IOŚ-PIB Environmental Protection and Natural Resources
Ochrona Środowiska i Zasobów Naturalnych
sciendo
Vol. 33 No 3(93): 1-9
DOI 10.2478/oszn-2022-0008

Krystian Szczepański*, Zdzisław Chłopek**, Katarzyna Bebkiewicz*, Hubert Sar**

Assessment of pollutant emission in Poland from various categories of transport

* Institute of Environmental Protection – National Research Institute, 5/11D Krucza Str., 00-548 Warsaw, Poland
e-mail: krystian.szczepanski@ios.edu.pl
** Institute of Vehicles and Construction Machinery Engineering, Warsaw University of Technology,
84 Narbutta Str., 02-524 Warsaw, Poland

Keywords:
pollutant, , transport categories, inventor of emission, road transport, railway transport, national annual emission

Abstract
This paper refers to the inventory of pollutant emissions in Poland from different transport categories over the period 1990–2020. The changes in the annual national emissions of selected pollutants, i.e. nitrogen oxides, non-methane volatile organic compounds, sulfur oxides, PM2.5, PM10, total suspended particulate matter, carbon monoxide, and lead were analysed. The shares of the national annual emissions of the examined pollutants from each studied transport category in the national annual emission from total transport were assessed. The sensitivity of the national annual pollutant emission inventory with regard to the transport categories and emitted substances under the study was assessed.
The trend of decrease in the national annual emissions of the substances analysed was appraised as positive in the face of a substantial intensification of transport activities. Taking into account the fact that road transportation is responsible for a dominant share of the national emission of pollutants, important progress in the reduction of emissions is attributable to the substantial technical improvement of the internal combustion engines of road vehicles.

1. INTRODUCTION

The present study refers to the emission of pollutants in Poland from different transport categories in the period 1990–2020 [Poland's Informative Inventory Report 2022].
The aim of the study was to assess the contribution of pollutant emissions from road transport to pollutant emissions from total transport methods.
The analysis was carried out with authorised results from the pollutant emissions inventory carried out by the National Centre for Emissions Management (KOBiZE) at the Institute of Environmental Protection – National Research Institute (IOŚ-PIB). The results obtained by KOBiZE are reported to the United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Transboundary Air Pollution (CLRTAP) and to the European Union compliant with the Directive (EU) 2016/2284 of the European Parliament and of the Council of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants (the EU National Emission Ceilings Directive). Data included in the reports prepared by KOBiZE is also used in the reports published by Statistics Poland (GUS).
The following categories [EEA/EMEP Emission Inventory Guidebook 2019, Poland's Informative Inventory Report 2021] were considered in the present study:

- road transport,
- railway transport,
- national navigation,
- air transport (pollutant emissions from landing/take-off – LTO[1])
- other types of transport: mobile machines, among others, handling transport with the use of working and agricultural machines,
- total transport.

Along with the recommendations of the European Monitoring and Evaluation Programme - European Environment Agency (EMEP EEA) for reporting on the national annual emission of pollutants, the additional substances adopted are listed in Table 1 [EEA/EMEP Emission Inventory Guidebook 2019].
The emissions of pollutants harmful to health and those enhancing the intensification of the greenhouse effect in the atmosphere (the increase of greenhouse gases) are also reported.
In the present study, the pollutants harmful to the health of living beings were examined. The following substances were selected for the analyses carried out under the present study:

1 LTO cycles refer to landing and take-off cycles. The International Civil Aviation Organization (ICAO) defines an LTO cycle as those activities occurring up to 3000 ft (914.4 m) above ground level.

Open Access. © Author(s), published by Sciendo. BY-NC-ND This is an open access article licensed under the Creative Commons Attribution-NonCommercial-NoDerivs License (http://creativecommons.org/licenses/by-nc-nd/3.0/).

- nitrogen oxides,
- non-methane volatile organic compounds,
- sulfur oxides,
- particulate matter PM2.5,
- PM10 particulate matter,
- total suspended particulate matter TSP,
- carbon monoxide,
- lead.

There were two reasons behind the selection of the above substances. The first reason is that the emissions of nitrogen oxides, non-methane volatile organic compounds, particulate matter PM2.5, particulate matter PM10, total suspended particulate matter TSP, and carbon monoxide are related to the emissions of pollutants that are subject to the regulations for motor vehicles in force in Europe (commonly called 'Euro') [DieselNet: Engine & Emission Technology; Worldwide emission standards 2020/2021; Worldwide emissions standards heavy duty and off-highway vehicles. 2016/17]. The second reason is the issue of substances, the content of which is limited in fuels, such as lead and sulfur [DieselNet: Engine & Emission Technology; Worldwide emission standards 2020/2021; Worldwide emissions standards heavy duty and off-highway vehicles. 2016/17]. In actual fact, the presence of lead and sulfur in fuels has been radically reduced [Advanced Combustion and Emission Control Roadmap 2018; DieselNet: Engine & Emission Technology; Worldwide emission standards 2020/2021; Worldwide emissions standards heavy duty and off-highway vehicles. 2016/17].

