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ASSESSMENT OF IMPACT OF VEHICLE TRAFFIC CONDITIONS: URBAN, RURAL AND HIGHWAY, ON THE RESULTS OF POLLUTANT EMISSIONS INVENTORY

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Abstract:

The use of motor vehicles varies considerably under distinct traffic conditions: in cities, outside cities as well as on motorways and expressways. The impact of road traffic on the natural environment has been studied for many years, including in terms of the nature of the operation of motor vehicles. This problem is particularly important in highly urbanized areas, where traffic congestion is the source of increased emissions of harmful compounds contained in exhaust gases. For this reason, many cities have traffic restrictions, especially for those cars that do not meet the most stringent emission standards. Environmental protection is the driving force behind the development of modern combustion engine supply systems, which allow for proper control of the combustion of petroleum-derived fuels. The exhaust gas cleaning systems in the form of catalytic converters or particulate matter filters are also playing a very important role. Considerable differences in internal combustion engine operating states, both static and dynamic, result in important differences in pollutant emissions. Likewise, the national annual pollutant emission is affected by the share of distances travelled by vehicles under various traffic conditions. At the same time, it is very difficult to estimate exhaust emissions from road transport sources. Very interesting method of emission estimation is the application of the data included in the emission inventory which are a valuable source of information on exhaust emissions under various operating conditions. In the present study, the annual pollutant emissions were analyzed: at a national level (total pollutant emission) and in distinct traffic conditions. There were found large differences between individual pollutants' shares in the emissions from vehicles under the tested traffic conditions. This is particularly evident for nitrogen oxides with the highest emission share outside cities, as opposed to other substances with the highest emission shares in cities, where traffic congestion is taking place.

Keywords: *pollutant emissions modelling, traffic conditions, pollutant emissions inventory*

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1. Introduction

Traffic conditions in cities, outside cities, on highways and expressways differ considerably, which results in large differences in the operation states of internal combustion engines (Arregle et al., 2006; BUWAL, 1995; Chłopek, 1999; Chłopek et al., 2016). Simultaneously, it is very difficult to estimate emission from motor cars, including different traffic conditions and different automobiles. A relatively low engine load and low rotational speed are characteristic of traffic conditions in cities, and then the share of vehicle engine dynamic states is the highest (Arregle et al., 2006; BUWAL, 1995; Chłopek, 1999; Chłopek et al., 2016;). In the case of traffic on motorways and expressways, vehicle engine load and rotational speed are high and the share of dynamic states of engine operation is relatively low (Arregle et al., 2006; Chłopek, 1999; BUWAL, 1995; Chłopek et al., 2016). Conceptual and research works on combustion engines have described the extent of the influence of the aforementioned differences in engine operation states on pollutant emission (Arregle et al., 2006; BUWAL, 1995; Chłopek, 1999; Merkisz and Pielecha, 2015; Wang et al., 2006). A comprehensive description of this issue would exceed the length of the present paper. In short, it can be stated that the operation of the engines with high loads leads to a considerable increase in the emission of nitrogen oxides and, under very high load, also carbon monoxide and particulate matter emissions (Alkafoury et al., 2013; André et al., 2009; Arregle et al., 2006; Bermúdez et al., 2008; BUWAL, 1995; Chłopek, 2016; Wang et al., 2006). A large share of dynamic states of internal combustion engines, observed when obstacles in vehicle traffic occur, results in an increase in the emission of carbon monoxide and hydrocarbons (Arregle et al., 2006; Bermúdez et al., 2008; BUWAL, 1995; Merkisz and Pielecha, 2015; Wang et al., 2006), whereas a rapid increase in the steering of the compression-ignition engine leads to a strong increase in the emission of particulate matter (Arregle et al., 2006; Bermúdez et al., 2008; BUWAL, 1995; Merkisz and Pielecha, 2015; Wang et al., 2006).

Methodology applied in the paper is based on the application of mathematical apparatus, which is in depth described in section Methodology, where the mathematical approach to modelling the basic parameters responsible for emissions modelling is presented. Moreover, such approach to estimation of emissions is not very popular in scientific society, but it allows for obtaining crucial data regarding emission from emissions inventory data, which character is global. However, there are available some specialist works on pollutant emissions from road vehicles under different traffic conditions, with the results obtained in empirical studies as well as those focused on emission modelling. In results there are shown the results of the analyses regarding annual pollutant emissions and total distance travelled, annual energy consumption, shares of the distance travelled by all vehicles and average specific distance emission of carbon monoxide from all vehicles under all traffic conditions. In section Discussion there is among others mentioned the significant decrease of the average specific distance emission of pollutants from motor vehicles in Poland over the period 1990–2017. Section Conclusions summarizes the achievements of the work presented by the Authors.

