

# EVALUATING THE ENVIRONMENTAL COSTS IN POLAND OF CITY BUSES MEETING THE EURO VI NORM BASED ON TESTS IN REAL OPERATING CONDITIONS

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## Abstract:

The article analyzes the environmental costs which consisted of determining the annual cost for gases and particles released into the atmosphere by city buses meeting the Euro VI norm. To this end, exhaust emissions of a city bus equipped with a conventional drive system were performed. The vehicle had a length of 18m and was powered by a CI engine with a swept volume of 10,5 dm<sup>3</sup>, with a maximum power of 240 kW. In order to measure the ecological indicators, tests were performed in real driving conditions using the PEMS system. The apparatus made it possible to measure the concentration of gaseous compounds and particulate matter in the exhaust, which made it possible to determine the road exhaust emissions of the tested vehicle. The research was carried out on a test route including urban and suburban roads in accordance with legislative guidelines. The measurements showed that the bus met the exhaust emission limits determined on the basis of measuring windows defined in relation to the work generated by the drive system. In addition to information on the emissivity of the vehicle, the annual emissions from city buses meeting the Euro VI standard in Poland were also estimated. The information contained in the central vehicle register for the number of vehicles registered in Poland that meet the latest emission standards has been used for this purpose.

**Keywords:** exhaust emissions, HDV, RDE, PEMS

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## 1. Introduction

Due to the concentration limits of gaseous compound and particles suspended in the air being frequently exceeded in large cities. The legal regulations on exhaust emissions from vehicles are being tightened, which generally leads to the application of new technological solutions in vehicle propulsion systems, especially in the aspect of exhaust after-treatment systems. However, as work (Merkisz, 2011; Merkisz et al., 2010) indicates, vehicle emission limits are often exceeded in their real operating conditions, thus pushing the development of new emission testing methods. Taking into account current trends in transport problems, eg. flow and organization of traffic for various scenarios in national transport system is used programs for modelling this issues (Jacyna and Merkisz, 2014). Public transport is considered an alternative to passenger cars, whose large numbers have a significant impact on air quality. Therefore, it is necessary to carry out exhaust emission tests for this group of mass transport vehicles, especially city buses. In order to fully and properly evaluate the environmental costs of Euro VI conforming city buses, it is necessary to conduct measurements in real driving conditions, in accordance with the approved standards for conformity in service (European Commission, 2011). The values obtained should be referred to the population of the considered vehicle group as well as the guidelines contained in (Sejm RP, 2017).

The state environmental monitoring service is the most important source of information about the environment in Poland. It is a system that includes the measurements of pollutants along with an assessment of the state of the environment. This data is collected, processed and disseminated. The Regulation (Sejm RP, 2017) sets the air concentration limits for certain substances, their target levels, long-term data with information about those substances, as well as alert levels, whose exceedance, even for a short period of time can lead to serious health risks. However, Merkisz (2011) lists the conditions in which the level of substances (such as temperature and pressure) is measured, the time frames for which the measurement results and the exposure concentration value are averaged (Gis, 2017; Merkisz, 2011; Merkisz et al., 2010; Rymaniak, 2016; Sejm RP, 2001).

## 2. Current legal framework concerning exhaust emissions of heavy vehicles

The Euro VI norm is a set of legislative guidelines introduced in 2014, which provides assessment methods of the environmental performance of heavy vehicles together with limit values that they are expected to meet. This norm applies to all motor vehicles with a maximum permissible mass over 3 500 kg with compression ignition, spark ignition or natural gas fueled engines. Euro VI also includes limits on the number of particles (PN) and a number of new test requirements (such as WHSC, WHTC) including also real-time measurements (RDE) with the use of PEMS, which is a new addition compared to previous standards. The tests are carried out in normal road traffic divided into three road section types, the last of which does not apply to city buses:

- urban – cruising speed between 0–50 km/h,
- rural – cruising speed between 50–75 km/h,
- motorway – cruising speed over 75 km/h (Fuć et al., 2015; Merkisz et al., 2010).