The topics related to inventorying pollutant emissions from various source categories, with respect to pollutants harmful to the health of living beings, as well as greenhouse gases, have been developed in many centres worldwide [1990–2015 air pollutant emission inventory report; Air Quality Pollutant Inventories for England, Scotland, Wales and Northern Ireland: 2005–2019; Bebkiewicz et al. 2020b; Bebkiewicz et al. 2021; Bebkiewicz et al. 2021c; Bebkiewicz et al. 2021b; Bebkiewicz et al. 2020a; Chłopek et al. 2018b; EEA/EMEP Emission Inventory Guidebook 2019; Emissions of air pollutants from transport. European Environment Agency 2021; Ireland's Final Greenhouse Gas Emissions 2021; Kara et al. 2014; Keller 2010; Kurien et al. 2018; Lemana 2016; Lestari et al. 2020; Poland's Informative Inventory Report 2022; Progiou, Ziomas 2011; Saikawa 2012; UK Spatial Emissions Methodology 2019]. Most publications contain annual emission data for individual countries [1990–2015 air pollutant emission inventory report 2016; Advanced Combustion and Emission Control Roadmap March 2018; Air Quality Pollutant Inventories for England, Scotland, Wales and Northern Ireland: 2005–2019; Bebkiewicz et al. 2020b; Bebkiewicz et al. 2021a; Bebkiewicz et al. 2021c; Bebkiewicz et al. 2021b; Bebkiewicz et al. 2020a; Chłopek et al. 2018b; Ireland's Final Greenhouse Gas Emissions 2021; Poland's Informative Inventory Report 2022; Saikawa 2012] or centres [Bebkiewicz et al. 2020b; DieselNet: Engine & Emission Technology; Kara et al. 2014; Kurien et al. 2018; Lemana 2016; Lestari et al. 2020; UK Spatial Emissions Methodology 2019].

Table 1. Substances, emitted to the environment, inventoried according to EMEP EEA procedure [EEA/EMEP Emission Inventory Guidebook 2019]

Substance
Carbon monoxide
Volatile organic compounds
Non-methane volatile organic compounds
Polycyclic aromatic hydrocarbons
Hexachlorobenzene, polychlorinated biphenyls, dioxins, and furans
Nitrogen monoxide
Nitrogen dioxide
Nitrogen oxides as nitrogen dioxide
Particulate matter PM10
Particulate matter PM2.5
Total suspended particulate matter TSP
Carbon black (soot)
Sulfur oxides as sulfur dioxide
Ammonia
Heavy metals: lead, cadmium, mercury, arsenic, chromium, copper, nickel, zinc, selenium

The pertinent studies [Emissions of air pollutants from transport. European Environment Agency 2021; Keller 2010] contain forecasts of pollutant emissions from transport.

The subject literature also includes the methodology used in the emissions inventory [1990–2015 air pollutant emission inventory report 2016; Air Quality Pollutant Inventories for England, Scotland, Wales and Northern Ireland: 2005–2019; Chłopek et al. 2018a; EEA/EMEP Emission Inventory Guidebook 2019; UK Spatial Emissions Methodology 2019]. In Poland, the pollutant emissions inventory carried out by KOBiZE at IOŚ-PIB uses the methodology recommended by EMEP EEA [EEA/EMEP Emission Inventory Guidebook 2019]. The methodology is legitimately described in the article [Chłopek et al. 2018a]. The team of authors from IOŚ-PIB has carried out comprehensive, up-to-date analyses of pollutant emissions from road transport. The studies [Bebkiewicz et al. 2020b; Chłopek et al. 2018] comprised the analyses of the emission of greenhouse gases in 1988–2017. The studies [Bebkiewicz et al. 2021b; Bebkiewicz et al. 2020a] concerned the analysis of road transport emissions of substances harmful to the health of living beings, and above all, particulate matter emissions. The studies from Bebkiewicz et al. (2021b; 2020a) focused on the influence of road vehicle operating conditions on emissions. In Bebkiewicz et al. (2021b), the effects on pollutant emissions from the following vehicle operation conditions were examined: urban, rural, highways, and expressways.

Whereas in Bebkiewicz et al. (2021b), the effect of thermal condition of internal combustion engines on pollutant emissions was examined. The authors from IOŚ-PIB have not yet published any papers containing the results of the studies on the inventory of pollutant emissions from the categories of transport other than road transport. As a matter of fact, this topic has not been dealt with in the subject literature. An exception is the paper Emissions of air pollutants from transport. European Environment Agency 2021, which presents an overview of the shares of pollutant emissions from different transport categories in European countries – averaged for the reporting years – and refers to the changes in the relative annual emissions of the studied pollutants from the total transport over the period of 1990–2017.

The present study focused on changes in the national annual emissions of selected pollutants from specific transport categories in Poland in the period 1990–2020. There were also examined the shares of the national annual emissions of the pollutants from the transport categories under the study in the national annual emission from the total transport. Furthermore, the sensitivity of the annual national pollutant emission in terms of the transport categories and the substances emitted was assessed using an analysis of the coefficient of variation in the annual national pollutant emissions.

2. PROCESS OF POLLUTANT EMISSIONS FROM TRANSPORT CATEGORIES IN POLAND OVER THE 1990–2020 PERIOD

Figures 1–8 present process in the national annual emissions (E_a) of the examined substances from the specific transport categories in the years 1990–2020.

Even with the substantial intensification of transport [Poland's Informative Inventory Report 2022], the national annual emissions of the pollutants under the study show a decrease over the consecutive years of the study period. This is particularly noticeable in the case of carbon monoxide and non-methane volatile organic compounds, i.e. the products of incomplete and half-finished combustion of fuels in engines, as well as in the case of sulfur compounds and lead compounds. The decrease in emissions of incomplete and half-finished combustion products is due to the implementation of numerous technical solutions in internal combustion engines, enabling the formation of the combustible mixture in the cylinders, with precise composition and spatial uniformity adjusted to the engine type (spark ignition engines, spark ignition engines for combustion of mixtures, compression ignition engines), as well as thanks to the use of the catalytic exhaust gas after-treatment systems [Advanced Combustion and Emission Control Roadmap 2018; DieselNet: Engine & Emission Technology Online; Kurien et al. 2018; Lemana 2016; Worldwide emission standards 2020/2021; Worldwide emissions standards heavy duty and off-highway vehicles. 2016/17]. The introduction of the latter solution was