2. Literature review

One of the crucial publications on modeling the emission of pollutants from road vehicles under various traffic conditions is the BUWAL study (BUWAL, 1995). Under the framework of works described in (BUWAL, 1995) and used in INFRAS AG (INFRAS AG, 2014), a number of test procedures have been developed to characterize vehicle traffic under a wide range of conditions: starting from congestion, and traffic in cities without or with light signals, through different levels of traffic obstruction, to test procedures for vehicle traffic outside cities and on motorways. In these tests, the specific distance emission of pollutants was determined with the use of the chassis dynamometer for different categories of vehicles. The results obtained were utilized to develop INFRAS AG software. The test results were used in COPERT software as well (COPERT 5 – Manual, 2021).

The study (André et al., 2009) presents the scope of work carried out under the framework of the program ARTEMIS (ARTEMIS, 2003)– the teamwork of more than 40 European research centers, with a budget of about 9 million euro. There have been developed test procedures that characterize the use of vehicles of manifold categories under different traffic conditions. The tests procedures developed have been utilized to determine characteristics of automotive pollutant emissions tested with the use of the chassis dynamometer.

There have been established many other research programs, the results of which have made it possible to simulate vehicle traffic under various conditions, such as those carried out by ADAC (ADAC, 2021) or EMPA (Empa, 2010). In most cases, the tests procedures have been developed on the basis of similarities in the time domain (Chłopek, 1999; Chłopek, 2016).

The article (Chłopek et al., 2016) describes the concepts of tests designed to examine vehicle performance under conditions simulating the real vehicle use, as the realization of the stochastic processes of vehicle speed. There have been developed the tests for the stochastic processes of passenger car driving speeds: in traffic jams, in cities – without traffic jams, outside cities and on motorways and expressways. Empirical tests were carried out on the chassis dynamometer, and there were determined statistical characteristics of the specific distance emission of pollutants under pseudorandom conditions of operation of the internal combustion engine.

The paper (Chłopek, 2016) proposes a unique method for creating the test procedures based on the principle of similarity of characteristics in the frequency domain. The implementation of stochastic driving test processes was simulated in the frequency domain of the FTP 75 approval test (Continental, 2019) corresponding to city traffic conditions. The statistical characteristics of the realizations of selected tests were examined.

Many more studies on the emission from road transport have been carried out under city traffic conditions (Alkafoury et al., 2013; Chłopek, 1999; Chłopek et al., 2016; Chłopek, 2016, Cheewaphongphan et al., 2017; Hu et al., 2018; Luo et al., 2017; Pallavidino et al., 2014), as compared to those conducted under other conditions (Chłopek, 1999; Chłopek et al., 2016; Pallavidino et al., 2014). This is largely due to incomparably higher harmfulness of local pollutant emissions to human health in large urban agglomerations in contrast with that under other traffic conditions.

The study (Pallavidino et al., 2014) compares pollutant emissions from road transport in the Province of Turin, calculated with the use of pollutant emissions modelling, in addition to the assessment of vehicle traffic parameters, as well as relevant data on pollutant emissions from the authorized emission inventory carried out in Piedmont. A relatively poor consistency of the results was obtained: the relative difference of the results was several dozen percent (even – over 70%).

The study (Alkafoury et al., 2013) presents an analysis of the models used in estimating pollutant emission from road transport in urban areas. Different models of pollutant emissions were compared with each other in terms of their limitations and possibilities of application.

Luo et al., 2017 shows the results of the analyses on energy consumption and pollutant emissions from taxis, including their time and space distribution in Shanghai, with the use of GPS data analysis of taxi traffic and vehicle emission modeling.

Hu et al., 2018 presents the method for determining the momentary specific distance emission of pollutants, based on the projected speed of vehicles (passenger cars, light trucks and buses). COPERT 4 software was used in the analyses.

Cheewaphongphan et al., 2017 presents the results of modelling pollutant emissions from vehicles circulating in Bangkok, with the use of the GAINS model. In the period 2007–2015, there were studied the emissions of: tropospheric ozone precursors (carbon monoxide, nitrogen oxides and non-methane volatile organic compounds), greenhouse gases (carbon dioxide, methane, nitrous oxide), acidic substances (nitrogen dioxide and ammonia) as well as particulate matter (*PM2.5*, *PM10*), black carbon – *BC* and organic carbon – *OC*.

3. Methodology

In dynamic conditions, pollutant emission from internal combustion engines depends on engine operation states at the level of operator function. The value used as a zero-dimensional characteristic of pollutant emission is the specific distance emission (g/km). The specific distance emission of a given pollutant – b is a derivative of the emission of pollutants from a vehicle – m in relation to the distance travelled by this vehicle – s (Chłopek, 1999).

$$b = \frac{dm}{ds} \tag{1}$$

Therefore, the operator function of the specific distance emission and the states of engine operation can be expressed (Chłopek, 1999):

$$b(t) = \Im\left[n(t), M_e(t), \boldsymbol{T}(t)\right] \tag{2}$$

where:
n – engine speed,
M_e – engine torque as a measure of engine load,
T – engine thermal state described as a set of temperatures of engine components and consumables (coolant and engine oil),
t – time.