The following parameters were measured during the tests – concentration of THC, CO, NO<sub>x</sub>, CO<sub>2</sub> and CH<sub>4</sub> in the exhaust, exhaust flow, fuel consumption, vehicle speed, engine torque and speed, intake manifold temperature, coolant temperature, ambient temperature and pressure. The particle mass and number are not measured (Merkisz et al., 2010; Rymaniak, 2016)

## 3. City buses meeting the Euro VI norm in Poland

City buses, despite achieving increasingly favorable ecological indicators, continue to have a negative impact on the still deteriorating condition of the natural environment. The environmental conditions and efficiency of transport systems decrease with the increase in traffic, which also applies to vehicles used in public transport.

Internal combustion engines, which are the main drive sources for city buses, emit pollutants that are a serious threat to human health as well as the environment. This forms a certain barrier to the further development of public transport and is associated with the increasing use of hybrid and electric drives in those vehicles. Restrictive requirements and the need to reduce the negative impact of transport on the environment results in the city bus fleets being

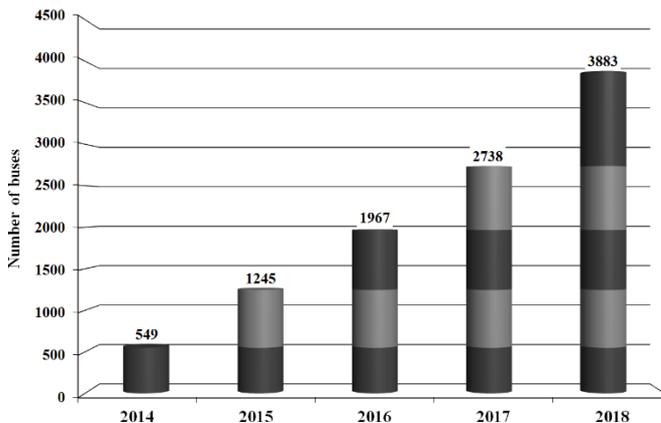


Fig.1. Number of city buses meeting the Euro VI norms registered in Poland [16]

often modernized and regularly renovated. As a result, the share of operated buses equipped with modern drive units that meet the latest emission norms for gaseous and particle emissions continues to increase (Fuć et al., 2015; Gis, 2017; Merkisz et al., 2010). According to the analysis based on the central vehicles registration data for 2014-2018, 3883 city buses meeting the Euro VI standard were registered in Poland (Figure 1) (Rymaniak, 2016).

#### 4. Method

An eighteen meter bus was used for the tests. The vehicle was equipped with a 6-cylinder in-line combustion engine with a maximum power of 240 kW and a displacement volume of 10.8 dm<sup>3</sup> and powered by diesel oil. The bus was approved for use, it was fully functional and equipped with all the standard functional systems. In order to reflect the weight of passengers during daily use, a set of additional weights was loaded onboard the vehicle for the duration of the tests. According to the norm, the added weight was 60% of the maximum total passenger weight. The parameters of the tested vehicle are shown in tab. 1.

The AVL M.O.V.E iS equipment was used to measure the ecological indicators. It is a system from the PEMS group adapted to measure the real emissions from road vehicles. It provides all the required technical data that is necessary to determine the level of exhaust emissions. The apparatus allows testing in accordance with the RDE proce-

dures contained in the Regulation (European Commission, 2011). AVL MOVE allows the measurement of CO<sub>2</sub> and CO concentrations by using an NDIR (non-dispersive infrared) sensor, NO<sub>x</sub> using an NDUV (Non-Dispersive Ultra Violet) and PM using a DC (Diffusion Charger).

The research route has been chosen in such a way as to incorporate both urban and suburban roads. The total length of the test drive section was 156 km, where the vehicle generated a total work of 258.6 kWh. The share of driving time in extra-urban conditions accounted for 31.5%, which is in line with the legislative guidelines. A span and zeroing with reference gases took place before and after the measurement. In addition, the apparatus referred to ambient conditions every 60 minutes.

