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THE IMPACT OF SELECTED PASSENGER CAR MODELS ON ENVIRONMENTAL ELEMENTS

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Purpose: Educating the public about the impact of transport on the environment and health, which can lead to more informed consumer decisions and behaviours, as well as encouraging the use of more environmentally friendly means of transport, such as carpooling, electric vehicles or rail transport.
Design/methodology/approach: The Copert program was used to calculate the pollutant emissions from three Opel car models, while a measuring system consisting of a Bushnell vehicle speed meter, a microphone and a data acquisition card was used to determine the noise emissions. The measurements were carried out on specially selected sections of roads of different categories, characterized by different noise propagation conditions and acoustic obstacles. Sound pressure was measured during the passage of a single vehicle with speed measurement.
Findings: The opinion that diesel cars have the most negative impact on the environment is firmly established in the public consciousness. However, the analyses carried out clearly indicate that this view is true only in the case of nitrogen oxide emissions. Although NOx is one of the main greenhouse gases affecting global warming, its presence in the environment leads to the formation of photochemical smog, acid rain and tropospheric ozone, which is harmful to our health and vegetation. However, it should be noted that the remaining emissions and their level in both diesel and petrol engines are at a similar level, which is caused by the evolution of diesel engine technology, which currently meets strict emission standards (Euro 6 and higher), thanks to which they emit less NOx and PM than older models.
Social implications: The obtained results may increase public awareness of the negative impact of road transport on the environment and the need to change attitudes/habits in order to improve the quality of life.
Originality/value: This article presents the impact of three Opel passenger car models on selected environmental elements, taking into account noise emissions, as well as emissions of pollutants such as NOx, SOX, CO, CO_2, as well as emissions of suspended particulate matter PM2.5 and PM10.
Keywords: environmental pollution, transport, noise, gaseous pollution, Copert program.
Category of the paper: research paper.

1. Introduction

There are currently around 1.5 billion passenger cars in the world, and over 250 million cars on European Union roads alone (OICA, 2024). At the end of 2022, there were around 26.7 million passenger cars registered in Poland, but after taking into account the so-called vehicles that are no longer in use but were still in the register, the real number was around 19.7 million. The number of passenger cars per 1000 inhabitants in Poland is 517, which puts the country in the European average, even though theoretically there are 700 vehicles per 1000 people, including older, unused cars. The average age of vehicles in Poland is around 14.9 years (GUS, 2024), which is a relatively high result, especially compared to other European Union countries, e.g. in Germany it is around 9.6 years, and in France 9 years, which places these countries among the countries with the younger car fleet in Europe (OICA, 2024). The number of cars in the world is expected to reach 2 billion by 2040 if the current growth rate is maintained. The increase in the number of cars is mainly driven by population growth, urbanization and increased access to vehicles in developing countries such as India and China.

The European Union is taking a number of actions to minimize the impact of transport on the environment, using various political, regulatory and technological tools. As part of its policy, the EU focuses on sustainable development, promoting more ecological forms of transport, as well as introducing strict standards and regulations on emissions. All of these actions require cooperation between governments, businesses, non-governmental organizations and society. Their success depends on a comprehensive approach and consistency in the implementation of the adopted strategies (Motowidlak, 2016).

Such a huge number of vehicles generates significant amounts of greenhouse gas emissions and air pollutants, such as NOx, PM2.5, CO2 and CO and noise (Wisniewski, 2020; Souza de Abreu, 2022; Lin, 2021). The main causes of road noise include: high traffic density, vehicle speed, the share of heavy goods vehicles in traffic, poor technical condition of the road surface and vehicles, inefficient urban planning and the lack of provisions in noise regulations (Perzynski, 2019).

These vehicles also affect the degradation of ecosystems and the depletion of natural resources (Ferreira, 2018).

The current level of pollution and environmental exploitation by passenger cars emphasizes the need to develop low-emission technologies (e.g. EV, hydrogen), implement sustainable practices (car sharing, public transport), as well as introduce stricter emission regulations and promote recycling. It should be noted that the level of recycling of decommissioned motor vehicles in Poland is almost 100% (Ochocka, 2020), a perfect example of which is the recycling of used lead-acid batteries, which are most often used in this type of vehicles. EU Directive 2006/66/EC requires that lead-acid batteries be recycled at a rate of 65% (Directive, 2006), and in Poland the achieved level of recycling lead-acid batteries is above 95% (Baterpol).

In the presented work, research was conducted on the impact of selected brands of passenger cars on the emission of gaseous pollutants and noise levels.

2. Methodology

Three Opel car models were used in the study, i.e. Astra V with a petrol engine, Astra V with a diesel engine and Mokka with a petrol engine. The above-mentioned cars were manufactured in 2020, their mileage was 53,600 km, 55,000 km and 54,000 km, respectively. It should be noted that all the cars analyzed meet the strict Euro 6d standards. The technical parameters of the above-mentioned vehicles are presented in Table 1-3.

