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IDENTIFICATION AND ANALYSIS OF PARAMETERS FOR THE AREAS OF THE HIGHEST HARMFUL EXHAUST EMISSIONS IN THE MODEL EMITRANSYS

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Abstract

In the assumptions regarding the transport, policy both at the level of country and Europe there is the concept of sustainable development of transport. It assumes a balance between social and economic factors and the development of spatial and environmental protection. The transport system, which takes into account the concept of sustainable development, can be called proecological. Warsaw University of Technology in cooperation with Poznan University of Technology performs research work concerning the shaping of environmentally friendly transport system - Project EMITRANSYS. One of its components is to develop a mathematical model taking into account both the minimization of the negative impact of transport on the environment and minimization of the transportation costs. In this model, one of the conditions is to reduce emissions of harmful exhaust gases from transport. The paper identifies the parameters that were used to describe the emission of harmful exhaust compounds by means of transport, in particular by means of road transport. It presents the limits of individual parameters by EURO standard. It also presents the factors affecting the size of the air pollution from transport. In the paper, the areas with excessive concentrations of air pollutants in Poland have been characterized. An analysis of the possible causes of excessive concentrations have been carried out. Areas where traffic should be limited in order to contribute to the reduction of pollution have been identified.

Keywords: *proecological transport system, transport, air pollution, emission of exhaust gases, EMITRANSYS*

1. Introduction

In all documents expressing the position of the European Union and Poland, concerning the transport appears the concept of sustainable transport. Sustainable transport system can be defined as a system, which provides a balance between social and economic factors, and spatial development and environmental protection in the country. Therefore, shaping proecological transport system takes into account the balance between the economic aspects, social aspects, spatial development and environmental protection.

As can be seen from the foregoing proecological transport, the system should be friendly for the environment and human, so it should be:
– safe for human health and life,
– saving energy consumption,
– ecological, i.e. not a polluter of air, water or land.

The fact that Poland has not yet reached this balance in the development of the transport system providing tasks determined in the latest transport policy documents. The main problems of the Polish transport, which should be resolved until 2025, are [14]:
– congestion on the roads, particularly on domestic roads and roads in large urban areas,
– growing negative impact on the natural environment and civilization,
– high health and life risk in transport especially road transport,
– bad condition of technical infrastructure, especially road infrastructure,
– low productivity of railways and its low competitiveness,
– risks resulting from market opening.

One of the problems relates to the negative impact on the natural environment and civilization. It is expressed by [14]:
– greenhouse gas emissions which contribute to climate change,
– local emission of air pollution negatively influencing on people health and the local natural environment,
– occupying of valuable naturally areas and trenching of their continuity (fragmentation) of the new building of sequences of technical infrastructure, contributing to the loss of biodiversity,
– noise emission threatening human health.

The transport policy documents show that the above-mentioned problems should be minimized until 2025. We should look for the tools that will support realization of the objectives of the Poland transport policy, especially in terms of environmental aspect. In October 2012 at the Faculty of Transport of Warsaw University of Technology, together with Institute of Combustion Engines and Transport in the Faculty of Machines and Transport of Poznan University of Technology, started the Project *EMITRANSYS* concerning to the shaping of the transport system in the aspect of proecological. It is funded by the National Centre for Research and Development. A measurable result of the project will be provided, mainly the development of guidelines for the shaping of proecological transport system.

The development of guidelines can be achieved through a multi-faceted analysis using computer implementation of the mathematical model of shaping the proecological transport system in the environment PTV VISUM. The article focuses on the identification of factors affecting the level of emissions of harmful exhaust gases and presents the parameters specifying the amount of air pollution. In the paper characteristics of the areas located on Polish territory were have also been presented with the highest air pollution and the causes of exceeding concentrations analysed.

2. Factors affecting the level of emissions of harmful exhaust gases

Referring to the definition, the transport system is a set of technical and organizational measures and human resources connected to each other in such a way to carry out efficiently the movement of people and (or) cargo in space and time [9]. In this context, the proecological transport system is a collection of organizational and with surroundings connected to each other elements in such a way to efficiently carry out transportation in the transport network having with to minimizing the total social cost of transport. One of the indicators of the impact of transport on the environment are parameters related to air pollution.

Air pollution [4] depends on several factors. These include the composition of fuel, the type and the basic characteristics of the vehicle, the deployment of infrastructure, speed, place of formation of congestion, etc. (Fig. 1).