Table 1. Parameters of the tested bus (Source: INFOBUS)

Parameter	
Vehicle length [m]	18
Ignition system	compression
Cylinder number/arrangement	6/in-line
Swept volume [dm <sup>3</sup> ]	10.8
Max power [kW]	240
At engine speed [rpm]	1695
Max torque [Nm]	1400
At engine speed [rpm]	1000–1650
Emission norm	Euro VI
Total capacity [persons]	175
Vehicle mass (with extra weight) [kg]	24 000

## 5. Environmental costs

Environmental costs is a general concept for various costs related to environmental protection activities. They refer, among others, to environmental pollution and the introduction of changes into the environment. The principles of calculating and paying fees are set out in The “Law on Environmental Protection” (Sejm RP, 2001) for example as well as in subsequent implementing acts (Ferens, 2015; Małecki and Urbaniec, 2014).

Emission norms are set for each source of pollution and location where gases or particles are released into the atmosphere. The emission limit is expressed in Mg/year for the entire system. The determined types and amount of gases or particles permitted to be released into the atmosphere are expressed in mg/m<sup>3</sup> of exhaust gases in a dry state at 273 K and a pressure of 101.5 kPa, or in kg/h or in kg per unit of fuel used, raw material or resulting product (Sejm RP, 2001).

Fees exists for releasing gases or particles into the atmosphere, considered as fees for environmental exploitation. These fees are set based on the annual actual emissions as stated in the relevant report, including, among other things, information on the types of substances released and the emission values. In case of excessive environmental exploitation or when violating the conditions, the beneficiary of the environment is to pay an administrative fine in addition to the fee. The amount of fees for the use of the environment and administrative fines depends on

the quantity and type of gases or particles released into the atmosphere (Sejm RP, 2001).

The Regulation (Sejm RP, 2017) defines detailed methods for calculating environmental costs together with specific rate values for fees for gases or particles released into the atmosphere, which are presented in Table 2.

Table 2. Specific fee rates for released gases or particles (Source: Merkisz et al., 2013)

Types of gases and particles	Rate [PLN/kg]
Carbon dioxide (rate in PLN/Mg)	0.29
Fuel combustion dusts and particles	0.35
Carbon monoxide	0.11
Nitrogen oxides (converted to NO <sub>2</sub> )	0.53
Ring and aromatic hydrocarbons and their derivatives	1.44

## 6. Analysis of city bus environmental indicators

In order to evaluate the environmental indicators obtained during the tests in real driving conditions, the analysis of road emissions from the tested vehicle was performed (Figure 2). The test route included urban and suburban sections – in accordance with the legislative guidelines (European Commission, 2011).

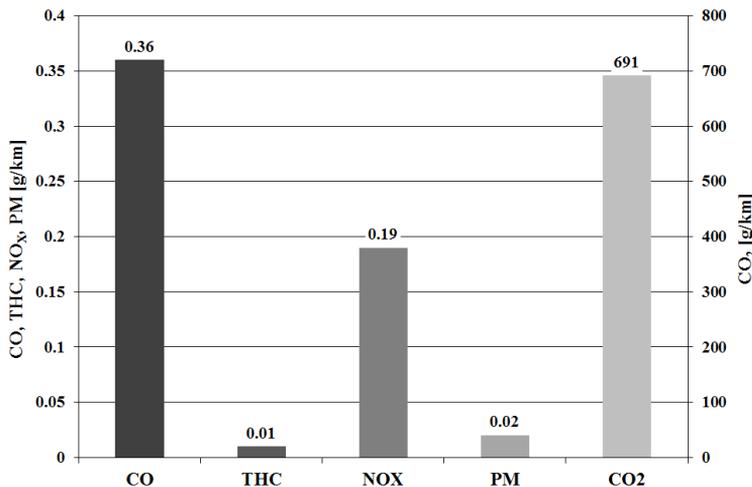


Fig. 2. Road exhaust emission determined on the basis of tests in real driving conditions