Table 1.
Technical data Opel Astra V, petrol engine, year of production 2020 (Automobile Catalog)

Engine	petrol 1.6 Turbo 200KM
Capacity (cm3)	1598
Gearbox	6-speed manual
Max power (HP at rpm)	200/4700-5500
Torque (Nm at rpm)	300/1700-4700
Current weight (kg)	1350
fuel consumption (extra-urban/urban/combined) (l/100 km)	5,0/8,0/6,1
CO_2 emissions (g/km)	141

Table 2.
Technical data Opel Mokka, petrol engine, year of production 2020 (Automobile Catalog)

Engine	Benzynowy 1.4 Turbo 140 KM
Capacity (cm3)	1364
Gearbox	6-speed manual
Max power (HP at rpm)	103 przy 4900-6000
Torque (Nm at rpm)	200 przy 1850-4900
Current weight (kg)	1295 kg
fuel consumption (extra-urban/urban/combined) (l/100 km)	5,0/7,4/5,9
CO_2 emissions (g/km)	139 (158)

Table 3.
Technical data Opel Astra V, diesel engine, year of production 2020 (Automobile Catalog)

Engine	Diesel 1.6 CDTI 136KM
Capacity (cm3)	1598
Gearbox	6-speed manual
Max power (HP at rpm)	136/3500-4000
Torque (Nm at rpm)	320/2000-2250
Current weight (kg)	1350
fuel consumption (extra-urban/urban/combined) (l/100 km)	3,6/5,2/4,2
CO_2 emissions (g/km)	111

The first stage of the research was to measure the external noise generated by selected motor vehicles such as Opel Astra V and Opel Mokka. The measurements were carried out on specially selected sections of roads of different categories, characterized by different noise propagation conditions and acoustic obstacles. During the measurements, sound pressure measurements were carried out during the passage of a single vehicle with speed measurement, and the microphone was placed in all analyzed cases at a height of 1.5 m. The view of the measurement system is shown in Figure 1.

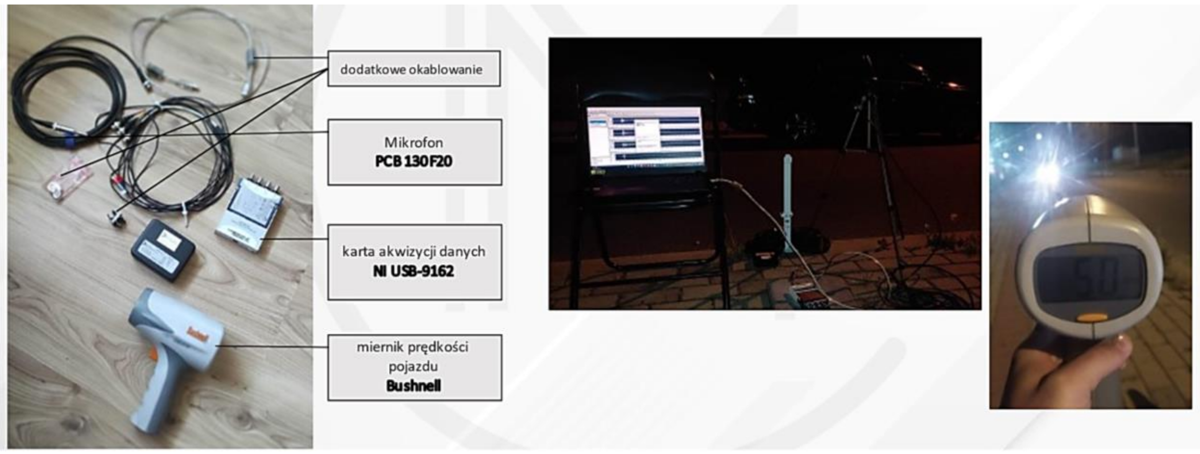

Figure 1. The measurement system used for research.

The research was carried out at four measurement points, i.e.:

- housing estate road - Mysłowice, Wybickiego Street,
- expressway - Sosnowiec S1,
- two-lane rural road - Mysłowice, Obrzezna Street,
- single-lane rural road - Jaworzno, Promienna Street.

The next stage of the research was modelling and estimating the emissions of selected chemical compounds emitted by the analysed vehicles using the Copert programme. Emissions in the programme are divided into 3 types: hot emissions - emitted from vehicles in motion, cold emissions - during engine start-up and evaporation during vehicle operation. Emissions of each group depend on the vehicle class, engine capacity and fuel type. It was necessary to determine the meteorological conditions (air temperature and humidity) for calculating air pollution emissions in the COPERT programme, as they affect air pollution, its intensity and duration. These data were downloaded from the archival sources of the website olframalpha.pl (table 4).

Table 4.
Monthly temperature and humidity in Katowice in 2023 (olframalpha)

Month	min Temperature [°C]	max Temperature [°C]	Humidity [%]
January	-5,0	15,0	88,0%
February	-14,0	10,0	83,0%
March	-8,0	19,0	73,0%
April	-8,0	22,0	76,0%
May	-3,0	24,0	67,0%
June	2,0	30,0	68,0%
July	7,0	33,0	69,0%
August	6,0	31,0	77,0%
September	5,0	29,0	77,0%
October	-3,0	25,0	83,0%
November	-6,0	17,0	86,0%
December	-9,0	10,0	87,0%

3. Results and discussion

Example results of external noise measurements generated by selected motor vehicles are presented in Figures 2-5.