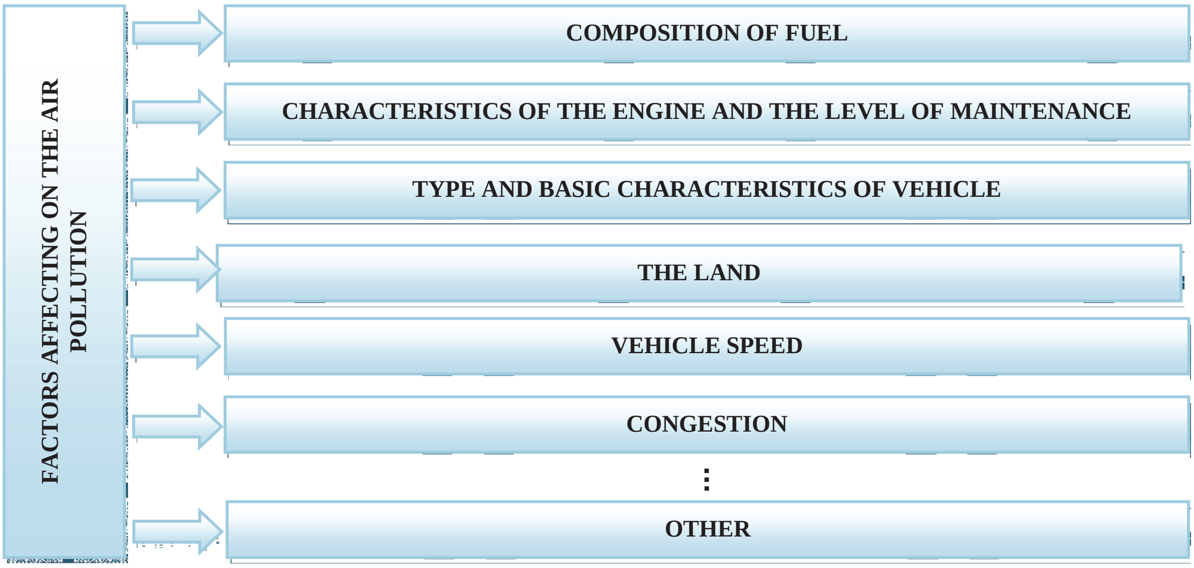

Fig. 1. Factors affecting the air pollution coming from the sphere of transport. Source: own work based on [4]

The level of air pollution from a means of transport is measured in concentrations of individual primary pollutants i.e. harmful compounds of exhaust gases generated when driving. These can be: nitrogen oxides – NO_x, carbon monoxide – CO, sulphur dioxide – SO_2, lead – Pb and particulate matter – PM_{10} and $PM_{2.5}$ as well as dust and soot. Fig. 2 presents the contribution of individual air pollutants emitted by road vehicles.

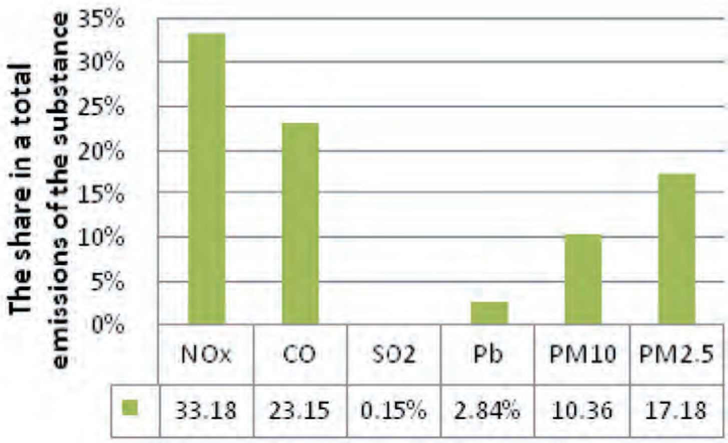

Fig. 2. The share of road transport in air pollution. Source: own work based on 0

Figure 3 shows the characteristics of harmful compounds of exhaust gases produced when driving road vehicles. They negatively interact with the environment and influence people’s lives. In order to reduce the emissions of harmful compounds of exhaust gases from road transport modern technology is introduced in the construction of engines, which is associated with the introduction of vehicles with a higher EURO standard.

The European Union introduced the European emissions standard, covering all new cars. The purpose of the EURO standards is to reduce emissions of several major harmful exhaust gases – nitrogen oxides (NOx), hydrocarbons (HC), carbon monoxide (CO) and particulate matter (PM). In the tables (Tab. 1-3) shows the emission limit values for new vehicles with engines of different types. Vehicles that do not comply with these standards are classified into standard EURO 0.

