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Transportation Research Procedia 93 (2026) 57–70

Transportation Research Procedia

www.elsevier.com/locate/procedia

16th International Scientific Conference on Sustainable, Modern and Safe Transport

Comparative analysis of Road Safety, Air Pollution, Public Transport and Noise Disturbance Policies in the V4 countries

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Abstract

This study investigates disparities in road traffic fatality rates, noise pollution, PM2.5 concentrations, and public transport utilization among the Visegrad Four (V4) countries—Czechia, Slovakia, Hungary, and Poland. The research addresses the pressing question of how these differences reflect the implementation and effectiveness of transport policies in the region. Using a comparative analysis of secondary data sourced from European environmental and transport databases, the study applies a mixed-method approach to identify patterns and trends from 2015 to 2023. Key findings reveal significant differences in transport safety, air quality, and public transport reliance across the V4 countries. For instance, Poland exhibits the highest road traffic fatality rates, whereas Czechia leads in addressing noise pollution. PM2.5 exposure remains a critical challenge across the region, with Hungary and Slovakia showing substantial room for improvement. Public transport utilization, notably affected by the COVID-19 pandemic, highlights contrasting recovery dynamics in the V4 countries. The study underscores the need for targeted policy interventions tailored to the specific challenges of each country. Recommendations include prioritizing sustainable transport systems, enhancing public transport infrastructure, and enforcing stricter environmental regulations. The findings provide actionable insights for policymakers and serve as a foundation for future research on sustainable mobility in Central Europe.

Peer-review under responsibility of the scientific committee of the TRANSCOM 2025: 16th International Scientific Conference on Sustainable, Modern and Safe Transport

Keywords: road traffic fatalities; PM 2.5 concentrations; public transport; noise pollution

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Peer-review under responsibility of the scientific committee of the TRANSCOM 2025: 16th International Scientific Conference on Sustainable, Modern and Safe Transport
10.1016/j.trpro.2025.11.010

1. Introduction

In the last decade, numerous studies have focused on the role of transport systems in shaping urban environments and their impact on public safety, noise pollution, and air quality. Many studies have highlighted the connection between transport infrastructure and road traffic fatalities, the adverse health effects of traffic-generated noise, and the contribution of transport emissions to increasing concentrations of fine particulate matter (PM2.5) in cities (Xu et al., 2023; Zhang et al., 2021). These findings underscore the dual nature of transport systems—on the one hand, they are essential for economic activity and urban connectivity, while on the other, they are a significant source of environmental and social challenges. Despite extensive literature, many questions in this area remain unanswered.

It is still unclear why certain urban areas experience disproportionately higher rates of road traffic fatalities, more intense noise pollution, and deteriorated air quality, even when investments in transport infrastructure are comparable. The dynamics between the socioeconomic status of residents, urban planning, and the distribution of these externalities remain insufficiently explored. Moreover, the interplay of these factors and their cumulative impact on achieving SDG 11, particularly in the context of safe and sustainable cities, remains unclear (Berhanu et al., 2023; Jima and Sipos, 2022; Filippini and Obrist, 2022). This gap limits the ability to develop targeted policies and effective measures to mitigate these issues.

Urban mobility and its impact on safety and quality of life are closely linked to achieving SDG 11. The intensity of road traffic and the quality of transport infrastructure directly influence road traffic fatality rates. Studies confirm that improving road networks and implementing intelligent transport systems lead to a reduction in fatal accidents (Pollák et al., 2021), with speed control and the safety of urban infrastructure playing a crucial role (Park et al., 2021, Nagaraj et al., 2022). Noise pollution caused by road and rail transport poses a significant environmental and health challenge in urban areas. Prolonged exposure to high noise levels is associated with increased stress, sleep disorders, and cardiovascular diseases (Johnson et al., 2021). Integrated transport planning that addresses noise pollution has the potential to enhance the quality of life in urban areas. Effective measures include the introduction of noise barriers, the electrification of transport, and the promotion of quieter public transport systems (Mouratidis and Serrano, 2021; Cavallaro and Nocera, 2021).

Air pollution from fine particulate matter (PM2.5) is closely linked to emissions from road transport. High concentrations of these particles in urban areas contribute to premature deaths from respiratory and cardiovascular diseases (Basith et al., 2022, Valent, 2022). Vehicle electrification, support for cycling infrastructure, and the establishment of low-emission zones are key solutions to mitigate this issue. Urban areas that have invested in public transport development and cycling infrastructure have reported significant improvements in air quality and public health (Li et al., 2021; Donkelaar et al., 2021).

Road safety, noise pollution, and air pollution are intrinsically connected to urban strategies and transport policies. A comparison of different cities shows that integrated transport systems and measures promoting sustainable transportation significantly contribute to improving quality of life and achieving SDG 11 (Soviar et al., 2021; Drescher and Janzen, 2021; Trencher and Edianto, 2021; Wyer et al., 2022).

The Visegrad Group (V4), comprising Slovakia, Czechia, Hungary, and Poland, has implemented various transport policies to address urban mobility challenges, road safety, and environmental concerns. While there are similarities in their approaches, national strategies and policy implementations differ based on economic conditions, urban planning priorities, and environmental commitments (Polom, 2022).

Slovakia's transport policies align with EU directives on sustainable mobility and emission reductions. The "National Transport Development Strategy 2030" prioritizes the development of integrated public transport networks, railway modernization, and the expansion of cycling infrastructure. The government has introduced incentives for electric vehicles (EVs) and low-emission zones in major cities such as Bratislava and Košice. The introduction of intelligent transport systems (ITS) aims to improve road safety by reducing congestion and optimizing traffic flow (Székely and Novotný, 2022; Kendra et al., 2023).

Czechia has taken significant steps towards sustainable urban transport through its "Transport Policy of the Czech Republic 2021-2027." The policy emphasizes reducing dependence on fossil fuels, promoting public transport, and expanding rail networks. Prague and Brno have implemented low-emission zones and adopted measures to reduce noise pollution, such as stricter vehicle regulations and the expansion of tram networks. The country has also invested

in modernizing road infrastructure to enhance safety and reduce accident rates (Fitzová et al., 2021; Vichova et al., 2021).

Hungary's transport policy is outlined in the "National Transport Infrastructure Development Strategy," which focuses on multimodal transport systems, electrification of public transport, and reducing urban congestion. Budapest has led initiatives in low-emission public transport, including the introduction of electric buses and an expanded metro network. The government has also strengthened road safety regulations by enforcing stricter speed limits and improving pedestrian infrastructure (Wendet et al., 2021; Orgyzek and Wolny-Kucińska, 2021).