Based on the guidelines of the said norms, the exhaust emissions were determined in relation to measuring windows defined based on the work output of the drive system. The norm (Merkisz, 2011) requires defining the specific exhaust emissions, but for the purposes of this work these values have been converted into road emission. The measurement of vehicle motion parameters was carried out with a GPS correlated with the PEMS equipment used. The test vehicle provided carbon monoxide emission value equal to 0.36 g/km, while for carbon dioxide a value of 691 g/km was obtained. The road emission of hydrocarbons, nitrogen oxides and particulate matter was 0.01 g/km, 0.19 g/km and 0.02 g/km, respectively. All values obtained comply with the Euro VI norm that the vehicle met.

Taking into account the data shown in Figure 1, the annual emissions from city buses meeting the Euro VI standard were estimated (Figure 3). Based on Dobrzyński (2015), it was assumed that a statistical city bus covers 75 thousand kilometers annually. The number of vehicles was determined according to the information obtained from the central register of vehicles in 2014-2018 in Poland (Rymaniak, 2016). On this basis, it was determined that the annual emission of carbon dioxide is 201 million kg, carbon

monoxide – 105 thous. kg, hydrocarbons 2.91 thous. kg, nitrogen oxides - 55 thous. kg, while solid particles - 5.82 thous. kg.

### 7. Analysis of the environmental costs of city buses meeting the Euro VI norm in Poland

The environmental costs analysis consisted of determining the annual cost for gases and particles released into the atmosphere by city buses (Figure 4). The annual emission of harmful exhaust emissions has been referred to the specific fee rates contained in the Regulation (Sejm RP, 2017). Based on the analysis performed, it was found that the largest annual fee for all city buses complying with the Euro VI standard in Poland is PLN 58 392 (PLN 15.04/vehicle) and relates to the emissions of carbon dioxide. The value obtained is greater than the total fees for all other toxic exhaust compounds. The cost of carbon monoxide emission is PLN 11 532 (PLN 2.97/vehicle). The smallest fees apply for the emission of particles into the air, which means particles and they constitute a cost of 2039 PLN (0.52 PLN/vehicle). Fees covering the emission of hydrocarbons and nitrogen oxides are PLN 4194 (PLN 1.08/vehicle) and PLN 2933 (PLN 0.76/vehicle), respectively.

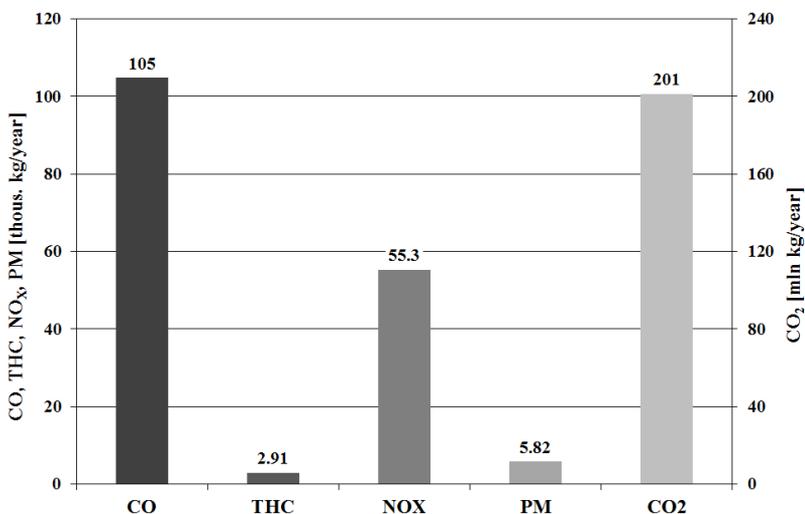


Fig. 3. Annual exhaust emissions from city buses meeting the Euro VI norm based on the results of tests in real driving conditions