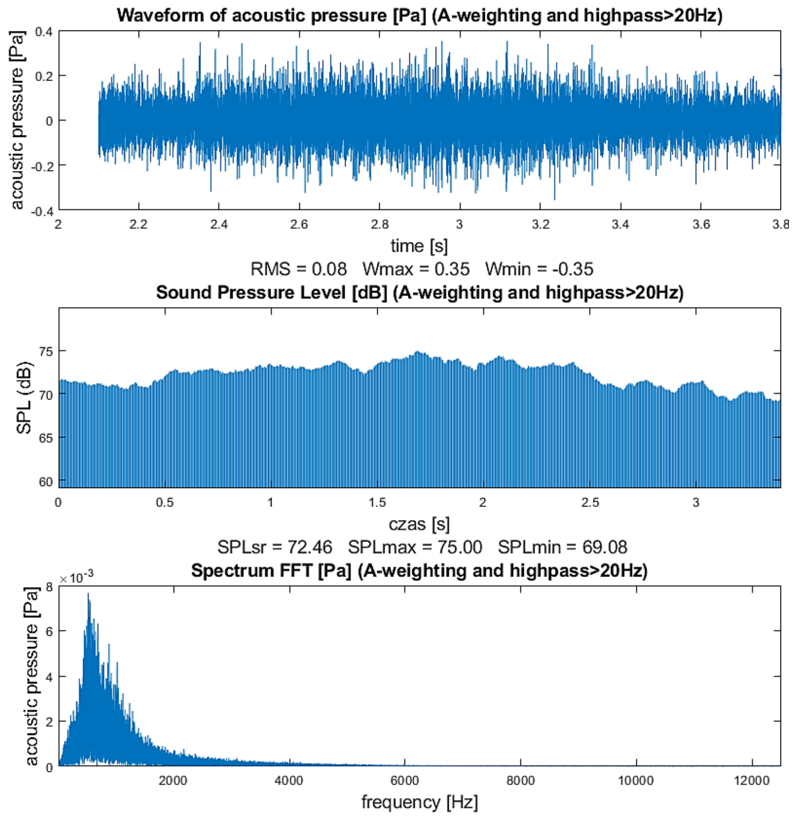

Figure 2. Opel Astra V, petrol engine, expressway, speed 85 km/h.

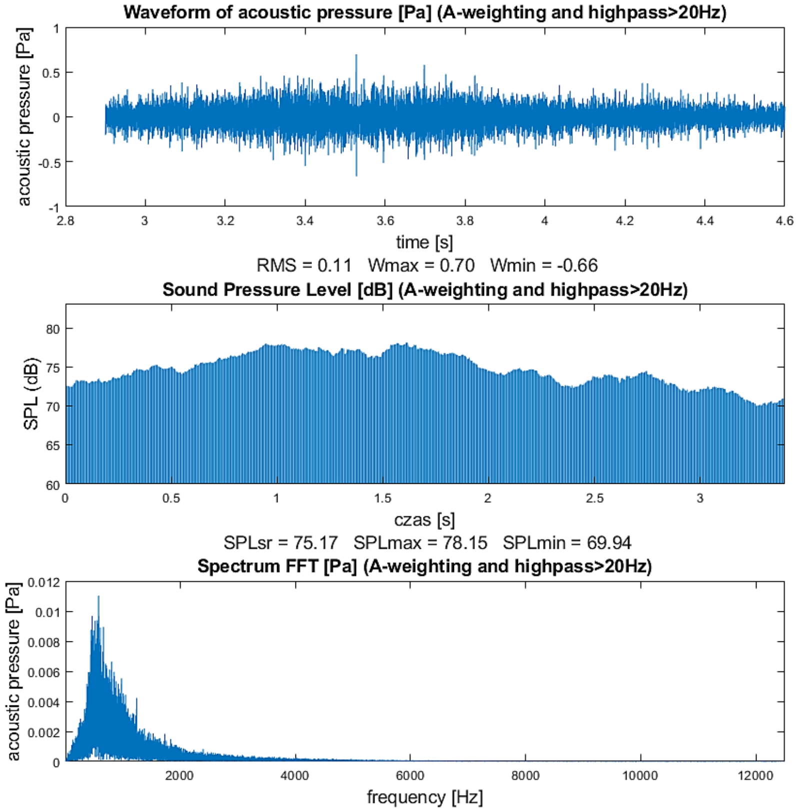

Figure 3. Opel Mokka: petrol engine, expressway, speed 85 km/h.