Poland has made significant progress in sustainable transport through its "National Transport Policy 2030," which emphasizes the development of green transport corridors, investments in high-speed rail, and urban air quality improvements. Warsaw and Kraków have implemented congestion charges and introduced extensive bike-sharing programs. Additionally, the Polish government provides subsidies for electric and hybrid vehicles to encourage cleaner transportation alternatives (Wolek et al., 2021; Zukowska et al., 2022).

These diverse policy approaches across V4 countries illustrate the varying strategies to tackle urban transport challenges. While investments in public transport and road safety improvements are common themes, differences in legislative priorities and infrastructure investments contribute to disparities in achieving SDG 11 goals.

2. Objectives and methods

The aim of this study is to examine the disparities in progress toward achieving SDG 11 across the V4 countries, based on a selected set of indicators. The structure of the article is as follows: first, we present a literature review and research methodology, followed by the results of our investigation, then a discussion of the findings, and finally, recommendations for further research.

By decomposing the research problem in the context of the study objectives, we formulate the following research question:

"What are the differences in road traffic fatality rates, noise pollution, PM2.5 concentrations, and public transport across the V4 countries, and what do these differences suggest about the implementation of transport policies?"

The data used in this study are sourced from the Eurostat database. The analyzed indicators include:

- Number of road traffic fatalities
- Noise pollution
- PM2.5 air concentrations
- Public transport indicators

Data were collected for the period from 2015 to 2023. The sources include official statistics and reports related to transport and environmental conditions in Slovakia, the Czech Republic, Hungary, and Poland.

The methodology involves a comparative analysis to assess differences among the V4 countries based on the selected indicators. The analysis includes:

1. Creating statistical summaries for each country, detailing values for each indicator over the study period.
2. Comparing trends in the indicators between countries using descriptive statistics.
3. Identifying deviations and trends through visualizations such as graphs and tables.
4. Interpreting differences and their potential causes within the context of transport and environmental policies.

The comparative analysis is expected to reveal significant differences among the V4 countries in terms of road traffic fatality rates, noise pollution, and PM2.5 concentrations. For instance, countries with more developed transport infrastructure and stricter environmental regulations are anticipated to demonstrate better indicator values. The results will be presented through graphs, tables, and descriptive summaries, facilitating the identification of key trends and weaknesses in each country.

3. Results

3.1 Threat of PM in the context of road traffic fatalities

The analysis begins with examining road traffic fatalities as a critical indicator of transport safety in the V4 countries. Graph 1 illustrates the trends in road traffic fatality rates by road type in the V4 countries (Czech Republic, Slovakia, Hungary, and Poland) from 2015 to 2022. The data are presented as the number of fatalities per 100,000

inhabitants. The graph reveals a positive downward trend in fatality rates across all four countries, with varying rates of decline and fluctuations indicating differences in the implementation of road safety measures.

However, an alarming connection emerges when considering fatalities caused by exposure to fine particulate matter (PM2.5). Graph 2 highlights the number of premature deaths due to PM2.5 exposure in the same countries over the same period. The intersection between these datasets suggests a compounded risk in urban areas where traffic accidents and air pollution exacerbate public health challenges. For example, Poland's highest traffic fatality rates overlap with its significantly higher premature deaths from PM2.5 exposure, underlining the urgent need for integrated transport and environmental policies. This dual threat highlights the necessity to address road safety and air quality collectively.

This chapter identifies PM2.5 as a serious hazard, not only due to its direct health impacts but also its potential to aggravate traffic-related fatalities. Effective policies must prioritize reducing PM2.5 levels through cleaner energy sources, vehicle electrification, and improved urban planning.

Figure 1 and Table 1 illustrates the trends in road traffic fatality rates by road type in the V4 countries (Czech Republic, Slovakia, Hungary, and Poland) from 2015 to 2022. The data are presented as the number of fatalities per 100,000 inhabitants. The graph reveals a positive downward trend in fatality rates across all four countries, with varying rates of decline and fluctuations indicating differences in the implementation of road safety measures.

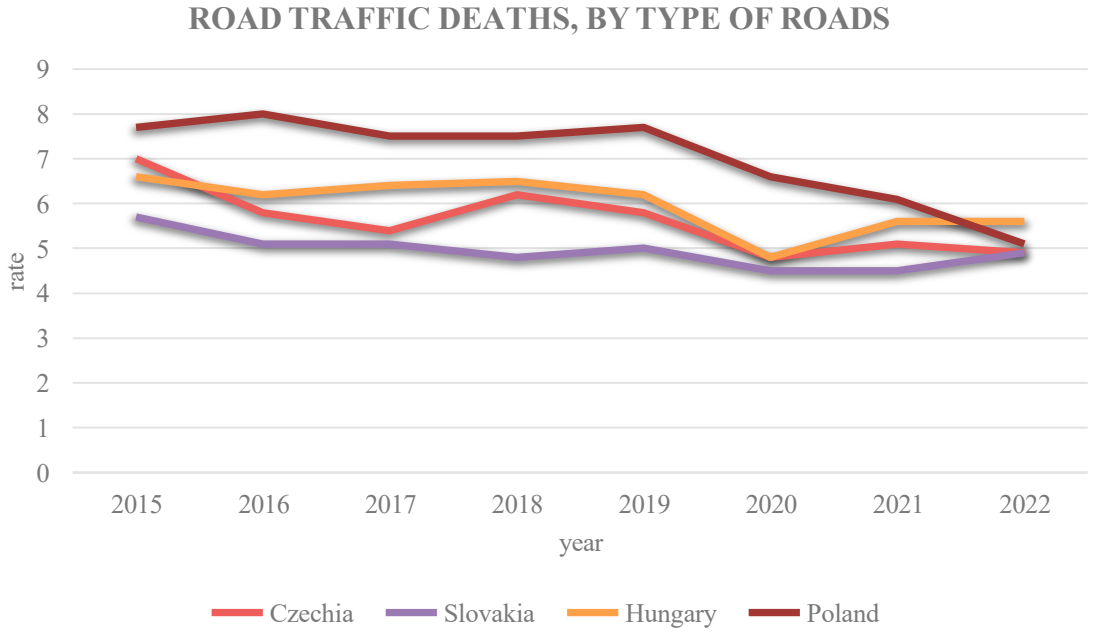

Fig. 1. Road traffic deaths, by type of roads (2015-2022).

Table 1. Number of Road traffic deaths (own processing based on data from Eurostat (2025).