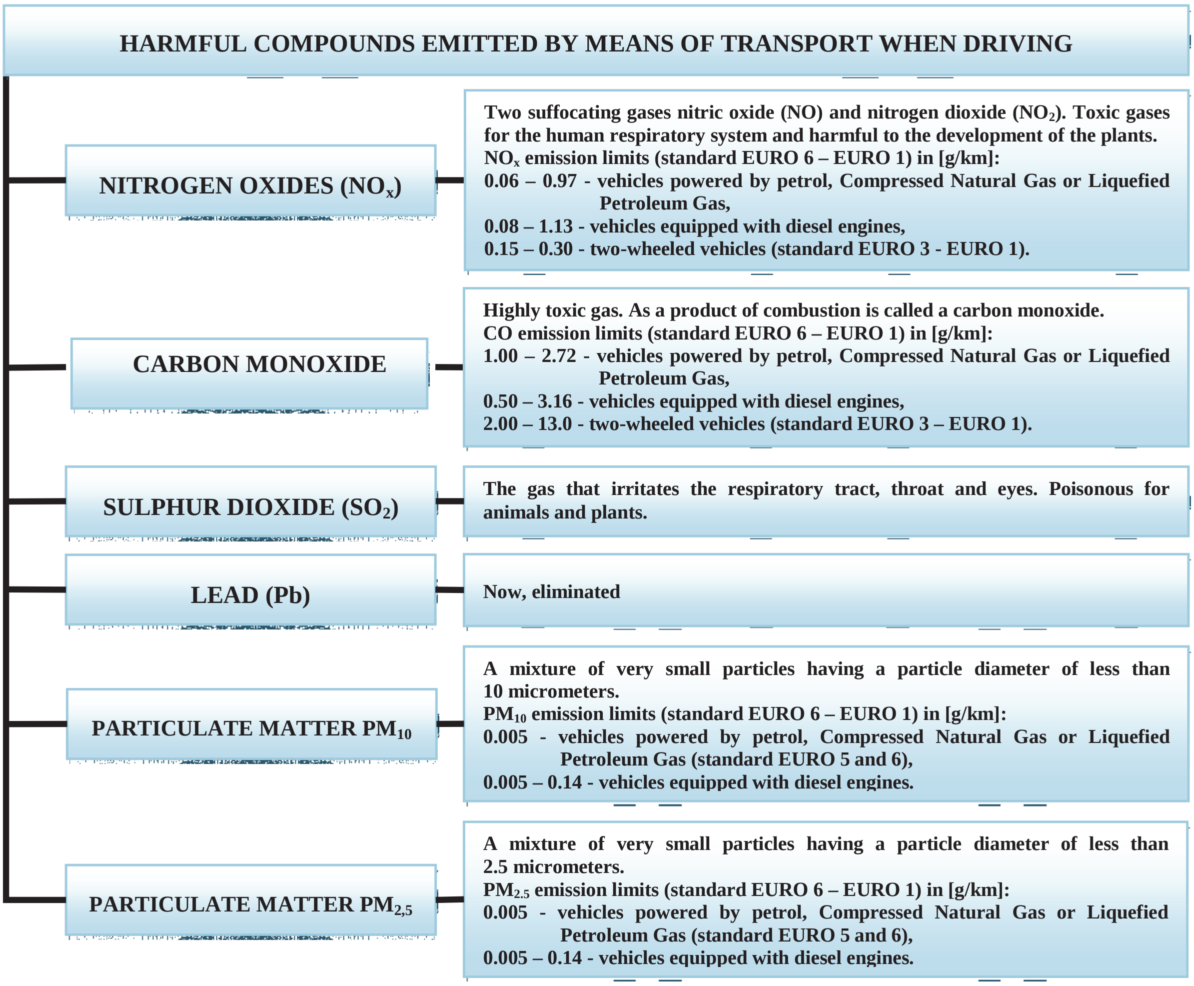

Fig. 3. Harmful compounds emitted by means of transport when driving. Source: own work based on [6, 11]

Although works continue on the introduction of more and more modern vehicles, environmental pollution caused by transport activities is not reduced. This is mainly due to the growing development of the automotive industry. Therefore, it is necessary to carry out research, not only in the technical aspect but also in the organizational aspect of transport.

The Project EMITRASYS focused mainly on developing a model of proecological transport system allowing multi-faceted analysis of traffic organization taking into account the needs of buyers of transport services, the structure of moving vehicles and transport infrastructure. For this purpose, it was assumed that the developed model of proecological transport system would allow the development of the organization of traffic and choice of system equipment to allow a reduction of air pollution caused by transport activities.

Tab. 1.Limit values for emissions from vehicles powered by petrol, Compressed Natural or Liquefied Petroleum Gas. Source: own work based on [15, 17]

Standard	CO [g/km]	HC [g/km]	NO_x [g/km]	HC + NO_x [g/km]	PM [g/km]
EURO 1	2.72	—	—	0.97	—
EURO 2	2.20	—	—	0.50	—
EURO 3	2.30	0.20	0.15	—	—
EURO 4	1.00	0.10	0.08	—	—
EURO 5	1.00	0.10	0.06	—	0.005
EURO 6	1.00	0.10	0.06	—	0.005

Tab. 2. Limit values for emissions from vehicles equipped with diesel engines. Source: own work based on [15, 17]