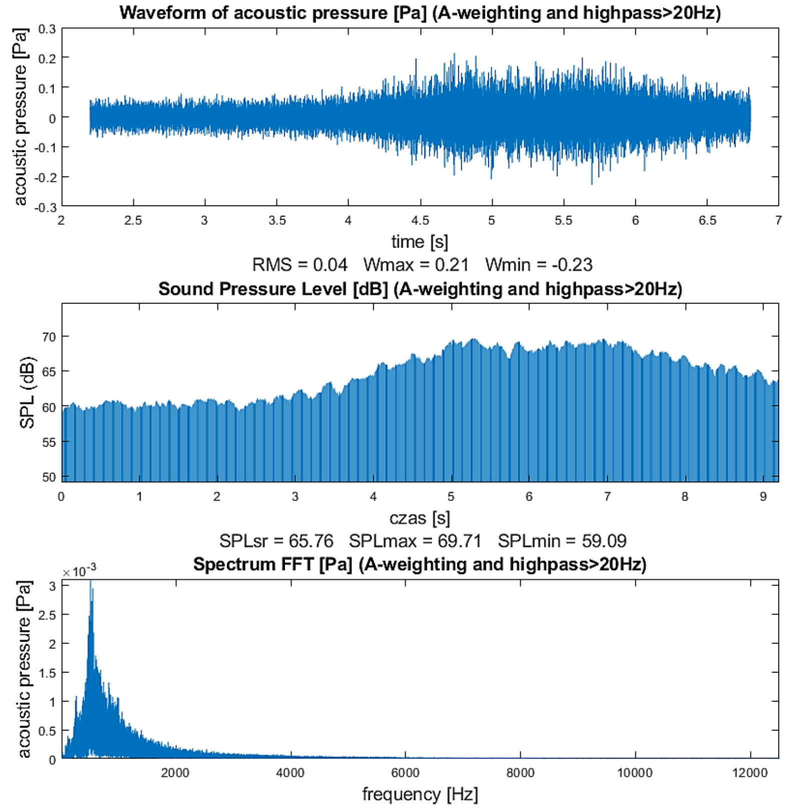

Figure 4. Opel Astra V, petrol drive, extra-urban road, speed 57 km/h.

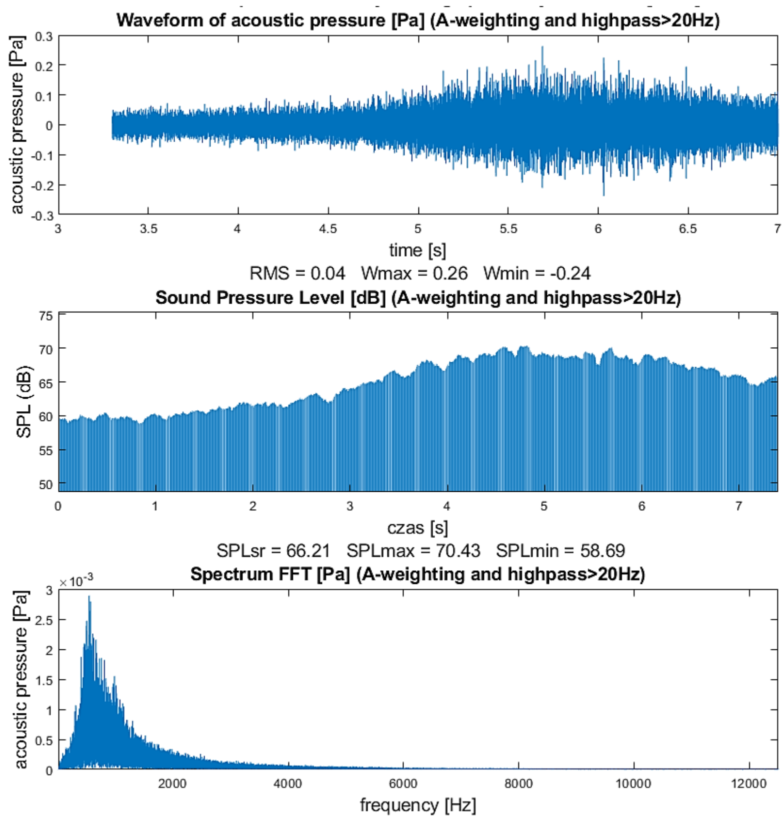

Figure 5. Opel Mokka, petrol engine, extra-urban road, speed 62 km/h.

In turn, example average values of sound levels on single- and two-lane expressways and suburban roads for the analyzed vehicles are presented in Figures 6-8.

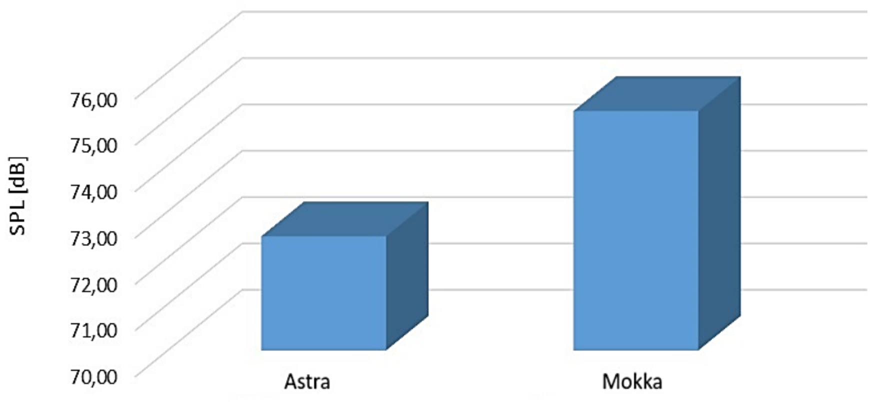

Figure 6. Average sound level values on an expressway for a petrol-powered Opel Astra V and Mokka vehicle at a speed of 85 km/h.