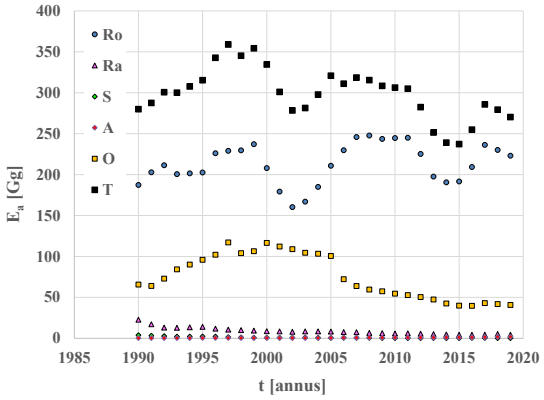


Figure 1. National annual emissions – E_a of nitrogen oxides – NO_x for transport categories: Ro - road transport, Ra - rail transport, S - water transport, A - air transport, O - other transport modes, T - total transport

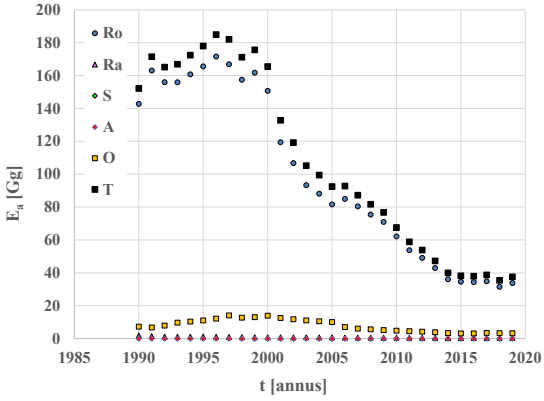


Figure 2. National annual emissions – E_a of non-methane volatile organic compounds – NMVOCs for transport categories: Ro - road transport, Ra - rail transport, S - water transport, A - air transport, O - other transport modes, T - total transport

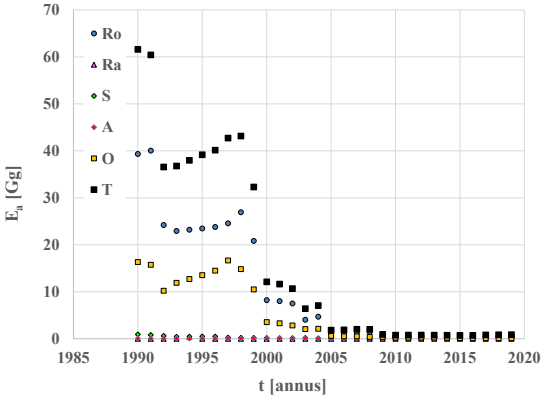


Figure 3. National annual emission – E_a of sulfur oxides – SOx for transport categories: Ro - road transport, Ra - rail transport, S - water transport, A - air transport, O - other transport modes, T - total transport

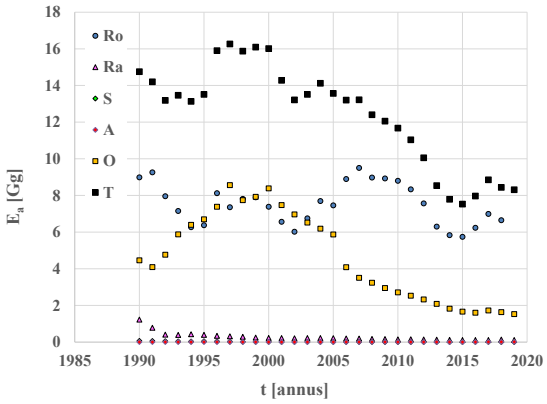


Figure 4. National annual emission – E_a of particulate matter PM2.5 for transport categories: Ro - road transport, Ra - rail transport, S - water transport, A - air transport, O - other transport modes, T - total transport

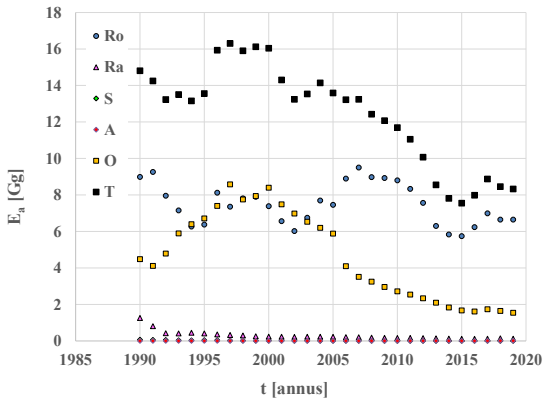


Figure 5. National annual emission – E_a of PM10 for transport categories: Ro - road transport, Ra - rail transport, S - water transport, A - air transport, O - other transport modes, T - total transport

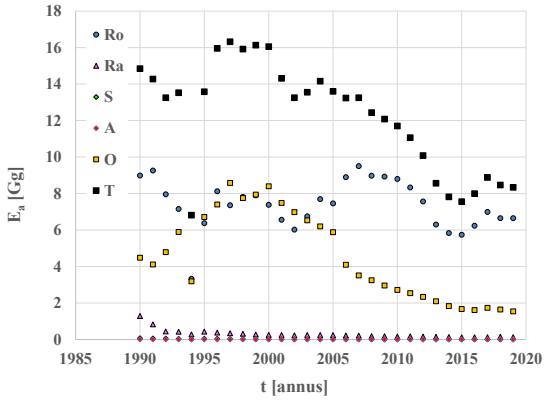


Figure 6. National annual emission – E_a of total particulate matter – TSP for transport categories: Ro - road transport, Ra - rail transport, S - water transport, A - air transport, O - other transport modes, T - total transport

