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IMPACT OF PRIVATE TRANSPORT ON THE ENVIRONMENT AND SOCIETY IN THE CONCEPT OF CITY LOGISTICS AND LIFE CYCLE ASSESSMENT

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Abstract: Changes taking place in the economy generate negative consequences for the environment and society. This is the case of, inter alia, agglomerations. In recent years, the concept of city logistics has been developed, the aim of which is to draw attention to sustainable development in urban agglomerations. There are many studies on the advantages of ecological means of transport, but they do not show the impact on other environmental factors. This is undoubtedly a research gap that needs to be explored. The article presents the idea of city logistics and the impact of private transport on agglomerations. Introducing new, innovative solutions in the field of private transport, such as electric cars and hybrids, does not have a positive impact. The article presents statistics on the number of cars in relation to the ecological ones. Moreover, with the help of the SimaPro program, their environmental and social impact was analyzed. The analysis was enriched by participant observations, consisting of the analysis of the number of means of transport and their use in one of the Polish cities. The aim of the article is to present the impact of passenger transport on the environment and social life. The analysis was carried out on the basis of three countries with similar economic development: the Czech Republic, Poland and Slovakia.

1 Introduction

Europe is a highly urbanized area. The vast majority of Europeans live in cities, which has an impact on the natural environment. The development of the agglomeration contributes to more and more interference in the landform by the need to expand residential buildings along with the supply infrastructure - where new housing estates are built. There are also roads, sidewalks, service buildings and public places. Larger agglomerations are also accompanied by greater traffic, especially passenger cars. As a consequence, it is worried about high air pollution in city centres, transport congestion, excessive noise and long travel times. This has a negative impact on the quality of life of the agglomeration's inhabitants and the attractiveness of a given region. Due to the emission of harmful compounds into the atmosphere, the authorities of the European Union are implementing projects aimed at reducing the number of passenger cars, especially those with internal combustion engines, in favour of public transport, electric cars or plug-ins. These are the tasks related to, inter alia, with the removal of diesel transport from the city centre. They are, to some extent, related to urban logistics. The aim of the article is to present the impact of passenger transport on the environment and social life. The analysis was carried out on the basis of three countries with similar economic development: the Czech Republic, Poland and Slovakia.

2 City logistics and passenger transport

The concept of urban logistics is defined by many authors. For example, M. Szymczak defines urban logistics as the process of planning the implementation and control of flows: initiated outside and directed to the city, initiated in the city and directed outside, passing through the city, internal in the city, and the accompanying information flows, aimed at meeting the city's needs in terms of quality of management, quality of life and development" [1]. On the other hand, Szołtysek defines the city's logistics as "all processes of managing the flow of people, cargo and information within the city's logistics system, in accordance with the city's development needs and goals, respecting the protection of the natural environment, taking into account that the city is a social organization whose primary goal is to meet the needs of the city. its users" [2].

Flows in cities affect the quality of life of their inhabitants. That is why it is so important to implement measures aimed at reducing the negative effects of transport and making urban transport options more attractive for passengers, and thus reducing the emission of harmful substances from passenger transport [3-5]. J. F.

Ehmke described these projects as taking steps to create a travel system in the city, which would have a positive impact on travel time, but also on the level of harmful emissions [6]. Transport is responsible for the emission of greenhouse gases at the level of about 20%, and therefore, due to its high impact on the natural environment, the EU authorities have implemented numerous legal regulations to reduce the scale of the negative impact [7]. These can include, among others 2011 White Book of Transport, which envisages a significant reduction in greenhouse gas emissions by 2030 and the elimination of combustion vehicles from cities by 2050 [8] and the "Green Deal" from 2019, which assumes that by 2050 Europe will become the world's most completely neutral continent for the environment [9]. The transport congress and the regulation of city traffic is one of the goals of the city's logistics concept. Actions taken by city authorities should also be consistent with the maintenance of sustainable development and the quality of life of the inhabitants, and the attractiveness of the region for investors.

3 Methodology

LCA (*Life Cycle Assessment*) is a method of assessing the life cycle of a product, which describes the impact of a given product on the environment, analyzing its life cycle from the moment of raw material extraction, through production, use until its end of life and handling a given product as waste. All recommendations for the product life cycle assessment are regulated by ISO 14000 standards (from 14040 to 14049) [10]. There are four interacting phases of the product life cycle assessment, the interrelationships of which are illustrated in the diagram below (Figure 1).