Country	2015	2016	2017	2018	2019	2020	2021	2022
Czechia	7	5.8	5.4	6.2	5.8	4.8	5.1	4.9
Slovakia	5.7	5.1	5.1	4.8	5	4.5	4.5	4.9
Hungary	6.6	6.2	6.4	6.5	6.2	4.8	5.6	5.6
Poland	7.7	8	7.5	7.5	7.7	6.6	6.1	5.1

The Czech Republic started with a rate of 7 fatalities in 2015, which gradually decreased to 4.9 in 2022. An exception occurred in 2018, with a slight increase to 6.2 fatalities. This trend is likely to reflect improvements in transport infrastructure and the introduction of speed control systems. A key factor behind the Czech Republic's progress is its relatively early investment in intelligent transport systems, stricter enforcement of speed limits, and the modernization of highways and urban road networks. Historically, the country has had a well-developed road infrastructure compared to other V4 nations, and continuous investments in safety measures have contributed to the steady decline in fatalities. Additionally, the Czech Republic has a higher rate of public transport usage, particularly in urban areas, which reduces the number of private vehicles on the roads and, consequently, the risk of accidents.

Slovakia shows a relatively steady decline, from 5.7 fatalities in 2015 to 4.9 in 2022. The year-to-year differences are minimal, indicating gradual but not significant progress. Slovakia consistently maintains lower fatality rates compared to the other V4 countries, which may be attributed to its smaller population and road network, leading to lower traffic density than in Poland or Hungary. However, Slovakia has historically faced challenges related to the maintenance of rural road infrastructure, which may explain the slower pace of improvement. While the country has introduced stricter regulations on road safety, including higher penalties for traffic violations, the impact of these measures has been gradual rather than transformative. The relatively slower expansion of high-speed rail and public transport networks outside major cities has also contributed to a continued reliance on personal vehicles, limiting the potential for a sharper decline in road fatalities.

Hungary began with 6.6 fatalities in 2015 and demonstrated substantial improvement, reaching 5.6 in 2022. This trend suggests significant advancements, likely driven by investments in safety measures and modernization of the road network. One of the key drivers of Hungary's progress has been its extensive infrastructure development, particularly in expanding and upgrading highways. The Hungarian government has implemented several EU-funded projects to improve road quality and safety features such as better signage, improved lighting, and enhanced pedestrian protection measures. However, economic factors also play a role—Hungary has experienced fluctuations in economic growth, which impact both the affordability of newer, safer vehicles and the ability of municipalities to sustain infrastructure investments. The country also faces challenges related to road safety culture, with relatively high instances of speeding and non-compliance with regulations, which continue to hinder faster improvements in traffic safety.

Poland recorded the highest fatality rate among the V4 countries in 2015 (7.7), likely due to a combination of less developed transport infrastructure and less effective regulatory measures. However, Poland made notable progress, reducing its fatality rate to 5.1 in 2022. This improvement is largely linked to significant investments in road modernization, including the construction of expressways and highways, as well as stricter enforcement of traffic laws. Poland has historically struggled with an outdated road network, particularly in rural areas, where accident rates remain disproportionately high. Moreover, Poland's high vehicle density and strong reliance on private transportation—partly due to the late development of an extensive public transport network outside major cities—have contributed to higher accident risks. Recent improvements have been driven by EU funding for transport projects, which have enhanced road safety through better infrastructure and increased public awareness campaigns. However, continued economic disparities between regions mean that some areas lag behind in implementing road safety measures, contributing to persistent differences in fatality rates.

Overall, the trend indicates that all V4 countries are working to enhance road safety, albeit at different rates and with varying results. Key contributing factors include infrastructure modernization, the implementation of intelligent transport systems, speed control measures, and the promotion of public transport. These efforts are pivotal in reducing fatalities and improving road safety. However, the historical development of transport infrastructure, economic capacity, enforcement of safety regulations, and public transport availability all play crucial roles in explaining the observed differences between countries.

Achieving even lower fatality rates will require further harmonization of measures at the regional level and increased investment in sustainable and safe transport solutions. Coordinated efforts to improve cross-border transport safety, integrate more sustainable mobility options, and enforce stricter road safety policies will be essential in ensuring further progress in road safety across the V4 region.

Figure 2 and Table 2 presents the number of premature deaths caused by exposure to fine particulate matter (PM2.5) in the V4 countries (Czech Republic, Slovakia, Hungary, and Poland) from 2015 to 2021. The data are shown in absolute numbers, reflecting differences in air pollution levels and the effectiveness of measures implemented to reduce pollution.

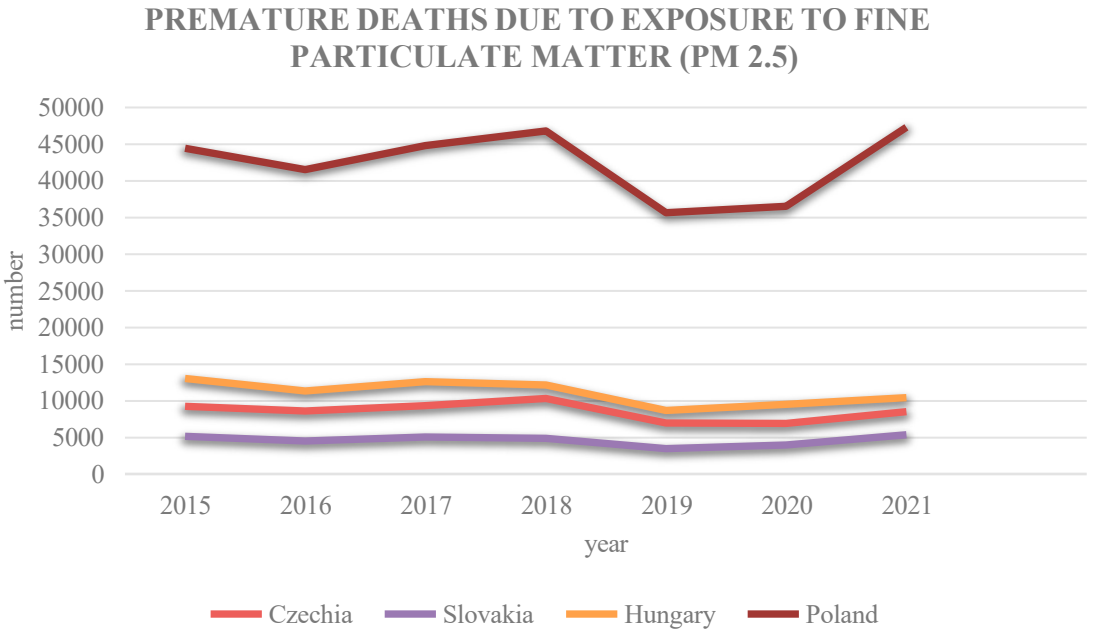

Fig. 2. Premature deaths due to exposure to fine particulate matter PM2.5 (2015-2021).

Table 2. Number of Premature deaths (own processing based on data from Eurostat (2025).