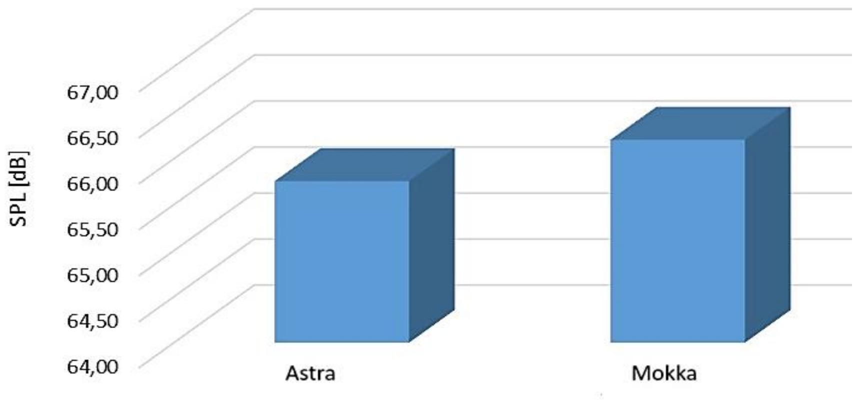

Figure 7. Average sound level values on a 2-lane suburban road for a petrol-powered Opel Astra and Mokka, at a speed of 60 km/h.

As shown in Figures 7 and 8, the average sound level on a suburban road generated by the petrol version of the Opel Mokka is higher than that of the Opel Astra V in the same fuel version for several reasons. The Opel Mokka is an SUV, with a higher silhouette than the Opel Astra V, which is a compact hatchback. The tall silhouette of the Opel Mokka (with a higher centre of gravity) can cause the generated air and wind noise, at higher speeds, to be more audible than in the lower Astra V. The Mokka, as an SUV, generates more air and mechanical noise, while the more compact Astra V, with better aerodynamics, is more effective in noise suppression.

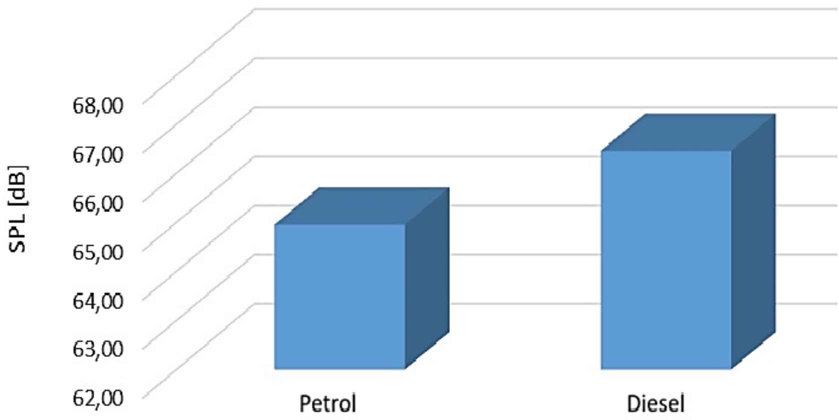

Figure 8. Average sound level values on a single-lane suburban road, for an Opel Astra petrol and diesel vehicle, at a speed of 60 km/h.

As Figure 8 shows, the average noise level of a car on a suburban road depends on many factors, and the higher noise level of diesel engines compared to petrol engines, as in the case of the Opel Astra V, may be due to several reasons. One is that diesel engines are noisier than petrol engines because they operate at a higher compression ratio. This creates higher cylinder pressures, which translates into higher engine noise. Additionally, diesel engines often have a rougher operating characteristic (more "knocker"), which can result in higher noise levels compared to petrol engines, which have a smoother operation. Diesel engines tend to operate at a lower RPM than petrol engines, but they generate more noise at the same speeds, due to the nature of the combustion and the difference in ignition technology.

When accelerating on a suburban road, where the engine load can vary, diesel engines often produce higher noise levels. Compared to petrol engines, diesel engines generate greater vibrations, which can contribute to increased noise inside the vehicle and can also affect the noise level outside the vehicle. The next stage of the study was to calculate the emissions of selected chemical compounds, i.e. CO, CO_2, NOx, and PM2.5 dust for the Opel Astra with petrol and diesel engines, and the Opel Mokka with petrol engines, as shown in Figures 9-12.