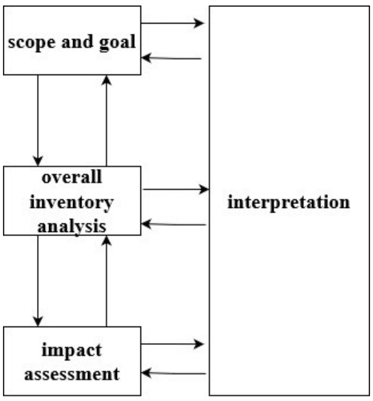

Figure 1 Four Stages of Life Cycle Assessment [11]

In the case analyzed in this publication, the product life cycle of passenger cars will be taken into account. The aim of the study is a comparative analysis of the environmental impact of passenger transport, taking into account the European exhaust emission standard and the type of fuel in accordance with the Eco Indicator 99 (E) procedure, which is used to determine the impact of the product on the natural environment. The resources of the SimaPro 9.1 program, developed by Dutch developers from PreConsultant, were used. Thanks to the use of the SimaPro software and the use of Eco Indicator 99, it will be possible to determine the impact of the analyzed means of transport. They will be analyzed in relation to eleven categories of impacts, which, grouped into groups, constitute three categories of damage. This division is presented in Table 1 below.

Table 1 Division of damage categories into impact categories

Impact category	Damage category
minerals fossil fuels	resources
the exploitation of the land acidification ecotoxicity	ecosystem quality
radiation the climate change inorganic compounds carcinogenic compounds organic compounds ozone hole	human health

Potential impacts causing damage are expressed in units depending on the damage category. For ecosystem quality, the unit PDF (*Potentially Disappeared Fraction*) is used, which is multiplied by a square meter of land and a year (PDF * m^2 * year). Damage caused in the human health category is expressed in the DALY unit (*Disability Adjusted Life Years*), while the damage in the resources category is expressed in MJ (Mega Joule), which refers to the possible use of additional energy to obtain the used raw materials [12].

4 Result and discussion

In order to adopt the appropriate parameters for the assessment of the life cycle of passenger cars in the SimaPro program, prior to the commencement of the research, the use of passenger cars in urban traffic was assessed using the empirical method. The measurement lasted 60 minutes. It was performed twice in the same location (Lwowska-Podgórna-Waryńskiego intersection in Zielona Góra), 2 hours apart on the same day. The same analysis was performed throughout the week (7 days). The following tables (2 and 3) present the average results for the entire week.

Table 2 Average number of car trips- study I.

Number of people in the car	Number of cars
1	344
2	96
3	20
4	4
5	1
Sum	**465**

Table 3 Average number of car trips- study II.

Number of people in the car	Number of cars
1	282
2	85
3	8
4	0
5	2
Sum	**377**

Table 2. was compiled from the results of the first observation. During the entire measurement, a total of 465 passenger cars were recorded. 344 drivers drove alone, which is 74% of the vehicles considered in the study, much less because 96 drivers travelled with one passenger (21%), there were three people in 20 cars (4%), and four travellers in four cars (0.7%) and 5 people (0.3%) were observed in only one car.

Table 3 is based on the results of the second observation. The total number of cars passing during the study was 377. 282 cars with one person (74.8%), 85 cars with two people in the vehicle (22.5%), 8 cars with three drivers people (2.1%) and two cars with 5 people inside (0.5%). During the second observation, no car with four people passed.

From the results obtained during the two observations, it was assumed that most passenger cars are transported only by the driver, which was taken into account when entering the input data to the SimaPro program.

4.1 Results of the LCA assessment of passenger vehicles

The aim of the study was to compare the impact of the life cycle of passenger transport using various fuels (petrol, diesel, gas), taking into account the European EURO exhaust emission standard (in the analyzed set, the EURO 3 standard is the oldest and least restrictive standard) and an electric passenger vehicle with regard to three categories of damage, which include: human health, ecosystem quality and resource consumption. It was assumed that each of the analyzed vehicles carried only the driver over a distance of 100 km. The results of the analysis are presented in the diagram below (Figure 2).