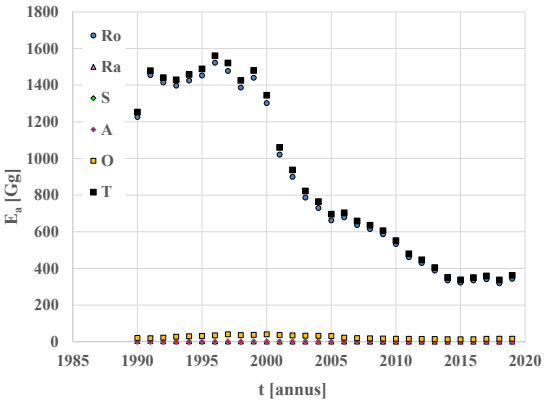


Figure 7. National annual emission – E_a of carbon monoxide – CO for transport categories: Ro - road transport, Ra - rail transport, S - water transport, A - air transport, O - other transport modes, T - total transport

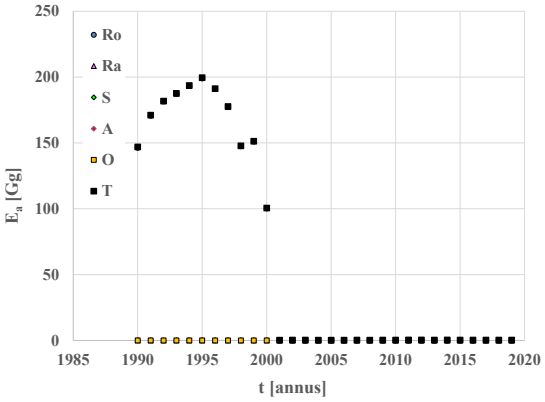


Figure 8. National annual emission – E_a of lead – Pb for transport categories: Ro - road transport, Ra - rail transport, S - water transport, A - air transport, O - other transport modes, T - total transport

demanded to radically reduce sulfur and lead contents in fuels, as the presence of these substances in fuel put catalytic reactors at risk of destruction. Lead and sulfur compounds have adverse effects on the active surface of catalytic reactors. Obviously, changes in the levels of sulfur and lead compounds contained in fuels resulted in changes in fuel composition and the technology used for its production, e.g. application of isoalkane additives to petrols (reformed petrols) so as to ensure sufficient resistance to engine knock.

Essential reductions in the national annual emissions of sulfur compounds since 2005 and of lead compounds since 2001 have occurred as a result of new limits for sulfur and lead contents in fuels.

Reduced contents of sulfur and lead compounds in fuel have resulted in the environmental benefit – a significant decrease in the emissions of these compounds.

As far as nitrogen oxides and particulate matter are concerned, the progress in the reduction of their emissions is slower when compared to carbon monoxide and organic compounds. In the case of carbon monoxide and organic compounds, there still occur difficulties in catalytic treatment of exhaust gases so as to decrease the emissions of these substances [Advanced Combustion and Emission Control Roadmap 2018; Kurien et al. 2018; Lemana 2016; Worldwide emission standards 2020/2021; Worldwide emissions standards heavy duty and off-highway vehicles. 2016/17].

It is noteworthy that practically all emissions of lead compounds originate from road transport as spark ignition engines fuelled with petrol containing lead compounds are used in this transport category. Other transport sectors use mainly compression ignition engines. In the case of carbon monoxide emissions, the situation is similar to that with lead compounds – carbon monoxide emissions come mainly from spark ignition engines, i.e. mainly from road transport.

3. ANALYSIS OF POLLUTANT EMISSIONS FROM TRANSPORT CATEGORIES IN POLAND IN THE YEARS 1990–2020

Figures 9–16 show changes in the shares of the national annual emissions of the pollutants from the transport categories under the study in the national annual emission from the total transport.

In the case of nitrogen oxides, the foremost source of emissions is the category of road vehicles, followed by mobile machinery. The dominance of the share of nitrogen oxides emission in the case of road vehicles results, first of all, from the number and the intensity of use of means of transport in this category [Poland's Informative Inventory Report 2022]. Mobile machines are powered by compression ignition engines, most often with environmental properties because their pollutant emissions are much higher than those of automotive vehicle engines [DieselNet: Engine & Emission Technology Online; Worldwide emissions standards heavy duty and off-highway vehicles. 2016/17].

In the case of non-methane volatile organic compounds and carbon monoxide, a similar pattern is observed. However, the dominance of the emissions of non-methane volatile organic compounds and carbon monoxide from road vehicles is higher when compared to nitrogen oxides. Trends analogous to that of of nitrogen oxides are observed in the shares of the national annual emissions of sulfur oxides.

As for the share of the national annual emissions of particulate matter, in the 21st century, there has been observed a trend toward increasing. At the same time, there has occurred a tendency to decrease for the share of the national annual emissions from mobile machines.