Country	2015	2016	2017	2018	2019	2020	2021
Czechia	9245	8634	9335	10305	6941	6900	8482
Slovakia	5130	4470	5032	4857	3462	3916	5354
Hungary	13030	11290	12614	12161	8667	9502	10381
Poland	44471	41552	44821	46792	35647	36541	47298

The Czech Republic demonstrates relatively stable values, with premature deaths ranging from 9,245 in 2015 to 10,305 in 2018. A decrease to 6,941 was observed in 2019, but the number increased again to 8,482 in 2021. This trend may reflect seasonal and economic factors influencing PM2.5 concentrations. One of the key determinants in the Czech Republic is the structure of energy production and industrial activity. Although the country has made progress in reducing coal dependency, lignite remains an important energy source, contributing to air pollution. Additionally, industrial hubs, particularly in the Moravian-Silesian region, continue to produce high emissions. However, improvements in air quality regulations, stricter emission limits, and investments in cleaner technologies contributed to the temporary decline observed in 2019. The subsequent increase in 2021 could be linked to a combination of economic recovery post-pandemic, changes in meteorological conditions, and increased energy consumption during colder winters.

Slovakia records the lowest figures among the V4 countries, potentially due to its smaller population and lower industrial activity. Deaths ranged from 5,130 in 2015 to 5,354 in 2021. A notable decline occurred in 2018 and 2019, followed by a slight increase in recent years. Slovakia's relatively lower numbers can be explained by a less industrialized economy compared to Poland or the Czech Republic, as well as a greater share of renewable energy in the electricity mix. However, local factors such as household heating using solid fuels in rural areas still contribute to PM2.5 emissions. The decline observed in 2018–2019 coincides with improvements in emission control technologies, EU-funded environmental policies, and the modernization of heating systems. The recent increase suggests that while progress has been made, challenges persist, particularly in reducing emissions from transportation and residential heating.

Hungary shows the second-highest values after Poland, with deaths ranging from 13,030 in 2015 to 12,214 in 2017. Despite a temporary decline in 2019 and 2020 (8,667 and 9,502), the numbers rose again in 2021, indicating either worsening air quality or insufficient emission reduction measures. Hungary's air pollution issues stem from a mix of industrial activity, coal-based energy production, and a high reliance on older diesel vehicles, particularly in urban areas. The temporary decrease in 2019 and 2020 may be attributed to reduced economic activity during the COVID-19 pandemic, which led to lower emissions from industry and transport. However, the resurgence in 2021 suggests that pollution levels quickly rebounded as industrial and economic activity normalized. Additionally, Budapest and other major cities experience significant traffic congestion, further contributing to PM2.5 levels.

Poland exhibits the highest figures, with a significantly greater number of premature deaths attributed to PM2.5 exposure. Deaths ranged from 44,471 in 2015 to 47,298 in 2021. Although a decrease was observed in 2018 and 2019 (approximately 35,641 deaths), the numbers surged dramatically in 2021. This trend highlights severe air pollution issues, potentially linked to the reliance on fossil fuels and numerous industrial emission sources. Poland remains one of the most coal-dependent countries in Europe, with a high share of domestic heating reliant on outdated coal stoves, particularly in rural areas. Additionally, Poland has a large industrial base, including heavy manufacturing and chemical production, which contribute to persistent air quality challenges. While efforts to curb pollution through stricter regulations and financial incentives for cleaner heating systems have had some success, the slow pace of energy transition continues to pose a challenge. The sharp increase in 2021 may also reflect increased energy demand following the economic recovery, coupled with unfavorable weather conditions that trap pollutants in the atmosphere.

Overall, the graph underscores the seriousness of air pollution caused by PM2.5 in the V4 countries and its adverse health impacts. While some countries achieved temporary improvements, the problem remains pressing. The differences in premature death rates can be largely explained by variations in energy production, industrial activity, transportation policies, and household heating practices. The observed fluctuations suggest that while short-term improvements are possible through regulatory measures and economic shifts, long-term progress requires structural changes.

Effective solutions require comprehensive measures, including a transition to greener energy sources, transport electrification, and modernization of industrial technologies. In particular, reducing coal dependency, expanding the use of renewable energy, and incentivizing cleaner household heating options will be crucial in mitigating PM2.5-related health risks across the region. Regional cooperation within the V4 and alignment with EU environmental policies will also play a key role in achieving lasting improvements in air quality.

3.2 Public transport in the context of noise disturbance

Figure 3 and Table 3 illustrates the share of buses and trains in domestic passenger transport in the V4 countries (Czech Republic, Slovakia, Hungary, and Poland) from 2015 to 2022, expressed as a percentage. These data show the proportion of total passenger transport facilitated by public transport modes, specifically buses and trains.

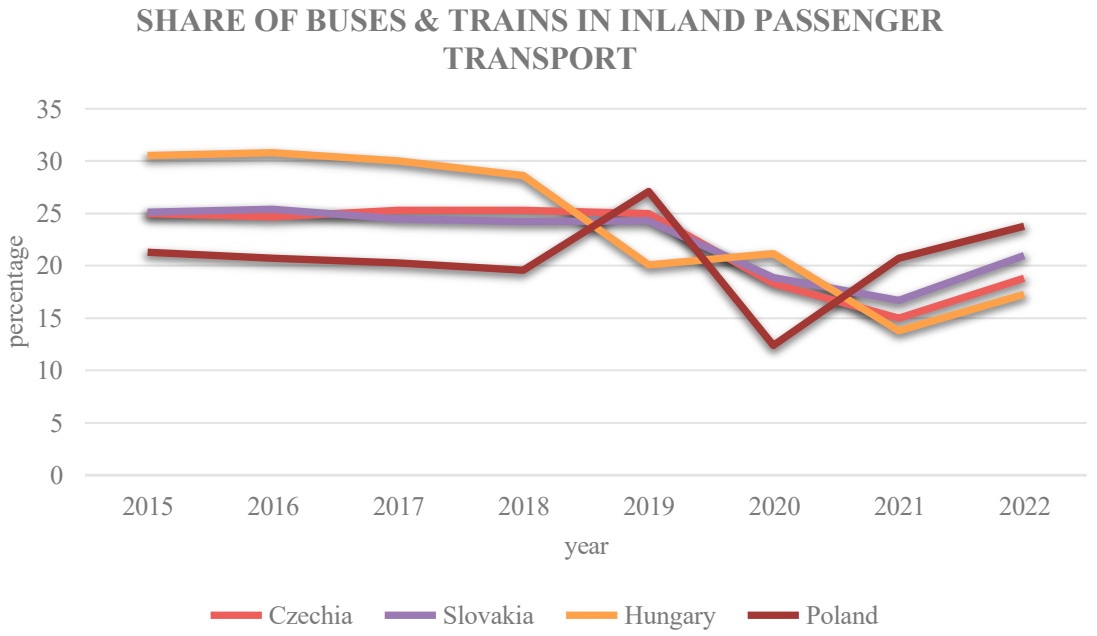

Fig. 3. Share of buses and trains in inland passenger transport (2015-2022).