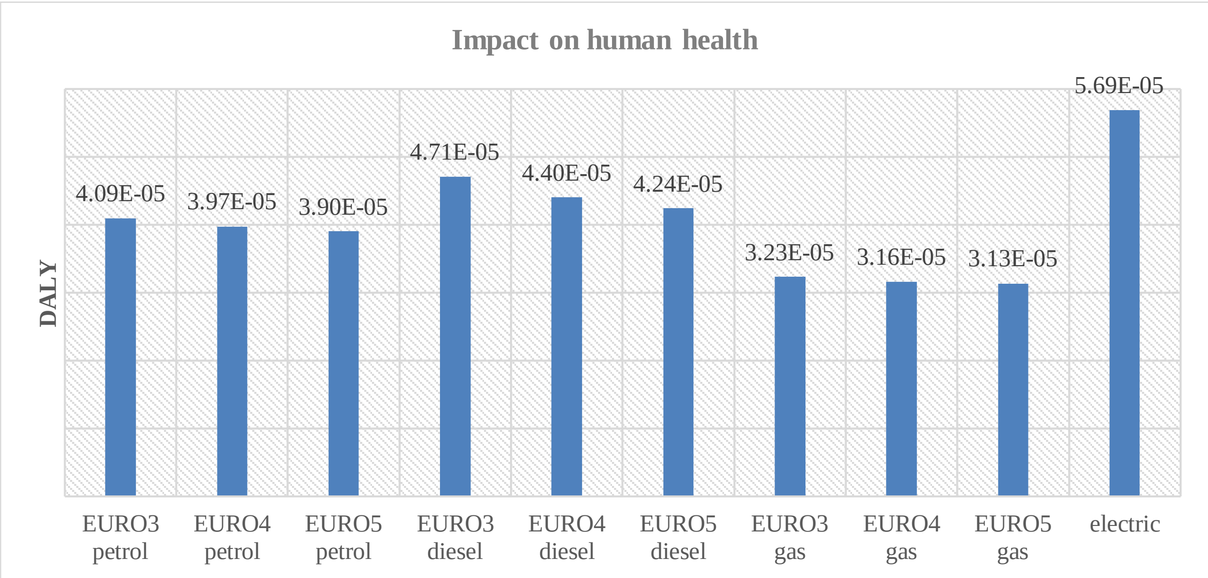

Figure 2 The impact of passenger transport on human health

The following conclusions can be drawn from this analysis regarding the impact of passenger transport on human health:

- The category of harm to human health takes into account the contribution of a given vehicle to harmful phenomena such as radiation, climate change, emission of inorganic, organic and carcinogenic compounds and contributing to the formation of an ozone hole.
- The conducted analysis shows that electric vehicles have the greatest negative impact on human health, while gas-burning vehicles that meet the requirements of the EURO5 standard have the smallest impact.
- In the case of internal combustion vehicles, the newer the vehicle is and meets the criteria of stricter exhaust emission standards, the less impact it has on this category of damage.
- Diesel cars are more harmful in their life cycle than cars that burn petrol or gas.
- The high degree of harmfulness of an electric car results from the formation of harmful compounds during the production of the battery necessary for the operation of such a vehicle. The battery consists of, among others, from the cathode and anode, which includes graphite, which negatively affects the air. In the battery production process phase, among others, PM_{10} dust,

nitrogen oxides NO_x and sulfur dioxide are emitted [13]. The harmful dust includes, for example, benzo(a)pyrene that negatively affects the quality of the inhaled air or dioxyne, which have a negative effect on the quality of water.

