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ASSESSMENT OF ACTUAL VEHICLE EMISSIONS IN THE CONTEXT OF LOW EMISSION ZONES

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Abstract – In 2024, Clean Transport Zones were established in the first Polish cities, restricting the right to enter the centers of the largest agglomerations for vehicles that do not meet the latest exhaust emission standards. This solution aims to both counteract air pollution in the vicinity of the largest population centers, but also to limit car traffic in the centers of the largest cities. The imperfection of the vehicle selection key is limited to meeting the appropriate EURO standard, which may not clearly define the actual emission. The aim of the work is to determine the methodology for effective comparison of the results of total vehicle exhaust emissions.

Key words – Clean Transport Zones, emission, PC cars, pollution

JEL Classification – R4, Q5, L9

INTRODUCTION

In 2024, clean transport zones were established in the first Polish cities, limiting the right to enter the centers of the largest agglomerations with vehicles that do not meet the latest exhaust emission standards. This solution is aimed at both counteracting air pollution in the vicinity of the largest clusters of people, but also limiting car traffic in the centers of the largest cities. The vehicle selection limited only to whether the vehicle meets the relevant EURO standard is inadequate for it may not unambiguously determine the actual emissions.

Fig. 1. Signs D-54 and D-55 [24]

Information about the works on the Polish zones, the area of which is marked with signs D-54 and D-55 (Fig. 1), triggered a public debate on the advisability of their adoption and the fairness of the selection of vehicles allowed to enter the zone. When introducing the Warsaw clean transport zone, public consultations lasted 3 months and over 3,000 comments and conclusions were received during this time [8]. The final shape of the project was greatly influenced, among others, by people associated with the Youngtimer Warsaw foundation, whose area of activity was covered by the regulations of the Warsaw SCT (Fig. 2).

1. Clean Transport Zones in Poland

Warsaw SCT

The clean transport zone in Warsaw was established by Resolution No. XCI/2974/2023 of the Capital City Council of Warsaw of December 7, 2023 and came into force on July 1, 2024. In its original form, it allows the entry of passenger cars with SI engines with a minimum Euro 2 emission standard and with CI engines with a minimum Euro 4 emission standard (Fig. 3).

The following are excluded from the Warsaw SCT regulation [11]:

- vehicles registered before 1 January 2024, owned or co-owned by a resident of Warsaw (until 31 December 2027),
- vehicles registered before 1 January 2024, owned or co-owned by a person who in 2023 is at least 70 years old and is its driver or passenger,
- historic vehicles (Fig. 4) understood in accordance with the definition set out in art. 2 para. 1 point 11 of the Act of 22 May 2003 on compulsory insurance,
- vehicles participating in an organized gathering or cultural event,
- all vehicles for no more than 4 days during the calendar year.

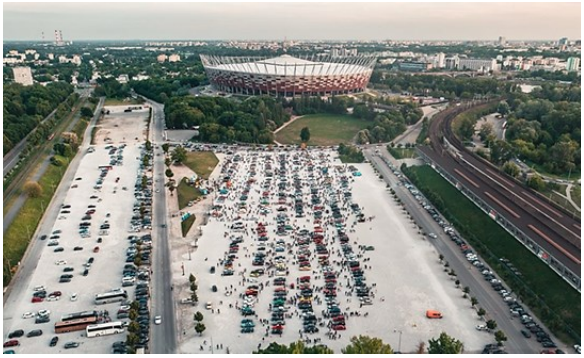

Fig. 2. A gathering of conventional vehicles at the Warsaw SCT [9]

Fig. 3. Stages of implementation of the Warsaw SCT [10]