Standard	CO [g/km]	HC [g/km]	NO_x [g/km]	HC + NO_x [g/km]	PM [g/km]
EURO 1	3.16	—	—	1.13	0.14
EURO 2	1.00	0.15	0.55	0.70	0.08
EURO 3	0.64	0.06	0.50	0.56	0.05
EURO 4	0.50	0.05	0.25	0.30	—
EURO 5	0.50	0.05	0.18	0.23	0.005
EURO 6	0.50	0.09	0.08	0.17	0.005

Tab. 3. Limit values for emissions from two-wheeled vehicles. Source: own work based on [15, 17]

Standard	CO [g/km]	HC [g/km]	NO_x [g/km]
EURO 1	13.00	3.00	0.30
EURO 2	5.50	1.00	0.30
EURO 3	2.00	0.30	0.15

It should be noted that environmental pollution does not come only from transport. The other sources of emissions (resulting from the combustion of fuels) include [8]:
– combustion processes in the production and transformation of energy (such as fuel combustion in power plants, thermal power stations, heating plants),
– combustion processes in the municipal-housing,
– combustion processes in industry, including manufacturing processes,
– production and distribution of fossil fuels,
– waste management,
– agriculture (e.g. burning stubble).

3. Identification of areas with the highest air pollution

3.1. General assumptions

As part of work on the mathematical model of proecological transport system, the following were defined:
– $\boldsymbol{ST} = \{st : st = 1, \ldots, ST\}$ – numbers of types means of transport such as $st = 1$ mopeds and motorcycles, $st = 2$ – passenger cars, $st = 3$ – minibuses having seating capacity from 6 to 9, $st = 4$ – buses having seating capacity from 10 to 15, st = 5 – buses having seating capacity from 16 to 45, etc.,
– $\boldsymbol{S} = \{s : s = 1, \ldots, S\}$ – numbers of harmful substances generated when driving: $s = 1$ – carbon monoxide (CO), $s = 2$ – hydrocarbons (HC), $s = 3$ – nitrogen oxide (NO), $s = 4$ – nitrogen dioxide (NO_2), s = 5 – particulate matter (PM), s = 6 – carbon dioxide (CO_2),
– $\boldsymbol{RSP} = \{rsp : rsp = 1, 2, 3, 4\}$ – numbers and types of engine and fuel,
– $\boldsymbol{NEU} = \{neu : neu = 0, 1, 2, 3, 4, 5, 6\}$ – numbers of the EURO standards.

All sections of the road and rail network are described by these characteristics allowing a use of the model to assign the traffic flow on both the national transport network and for different areas and to estimate the amount of pollutants emitted into the environment.

Considering the above, each of the connections (i, i') can be characterized by a vector of compounds harmful gases that are emitted by various means of transport, i.e. $\langle \alpha(1, 1, i, i'), \ldots, \alpha(s, st, i, i'), \ldots, \alpha(S, ST, i, i')\rangle$.

In order to identify the areas with the highest environmental pollution caused by the effects of transport activities defined collection ***CS***, ***CS*** = {*cs* : *cs* = 1, …, *CS*} numbers factors determining the size of pollution. Polish transport network is divided into areas. Index ob designated a single location. Collection of all areas will have the form: ***OB*** = {*ob* : *ob* = 1, …, *OB*}.

The total impact of various factors affecting each harmful gas component generated when driving and contributing to air pollution can be presented as a function ***F***(***CS***, ***ST***, ***S***, ***OB***) (Fig. 4).