- In the case of electric cars, the fact of the origin of the electricity used to charge the batteries of this type of vehicle is not without significance. If energy is produced from coal, the negative impact of electric vehicles on human health is greater.
- Vehicles burning petrol in their life cycle emit mainly solid particles with a soot content with a diameter of not more than 2.5 μm, which negatively affect the quality of the inhaled air. Particulate matter contributes to the formation of harmful dust that causes respiratory diseases. Gasoline vehicles also emit carbon dioxide and nitrogen oxides, which have a negative impact on climate change. Arsenic is also emitted, the presence of which in the air and in water can cause severe poisoning.
- Passenger cars with petroleum-burning engines, similarly to gasoline vehicles, emit harmful solid particles into the atmosphere with a diameter of less than 2.5 μm, but additionally emit more particles with a diameter of up to 10 μm compared to gasoline engines. Diesel vehicles also generate severe air pollution with nitrogen oxides and carbon dioxide during their life cycle. Water and the atmosphere are also polluted by arsenic emissions.
- Analysis for transport gas burning is similar to the results of the previous two combustion vehicles in terms of the type of destruction. Gas vehicles also emit particulate matter less than 2.5 μm in diameter, carbon dioxide and arsenic, albeit at a lower level than the other analyzed combustion vehicles.
- In newer types of combustion vehicles, in order to minimize the emission of harmful compounds, better and better filters are installed, whose task is to prevent emissions, e.g. particles into the air. For this reason, the newer the vehicle, the lower its harmfulness.

In the next step, the impact of passenger cars on the quality of the ecosystem was analyzed, as shown in Figure 3.

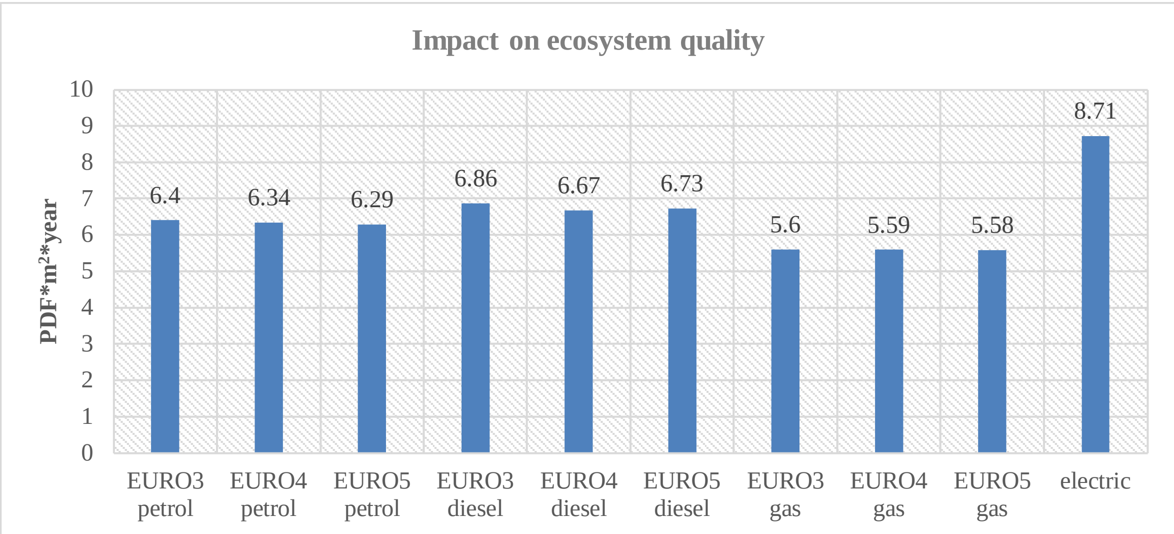

Figure 3 The impact of passenger cars on ecosystem quality

Several interesting conclusions can be drawn from the analysis of The impact of passenger cars on ecosystem quality:

- In the case of determining the impact of the product on the quality of the ecosystem, the impact of vehicles on such phenomena as acidification, ecotoxicity and land use was investigated.
- As assumed by the EcoIndicator 99 indicator, the electric vehicle exerts the greatest impact on the quality of the ecosystem in the analyzed case, while the gas combustion with the EURO5 standard has the least impact.
- According to the results of the analysis, electric cars in their life cycle generate large amounts of heavy metals such as zinc, which negatively affect soil, water and air. This type of vehicle also has a significant negative impact on aquatic organisms and the spatial layout of cities and suburbs due to the need to build the infrastructure required to use this type of vehicle, such as charging stations, but also factories, e.g. batteries or power plants, which produce electricity to power electric cars.
- The Eco Indicator 99 for gasoline and diesel vehicles identifies the main problem in this category as the emission of heavy metals such as copper that enter the waters (the share of gasoline at the level of 3.36 PDF * m^2 * year, diesel 3.56 PDF * m^2 * year). Occupation and wear of the road network, the transformation of

land for the extraction of raw materials and construction of new traffic routes were also identified as a problem for all analyzed combustion vehicles, which affects the topography.
- In the case of gas-burning vehicles, the transformation of land for mineral extraction was also distinguished.