Table 3. Number of Share of buses and trains in inland passenger transport (own processing based on data from Eurostat (2025).

Country	2015	2016	2017	2018	2019	2020	2021	2022
Czechia	25	24.7	25.3	25.3	25	18.3	15	18.8
Slovakia	25.1	25.4	24.5	24.2	24.3	18.9	16.7	21
Hungary	30.5	30.8	30	28.6	20.1	21.2	13.8	17.3
Poland	21.3	20.7	20.3	19.6	27.1	12.4	20.7	23.8

In the Czech Republic, the share started at 25% in 2015, followed by a gradual decline, reaching its lowest point at 15% in 2021. By 2022, the share increased slightly to 18.8%. This trend may reflect the expansion of private transportation or the impact of the COVID-19 pandemic, which reduced public transport use. A key factor behind the decline is the increasing affordability and accessibility of private vehicles, supported by economic growth and rising incomes. Additionally, investments in road infrastructure have improved the convenience of car travel. The sharp drop in 2020–2021 can be directly linked to pandemic-related restrictions and concerns over virus transmission in shared spaces. The slight recovery in 2022 suggests that efforts to modernize public transport, such as investments in new railway connections and urban mobility projects, may have started to counteract the decline.

Slovakia recorded a 25.1% share in 2015, which remained relatively stable until 2018. However, the share dropped to 16.7% in 2021 but rebounded to 21% in 2022. This increase suggests improvements in the availability and use of public transport. Slovakia's public transport network, particularly in urban areas, has faced challenges such as aging infrastructure and service reliability issues, which may have contributed to the declining trend. However, targeted investments in recent years, including EU-funded modernization projects and the integration of digital ticketing systems, have likely played a role in the post-pandemic rebound. Moreover, policies promoting public transport as a sustainable alternative to individual car use, such as discounts for students and seniors, may have encouraged higher usage rates.

Hungary showed the highest share of public transport use during the observed period, starting at 30.5% in 2015. Over time, the share declined dramatically, reaching a low of 13.8% in 2021. A slight recovery was seen in 2022, with a share of 17.3%. This sharp decline could be attributed to increasing car ownership and restrictions on public transport during the pandemic. The dramatic drop in Hungary is also linked to changes in commuting habits, as suburbanization and urban sprawl have led more people to rely on private vehicles. Budapest, while having an extensive public transport system, has seen a shift towards car travel due to road expansions and rising disposable incomes.

Additionally, the COVID-19 pandemic significantly impacted public transport ridership, as health concerns and remote work trends led to fewer daily commutes. The modest recovery in 2022 may indicate a partial return to pre-pandemic travel patterns and efforts by local governments to improve the attractiveness of public transit.

Poland began with the lowest share among the V4 countries in 2015 (21.3%). After a modest increase to 27.1% in 2018, the share declined during 2020–2021 but rose again to 23.8% in 2022. This resurgence may indicate investments in public transport or a shift in passenger behavior. Poland's trends can be explained by varying regional dynamics: while major cities like Warsaw and Kraków have invested heavily in public transport expansion, smaller towns and rural areas still face accessibility issues. The increase in 2018 likely reflects the impact of new infrastructure projects and urban transport reforms, including better connectivity and electrification of bus fleets. However, the pandemic led to a temporary decrease, as mobility restrictions and fear of infection discouraged public transport use. The renewed growth in 2022 suggests that passengers are returning, possibly due to improvements in service quality, rising fuel prices making private transport less attractive, and government initiatives promoting sustainable mobility.

Overall, the graph highlights a general decline in the share of public transport during the observed period across all countries, with the most significant drops occurring in 2019 and 2020. The primary reasons for this trend include rising car ownership, infrastructure developments favoring private transport, and the impact of the COVID-19 pandemic on mobility habits. Additionally, differences in national transport policies, the extent of urbanization, and investments in public infrastructure play a crucial role in shaping the trends observed in each country.

The post-pandemic period (2021–2022), however, shows a modest revival in the use of buses and trains, possibly driven by increased investments in transport infrastructure, policy changes, or the return of passengers to public transport. To sustain and enhance this positive shift, governments must focus on improving the efficiency, affordability, and environmental sustainability of public transport systems. Strengthening multimodal transport networks, expanding electrification efforts, and implementing congestion charges for private vehicles in urban centers could further encourage public transport use in the V4 region.

Figure 4 and Table 4 depicts the proportion of the population living in households reporting noise disturbance, categorized by their economic status, in the V4 countries (Czech Republic, Slovakia, Hungary, and Poland) from 2015 to 2023. The data, expressed as percentages, provide insight into the perception of noise as an environmental issue under varying socioeconomic conditions.

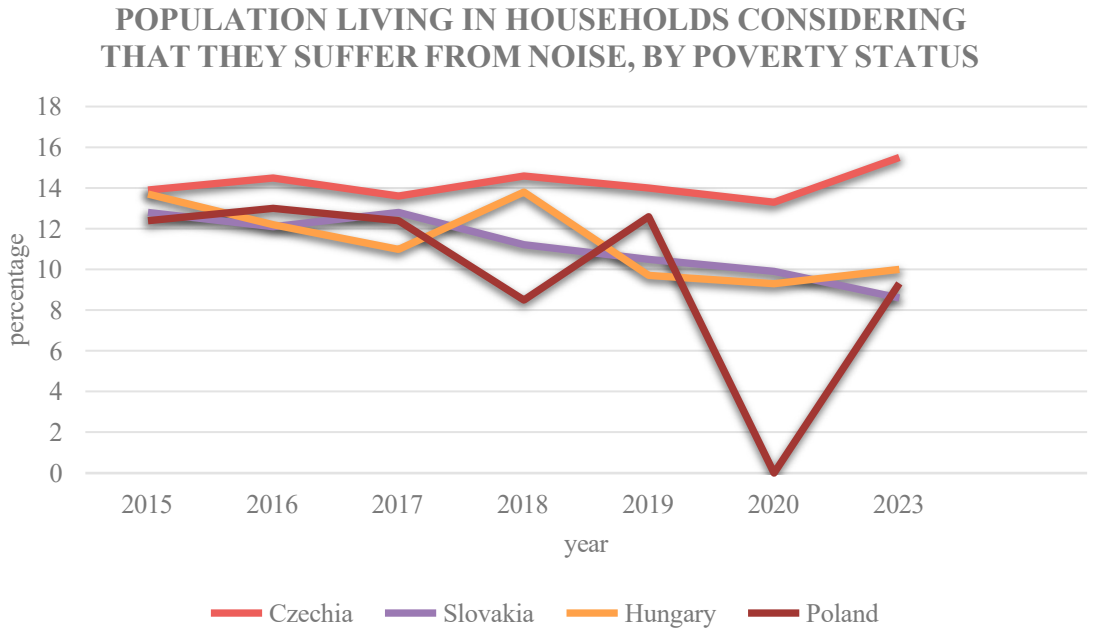

Fig. 4. Population living in households considering that they suffer from noise, by poverty status (2015-2023).