The arguments of the operator function (2) (generalised function) are presented in square brackets, as opposed to the arguments of the function with numerical values – presented in round brackets (Bermúdez et al., 2008; BUWAL, 1995).
Engine thermal state is described by slow-changing processes as compared to the processes associated with engine operation (Chłopek, 1999). Generally, this state can be considered as static – for an engine heated to a stabilized operation temperature and as a state corresponding to engine warm-up.
Under the conditions of the use of vehicle internal combustion engine, the processes of engine rotational speed and load are for the most part determined by the travel speed process – $v(t)$ (Chłopek, 1999).

$$b(t) = \Re\left[v(t), \boldsymbol{T}(t)\right] \tag{3}$$

When examining separately engine operation during warm-up and engine operation once it reached a stabilized operation temperature, for each case the function (3) can be articulated (Chłopek, 1999):

$$b(t) = \aleph\left[v(t)\right] \tag{4}$$

Because of a considerable similarity between the zero-dimensional characteristics of the realization of each speed process, the mean time "τ" of the specific distance emission of pollutants – b_{AV} can be presented as a dependence on zero-dimensional characteristic of the speed process – the mean value – v_{AV} (Chłopek, 1999).

$$b_{AV} = \frac{1}{\tau}\int_0^\tau b(t)\,dt = f\left(v_{AV}\right) \tag{5}$$

where:

$$v_{AV} = \frac{1}{\tau}\int_0^\tau v(t)\,dt \tag{6}$$

The average speed is an effective zero-dimensional characteristic of the vehicle speed process, describing traffic conditions (André et al., 2009; BUWAL, 1995; Chłopek, 1999; Chłopek et al., 2016; COPERT 5 – Manual, 2021; European Environment Agency, 2019; INFRAS AG, 2014). It is used as an independent variable associated with pollutant emission characteristics, used e.g. in INFRAS AG software (INFRAS AG, 2014) and COPERT software (COPERT 5 – Manual, 2021), as well as in the EEA/EMEP Emission Inventory Guidebook 2019 (European Environment Agency, 2019).
The relationship between the average specific distance emission of pollutants with the average vehicle speed may be treated as the function of numerical values (Chłopek, 1999).
In the present study, the average operating speed is used to assign the vehicle to specified traffic conditions (André et al., 2009; BUWAL, 1995; Chłopek, 1999; Chłopek et al., 2016; COPERT 5 – Manual 2021; European Environment Agency, 2019; INFRAS AG, 2014; Merkisz et al., 2016; Pielecha and Gis, 2020; Pielecha and Skobiej, 2020; Rudyk et al., 2019; Rymaniak et al., 2019):
– in cities,
– outside cities,
– on highways and expressways.
In the study, there were used the authorized results of the inventory of pollutant emissions from road transport, developed by the National Centre for Emissions Management – Institute of Environmental Protection – National Research Institute (KOBiZE) (KOBiZE, 2017; KOBiZE, 2019). The data set used included the annual inventory carried out in the years 1990–2017.
The inventory of pollutant emissions from road transport has been carried out in accordance with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Eggleston et al., 2006) and the EEA/EMEP Emission Inventory Guidebook 2019 (European Environment Agency, 2019). COPERT5 software is currently used to determine the national annual emission (COPERT 5 – Manual, 2021).
In the emission inventory, motor vehicles are classified as objects of the category (André et al., 2009; BUWAL, 1995; Chłopek, 1999; COPERT 5 – Manual, 2021; Eggleston et al., 2006; European Environment Agency, 2019; INFRAS AG, 2014). In philosophy, the concept of category refers to the structure,

therefore, the category is understood as a set of objects having specific features and interrelationships. In the emission inventory, the basic criteria to designate motor vehicles to the category are (André et al., 2009; Chłopek, 1999; BUWAL, 1995, COPERT 5 – Manual, 2021; Eggleston et al., 2006; European Environment Agency, 2019; INFRAS AG, 2014):

– purpose of the vehicle,
– type of internal combustion engine with regard to: thermal circuit, combustion system, fuel supply system,
– conventional size of the vehicle or internal combustion engine,
– characteristics of the vehicle with regard to construction solutions,
– fuel used,
– vehicle technology level, primarily in terms of pollutant emissions.

Depending on the study purposes, other characteristics may be added to the above criteria, e.g. vehicle production date (BUWAL, 1995; Chłopek, 1999; INFRAS AG, 2014).