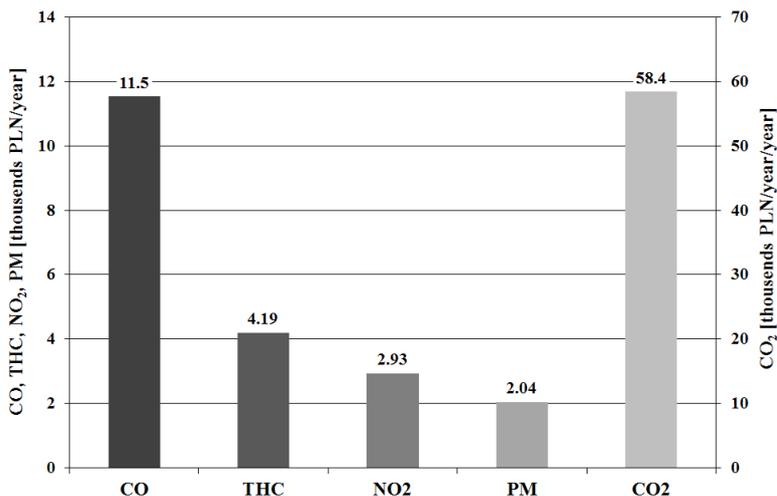


Fig. 4. The annual cost for releasing exhaust gases and particles into the atmosphere from city buses meeting the Euro VI norm in Poland

## 8. Conclusions

The paper evaluates the environmental costs of city buses meeting the Euro VI norm in Poland. This was done based on results of tests carried out in real operating conditions, in accordance with the accepted standards for conformity assessment in operation. Authors' research showed that the bus met strict exhaust emission limits as found based on measuring windows determined for the work performed by the vehicle drive system. The emission limit value has also not been exceeded for particle emissions, however, this compound is not taken into consideration when performing real driving emission tests. For the purpose of the article, the road emission values were determined using calculation procedures in accordance with the legislative guidelines.

Standards for the release of gases and particles into the atmosphere are set for the transport and industry sector, stating the rates related to the use of the environment. Tests of a city buses meeting the Euro VI norm carried out in real operating conditions, the Regulation (European Commission, 2011) and the average annual mileage adopted were used to perform an analysis of the resulting environmental costs. Annual exhaust emissions in Poland from buses with the Euro VI standard amounts to approximately 201.5 million kg, of which the largest share is carbon dioxide 99.75%. The remaining emitted

toxic compounds constitute 168.9 thousand kg. The total cost for the entire analyzed population is therefore PLN 79 090, while for a single vehicle it is at the level of PLN 20.40. Analyzing the obtained results, it should be noted that city buses are characterized by a variable passenger load, travel on different routes in different road conditions, and the adopted annual average mileage is an assumption based on an estimate. At the same time, it is not possible to determine the actual exhaust emission for all vehicles operated in Poland in road conditions. However, the methodology adopted in the work (RDE tests in accordance with the Regulation - European Commission, 2011) allows obtaining results that are very close to reality.

The largest rates for specific emissions of gas and particles concern ring and aromatic hydrocarbons and their derivatives (PLN 1.44 / kg). The emission of this toxic compound is characteristic for vehicles and machines that have low efficiency or have a significant degree of wear. It is often associated with the combustion of lubricating oil in internal combustion engines, the loss of gas tightness in cylinders, or the age and wear of vehicle drive systems. This fee is therefore beneficial in the aspect of stimulating owners to maintain machines in good technical condition and to renew their fleet of vehicles and machines.

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## List of abbreviations and symbols

CH <sub>4</sub>	– Methane
CI	– Compression Ignition
CO	– Carbon Monoxide
CO <sub>2</sub>	– Carbon Dioxide
DC	– Diffusion Charger
GPS	– Global Positioning System
HDV	– Heavy-Duty Vehicle
NDIR	– Non-Dispersive Infrared
NDUV	– Non-Dispersive Ultraviolet
NO <sub>x</sub>	– Nitrogen Oxides
PEMS	– Portable Emission Measurement System
PM	– Particulate Matter
PN	– Particle Number
RDE	– Real Driving Emissions
THC	– Total Hydrocarbons
WHSC	– World Harmonized Stationary Cycle
WHTC	– World Harmonized Transient Cycle

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