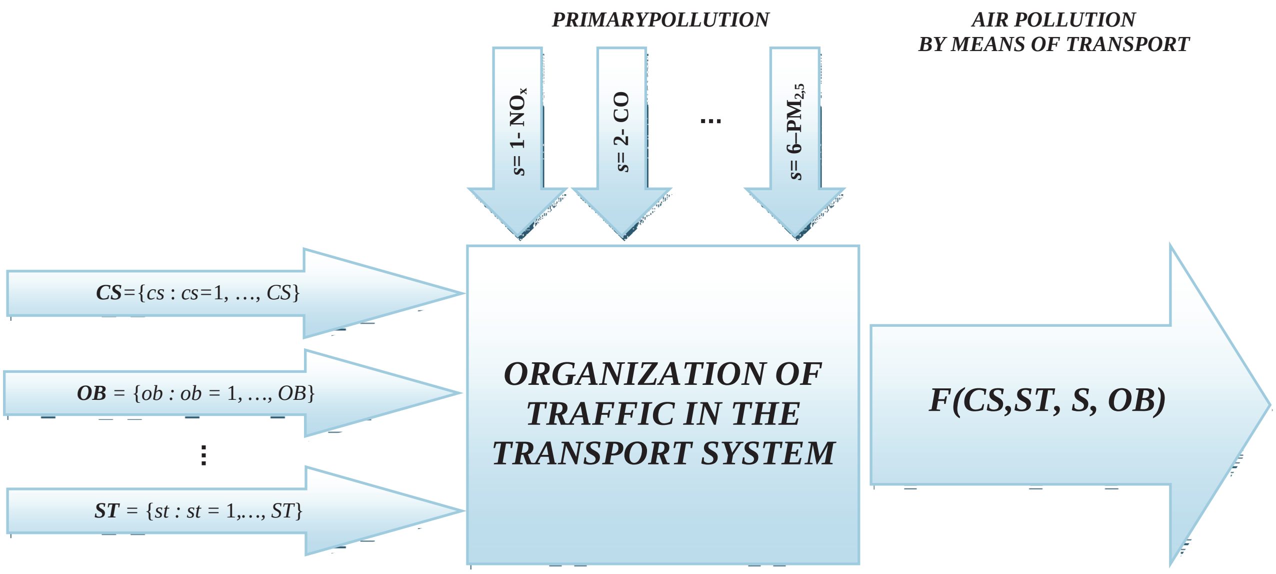

Fig. 4. Air pollution by means of transport. Source: own work

3.2. Analysis of Polish areas due to the concentration of various harmful gases

Chief Inspectorate of Environmental Protection in Poland on the basis of data from individual voivodships provides an annual assessment of air quality in specific areas of Poland [7]. The last document, which includes an analysis in 2011, was prepared in October 2012. Assessment has been carried out taking into account two criteria:

– due to the protection human health (criterion f_1),
– due to the protection plants (criterion f_2).

Assessed for the first criterion are: sulphur dioxide, nitrogen dioxide, carbon monoxide, benzene, ozone, particulate matter PM_{10}, lead, arsenic, cadmium, nickel and benzo(a)pyrene contained in PM_{10}, particulate matter $PM_{2.5}$. Due to the second criterion of evaluation are sulphur dioxide, nitrogen oxides and ozone. Highlighted substances are emitted by means of transport in the form of harmful gases. Measurements are performed in relation to areas (zones), comprising:

– agglomerations with a population of over 250 thousand inhabitants, (not to be assessed in terms of plant protection),
– cities (non-urban area) with a population of over 100 thousand inhabitants, (not to be assessed in terms of plant protection),
– remaining areas of the voivodships, not forming part of the agglomeration and city with over 100 thousand inhabitants.

The area (zone) because of the harmful substances is assigned to one of the classes depending on its concentration level:

– **A** – concentrations not exceeding the permissible level,
– **B** – concentration above the permissible level, but not exceeding the permissible level plus the margin of tolerance,
– **C** – concentration above the permissible level plus the margin of tolerance
– **D1** – concentrations not exceeding the level of the long-term target,
– **D2** – concentration above the level of long-term target.

As part of research in the Project EMITRANSYS Polish areas, were analysed for the concentration of different harmful substances. Fig. 5 and 6 shows the areas (zones) contaminated by nitrogen oxides (NO_x) emitted by means of transport too.

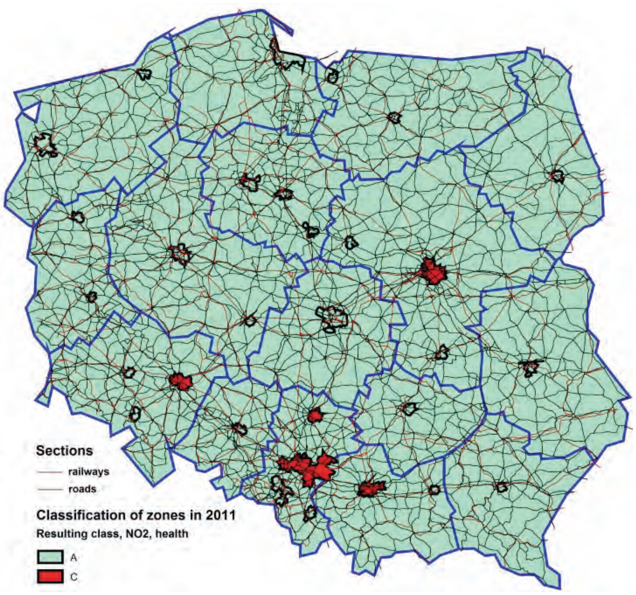

Fig. 5. Classification of zones in Poland for NO_2 in 2011 (criterion f_1). Source: printout from PTV VISUM based on [7]

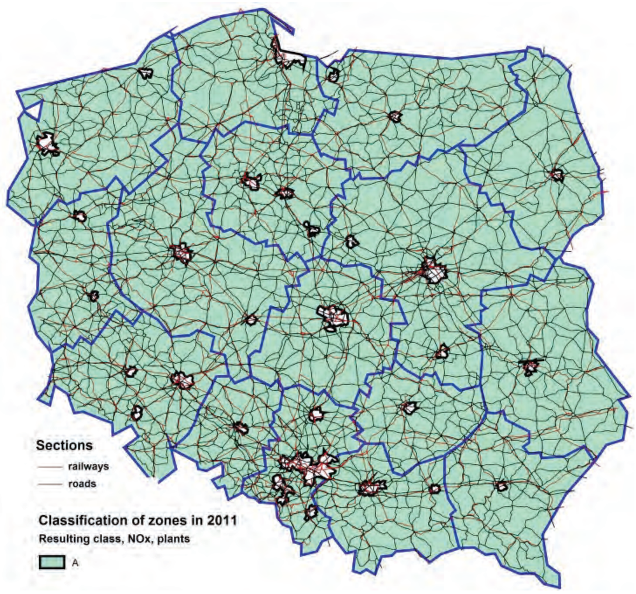

Fig. 6. Classification of zones in Poland for NO_x in 2011 (criterion f_2). Source: printout from PTV VISUM based on [7]