Table 4. Number of Share of buses and trains in inland passenger transport (own processing based on data from Eurostat (2025).

Country	2015	2016	2017	2018	2019	2020	2023
Czechia	13.9	14.5	13.6	14.6	14	13.3	15.5
Slovakia	12.8	12.1	12.8	11.2	10.5	9.9	8.6
Hungary	13.7	12.2	11	13.8	9.7	9.3	10
Poland	12.4	13	12.4	8.5	12.6	/	9.3

In the Czech Republic, the share was 13.9% in 2015, rising to 14.5% in 2016. After a slight decline in subsequent years, the value stabilized at around 13.3% in 2020. By 2023, there was a significant increase to 15.5%, potentially indicating growing noise issues in urban areas or a shift in the perception of noise. This increase may be attributed to multiple factors. Firstly, urbanization and increasing traffic density in major cities such as Prague and Brno may have contributed to higher noise exposure. Secondly, changes in infrastructure, such as new transport projects or road reconstructions, may have temporarily increased noise levels. Additionally, heightened public awareness of environmental issues might have played a role, leading to a greater perception of noise in recent years.

Slovakia recorded a share of 12.8% in 2015, which gradually declined to reach its lowest point of 8.6% in 2023. This trend suggests potential improvements in acoustic comfort or effective measures to reduce noise. The decrease may be the result of several factors, such as investments in modern transport infrastructure and more efficient traffic management, including restrictions on heavy goods vehicles in urban areas. Furthermore, a decline in industrial activity in certain regions and the implementation of stricter noise regulations could have contributed to this trend.

Hungary started at 13.7% in 2015, with the share decreasing over the years, reaching its lowest point of 9.3% in 2020. Since then, the situation has slightly stabilized, with the share at 10% in 2023. The declining trend may be linked to improvements in public transport systems, which could have reduced reliance on private vehicles, particularly in Budapest. Additionally, Hungary has undertaken several urban development projects that may have included noise mitigation measures, such as sound barriers along highways or restrictions on high-noise activities in residential areas.

Poland exhibited a relatively stable trend up to 2019, with the share fluctuating around 12-13%. There is no data available for 2020, but by 2023, the share had returned to 9.3%, representing a decline compared to previous years. Poland's high initial noise perception may be linked to the country's extensive road network and large urban centers with high traffic volumes. However, the recent decline might indicate the effects of investments in transport modernization, including improved public transit systems and better road surfaces that reduce vehicle noise. It is also possible that shifting economic activities or demographic changes have influenced this trend.

Overall, the data reveals diverse trends in noise perception across the V4 countries. While the Czech Republic shows an increasing rate of noise-related issues, Slovakia and Hungary demonstrate a decline, potentially due to infrastructure modernization and urban planning measures. Poland exhibits a unique pattern that may require further investigation, particularly regarding the effectiveness of noise reduction policies. These findings highlight the importance of integrated transport and environmental policies to improve acoustic comfort and overall urban quality of life.

4. Discussion

The findings of this study clearly show that there are notable differences in road traffic fatality rates, PM2.5 concentrations, public transport availability and noise pollution across the V4 countries. These disparities highlight the varied effectiveness of transport policies and their implementation within the region. Such differences underline the importance of tailoring transport strategies to the specific socio-economic and environmental conditions of each country.

"What are the differences in road traffic fatality rates across the V4 countries, and what do these differences suggest about the implementation of transport policies?"

The analysis revealed that Hungary consistently exhibited the highest road traffic fatality rates among the V4 countries, while Czechia reported the lowest. These differences suggest varying levels of road safety measures, infrastructure quality, and enforcement of traffic regulations. One possible explanation for Hungary's higher fatality rates is its historically aging road network, which may not provide the same level of safety as the more modernized infrastructure in Czechia. Additionally, differences in enforcement intensity and public compliance with traffic

regulations play a crucial role. Studies, such as those by Berhanu et al. (2023), indicate that countries with more rigorous enforcement of speed limits, seat belt use, and pedestrian safety measures tend to achieve lower fatality rates. Czechia's lower rates may reflect the effectiveness of its investment in intelligent transport systems, stricter penalties for traffic violations, and widespread road safety awareness campaigns. In contrast, Hungary's challenges in reducing fatality rates could be linked to gaps in law enforcement and slower implementation of advanced road safety technologies.

"What are the differences in PM2.5 concentrations across the V4 countries, and what do these differences suggest about the implementation of transport policies?"

The data showed that Poland consistently reported the highest number of premature deaths due to PM2.5 exposure, while Slovakia reported the lowest. These differences highlight variations in air quality management, industrial activity, and reliance on polluting energy sources across the V4 countries. Poland's high mortality rates are likely linked to its continued dependence on coal-based energy and the presence of heavy industry, which contribute to persistent air pollution levels. Additionally, the slow adoption of low-emission transport solutions and limited restrictions on older, high-emission vehicles may exacerbate the problem. On the other hand, Slovakia's lower PM2.5-related mortality may reflect stricter air quality regulations, a more diversified energy mix, and investments in cleaner transport alternatives. These findings align with research by Basith et al. (2022), which emphasizes the role of energy and environmental policies in shaping air pollution levels. While all V4 countries have introduced some measures to curb PM2.5 emissions, the differences in effectiveness suggest that Poland may need more aggressive strategies, such as transitioning further toward renewable energy sources and enhancing public transportation electrification.

"What are the differences in public transport availability across the V4 countries, and what do these differences suggest about the implementation of transport policies?"

Hungary had the highest share of buses and trains in inland passenger transport in 2015, but this share declined sharply over the years. In contrast, Slovakia showed a more stable trend, with a slight increase in recent years. Poland and Czechia experienced moderate declines followed by recoveries. These trends suggest that Hungary may be facing structural challenges in maintaining an attractive and competitive public transport system, possibly due to an increasing reliance on private vehicles or insufficient investment in modernizing public transport infrastructure. Slovakia's relative stability and recent increase in public transport usage may indicate successful policy interventions, such as fare subsidies, service expansion, and infrastructure modernization. According to Li et al. (2021), the availability and attractiveness of public transport are key indicators of sustainable mobility policies. The observed trends suggest that Slovakia has been more effective in sustaining public transport ridership, while Hungary's sharp decline raises concerns about potential policy shortcomings or shifting travel preferences that favor private transportation.