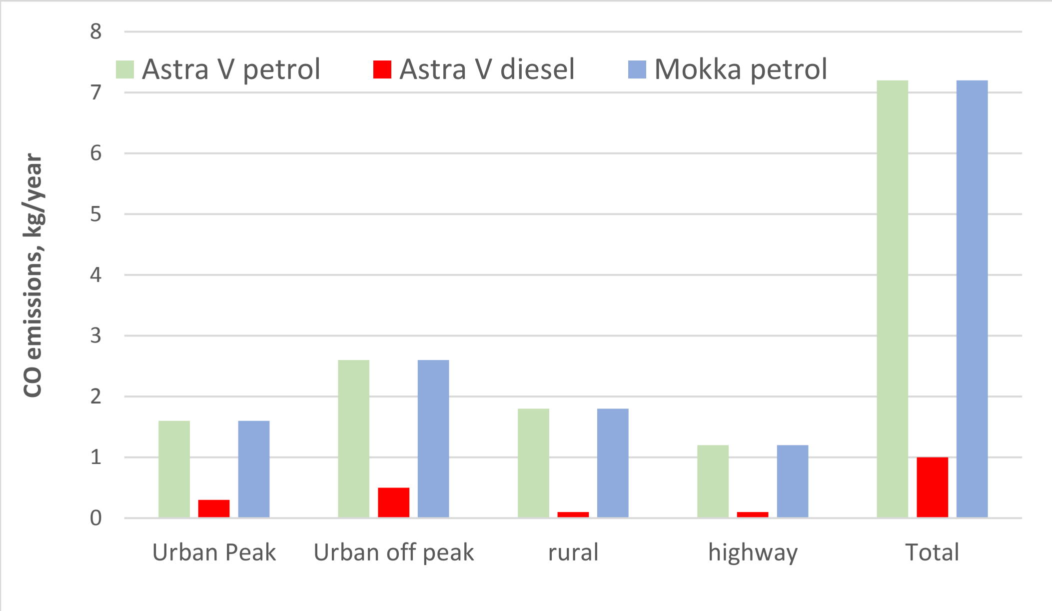

Figure 9. Emission of carbon monoxide (II) into the atmosphere in 2023 from the analyzed motor vehicles.

As shown in Figure 9, the Opel Astra with a diesel engine emits significantly less CO than the Opel Astra V and Opel Mokka with a petrol engine. It should be noted that diesel engines operate with an excess of air in the cylinder (a lean mixture), which means that they have more oxygen available to burn the fuel. This excess oxygen promotes complete combustion of the fuel, which reduces the formation of CO. Additionally, in petrol engines, where a mixture closer to stoichiometric (ideal air to fuel ratio) is used, a lack of sufficient oxygen at certain times can lead to incomplete combustion and increased CO emissions. In diesel engines, ignition occurs spontaneously as a result of compression, which causes the fuel to burn slowly and evenly, reducing the formation of carbon monoxide. In petrol engines, on the other hand, ignition is initiated by spark plugs, which leads to faster combustion. At higher loads or a lack of oxygen, incomplete combustion and increased CO emissions can occur. Diesel fuel used in diesel engines contains more hydrocarbons, but it burns better due to the specific combustion process in this type of engine, while petrol, due to its volatility and combustion characteristics, is more susceptible to incomplete combustion, which increases CO emissions.

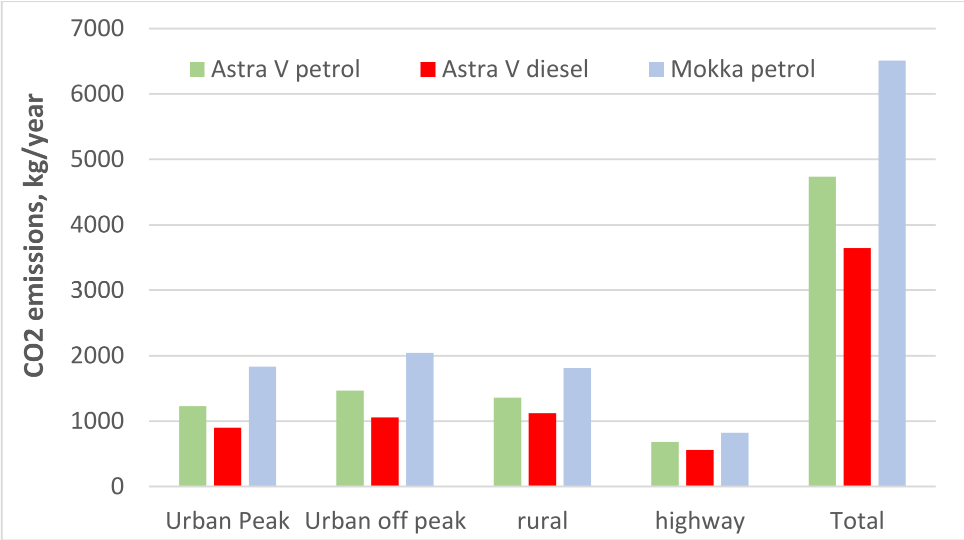

Figure 10. Emission of carbon monoxide (IV) into the atmosphere in 2023 from the analyzed motor vehicles.

As shown in Figure 10, petrol engines are characterized by higher CO_2 emissions than diesel engines, which results from differences in their design, combustion processes and fuel characteristics. Petrol engines have lower thermodynamic efficiency than diesel engines. This means that during the combustion process, a larger part of the energy from the fuel is converted into heat rather than into motion, which results in higher fuel consumption per unit of work. Higher fuel consumption leads to higher CO_2 emissions, because CO_2 is the main product of hydrocarbon combustion. In petrol engines, the combustion process takes place in a stoichiometric mixture, which is close to the ideal air-fuel ratio. In practice, this leads to more even combustion, but at the same time higher fuel consumption compared to diesel engines, which operate with excess air. Petrol engines usually operate at higher RPMs, which increases fuel consumption and CO_2 emissions, especially during dynamic driving. Diesels have a higher compression ratio (20:1 compared to 10:1 in petrol), which allows for more efficient use of the energy contained in the fuel. As a result, diesels use less fuel to travel the same distance, generating less CO_2. Additionally, petrol has a lower energy density, i.e. less energy per litre of fuel, than the diesel fuel used in diesel engines, so to generate the same amount of energy, a petrol engine must burn more fuel, which generates more CO_2.