The share of the national emission of lead shows a significant step change in 2000, which resulted from

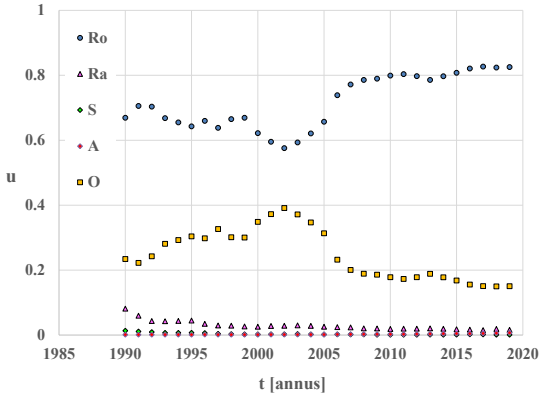


Figure 9. Shares of national annual emissions – u of nitrogen oxides – NO_x from individual transport categories: Ro - road transport, Ra - rail transport, S - water transport, A - air transport, O - other transport modes, in the national annual emission from total transport

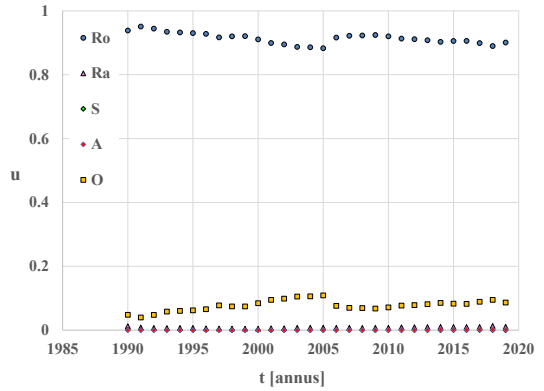


Figure 10. Shares of the national annual emissions – u of non-methane volatile organic compounds – NMVOCs from individual transport categories: Ro - road transport, Ra - rail transport, S - water transport, A - air transport, O - other transport modes, in the national annual emission from total transport

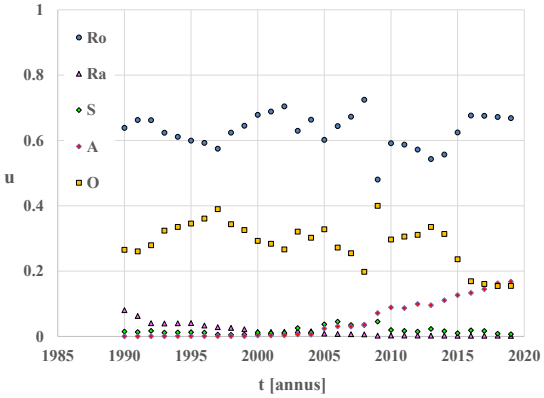


Figure 11. Shares of the national annual emissions – u of sulfur oxides – SO_x from individual transport categories: Ro - road transport, Ra - rail transport, S - water transport, A - air transport, O - other transport modes, in the national annual emission from total transport

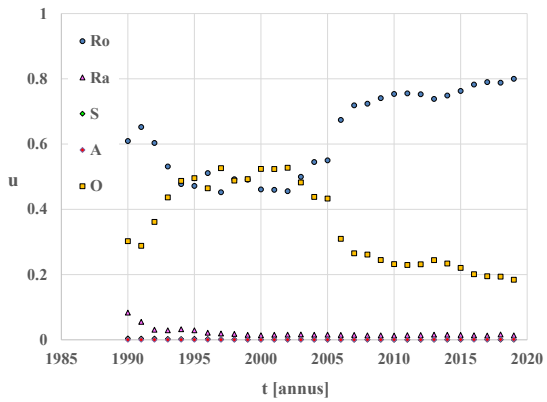


Figure 12. Shares of the national annual emissions – u of particulate matter PM2.5 from individual categories of transport: Ro - road transport, Ra - rail transport, S - water transport, A - air transport, O - other transport modes, in the national annual emission from total transport

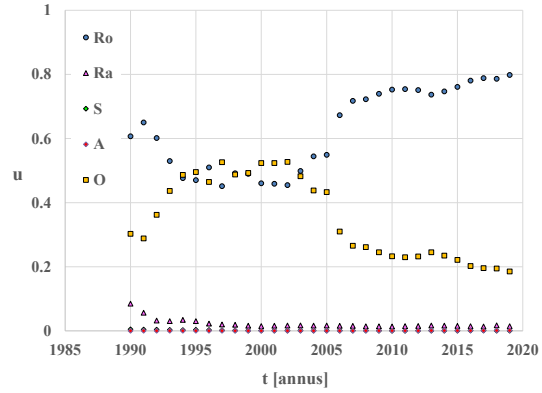


Figure 13. Shares of the national annual emissions – u of PM10 particulate matter from individual transport categories: Ro - road transport, Ra - rail transport, S - water transport, A - air transport, O - other transport modes, in the national annual emission from total transport

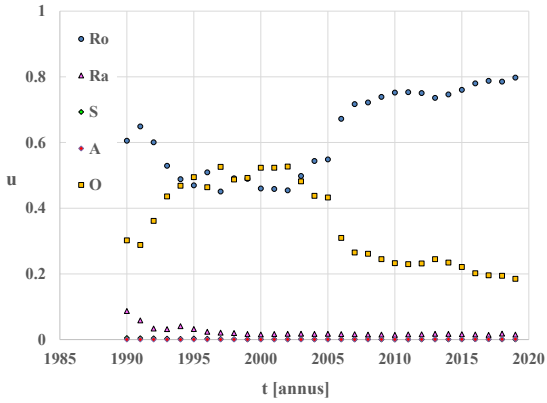


Figure 14. Shares of the national annual emissions – u of total particulate matter – TSP from individual transport categories: Ro - road transport, Ra - rail transport, S - water transport, A - air transport, O - other transport modes, in the national annual emission from total transport

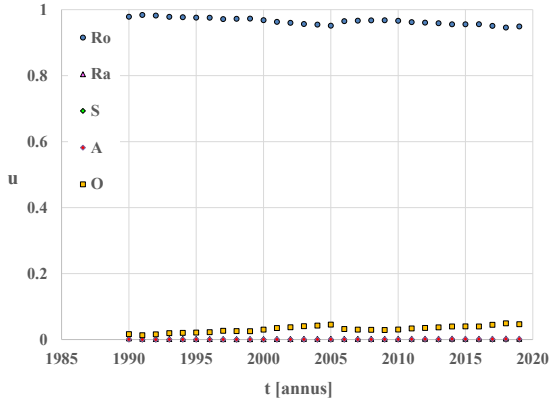


Figure 15. Shares of the national annual emissions – u of carbon monoxide – CO from individual transport categories: Ro - road transport, Ra - rail transport, S - water transport, A - air transport, O - other transport modes, in the national annual emission from total transport