The basic category of motor vehicles, in line with the adopted criteria, includes the vehicles with all the same characteristics under consideration.

The cumulative category of motor vehicles includes vehicles with not all the same characteristics under consideration. Therefore, there are many possibilities for adopting the general cumulative category of motor vehicles. The most universal cumulated category of motor vehicles is a set of all motor vehicles. The most basic category of the motor vehicles is every vehicle.

The following substances were selected for the analyses:

– carbon monoxide – CO,
– non-methane volatile organic compounds – NMVOC,
– nitrogen oxides – NO_x: nitrogen dioxide – NO_2,
– total suspended dust – TSP,
– carbon dioxide – CO_2.

The analyses for the years 1990–2017 regarded:

– national annual emissions of pollutants (total) – *T*,
– annual pollutant emissions in cities and their shares in the national annual emission of pollutants – *U* (urban),
– annual pollutant emissions outside cities and their shares in the national annual emission of pollutants – *R* (rural),
– annual emission of pollutants on motorways and expressways and their shares in the national annual emission of pollutants – *H* (highways).

There were also determined the shares of annual emissions of the pollutants under the study: in cities, outside cities, as well as on motorways and expressways, in the national annual emission of pollutants.

For the purpose of detailed analyses, the average specific distance emission of pollutants from all vehicles in cities, outside cities, on motorways and expressways under all the studied traffic conditions was determined:

$$b = \frac{E_a}{\sum_i N_i \cdot L_i} \tag{7}$$

where:
N_i – the number of vehicles in the elementary categories,
L_i – average annual mileage of vehicles in the elementary categories.

4. Results

Figures 1–10 show the results of the analyses regarding annual pollutant emissions. In particular, they represent annual emissions and shares of annual emissions of carbon monoxide, non-methane volatile organic compounds,, nitrogen oxides, total particulate matter and carbon dioxide.

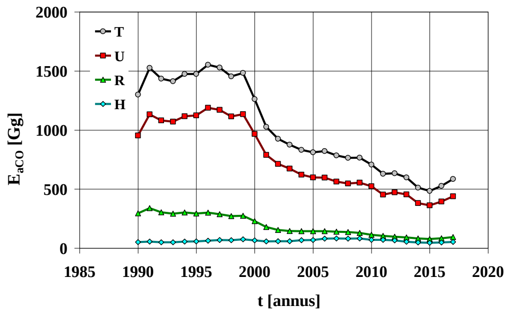

Fig. 1. Annual emissions of carbon monoxide – E_{aCO}: national – *T*, urban – *U*, rural – *R*, highways – *H*

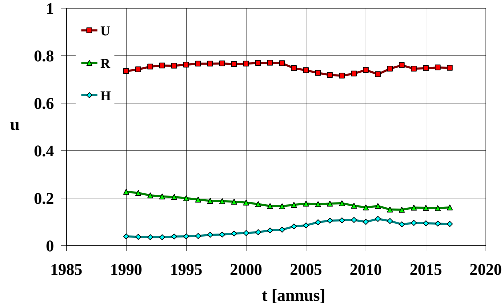

Fig. 2. Share of annual emission of carbon monoxide – *u*: urban – *U*, rural – *R*, highways – *H*, in the national annual emission

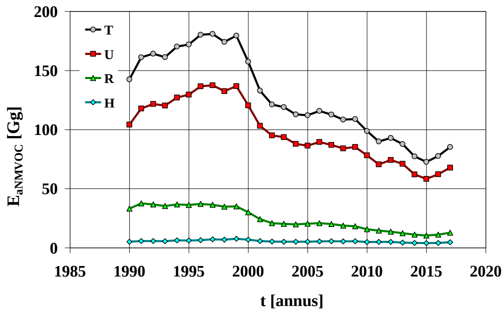

Fig. 3. Annual emissions of non-methane volatile organic compounds – E_{aNMVOC}: national – *T*, urban – *U*, rural – *R*, highways – *H*

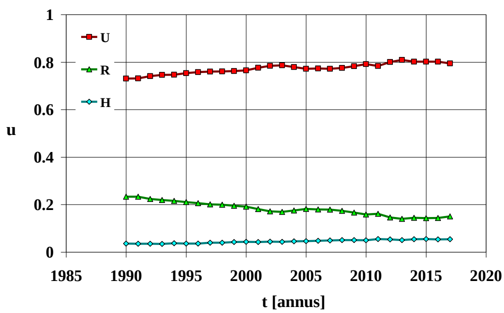

Fig. 4. Share of annual emission of non-methane volatile organic compounds – *u*: urban – *U*, rural – *R*, highways – *H* , in the national annual emission