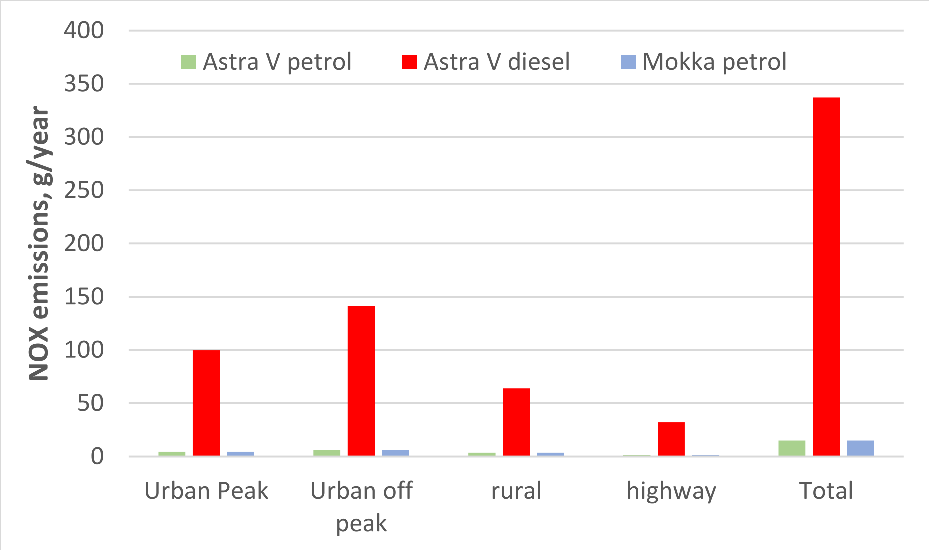

Figure 11. Emission of nitrogen oxide into the atmosphere in 2023 from the analyzed motor vehicles.

As shown in Fig. 11, nitrogen oxides (NOx) emissions are higher in diesel engines than in petrol engines due to differences in their operating principles and combustion conditions. Diesel engines operate at a much higher compression ratio than petrol engines, which leads to higher combustion temperatures, and the high temperature promotes the formation of nitrogen oxides (NOx), because nitrogen and oxygen from the air combine more intensively in such conditions. Diesel engines burn fuel in a lean mixture, with excess air. Such a mixture increases the combustion temperature, which also increases NOx emissions. In diesel engines, ignition occurs through compression (compression ignition), which causes faster and more violent combustion than in petrol engines. This characteristic increases the combustion temperature and NOx emissions.

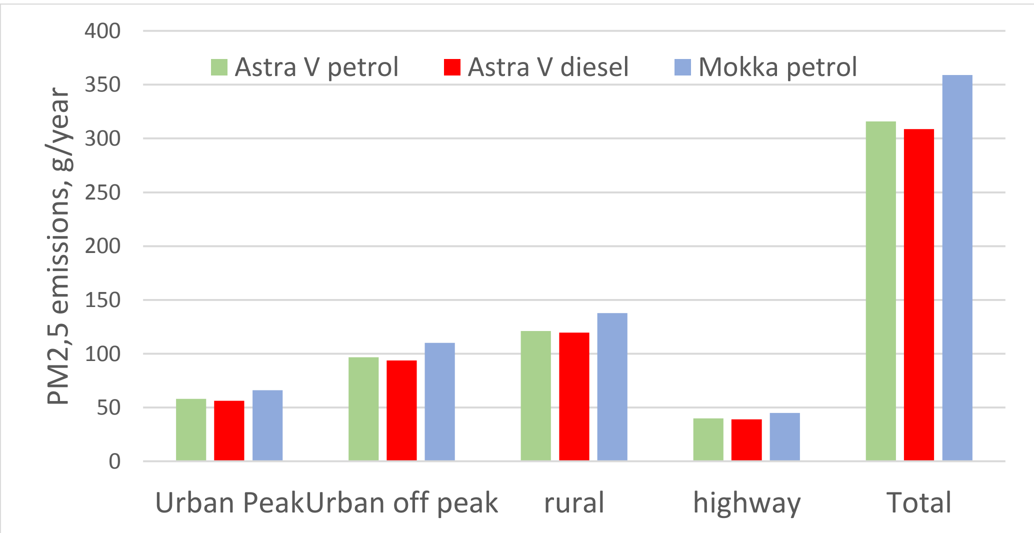

Figure 12. Emission of PM2,5 into the atmosphere in 2023 from the analyzed motor vehicles.

As shown in Fig. 12, the highest PM2.5 emission among the analyzed vehicles is from the Opel Mokka, regardless of the type of road traveled. This may be due to differences in construction, vehicle weight, materials used, and types of use. The Opel Mokka is a crossover, and the Astra V is a hatchback. In the case of crossovers such as the Mokka, tires with a wider tread are often used, which generate more dust during abrasion compared to tires used in hatchbacks.