The last aspect presented is the impact of means of transport on resources. The results and conclusions of the analysis carried out on the basis of the diagram (Figure 4) are presented below.

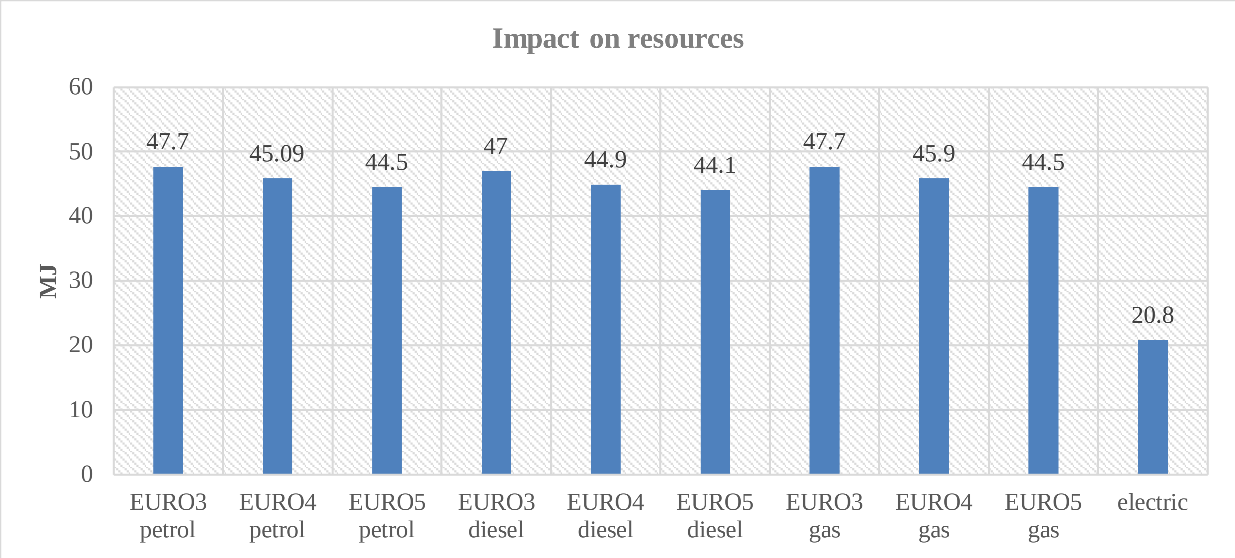

Figure 4 The impact of passenger cars on resources

The use of passenger cars and transport management in cities are related to environmental aspects. The chart (Figure 4) above shows the following conclusions about the resource impact of passenger cars:
- In the category of measuring the impact of products on resources, their share in the extraction of minerals and fossil fuels was taken into account.
- The results of the analysis for petrol and gas-fueled vehicles are very similar.
- Electric vehicles have the least impact, and diesel vehicles have the greatest impact.
- In the case of electric cars in this category of damages, they have the greatest impact on the process of gas and coal extraction, which are consumed by power plants that generate electricity to power the batteries of these vehicles. This impact depends on the method of obtaining electricity in a given area. These vehicles also affect the consumption of raw materials, including hard coal and lignite, and the consumption of copper, which is also used in the wires and systems of the power battery.
- Petrol and diesel vehicles negatively affect resources through the consumption of oil, natural gas and hard coal, which are part of the fuel.
- Passenger cars burning EURO5 standard gas have an impact on resources at the level of 44.5 MJ. In the case of this type of vehicle, they have the greatest impact on the consumption of natural gas, oil and hard coal.

In order to be able to better compare the analyzed vehicles and their total impact on the damage categories, the SimaPro program adopts the Pt unit, which means "one-thousandth of the annual environmental burden per one European inhabitant" [14]. Pt is an indicator that the SimaPro program is designed to illustrate the negative impact on the environment and thus on humans per capita. The normalized results of the analysis are presented in the table below (Table 4).