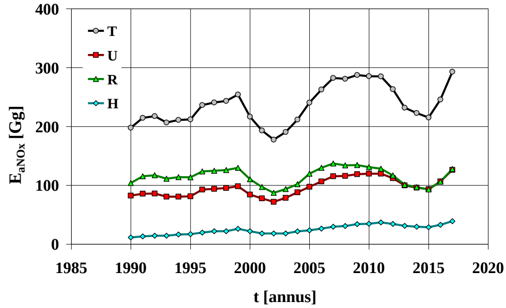

Fig. 5. Annual emission of nitrogen oxides – E_{aNOx}: national – *T*, urban – *U*, rural – *R*, highways – *H*

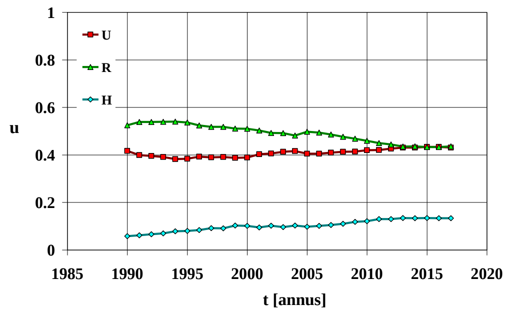

Fig. 6. Share of annual emission of nitrogen oxides – *u*: urban – *U*, rural – *R*, highways – *H*, in the national annual emission

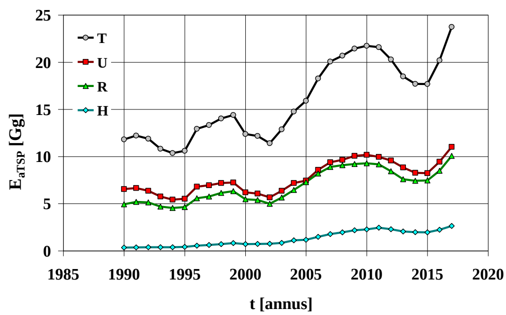

Fig. 7. Annual emission of total particulate matter – E_{aTSP}: national – *T*, urban – *U*, rural – *R*, highways – *H*, in the national annual emission

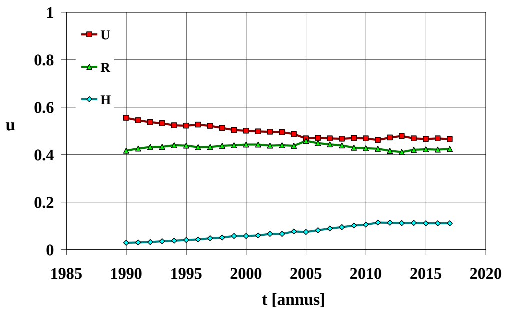

Fig. 8. Share of annual emission of total particulate matter – *u*: urban – *U*, rural – *R*, highways – *H*, in the national annual emission

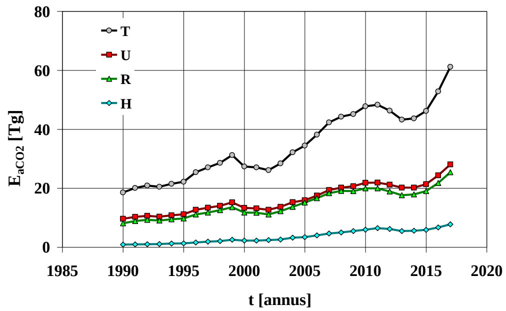

Fig. 9. Annual emission of carbon dioxide – E_{aCO2}: national – *T*, urban – *U*, rural – *R*, highways – *H*

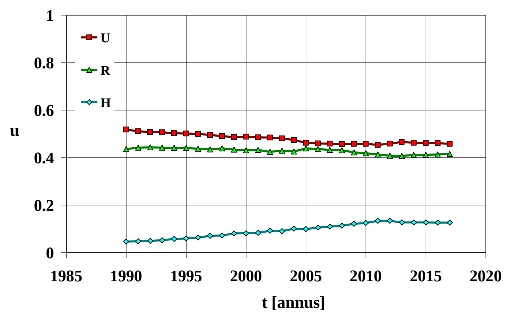

Fig. 10. Share of annual emission of carbon dioxide – *u*: urban – *U*, rural – *R*, highways – *H*, in national annual emissions

The annual emission of carbon monoxide and non-methane volatile organic compounds has been decreasing since 1999, despite a significant increase in the number and intensity of the use of vehicles , which is related to dynamic development of motorization in Poland after 1990 (Fig. 11). The decrease in the annual emission of carbon monoxide and non-methane volatile organic compounds is associated with a considerable technical progress in the construction of combustion engines and their catalytic exhaust gas cleaning systems, mainly in the case of spark-ignition engines (Continental, 2019; Delphi, 2017). No trend as such has been observed in the case of the annual emission of nitrogen oxides and total particulate matter. The progress in reducing the emission of nitrogen oxides and particulate matter, especially from compression-ignition engines, is much slower than that observed in the case of carbon monoxide and non-methane volatile organic compounds (Continental, 2019; Delphi, 2017). The increase in the annual emission of carbon dioxide is directly related to the increase in total fuel consumption due to dynamic development of motorization in Poland. The reduction of fuel consumption is restricted by the laws of nature, and especially, the second law of thermodynamics, resulting in thermodynamic efficiency limits of internal combustion engines. In Poland a trend of emission decrease from transport means is observed nearly ten years later compared to Canada in which a significant decrease of emission from transport means was observed starting from 1990 as presented in (Government of Canada, 2018).