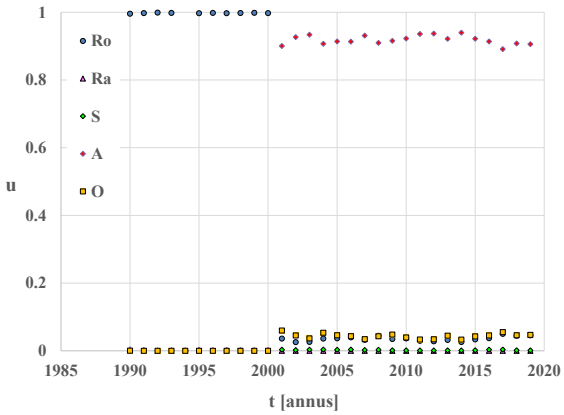


Figure 16. Shares of the national annual emissions – u of lead – Pb from individual transport categories: Ro - road transport, Ra - rail transport, S - water transport, A - air transport, O - other transport modes, in the national annual emission from total transport

the introduction of petrol with trace contents of lead compounds ('unleaded petrol') into the operation of motor vehicles. Yet, high lead compound contents have remained in traditional aircraft fuel.

In Figures 17 and 18, a different presentation layout was used to better visualise the influence of individual indicators, show the coefficient of variation of the national annual emission of the pollutants under the study from individual transport categories.

The coefficient of variation of a quantity characterises the sensitivity of this quantity to other physical quantities or categories of sets for which the coefficient of variation is determined. The coefficient of variation of the national annual emission of the examined pollutants from particular transport categories varies considerably, both for the types of substances and for the categories of transport.

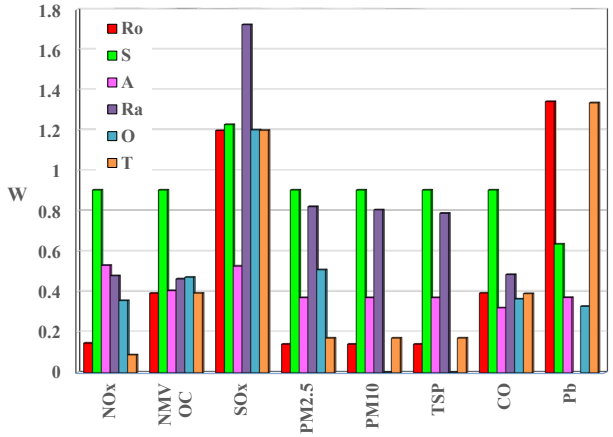


Figure 17. The coefficient of variation – W of the national annual emission of the following pollutants: NO_x - nitrogen oxides, NMVOC - non-methane volatile organic compounds, SO_x - sulfur oxides, particulate matter PM2.5, particulate matter PM10, total suspended particulate matter TSP, CO - carbon monoxide, and Pb - lead from individual transport categories: Ro - road transport, Ra - rail transport, S - water transport, A - air transport, O - other transport modes, T - total transport

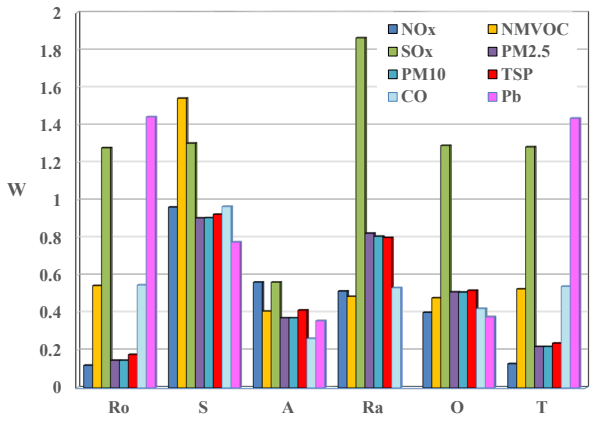


Figure 18. The coefficient of variation – W of the national annual emission of the following pollutants: NO_x - nitrogen oxides, NMVOC - non-methane volatile organic compounds, SO_x - sulfur oxides, particulate matter PM2.5, particulate matter PM10, total suspended particulate matter TSP, CO - carbon monoxide, and Pb - lead from individual transport categories: Ro - road transport, Ra - rail transport, S - water transport, A - air transport, O - other transport modes, T - total transport

The mean value of the coefficient of variation of the national annual emission is smallest for nitrogen oxides and for air transport means, and highest for sulfur oxides and water transport means.

4. CONCLUSIONS

Based on the results of the present study on the national annual emissions in Poland over the period 1990–2020, the following conclusions can be formulated:

1) Transport is a sector with very dynamic development patterns [Poland's Informative Inventory Report 2022]. It poses an obvious threat to the environment, primarily due to the emissions of pollutants. At the same time, efforts have been made to improve the performance of transport means – in particular, their engines – with respect to environmental impacts. This is particularly evident in the case of the effectiveness of the measures taken to reduce pollutant emissions from internal combustion engines. Figures 19 and 20 show schematically the values of the specific emissions of nitrogen oxides and particulate matter from compression ignition engines of vehicles with the reference mass higher than 2.61 Mg (trucks and buses) observed in static tests (the European Stationary Cycle [ESC] for Euro V regulations and the World Harmonized Stationary Cycle [WHSC]) for Euro VI regulations, as well as in dynamic tests (the European Transient Cycle [ETC] for Euro V regulations and the World Harmonized Transient Cycle [WHTC]) for Euro VI regulations[2] [DieselNet: Engine & Emission Technology Online; Worldwide emissions standards heavy duty and off-highway vehicles. 2016/17].
The difference in characteristics for the levels of regulations is clearly visible. It is mainly due to technical advancements that regardless of very high intensity of transport development, the national annual emissions of the studied pollutants tend to decrease in the consecutive study years, especially in the case of carbon monoxide and non-methane volatile organic compounds. In the case of nitrogen oxides and particulate matter, the progress in the reduction of their emissions is slower when compared to carbon monoxide and organic compounds because of higher difficulties in implementation of the methods for catalytic exhaust gas treatment with regard to these substances.