Fig. 4. Historical vehicle within the meaning of the Compulsory Insurance Act

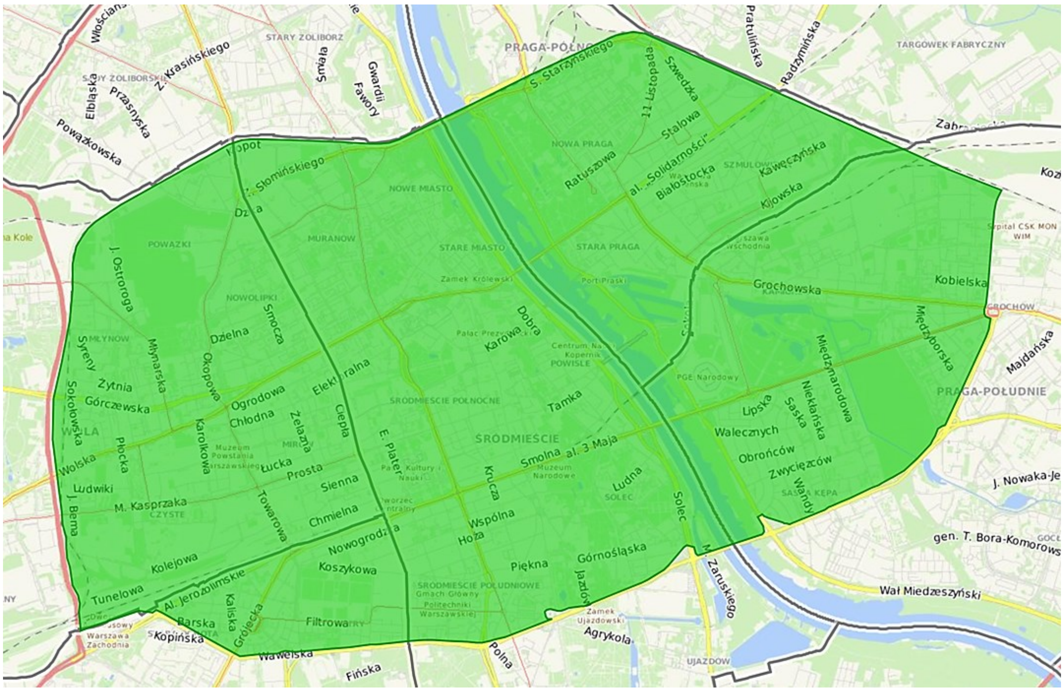

Fig. 5. Warsaw SCT area [12]

The zone covered an area of about 37 km^2, which accounts of approximately 7% of the city's area (Fig. 5). Districts partially covered by the clean transport zone:

- Downtown,
- Wola,
- Ochota,
- Prague-South (Praga Południe),
- Prague-North (Praga Północ).

The city authorities of Warsaw predict that SCT in its original form (from 1 July 2024) will limit entry to only 3% of vehicles moving around the city, some of which are additionally subject to exclusions. The expected decrease in emissions is estimated at 11% for nitrogen oxides and 20% for particulate matter [10].

CRACOW SCT

The resolution establishing the clean transport zone in Cracow was adopted by the City Council on November 23, 2022, more than a year earlier than in Warsaw [13]. Originally, the SCT was planned to come into force on 1 July 2024, similarly to Warsaw, but it was postponed to 1 July 2025 [14]. In the first year, the SCT is intended to operate in the implementation phase allowing the entry of passenger cars which meet the standards of min. Euro 1 for SI engines and Euro 2 for CI engines for cars registered before 1 March 2023.