Assessing areas for protection of human health, the level for nitrogen dioxide above the permissible was recorded in five areas (zones): in the agglomeration of Warsaw and Krakow and in the Silesian conurbation and in Czestochowa and Wroclaw. Due to the criterion of plant protection in the whole country the level of concentrations of nitrogen oxides shall not exceed the permissible level. Considering the data in Fig. 2 the share of road transport in total emissions of nitrogen dioxide is quite high and is at the level of 33.18%. Based on the preliminary analysis carried out in the Project and the data available in the study [7] it can be concluded that one of the reasons for exceeding the admissible concentration is intense traffic in city centres and in the agglomeration. The analysis shows that on movement of vehicles in these area should be included in the model *EMITRANSYS*.

Figure 7 shows the classification of the areas (zones) due to air pollution by carbon monoxide (CO), and Fig. 8 due to contamination with lead. Both substances were analysed only by the criterion of human health protection.

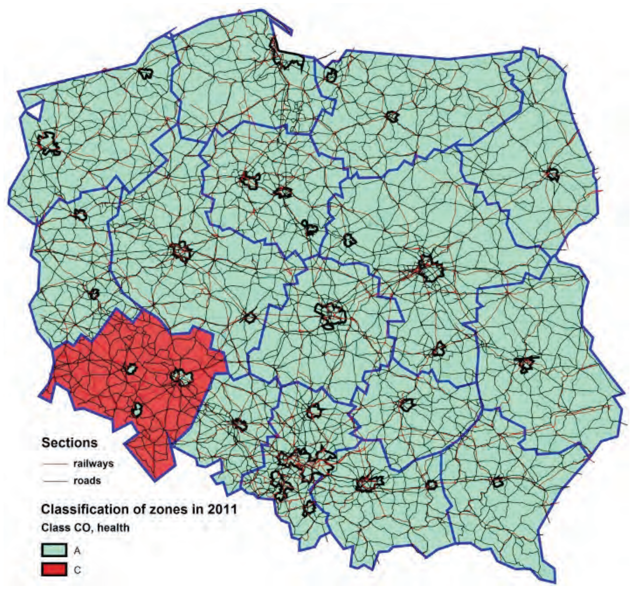

Fig. 7. Classification of zones in Poland for CO in 2011 (criterion f_1). Source: printout from PTV VISUM based on [7]

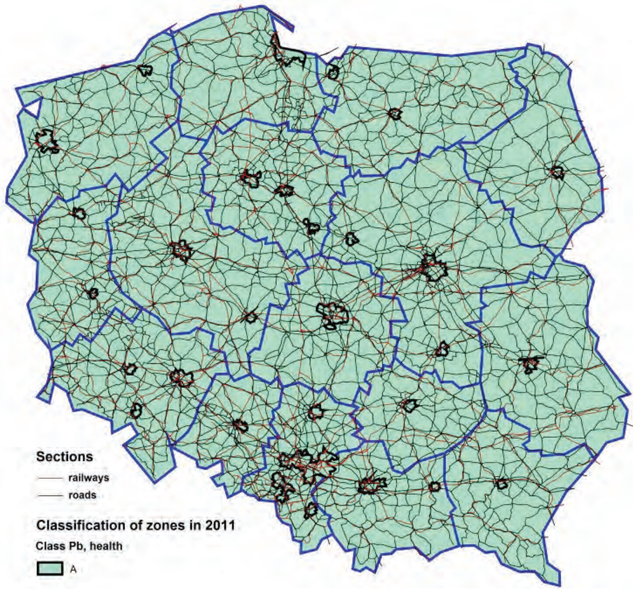

Fig. 8. Classification of zones in Poland for Pb in 2011 (criterion f_1). Source: printout from PTV VISUM based on [7]

Maximum concentrations of carbon monoxide have been exceeded in one location. This area is the Lower Silesia, due to the excess concentration in the health-resort Cieplice-Zdroj (located near Jelenia Gora). It should be noted that the concentrations of the standards for health resorts are much more stringent than for other areas. As can be seen from the data shown in Fig. 2 the share of road transport in the total emissions of this compound is high and the value is at the level 23.15%. Due to the location of the health resort area in the vicinity of major road transport routes with heavy traffic the road transport can cause excess of the limit.