"What are the differences in noise pollution levels across the V4 countries, and what do these differences suggest about the implementation of transport policies?"

Noise pollution levels, as measured by the percentage of households reporting disturbances from noise, exhibited divergent trends across the V4 countries. Slovakia and Hungary recorded a steady decline, suggesting successful noise mitigation efforts, such as improved traffic management, the introduction of low-noise road surfaces, and better urban planning strategies. In contrast, Czechia displayed an increasing trend, which may be attributed to growing urbanization, rising traffic volumes, or inadequate enforcement of noise reduction measures. Poland showed a unique pattern with fluctuations, including significant drops during the pandemic, likely due to reduced transport activity. These findings align with research by Mouratidis & Serrano (2021), which emphasizes the connection between urban density, transport policies, and noise pollution levels. The trends observed in Slovakia and Hungary suggest proactive approaches to noise reduction, possibly through stricter regulations on vehicle noise emissions and the expansion of quieter public transport options. However, Czechia's increasing noise levels indicate potential gaps in policy implementation, requiring further assessment of urban planning and transport management strategies.

This study was limited by the availability of comparable and up-to-date data across the V4 countries, particularly concerning noise pollution and PM2.5 concentrations. Future research could address these gaps by incorporating real-time monitoring systems and more granular data. Additionally, while this study focused on the transport sector, exploring the interplay between transport policies and other sectors, such as energy and urban development, could provide a more holistic understanding of sustainable mobility challenges in the V4 region. Expanding the scope to include non-V4 countries could also offer valuable insights into the best practices and innovative solutions for transport policy implementation.

5. Conclusion

This study provides a comprehensive comparative analysis of road traffic fatality rates, PM2.5 concentrations, public transport usage, and noise pollution across the V4 countries (Czechia, Slovakia, Hungary, and Poland). The findings hold significant implications for transport policies, public health, and environmental sustainability in the region, offering practical insights for policymakers and stakeholders aiming to improve the quality of life and promote sustainable development.

The most critical finding is the variation in road traffic fatality rates among the V4 countries. Czechia and Slovakia demonstrate relatively lower fatality rates compared to Hungary and Poland, which points to differences in road safety policies, infrastructure quality, and enforcement of traffic laws. These results suggest that adopting best practices from countries with lower fatality rates could be a practical approach to enhancing road safety across the region.

Road traffic fatality rates are closely connected to broader public health challenges, particularly the impact of air pollution. Regarding PM2.5 concentrations, the analysis reveals persistent air quality challenges, with Poland consistently exhibiting the highest premature death rates due to exposure to fine particulate matter. This emphasizes the urgent need for more aggressive air quality improvement measures, such as transitioning to cleaner energy sources, modernizing industrial practices, and promoting the use of environmentally friendly transportation modes. Addressing PM2.5 pollution not only improves health outcomes but may also indirectly enhance road safety by mitigating factors like reduced visibility and driver fatigue linked to poor air quality.

Public transport usage shows a declining trend across all V4 countries, particularly in Hungary and Poland, where the decline is most pronounced. This trend signals a potential shift towards private vehicle use, which could exacerbate traffic congestion, noise pollution, and air quality issues. Reinvigorating public transport systems through investments in infrastructure, increased accessibility, and improved service quality is essential to reversing this trend and fostering sustainable mobility.

In terms of noise pollution, the study highlights that Czechia has a notably higher percentage of households reporting noise disturbance, especially among those below the poverty line. This finding underscores the need for targeted interventions to mitigate noise pollution, particularly in urban and economically disadvantaged areas. Solutions such as stricter noise regulations, enhanced urban planning, and investments in noise-reducing technologies could prove beneficial. The link between noise pollution and declining public transport usage further highlights the importance of promoting quieter, sustainable transport systems.

Overall, the study's findings emphasize the need for coordinated efforts at both the national and regional levels to address these challenges. By leveraging the comparative insights provided, policymakers can design more effective transport policies that align with the goals of sustainability, public health, and economic development. Future research should focus on evaluating the implementation and effectiveness of specific transport policies and exploring their socioeconomic impacts to further enhance policy outcomes.

The study's primary limitation lies in the descriptive nature of the analysis, as it is based on secondary data and framework desk research. This limitation opens avenues for further investigation, including real-time data collection and more granular analysis. The study was also limited by the availability of comparable and up-to-date data across the V4 countries, particularly concerning noise pollution and PM2.5 concentrations. Future research should explore the interplay between transport policies and other sectors, such as energy and urban development, to provide a holistic understanding of sustainable mobility challenges. The authors aim to build on this foundational analysis, addressing these limitations in subsequent studies to advance the understanding and implementation of effective transport policies in the V4 region.

Acknowledgements

This article is one of the partial outputs of the currently implemented research grant VEGA no. 1/0110/24 & project of University of Economics in Bratislava no. I-25-105-00.

References

Basith, S., Manavalan, B., Shin, T.H., Chan, B.P., Lee, W.S., Kim, J., Lee, G. 2022. The Impact of Fine Particulate Matter 2.5 on the Cardiovascular System: A Review of the Invisible Killer. Nanomaterials 12, 2656. http://dx.doi.org/10.3390/nano12152656

Berhanu, Y., Alemayehu, E., Schroeder, D. 2023. Examining Car Accident Prediction Techniques and Road Traffic Congestion: A Comparative Analysis of Road Safety and Prevention of World Challenges in Low-Income and High-Income Countries. Journal of Advanced Transportation 2023, 1-18. http://dx.doi.org/10.1155/2023/6643412

Cavallaro, F., Nocera, S. 2021. Integration of passenger and freight transport: A concept-centric literature review. Research in Transportation Business & Management 43, 100718. http://dx.doi.org/10.1016/j.rtbm.2021.100718

Donkelaar, A., Hammer, M., Bindle, L., Brauer, M., Brook, J., Garay, M., Hsu, N., Kalashnikova, O., Kahn, R., Lee, C., Levy, R., Lyapustin, A., Sayer, A., Randall, M. 2021. Monthly Global Estimates of Fine Particulate Matter and Their Uncertainty. Environmental Science & Technology. http://dx.doi.org/10.1021/acs.est.1c05309

Drescher, K., Janzen, B. 2021. Determinants, persistence, and dynamics of energy poverty: An empirical assessment using German household survey data. Energy Economics 102, 105433. http://dx.doi.org/10.1016/j.eneco.2021.105433

Eurostat, 2025. Population living in households considering that they suffer from noise, by poverty status. https://ec.europa.eu/eurostat/databrowser/view/sdg_11_20/default/table?lang=en&category=sdg.sdg_11

Eurostat, 2025. Premature deaths due to exposure to fine particulate matter (PM2.5). https://ec.europa.eu/eurostat/databrowser/view/sdg_11_52/default/table?lang=en&category=sdg.sdg_11

Eurostat, 2025. Road traffic deaths, by type of roads. https://ec.europa.eu/eurostat/databrowser/view/sdg_11_40/default/table?lang=en&category=sdg.sdg_11

Eurostat, 2025. Share of buses and trains in inland passenger transport. https://ec.europa.eu/eurostat/databrowser/view/sdg_09_50/default/table?lang=en&category=sdg.sdg_11

Filippini, Massimo - Obrist, Adrian, 2022. Are households living in green certified buildings consuming less energy? Evidence from Switzerland. Energy Policy 161, 112724. http://dx.doi.org/10.1016/j.enpol.2021.112724

Fitzová, H., Kališ, R., Pařil, V., Kasa, M. 2021. Competition in long distance transport: Impacts on prices, frequencies, and demand in the Czech Republic. Research in Transportation Business & Management, 41, 100655.