The annual emission of pollutants is an extensive quantity, depending on the so-called transport activity, i.e. the number of vehicles on roads and their annual mileage. Figure 11 shows the total distance travelled by all vehicles: in cities, outside cities, on motorways and expressways, as well as - under all traffic conditions.

The share of the annual emission of pollutants under specific traffic conditions in the national annual emission of pollutants does not change much over the inventory years. There is observed an increasing trend in the annual emission of pollutants on motorways and expressways, caused by an increasing share of the distance travelled by vehicles under these conditions.

Figures 11 – 14 represent total distance travelled, annual energy consumption, shares of the distance travelled by all vehicles and average specific distance emission of carbon monoxide from all vehicles under all traffic conditions.

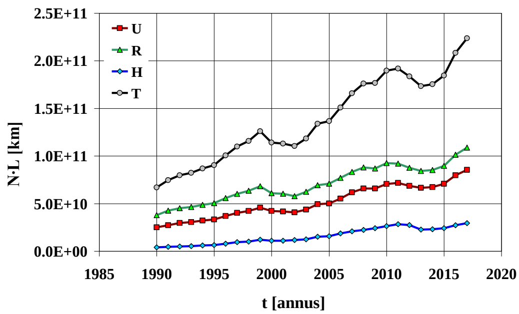

Fig. 11. Total distance travelled by all vehicles – *N·L*: urban – *U*, rural – *R*, highways – *H*, national – *T*, under all traffic conditions.

The relative increase in the total distance travelled by all vehicles between 1990 and 2017 is: over 230% under all the conditions studied, over 240% in cities, almost 190% outside cities, and over 615% – on motorways and expressways.

The considerable increase in road transport activity during subsequent years of the inventory of pollutant emissions is confirmed by rapidly rising annual energy consumption by vehicles – Figure 12.

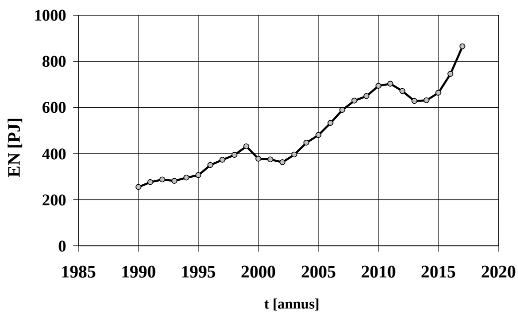

Fig. 12. Annual energy consumption – *EN* by all vehicles under all traffic conditions

In the years 1990 and 2017, under all traffic conditions, the relative increase in energy consumption by all vehicles amounts to over 240%.

Figure 13 shows the shares of the distance travelled by all vehicles: in cities, outside cities as well as on motorways and expressways.

When compared to 1990, the relative change in the share of the distances travelled by all vehicles in 2017 is: in cities – an increase of more than 2%, outside cities – a decrease of more than 15%, and on motorways and expressways – an increase of almost 55%. This is a result of dynamic development of road traffic infrastructure in Poland after the year 1990.

In order to assess the characteristics of intensive pollutant emissions, the average pollutant emission from all vehicles was determined – Figures 14–18.

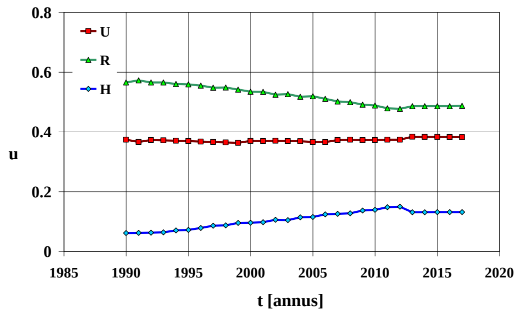

Fig. 13. Shares of the distance travelled by all vehicles – *u*: urban – *U*, rural – *R*, highways – *H*