All the analysed areas in Poland for the air pollution by lead were assigned to class A which are the areas where permissible concentration is not exceeded. It should be noted that the share of road transport in total emissions of Pb is relatively small and is at a level of 2.84% (Fig. 2).

Figure 9 and 10 shows the areas (zones) contaminated by sulphur dioxide (SO_2) also emitted by means of transport.

Assessing areas for protection of human health sulphur dioxide have been exceeded anywhere. Similarly, zones were classified in the case of plant protection criterion. The concentration of sulphur dioxide by any criterion is not exceeded. Considering the data in Fig. 2 the share of road transport in total emissions for this compound is very low and is at the level 0.15%.

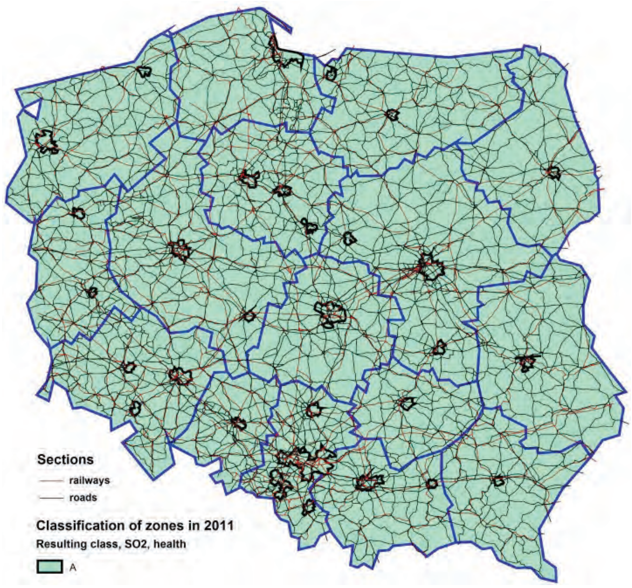

Fig. 9. Classification of zones in Poland for SO_2 in 2011 (criterion f_1). Source: printout from PTV VISUM based on [7]

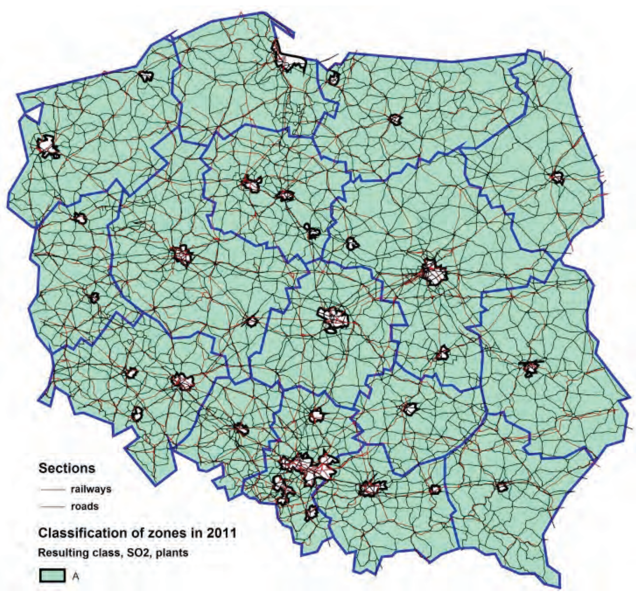

Fig. 10. Classification of zones in Poland for SO_2 in 2011 (criterion f_2). Source: printout from PTV VISUM based on [7]

Figure 11 presents the classification of zones for air pollution by particulate matter classified into a fraction PM_{10}, and Fig. 12 for the particulate matter $PM_{2.5}$. Both substances were analysed only by the criterion of human health protection.

From the point of view of criterion f_1 (human health) for PM_{10} air pollution in only four areas the acceptable level of concentration has not been exceeded. These zones are the cities of Elblag, Koszalin, Olsztyn and Zielona Gora. In other cities and in all voivodships permissible concentration has been exceeded. As can be seen from the data shown in Fig. 2 share of road transport in total

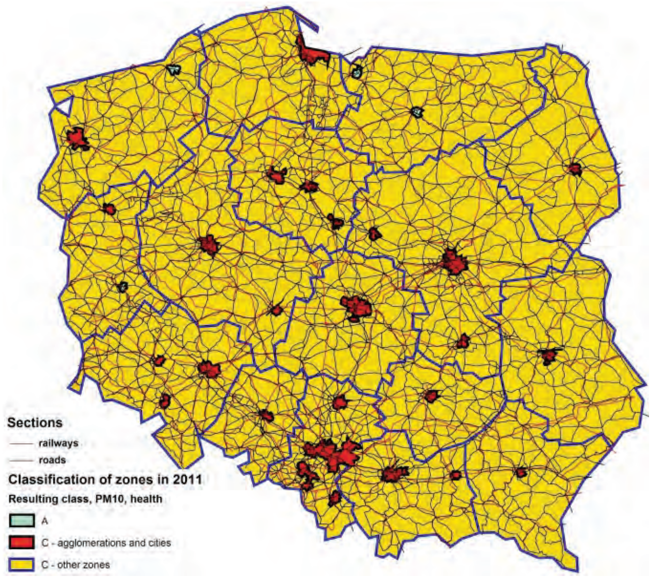

Fig. 11. Classification of zones in Poland for PM_{10} in 2011 (criterion f_1), source: printout from PTV VISUM based on [7]

