain categories of vehicles is obtained.

Also shown is the calculation of CO_2 emissions of EVs due to the type of energy source used to power those vehicles. The analysis was made so that the electric energy consumption of the vehicle given in Table 3 is multiplied by the CO_2eq given by the electricity producer in Bosnia and Herzegovina, which is 0.75 kg/kWh [23]. This equivalent contains all the pollutants that are formed during the production of electricity. The calculation shows that, in such a case, the annual CO_2 emission due to the power supply of EVs would amount to an additional 1,154,444 tons of CO_2. Although EVs locally do not directly impact the environment because they do not emit exhaust gases like vehicles using fossil fuels due to the type of source for producing electricity, EVs can also significantly contribute to CO_2 emissions. The emission mechanism of EVs due to the source of electricity is shown in Figure 6.

According to the calculation from Table 3, the required amount of electricity to power these vehicles annually is slightly more than 1,539 GWh (Gigawatt hour) of electricity. The current electricity production in Bosnia and Herzegovina is about 17,000 GWh, and consumption, according to official data in Bosnia and Herzegovina [25], is about 12,000 GWh of electricity. To conclude, the required electricity to power EVs would have to be provided from the difference sold to third parties or produced additionally, which would increase the amount of CO_2 shown in the calculation in Table 3.

In the following, the modelling of taxi vehicle emissions in Sarajevo will be analysed to gain better insight and more realistic possibilities of replacing them with EVs in the future.

Modelling Taxi Vehicle Emissions in the City of Sarajevo

Using the methodology from the previous chapter, an analysis of the fleet of taxi vehicles in the city of Sarajevo for the year 2021 was performed. Based on that data, these vehicles' exhaust gas emissions were analysed using the Copert program. Data on Sarajevo's fuel consumption and climatological conditions were taken from [21] and [22]. Table 4 shows the analysis of the taxi fleet in Sarajevo.

Using the data from Table 4 [20] and other input data in the Copert program, an analysis of the vehicle's exhaust gas emissions from Table 4 was performed. Figure 7 shows the result of the calculation. As in the previous example, the base ten logarithmic scale distribution was used here to display the results.

Table 4. Emission standards by fuel type for the taxi vehicles in Sarajevo [20]

	Emission standard (ES)							
Fuel	**Conventional**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Euro 6**	**NO ES**
Gasoline	0	0	0	0	2	7	4	0
Gasoline/LPG	0	0	1	6	29	42	23	0
Diesel	0	0	4	87	230	324	194	0
Diesel/CNG	0	0	0	0	0	0	0	0
Electro	0	0	0	0	0	0	0	0
Total	0	0	5	93	261	373	221	0
Total taxi vehicles				**953**				

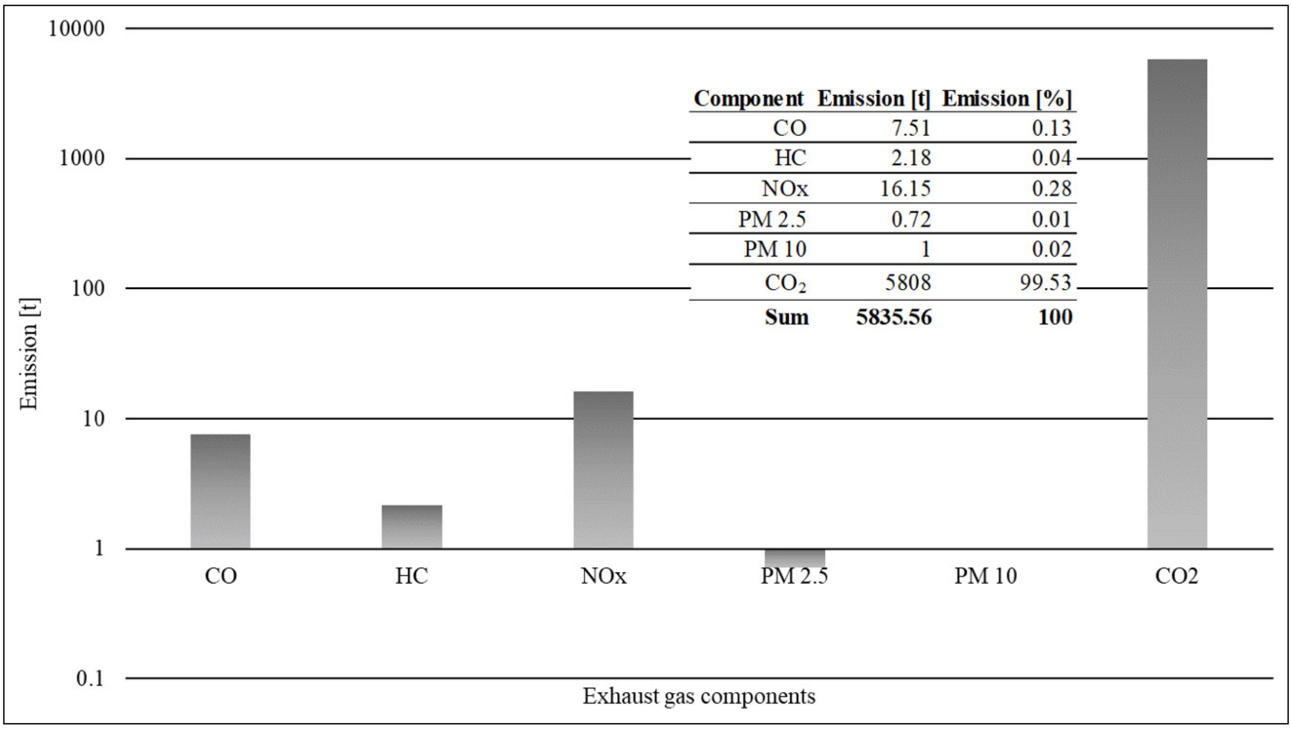

Figure 7. The results of modelling of exhaust gas emissions of taxi vehicles in Sarajevo.