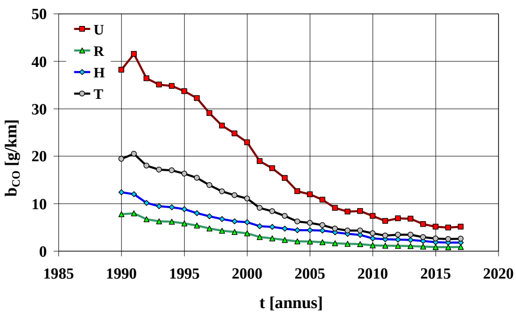

Fig. 14. Average specific distance emission of carbon monoxide from all vehicles – b_{CO}: urban – *U*, rural – *R*, highways – *H*, national – *T*, under all traffic conditions

The average specific distance emission of pollutants from motor vehicles in Poland decreased significantly over the years 1990–2017. This is the result of technological progress in the design and operation of cars, in particular internal combustion engines, and the change in the structure of used vehicles to more and more modern ones. Only in the case of carbon dioxide emissions does this trend occur. Carbon dioxide emissions directly depend on fuel consumption, and in line with the development trends of vehicles, their contractual size increases due to the requirements of driving comfort. This sometimes contributes to an increase in fuel consumption, especially in conditions where the driving speed increases due to the development of road traffic infrastructure, as is the case with motorways. The effect of an increase in driving speed and - as a consequence of the load on the internal combustion engine - on the increase in particulate matter emission on motorways is similar.

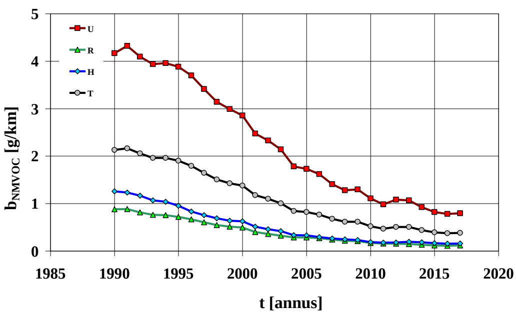

Fig. 15. Average specific distance emission of non-methane volatile organic compounds from all vehicles – b_{NMVOC}: urban – *U*, rural – *R*, highways – *H*, national – *T* and under all traffic conditions

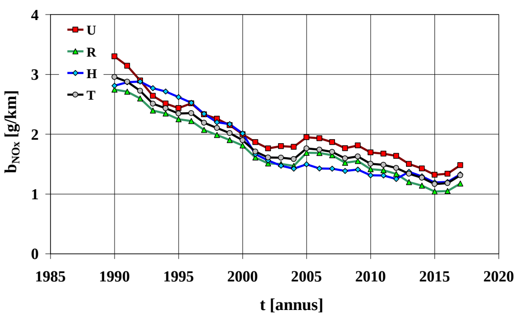

Fig. 16. Average specific distance emission o of nitrogen oxides from all vehicles – b_{NOx}: urban – *U*, rural – *R*, highways – *H*, national – *T*, under all traffic conditions

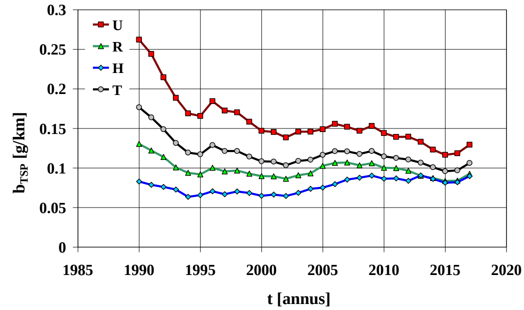

Fig. 17. Average specific distance emission of particulate matter from all vehicles – b_{TSP}: urban – *U*, rural – *R*, highways – *H*, national – *T*, under all traffic conditions

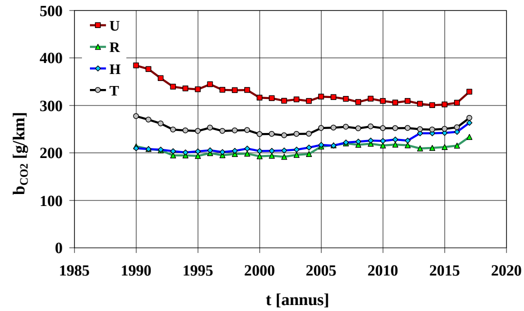

Fig. 18. Average specific distance emission of carbon dioxide from all vehicles – b_{CO2}: urban – *U*, rural – *R*, highways – *H*, national – *T*, under all traffic conditions

In general, the relative reduction in specific distance emission of carbon monoxide and non-methane volatile organic compounds in all traffic conditions is greater than (80 ÷ 85)%, nitrogen oxides - about 55%, total particulate matter - on average over 20%, and specific distance emission of carbon dioxide remain at similar level.

Such a significant reduction in specific distance emission of pollutants allows - despite a significant intensification of vehicle traffic - a general reduction in the annual emission of pollutants from vehicles.