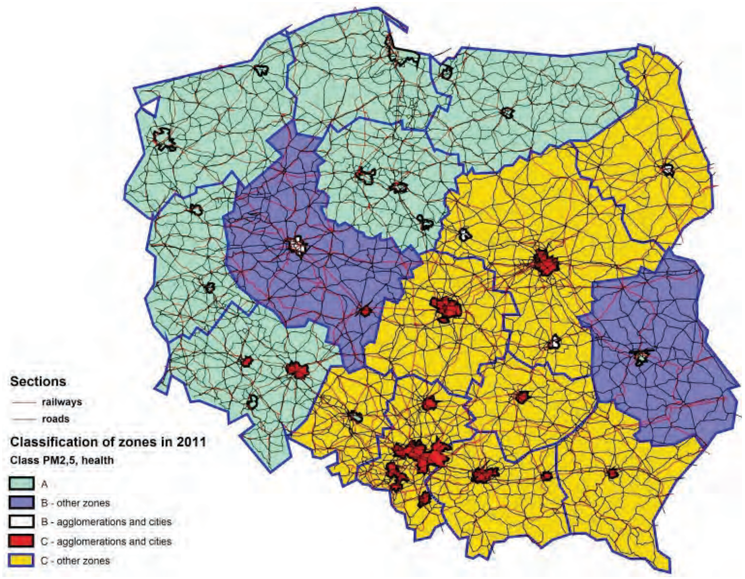

Fig. 12. Classification of zones in Poland for $PM_{2.5}$ in 2011 (criterion f_1). Source: printout from PTV VISUM based on [7]

emissions of particulate matter PM_{10} fraction is at the level 10.36%. Based on the preliminary analysis carried out in the Project and the data available in the study [7] it can be concluded that one of the reasons for exceeding the limit value can thus be heavy traffic, especially in cities and towns over 100 thousand inhabitants. This reason is not dominant that the engines of new cars must comply with ever-higher Euro emission standards.

Air pollution by particulate matter $PM_{2.5}$ fraction has qualified for three classes: A, B and C. To class A, not exceeding the limits, Northwestern area of Poland and the city of Lublin were classified. In five voivodships, all zones classified into this class (Pomorskie, Warminsko-Mazurskie, Zachodniopomorskie, Kujawsko-Pomorskie and Lubuskie). Six zones qualified to class B exceeding the limit value for particulate matter $PM_{2.5}$, but within the limits of tolerance,: Lubelskie, the Wielkopolskie voivodships, and the cities of Bialystok, Plock, Radom and Poznan. Southeastern Voivodships are areas where the permissible parameter value has been greatly exceeded. To class C classified all zones in the voivodships: Lodzkie Malopolskie, Podkarpackie, Silesian and Swietokrzyskie. The share of road transport in the total emissions of particulate matter $PM_{2.5}$ is at the level 17.18% (Fig. 2).

4. Summary and conclusions

The conducted considerations show that the development of proecological transport system should take into account the limitation of emissions of harmful gases. The mathematical model of development of proecological transport system should allow a multi-variant assessment of the distribution of the traffic flow in the transport network and on this basis, the development of its structure should be decided.

From the point of view of the plant protection criterion, the concentration of both sulphur dioxide and nitrogen oxides is not exceeded. The exhaust emissions from transport do not threaten plants. The situation is different in the case of the criterion of the protection of human health. Only the concentration of sulphur dioxide and lead did not exceed the permissible value. However, the share of road transport in the case of these compounds in their total emissions is quite small.

The shaping of proecological transport system should take into account:

– reduction of the emissions of nitrogen dioxide (NO_2) in large towns and cities by minimizing road traffic in the areas mentioned above,
– reduction of the emissions of carbon monoxide (CO) in the areas of health resorts by reducing the volume of traffic near these zones,
– reduction of the emissions of particulate matter PM_{10} in the whole country, especially in urban areas and agglomerations,
– reduction of the emissions of particulate matter $PM_{2.5}$ in the central and south-west Poland, which can be quite complicated as the share of road transport in their total emissions is significant and one of the factors affecting the emission of is the landform.

The actions indicated above will allow the development of a transport system safe for human life and health and efficient in terms of energy consumption, with reduced emissions and reduced environmental pollution.

Acknowledgements

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