2) The national annual emissions of sulfur compounds and lead compounds have been radically decreasing. This has been possible due to the practically complete elimination of these compounds from fuels used in road transport where fuel consumption is highest when compared to that in other transport categories [Poland's Informative Inventory Report 2022]. The practical elimination of sulfur and lead compounds from road transport fuels was due to the need to ensure the efficiency and durability of the catalytic reactors used to reduce pollutant emissions.

3) In the breakdown of the national annual pollutant emissions by the transport category, road transport is dominant, mainly due to the number and intensity of use of transport means in this category [Poland's Informative

2 Changes were made for the test methods at the level of Euro VI emissions. The ESC static test was replaced by the WHSC test and the ETC dynamic test by the WHTC test. Nevertheless, the test results are comparable.

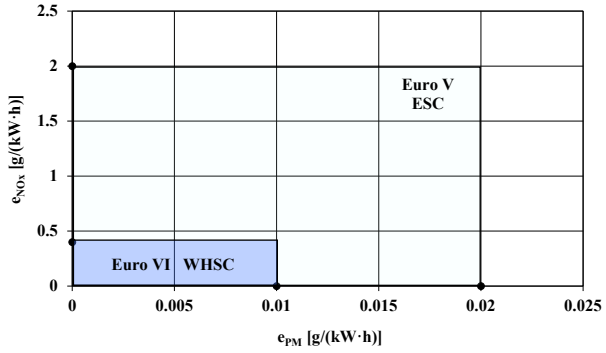


Figure 19. Specific emission values for nitrogen oxides and particulate matter from compression ignition engines of vehicles with the reference mass higher than 2.61 Mg (trucks and buses) in static tests (ESC for Euro V regulation level and WHSC for Euro VI regulation level)

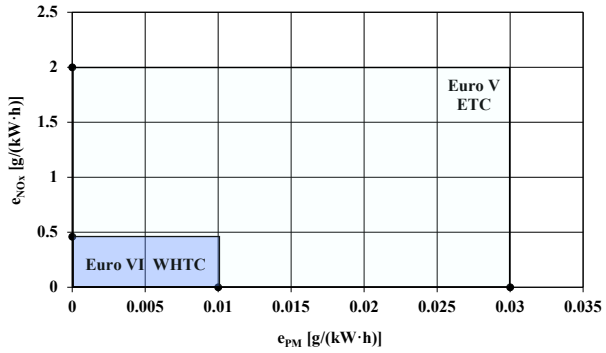


Figure 20. Specific emission values for nitrogen oxides and particulate matter from compression ignition engines of vehicles with the reference mass higher than 2.61 Mg (heavy duty trucks and buses) in dynamic tests (ETC for Euro V regulation level and WHTC for Euro VI regulation level)

Inventory Report 2022]. The shares of the national annual emissions from road vehicles in the case of non-methane volatile organic compounds and carbon monoxide are particularly large. This is mainly due to the fact that spark ignition engines, characterised by high emissions of carbon monoxide and organic compounds, are mainly used in light road vehicles [Poland's Informative Inventory Report 2022]. In the case of nitrogen oxides, their share in the national annual emission from mobile machinery is also relatively high, which is caused by the inferior quality of heavy compression ignition engines used in working machinery.

4) The sensitivity of the annual national emissions of pollutants from the transport categories studied is the lowest for nitrogen oxides and the highest for sulfur oxides. The sensitivity of the national annual emissions of pollutants regarding emitted substances is the lowest for air transport means and the highest for water transport means.

The analysis of the national annual emissions of pollutants from transport in Poland over the period 1990–2020 unambiguously confirms the effectiveness of rational measures aimed at reducing the harmful impact of transport on the environment. This is possible not only as a result of technical measures taken with respect to the construction of means of transport and, above all, the internal combustion engines that drive them, but also due to the improvement of consumables, chiefly fuels. An important role is also played by organisational activities in transport, mainly the rationalisation of transport works. These activities are aimed at reducing, as far as possible, the need to use transport, and they include the partial replacement of matter transport by transmission of information, i.e. through information networks.

REFERENCES AND LEGAL ACTS

1990–2015 air pollutant emission inventory report. Environment and Climate Change Canada. 2016.

Advanced combustion and emission control roadmap March 2018. US DRIVE (Driving Research and Innovation for Vehicle efficiency and Energy sustainability).

Air Quality Pollutant Inventories for England, Scotland, Wales and Northern Ireland: 2005–2019**.** Department for Environment, Food and Rural Affairs (Defra), The Scottish Government, The Welsh Government and The Northern Ireland Department for Agriculture, Environment and Rural Affairs.