Jima, D., Sipos, T., 2022. The Impact of Road Geometric Formation on Traffic Crash and Its Severity Level. Sustainability 14, 8475. http://dx.doi.org/10.3390/su14148475

Johnson, N., Hoffmann, A., Behlen, J., Lau, C., Pendleton, D., Harvey, N., Shore, R., Li, Y., Chen, J., Yanan, T., Renyi, Z. 2021. Air pollution and children's health—a review of adverse effects associated with prenatal exposure from fine to ultrafine particulate matter. Environmental Health and Preventive Medicine 26. http://dx.doi.org/10.1186/s12199-021-00995-5

Kendra, M., Skrúcaný, T., Dolinayová, A., Čamaj, J., Jurkovič, M., Csonka, B., Abramović, B. 2023. Environmental burden of different transport modes–Real case study in Slovakia. Transportation research part D: transport and environment, 114, 103552.

Li, Z., Shalaby, A., Roorda, M., Baohua, M. 2021. Urban rail service design for collaborative passenger and freight transport. Transportation Research Part E: Logistics and Transportation Review 147, 102205. http://dx.doi.org/10.1016/j.tre.2020.102205

Mouratidis, K., Serrano, V., 2021. Autonomous buses: Intentions to use, passenger experiences, and suggestions for improvement. Transportation Research Part F: Traffic Psychology and Behaviour 76, 321-335. http://dx.doi.org/10.1016/j.trf.2020.12.007

Nagaraj, N., Gururaj, H.L., Swathi, B.H., Hu, Y.C. Passenger flow prediction in bus transportation system using deep learning. Multimed Tools Appl 81, 12519–12542 (2022). https://doi.org/10.1007/s11042-022-12306-3

Ogryzek, M., Wolny-Kucińska, A. 2021. Sustainable development of transport as a regional policy target for sustainable development—a case study of Poland. ISPRS International Journal of Geo-Information, 10(3), 132.

Park, J., Byun, W., Kim, Y., Ahn, H., Shin, D., 2021. The Impact of Automated Vehicles on Traffic Flow and Road Capacity on Urban Road Networks. Journal of Advanced Transportation 2021, 1-10. http://dx.doi.org/10.1155/2021/8404951

Pollák, F., Vodák, J., Soviar, J., Markovič, P., Lentini, G., Mazzeschi, V., Luè, A., 2021. Promotion of Electric Mobility in the European Union—Overview of Project PROMETEUS from the Perspective of Cohesion through Synergistic Cooperation on the Example of the Catching- Up Region. Sustainability 13(3), 1545. https://doi.org/10.3390/su13031545

Połom, M. 2022. Diversification of policies for the development of electric public transport in the Czech Republic, Poland and Slovakia. Prace Komisji Geografii Komunikacji PTG, 25(4), 59-73.

Soviar, J., Holubčík, M., Vodák, J., Rechtorík, M., Pollák, F., 2019. The Presentation of Automotive Brands in the On-Line Environment—The Perspective of KIA, Peugeot, Toyota and VW in the Slovak Republic. Sustainability 11(7), 2132. https://doi.org/10.3390/su11072132

Székely, V., Novotný, J. 2022. Public transport-disadvantaged rural areas in relation to daily accessibility of regional centre: Case study from Slovakia. Journal of Rural Studies, 92, 1-16.

Trencher, G., Edianto, A., 2021. Drivers and Barriers to the Adoption of Fuel Cell Passenger Vehicles and Buses in Germany. Energies 14, 833. http://dx.doi.org/10.3390/en14040833

Valent, F.,2022. Road traffic accidents in Italy during COVID-19. Traffic Injury Prevention 23, 1-5. http://dx.doi.org/10.1080/15389588.2022.2047956

Vichova, K., Veselik, P., Heinzova, R., Dvoracek, R. 2021. Road transport and its impact on air pollution during the COVID-19 pandemic. Sustainability, 13(21), 11803.

Wendt, J. A., Grama, V., Ilieş, G., Mikhaylov, A. S., Borza, S. G., Herman, G. V., Bógdał-Brzezińska, A. 2021. Transport infrastructure and political factors as determinants of tourism development in the cross-border region of Bihor and Maramureş. A comparative analysis. Sustainability, 13(10), 5385.

Wołek, M., Wolański, M., Bartłomiejczyk, M., Wyszomirski, O., Grzelec, K., Hebel, K. 2021. Ensuring sustainable development of urban public transport: A case study of the trolleybus system in Gdynia and Sopot (Poland). Journal of Cleaner Production, 279, 123807.

Wyer, K., Kelleghan, D., Blanes-Vidal, V., Schauberger, G., Curran, T., 2022. Ammonia emissions from agriculture and their contribution to fine particulate matter: A review of implications for human health. Journal of Environmental Management 323, 116285. http://dx.doi.org/10.1016/j.jenvman.2022.116285

Xu, R., Huang, S., Shi, C., Wang, R., Liu, T., Li, Y., Zheng, Y., Lv, Z., Wei, J., Sun, H., Liu, Y., 2023. Extreme Temperature Events, Fine Particulate Matter, and Myocardial Infarction Mortality. Circulation 148, 312-323. http://dx.doi.org/10.1161/CIRCULATIONAHA.122.063504

Zhang, Z., Shu, H., Yi, H., Wang, X., 2021. Household multidimensional energy poverty and its impacts on physical and mental health. Energy Policy 156, 112381. http://dx.doi.org/10.1016/j.enpol.2021.112381

Zukowska, J., Gobis, A., Krajewski, P., Morawiak, A., Okraszewska, R., Woods, C. B., Volf, K., Kelly, L., Gelius, P., Messing, S., Forberger, S., Lakerveld, J., den Braver, N., Bengoechea, E.G., 2022. Which transport policies increase physical activity of the whole of society? A systematic review. Journal of Transport & Health, 27, 101488.