After normalizing the previously obtained results of the vehicle impact on the damage categories of the Eco Indicator 99, it is possible to identify the vehicles with the most negative impact on the natural environment. According to the Regulation of the European Parliament and of the Council on the approval and market surveillance of vehicles, the EURO 4 exhaust emission criteria have been in force since 2006, and EURO 5 has been in force since 2011 to 2015. The current standard is EURO 6, which was not included in the analysis. Converting the test results of three separate categories of damage to one unit showed that the oldest vehicles, i.e. those manufactured before 2006, are the most harmful when transporting a driver per 100 km by a passenger car. The electric vehicle also scores high due to its strong impact on human health and the use of resources. The obtained Pt levels prove that the newer the EURO exhaust emission standard, the more restrictive it is, thanks to which the vehicles have a smaller impact on the categories of damage.

Table 4 The impact of vehicles on the damage categories according to the normalized Pt unit

Vehicle type and Euro emission standard	Human health	Resources	Ecosystem quality	Total
Petrol – EURO3	1.85 Pt	0.448 Pt	1.7 Pt	3.998 Pt
Petrol – EURO4	1.8 Pt	0.443 Pt	1.64 Pt	3.883 Pt
Petrol – EURO5	1.76 Pt	0.44 Pt	1.59 Pt	3.79 Pt
Diesel – EURO3	2.13 Pt	0.48 Pt	1.68 Pt	4.29 Pt
Diesel – EURO4	1.99 Pt	0.466 Pt	1.61 Pt	4.066 Pt
Diesel – EURO5	1.92 Pt	0.471 Pt	1.58 Pt	3.971 Pt
Gas – EURO3	1.46 Pt	0.392 Pt	1.7 Pt	3.552 Pt
Gas – EURO4	1.43 Pt	0.391 Pt	1.64 Pt	3.461 Pt
Gas – EURO5	1.42 Pt	0.39 Pt	1.59 Pt	3.4 Pt
Electric	2.58 Pt	0.745 Pt	0.609 Pt	3.934 Pt

4.2. Use of private transport in selected countries

The movement of people is an inseparable element of their everyday existence. People migrate farther or shorter distances for work, education, or to meet their needs. Transport in cities is carried out using public transport, such as buses or trams, using pro-environmental solutions such as a city bike or scooter, or traditionally with the use of your own passenger car. The aim of the research is to present the dynamics of the use of private transport and its comparison between three European Union countries: the Czech Republic, Poland and Slovakia. For the purposes of this analysis, the following indicator was introduced:

$$NRV\begin{pmatrix}\text{number of registered vehicles}\\ \text{per one resident of the country}\end{pmatrix}=\frac{\text{the number of registered vehicles in the country}}{\text{the number of inhabitants of a given country}} \quad (1)$$

Where:
NRV – number of registered vehicles per one resident of the country.

The above indicator allows determining how many passenger cars, broken down by fuel type, are per one inhabitant of a given country. Thanks to the use of the index, it is possible to compare countries despite the different number of inhabitants and thus the number of registered vehicles. Unfortunately, due to the lack of up-to-date data in international databases, the years 2013-2019 were assumed for the analysis period. The data comes from the resources of the European Statistical Office and the Ministry of Economy of Slovakia. The value of the ratio of the number of registered vehicles per one resident of the country is presented in Figure 5. The analysis takes into account the type of passenger car drive broken down into selected countries: Czech Republic, Slovakia and Poland.