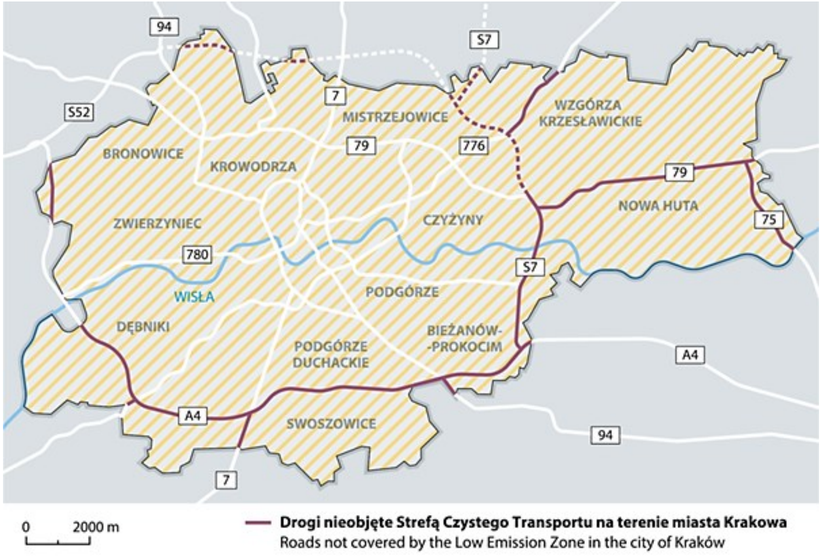

Fig. 6. Area of the Cracow SCT [14]

In the case of vehicles registered after March 1, 2023 and after the implementation period of SCT is closed, i.e., from July 1, 2026, only vehicles meeting the Euro 3 standard for SI engines and Euro 5 for CI engines will be allowed to enter the Cracow SCT. The exclusions apply to the same terms as in the Warsaw SCT. The current city's resolution does not assume enforcing stricter requirements after 2026. Cracow SCT will cover the entire area of the city of Cracow, i.e., 327km^2 [15] excluding main transit roads (Fig. 6).

PLANNED ZONES

Implementation of clean transport zones is of the milestones imposed in the National Recovery and Resilience Plan (KPO). KPO assumes that any city with population above 100,000 inhabitants which exceeds the assumed air pollution standards is obliged to establish an SCT. The shape of the zone is to be created by local government authorities with the restriction that it is to promote low-emission transport. 25 cities in Poland are obliged to establish SCT (Table 1.), in order to meet the requirements of the KPO, the establishment of zones should take place by March 31, 2025.

Table 1. 25 cities in Poland obliged to establish SCT

No	Voivodeship	City
1	Dolnośląskie	Wałbrzych
2	Dolnośląskie	Wrocław
3	Kujawsko-Pomorskie	Bydgoszcz
4	Kujawsko-Pomorskie	Włocławek
5	Lubuskie	Gorzów Wielkopolski
6	Łódzkie	Łódź
7	Małopolskie	**Kraków**
8	Małopolskie	Tarnów
9	Mazowieckie	Radom
10	Mazowieckie	**Warszawa**
11	Opolskie	Opole
12	Śląskie	Bielsko-Biała
13	Śląskie	Bytom
14	Śląskie	Chorzów
15	Śląskie	Częstochowa
16	Śląskie	Dąbrowa Górnicza
17	Śląskie	Gliwice
18	Śląskie	Katowice
19	Śląskie	Ruda Śląska
20	Śląskie	Rybnik
21	Śląskie	Sosnowiec
22	Śląskie	Tychy
23	Śląskie	Zabrze
24	Świętokrzyskie	Kielce
25	Wielkopolskie	Poznań

2. Alternative solutions to regulate vehicle traffic due to emissions

– *ULEZ (Ultra Low Emission Zone) London, United Kingdom*

The London low-emission zone covers the entire Greater London area, i.e., 1579 km^2, which makes it the largest zone of this type in the world. The requirements for vehicles entering the ULEZ are meeting the Euro 4 standards in terms of NOx emissions for CI and Euro 6 engines in terms of NOx emissions and particulate matter for SI engines. If the vehicle meets the emission requirements and was not approved for the relevant standard (it was produced before the adoption of the standard), it can still be allowed to enter ULEZ free of charge, e.g., BMW M3 E46 produced in 2003 equipped with a CI engine approved with the Euro 3 standard (Fig. 7) [17].

Fig. 7. 2003 ULEZ compliant vehicle [17-18]

– *Brussels, Belgium*

Belgian low-emission zone covering the entire Brussels-Capital Region, i.e., an area of 161.4 km^2. It is one of the most restrictive low-emission zones, which plans to exclude all currently produced combustion vehicles from traffic by 2035 [36]. In the case of vehicles with homologation certifying a different standard than the one assigned in the vehicle registration system, a request for correction of data can be submitted via the website. Vehicles that do not meet the requirements of the Brussels Low Emission Zone are entitled to paid entry 24 days a year – the cost of a one-day entry pass is €35 for passenger cars [36].