BEBKIEWICZ K., CHŁOPEK Z., LASOCKI J., SZCZEPAŃSKI K., ZIMAKOWSKA-LASKOWSKA M. 2020a. The inventory of pollutants hazardous to the health of living organisms, emitted by road transport in Poland between 1990 and 2017. Sustainability 12: 5387. DOI: 10.3390/su12135387

BEBKIEWICZ K., CHŁOPEK Z., LASOCKI J., SZCZEPAŃSKI K., ZIMAKOWSKA-LASKOWSKA M. 2020b. Analysis of emission of greenhouse gases from road transport in Poland between 1990 and 2017. Atmosphere 11, 4: 387. DOI: https://doi.org/10.3390/atmos11040387

BEBKIEWICZ K., CHŁOPEK Z., SAR H., SZCZEPAŃSKI K., ZIMAKOWSKA-LASKOWSKA M. 2021a. Assessment of environmental risks of particulate matter emissions from road transport based on the emission inventory. Applied Sciences 11: 6123. DOI: https://doi.org/10.3390/app11136123

BEBKIEWICZ K., CHŁOPEK Z., SAR H., SZCZEPAŃSKI K., ZIMAKOWSKA-LASKOWSKA M. 2021b. Influence of the thermal state of vehicle combustion engines on the results of the national inventory of pollutant emissions. Applied Sciences 11, 19: 9084. DOI: 10.3390/app11199084

BEBKIEWICZ K., CHŁOPEK Z., SAR H., SZCZEPAŃSKI K., ZIMAKOWSKA-LASKOWSKA M. 2021c. Assessment of impact of vehicle traffic conditions: urban, rural and highway, on the results of pollutant emissions inventory. Archives of Transport 60, 4: 57–69. DOI: 10.5604/01.3001.0015.5477

CHŁOPEK Z., DĘBSKI B., SZCZEPAŃSKI K. 2018a. Theory and practice of inventory pollutant emission from civilization-related sources: share of the emission harmful to health from road transport. The Archives of Automotive Engineering – Archiwum Motoryzacji 79, 1: 5–22. DOI: http://dx.doi.org/10.14669/AM.VOL.79.ART1

CHŁOPEK Z., OLECKA A., SZCZEPAŃSKI K., BEBKIEWICZ K. 2018. Share of road transport in greenhouse gas emissions in Poland in 1988–2015. Environmental Protection and Natural Resources – Ochrona Środowiska i Zasobów Naturalnych 77, 3: 13–20. DOI 10.2478/oszn-2018-0014

CHŁOPEK Z., OLECKA A., SZCZEPAŃSKI K. 2018. Greenhouse gas emission from motor vehicles in Poland in 2015. Environmental Protection and Natural Resources – Ochrona Środowiska i Zasobów Naturalnych 76, 2: 9–13. DOI 10.2478/oszn-2018-0008

CRISTIANE D. et al. 2013. Inventory of conventional air pollutants emissions from road transportation for the state of Rio de Janeiro. Energy Policy Volume 53: 125–135. DOI: 10.1016/J.ENPOL.2012.10.021

DieselNet: Engine & Emission Technology Online. https://dieselnet.com (2022-03-11).

EEA/EMEP Emission Inventory Guidebook 2019.

Emissions of air pollutants from transport. European Environment Agency. 2021.

Ireland's Final Greenhouse Gas Emissions. 1990–2019. Environmental Protection Agency. 2021.

KARA M., MANGIR N., BAYRAM A., ELBIR T. 2014. A spatially high resolution and activity based emissions inventory for the metropolitan area of Istanbul, Turkey. Aerosol and Air Quality Research 14: 10–20.

KELLER M. Pollutant emissions from road transport, 1990 to 2035. Federal Office for the Environment (FOEN). 2010.

KURIEN C., KUMAR A., THAKKAR V., SHARMA V. Application of Selective Catalytic Reduction System for Exhaust Emission Control of Compression Ignition Engines. Conference: International Conference on Advanced Materials, Energy and Environmental Sustainability (ICAMEES 2018)

LEMANA A.M. et al. Advanced Catalytic Converter in Gasoline Engine Emission Control: A Review. The 9th International Unimas Stem Engineering Conference (ENCON 2016) "Innovative Solutions for Engineering and Technology Challenges". MATEC Web of Conferences 87, 02020 (2017). DOI: https://doi.org/10.1051/matecconf/20178702020

LESTARI P., DAMAYANTI S., ARROHMAN M.K. Emission inventory of pollutants (CO, SO 2, PM 2.5, and NO X) in Jakarta, Indonesia. May 2020. IOP Conference Series Earth and Environmental Science 489, 1: 012014. DOI: 10.1088/1755-1315/489/1/012014

Poland's Informative Inventory Report 2022 Submission under the UN ECE Convention on Long-range Transboundary Air Pollution and Directive (EU) 2016/2284. Air pollutant emissions in Poland 1990–2020. National Centre for Emissions Management (KOBiZE) – Institute of Environmental Protection – National Research Institute.

PROGIOU A., ZIOMAS I. 2011. Road traffic emissions impact on air quality of the Greater Athens Area based on a 20 year emissions inventory. Science of the Total Environment Volumes 410–411, 1: 1–7. DOI: 10.1016/j.scitotenv.2011.09.050

SAIKAWA E. et al. 2012. Comparison of emissions inventories of anthropogenic air pollutants and greenhouse gases in China. Atmospheric Chemistry and Physics 17: 6393–6421.

SINDHWANI R., GOYAL P., KUMAR S., KUMAR A. 2015. Anthropogenic emission inventory of criteria air pollutants of an urban agglomeration – National Capital Region (NCR), Delhi. Aerosol and Air Quality Research 15: 1681–1697.

UK Spatial Emissions Methodology. A Report of the National Atmospheric Emission Inventory 2019.

Worldwide Emission Standards. Passenger cars and light duty vehicles. Delphi. Innovation for the Real World. 2020/2021.

Worldwide Emissions Standards Heavy Duty and Off-Highway Vehicles. 2016/17.