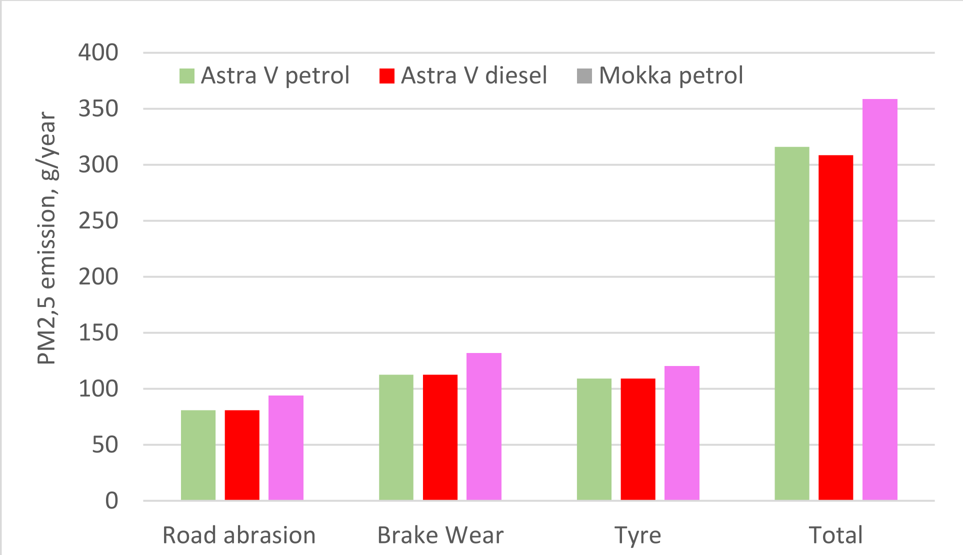

Figure 13. Sources and emissions of PM2.5 dust into the atmosphere from the analyzed motor vehicles.

As shown in Figure 13, PM2.5 dust emissions from the analyzed cars due to brake abrasion are significant, because the mechanical braking process uses the friction force between the brake pads and discs. As a result of this friction, fine particles are released, which are the main source of PM2.5 dust emissions. It should be noted that brake pads are made of a mixture of metals, resins, ceramic materials, and these materials are susceptible to disintegration under the influence of friction, and the products of this disintegration may contain fine PM2.5 particles. In addition, friction generates heat, which can cause degradation of the material of the pads and discs, releasing microscopic particles in the form of PM2.5 dust. Dust emissions from brakes go directly into the atmosphere at road level, which increases their impact on the environment and human health. In cities, where traffic is intense and requires frequent stopping, emissions related to braking are higher.

4. Conclusions

The analysis of the average sound level values shows that in all the analysed cases for the Opel Astra V with a diesel and petrol engine, higher values were recorded for the diesel-powered vehicle. The analysis of the sound level for the Opel Mokka with a petrol engine showed sound values similar to the levels recorded for the Opel Astra V with a diesel engine, despite the smaller engine capacity and lower total vehicle weight. This can be explained by the less aerodynamic shape of the Opel Mokka compared to the Opel Astra V.

In turn, the analysis carried out in the Copert program showed that CO2 emissions of Opel Astra V and Mokka cars with petrol engines are higher than in the case of diesel engines, which results from differences in their design, differences in combustion processes and differences in fuel characteristics. Petrol engines have lower thermodynamic efficiency than diesel engines, which means that during the combustion process, a larger part of the energy from the fuel is converted into heat, not into movement, which results in higher fuel consumption.

In the case of CO emissions, Opel Astra with diesel engines emit significantly less CO than Opel Astra V and Opel Mokka with petrol engines. It should be noted that diesel engines operate with excess air in the cylinder (lean mixture), which means that they have more oxygen available to burn the fuel. This excess oxygen promotes full fuel combustion, which limits the formation of this type of pollution.

A different situation is observed in the case of NOX emissions. Nitrogen oxides (NOx) emissions are higher in diesel engines than in petrol engines due to differences in their operating principles and combustion conditions. Diesel engines operate at a much higher compression ratio than petrol engines, which leads to higher combustion temperatures, and the high temperature promotes the formation of nitrogen oxides (NOx). In the case of PM2.5 emissions, the highest emission among the analysed vehicles was shown by the Opel Mokka, regardless of the type of road travelled. This may be due to differences in the design of the analysed cars, the materials used, and the way they are used. The Copert programme also showed that the highest NOx emissions come from brake abrasion, because the mechanical braking process uses the friction force between the brake pads and the discs. As a result of this friction, fine particles are released, which are the main source of PM2.5 emissions.

The view that diesel cars have a more negative impact on the environment than petrol cars is deeply rooted in public awareness. However, the analyses carried out clearly indicate that this view is true only in the case of nitrogen oxide emissions. It should be noted, however, that the remaining emissions and their levels in both diesel and petrol engines are at a comparable level, which is due to the evolution of diesel engine technology, which currently meets strict emission standards such as Euro 6 and higher.

It should be emphasized that the conducted analysis of pollutant emissions from motor vehicles concerned three car models, i.e. Opel Astra V with diesel and petrol engines and Opel Mokka with petrol engine. A broader analysis will require performing similar studies for a larger number of car brands and models.

The social pressure caused by the results of pollutant emission analyses motivates companies to invest in more ecological technologies, e.g. low-emission engines or electric drive. Transparency of emission data makes manufacturers more responsible to consumers and legal regulations.

Acknowledgements

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