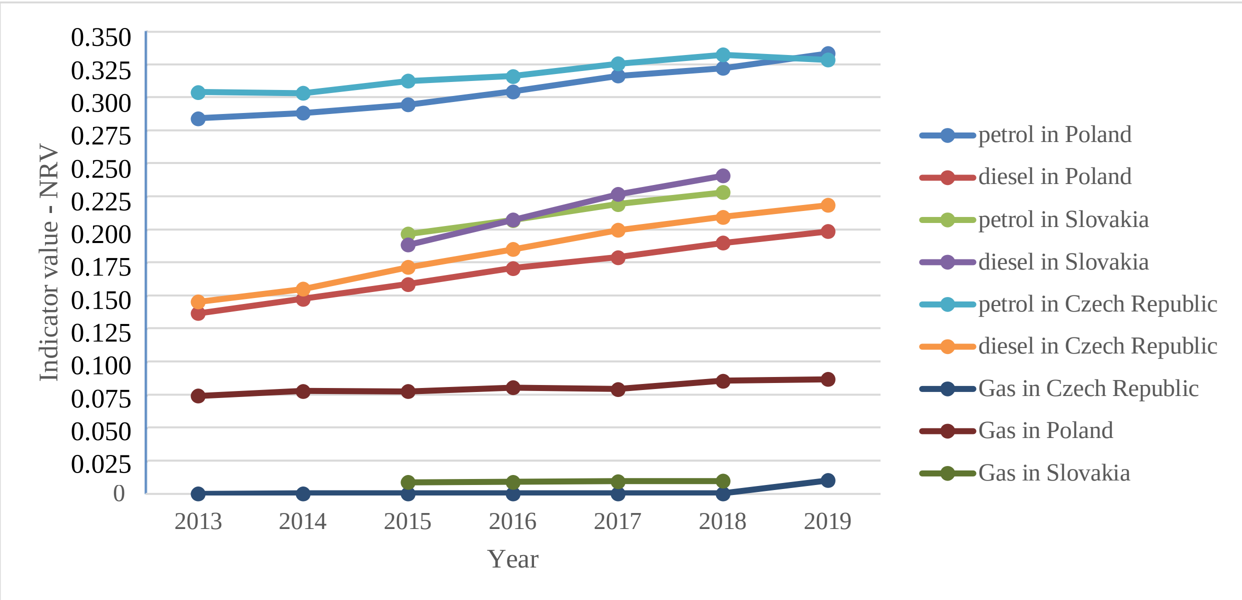

Figure 5 Number of registered vehicles per one resident of the country [15-22]

The conducted analysis of the use of passenger cars, taking into account the means of propulsion and taking into account the population of a given country, shows:

- In Poland, there are 4 times more registered passenger cars than in the Czech Republic and 8 times more than in Slovakia, yet the ratio of vehicles with gasoline and diesel engines for Poland and the Czech Republic is very similar, which means that there are approx. 0.33 of a passenger car that burns gasoline and about 0.2 of a car that burns oil.
- The lowest number of vehicles registered in Slovakia is compared to the other two analyzed countries. In Slovakia, the value of the index of the number of petrol and diesel vehicles is very similar, which distinguishes this country from the others.
- There is the least amount of gas-burning passenger vehicles. The car dealer offers the easiest way is to meet the vehicles on gasoline or diesel, which results in a smaller number of cars with factory-built LPG.
- In Poland, many vehicle owners invest in the installation of gas in the car because of the lower cost of gas compared with petrol or oil.
- Vehicles with a diesel engine are most suitable for driving long distances due to the greater energy efficiency of the fuel, which contributes to lower fuel consumption.
- Gasoline vehicles are generally cheaper than diesel vehicles.
- The popularity of a given type of internal combustion vehicle is not affected by the availability of petrol stations because usually, you can refuel each type of analyzed fuel in one location.

According to a report by the European Automobile Manufacturers Association (fr. Association des Constructeurs Europeens d'Automobiles- ACEA) [16] shows that Polish, Slovak and Czech people drive the oldest cars in Europe. The average age of vehicles in these countries is over 14 years. In the case of Polish drivers, as much as 80% of passenger vehicles are over 10 years old, i.e. at best, these vehicles meet at most the requirements of the EURO4 exhaust gas standard. In the Czech Republic and Slovakia, the situation is slightly better, with the proportion of older vehicles being 64% and 61%, respectively. Older vehicles emit harmful compounds to a large extent, which significantly affect the quality of the air inhaled and the formation of smog. It is because of the smog problem that many European cities are struggling with that the authorities are striving to reduce CO2 emissions and nitrogen oxides from, among others, from the exhaust pipes of Europeans' vehicles. To achieve this, one solution is to encourage the conversion of vehicles from combustion to electric vehicles [16].