5. Discussion

The average specific distance emission of pollutants from motor vehicles in Poland decreased significantly over the period 1990–2017. This is a result of technical progress in vehicle construction (in particular, in the case of combustion engines), as well as changes in the vehicle structure towards more and more modern vehicle designs. Only in the case of carbon dioxide emission a decreasing trend has not been observed. Carbon dioxide emission is directly dependent on fuel consumption, and with vehicle improvements, the vehicle conventional size increases because of driving comfort requirements. This sometimes promotes increased fuel consumption, especially when the speed of driving is increased as a result of traffic infrastructure development, as is the case with motorways. The impact of increased driving speeds and, as a consequence – internal combustion engine loads, on increased particulate emission on motorways is analogous. This is somehow the justification why in work (USA EPA Agency, 2017) there was shown the value of affected roadway width depending on a type of a highway.

In general, under all the traffic conditions examined, the relative decrease (80 ÷ 85)% of the specific distance emissions of carbon monoxide and non-methane volatile organic compounds has been greater than that of nitrogen oxides – about 55%, total particulate matter – more than 20% on average. The specific distance emission of carbon dioxide has remained at a steady level.

Even with considerable intensification of vehicle traffic, the observed substantial reduction of the specific distance emission of pollutants reinforces the reduction of total annual pollutant emission from road vehicles.

6. Conclusions

The following conclusions can be drawn from the present study:

1) There is a clear difference in both the annual emissions and the average specific distance emissions from all vehicles, depending on the inventory years and traffic conditions.
2) Regardless of the substantial increase in the road transport activity, the annual emissions of carbon monoxide and volatile non-methane organic compounds have been decreasing. The annual emission of nitrogen oxides has remained at a steady level, whereas the annual emission of the total particulate matter has been slightly increasing. Such outcome – despite a strong increase in road transport activity – is a result of important improvements in vehicle structure in terms of emission reduction. This is clearly visible in the presented graphs that show the average specific distance emissions of pollutants from all vehicles. The increase in annual carbon dioxide emission is associated with the considerable increase in fuel consumption (see Fig. 12 – energy consumption). The reduction of fuel consumption is problematic due to the laws of nature: the thermal efficiency of internal combustion engine cycles has its limitations due to the second law of thermodynamics.
3) Noteworthy are the considerably higher shares of the annual emission of carbon monoxide and volatile non-methane organic compounds from vehicles in cities when compared to those under other traffic conditions. This is a result of the high emission of these compounds under conditions of significant traffic obstructions. Then, combustion engines typically run under low load and operate in dynamic states. As for nitrogen oxides, the annual emission from vehicle traffic outside cities is the highest. In this case, the engine load is a decisive factor, which – admittedly – is higher for motorways and expressways, but the share of these traffic conditions is much smaller.
4) With regard to environmental performance of the vehicles studied, the greatest improvements were observed for the emission of carbon monoxide and non-methane volatile organic compounds. The reduction of emissions of total particulate matter and nitrogen oxides showed the least advancements. Unfortunately, transport means were the main source of nitrogen oxides' emission in the European Union in 2017 as presented in (EEA Report, 2019). The positive result is the fact that for the substances particularly hazardous to human health, i.e. nitrogen oxides, the emission share is the highest outside cities, and not in agglomeration centers, where many people may be exposed to risk. In the case of total particulate matter, the share of annual emissions in cities is similar to that outside cities.

The conducted research confirms that the traffic conditions of motor vehicles, determining the operating conditions of internal combustion engines, and

in the case of dust emission, also the operating conditions of the tribological systems in the vehicle-environment system, have a significant impact on the risk of environmental pollution in connection with road transport (Chłopek, Z., 1999). Despite significant technical progress, as evidenced by a very dynamic decrease in specific distance emissions (Continental, 2019; Delphi, 2017), the risk to the environment is determined by the extensive characteristics of pollutant emissions. In this study, such a characteristic is the pollutant emission intensity, called in the case of averaging over one year the annual emission of pollutants. The annual emission of pollutants is determined by the activity of road transport, which is linearly dependent on the number of vehicles and their annual mileage. The quantity that determines the harmfulness of pollutants for the environment is the immission - concentration of dispersed pollutants, which increases with increasing pollutant emission intensity (Chłopek, Z., 1999).
Increasing road transport activity is inevitable - it is one of the basic symptoms of civilization development. Practical conclusions can be drawn on the basis of the evaluation of trends in the last several years of the dynamic development of road transport in Poland. Apart from the continuous technical development of motor vehicles and their consumables, general investments in road traffic infrastructure are necessary. These should be measures enabling the greatest possible limitation of road transport activity in urban traffic conditions, mainly due to the construction of bypasses. This will enable motor vehicle traffic under conditions enabling a measurable reduction in pollutant emissions, which is quantitatively clear from the results of the research presented in this article.

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