Table 5. EVs that would replace the taxi fleet in Sarajevo

Vehicle class	Curb mass [kg]	Battery capacity [kWh]	Range [km]	Consumption of the el. energy [kWh/100 km]	Number of vehicles	Average annual mileage [km/yr]	El. energy consumption [kWh]	CO_2eq emission [t]
A	< 1,100	17.7	151	11.67	5	30,000	17,505	13
B	1,101-1,500	24.4	177	13.71	412	30,000	1,694,556	1,271
C	1,501-1,750	42.1	281	14.98	525	30,000	2,359,350	1,770
D	≥1,751	59.9	357	16.77	11	30,000	55,341	42
				Total	**953**		**4,126,752**	**3,095**

The next step is, as in the previous section, the analysis of emissions when all engine-powered vehicles are replaced with equivalent EVs. For this purpose, the criterion is again used according to the recommendations from the literature [1], that vehicles using fossil fuels are assumed to be replaced with EVs. Table 5 shows a suggested proposal to replace the taxi fleet in Sarajevo with EVs, according to the established criteria.

Table 5 also shows the results of the calculation of the required electrical energy and the CO_2 emissions that would be achieved by consuming that amount of electricity. According to the data of Public Enterprise Electric Utility of Bosnia and Herzegovina for Sarajevo, the total amount of electricity consumed in 2021 was 1,309 GWh [26]. The required electrical energy to power EV taxi fleet of Sarajevo would be 4.12 GWh, which is negligible compared to the actual consumption and distribution to current consumers in Sarajevo.

When looking at the CO_2 emissions given in Table 5 due to electricity consumption to power EV taxi fleet, a 47% reduction is noticeable compared to the CO_2 emissions emitted by taxis with vehicles using fossil fuels It is also important to note that in the calculation of taxi vehicles example in Sarajevo, vehicles were assumed to travel an average of 30,000 km per year, but when modelling the emissions of the vehicle fleet in the Federation of Bosnia and Herzegovina, an annual average of 20,000 km was taken.

CONCLUSIONS

This paper aimed to analyse the influence of energy sources on the emission of EVs in Bosnia and Herzegovina. Based on the available data, it has been shown that in Bosnia and Herzegovina, non-renewable sources are still used in a higher percentage to produce electricity, which results in a high coefficient of CO_2 emissions during electricity production.

To model the emission of vehicles using fossil fuels an analysis of the fleet of passenger vehicles in the Federation of Bosnia and Herzegovina was carried out. The study was performed using the Copert program. After that, the existing vehicle fleet was hypothetically replaced with EVs according to criteria from the literature. The CO_2 emission of EVs, which results from the electricity production that would power these vehicles, was calculated next. The adopted parameter used to compare emissions was CO_2, as the component that is most prevalent in the exhaust gases of vehicles using fossil fuels and globally has the most significant impact on the environment and climate. The results of vehicle CO_2 emissions for the year 2021 showed that vehicles using fossil fuels have an emission of 1.6 million tons of CO_2. In comparison, CO_2 emissions from electric vehicles would amount to 1.15 million tons. From this result, it can be concluded that the source from which the electrical energy is obtained is essential and that the emissions of EVs cannot be taken as zero. Although it is an indirect emission, it is still present and poses a significant global environmental problem. As for the required electricity to power EVs, it is calculated that the required amount would be 1,539 GWh per year. This means that the current resources from which the electricity is produced would have to be increased, or part of the electricity sold to third parties would have to be taken.

A similar analysis was carried out on the example of Sarajevo, where the fleet of taxi vehicles transporting passengers was analysed. As for the CO_2 emission, a very similar ratio was calculated as in the previous example, while the required electrical energy is significantly below the actual consumption that Sarajevo consumes annually.

It should be noted here that although in vehicles using fossil fuels, there are components in the exhaust gases such as CO, NO_x, HC, soot particles, etc. they were not considered here because these components are minimally represented in exhaust gases. Also, they are a local and not a global parameter. Furthermore, with the advancement of technology, these components are more and more efficiently removed from exhaust gases every day, so the CO_2 parameter is still the most significant global problem.

It is essential to point out that the emissions and pollution from EVs, in addition to the source of energy that powers them, are also affected by the production process of EVs and their components, primarily batteries, as well as their subsequent disposal after use. This parameter was not considered here, which leads to the conclusion that EV emissions and pollution are even higher than calculated. This is certainly a motivation for further research and deepening of this topic.

Based on the shown examples of fleet analysis, realistically, the example of taxi vehicles could take place, with the added fact that a grid of charging stations for these vehicles would have to be developed, which was not considered here.

In the end, it can be concluded, based on the conducted analysis, that in the conditions of the current energy situation in Bosnia and Herzegovina, where about 70% of electricity is produced from non-renewable sources and where there is a minimal representation of solar and wind power plants, it is still not possible to consider EVs as vehicles with zero emissions. In the future, if energy strategies are adopted and the transition to clean sources for electricity production is made, we should expect a lower CO_2 coefficient due to the production of electricity from clean sources and, thus, a reduction in indirect pollution by EVs.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

USE OF AI FOR WRITING ASSISTANCE

Authors declare no use of AI for writing assistance.

ETHICS

There are no ethical issues with the publication of this manuscript.

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