The same ACEA report from January 2021 shows that the percentage of electric vehicles, plug-in hybrids and electric hybrids in the entire passenger vehicle fleet in the Czech Republic and Poland are 0.3%, while in Slovakia, about 0.5%, with the European average about 1.2% [16]. The fairly poor results in this group of vehicles are influenced by:

- First, electric and hybrid vehicles are noticeably more expensive than conventionally powered vehicles. In countries where the value of GDP per capita is higher, more interest in this type of vehicle can be noticed.
- Second, the government has little support for private electric vehicle purchases. Only 11 countries in the European Union offer tax benefits both for the purchase and operation of an electric passenger vehicle for private use and for business purposes. In the Czech Republic and Slovakia, the government offers drivers two types of tax relief, while in Poland, there is only an exemption from tax on the purchase of an electric vehicle [16].
- Third, the number of charging stations for electric and electric hybrids is still unsatisfactory. According to a report by the European Court of Auditors, there are 1,020 charging points for electric vehicles in the Czech Republic. For comparison, there are 799 such points in Poland, and 623 in Slovakia [17]. The progress report on the transition to zero-emission mobility prepared by ACEA additionally specifies the number of recharging points per 100 km of road, as shown in Table 5 below.

Table 5 Summary of data on electric vehicles

Country	Total number of vehicles (as of 2019)	Share of electric cars, plug-in cars and electric hybrids in the total rolling stock	Number of charging points	Number of charging points per 100 kilometers of road
Czech Republic	5 989 538	0.3%	1020	0.6
Poland	24 360 166	0.3%	799	0.2
Slovakia	2 391 355	0.5%	623	1.1

Source: own study based on [15-17]

Vehicle charging stations are most often found on Slovak roads. The fact that there are more of them in Poland does not affect accessibility because Poland has a larger territory than Slovakia.

5 Conclusion

Changes and enrichment of society lead to many problems related to the effective management of the city. One of the problems that arises is too many cars and traffic jams in the city. Hence, the idea of city logistics is to balance private and city transport, as well as encourage residents to use buses, trams, city bikes, etc. The research shows that most cars are driven by only one person, which also seems uneconomical. A passenger car takes up city space even when not in use, as it occupies a parking space. About 7 bicycles can be parked on a parking space for cars with the minimum dimensions required by the regulation, and in the case of a double-decker rack, even 14 bicycles. The city bus does not need any parking spaces in the city centre. It carries out the transport, stopping at a stop, and after a while, it continues its journey.

An electric car has surprisingly the most negative environmental impact when considering the entire life cycle of a vehicle. The battery that powers the entire system contains many hazardous compounds. It is also difficult to talk about completely environmentally friendly electricity transport, which, for example, in Poland, is largely produced from coal, which contributes to climate change and the emission of hazardous substances into the atmosphere. If electricity was obtained exclusively from renewable sources, electric cars would fare better in life cycle analysis. Although the electric car performs unfavourably in its entire life cycle, in the use phase, it fares favourably in terms of exhaust gas emissions and noise in cities. The authorities of the European Union are primarily focused on reducing the pollution load in the city air and thus eliminating smog. In this aspect, the solution turns out to be, e.g. electric cars that are zero-emission, thus in line with the assumptions of the Green Deal.

In Poland, the Czech Republic and Slovakia, there are quite a few electric or hybrid vehicles. This is due to, inter alia, the fact that these vehicles are usually more expensive than traditional internal combustion vehicles. The vast majority of second-hand vehicles are internal combustion vehicles. People do not have adequate knowledge of these vehicles and are afraid to buy them. Most electric or hybrid vehicles are used in richer countries. There are more charging stations in the Czech Republic and Slovakia than in Poland. In Poland, in order to set up a station, it is necessary to contact the Office of Technical Supervision, which extends the time of obtaining a permit, generates additional costs and may ultimately discourage potential future owners of charging stations from establishing such a point. In other European countries, it is not so complicated. In addition, there are 7 times more petrol stations in Poland than there are charging stations. It should also be emphasized that the introduction of exhaust emission standards in Europe has contributed to the necessity of introducing solutions by passenger car manufacturers, which means that the latest combustion cars emit incomparably less harmful substances than vehicles from 15-20 years ago. A solution to lower the average age of vehicles in Poland could be the implementation of more restrictive vehicle registration conditions than just passing the technical inspection. Trends in the development of the economy are aimed at using and motivating society to use electric and hybrid cars. Certainly, a long time will pass until their share will be greater than that of cars running on fuel, diesel or gas. The cost of buying ecological cars is quite high, and the infrastructure (including vehicle charging stations) is not yet fully adapted to the needs. However, this is a good direction of development, although, as the article shows, their negative impact on the environment and society should be reduced.

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Review process
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