Table 2. Permits to enter the LEZ Brussels [36]

Exhaust emission standard	Permitted entry	
	SI engines	CI engines
Euro 6d – Euro 6e	2034	2029
Euro 6d-TEMP	2029	2027
Euro 6 b, c	2029	2027
Euro 5	2029	2024
Euro 4	2029	-
Euro 3	2027	-
Euro 2	2024	-

– *Umweltzone, Germany*

German low-emission zones have 52 designated areas covering more than 70 cities (Fig. 8). To enter any of them, the car owner is required to obtain a green environmental sticker.

It is available to passenger vehicles:
- meeting the Euro 1 standard for SI engines,
- meeting the Euro 4 standard for CI engines,
- meeting the Euro 3 standard for CI engines equipped with a particulate filter.

Cars meeting the definition of an Old Timer in the German regulation on vehicle registration [19], which is similar to the Polish definition of a historic vehicle, are exempt from the above regulations.

In 2023, eight low-emission zones were abolished in Baden-Württemberg due to the improvement of air quality, including those in Karlsruhe and Rottweil [35].

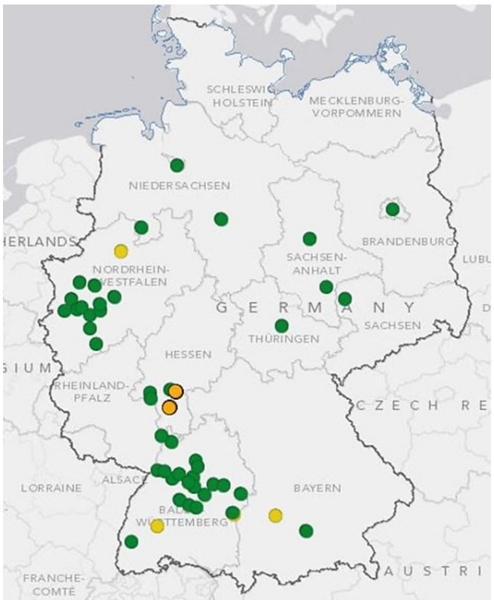

Fig. 8. Map of Umweltzone [20]

Research into Clean Transport Zones (CTZ) focuses on creating environments where transportation emissions are minimized, promoting sustainability, and improving urban mobility. Some key research problems in the context of Clean Transport Zones include:

1. Defining Boundaries and Scope:
   - Determining the ideal boundaries for a Clean Transport Zone (e.g., city-wide, district-level, or specific streets),
   - Deciding which transport modes (e.g., electric vehicles, public transport, bicycles) should be prioritized.
2. Technology Integration:
   - Developing efficient technologies for clean vehicles (e.g., electric, hydrogen, or biofuel-powered),
   - Addressing the infrastructure needs (charging stations, hydrogen refueling stations, etc.) for widespread adoption of clean technologies.
3. Environmental Impact Measurement:
   - Establishing accurate metrics to assess air quality improvements and the overall reduction in carbon emissions,
   - Considering other environmental effects (e.g., noise pollution reduction).

3. RESEARCH METHODOLOGY – RDE CHARACTERISTICS

To compare the emissions of harmful substances, the results of exhaust emissions measurements in road tests carried out using the RDE (Real driving emissions) test method were used, which allows for obtaining reliable data related to exhaust emissions with quite high repeatability. According to the EU directive [5], the RDE test was divided into three driving phases: urban, extra-urban and motorway. Each phase must cover a distance of at least 16 km and follow each other continuously. An exemplary route of the road test using the RDE method is presented below (Fig. 9). The additional guidelines include parameters such as:

- duration of the test from 90 to 120 minutes,
- outside temperature from 0°C to 30°C,
- topographic altitude below 700 m above sea level,
- total elevation less than 1200 m per 100 km of distance covered,
- maximum length of one stop 180 s,
- weight of passengers and test equipment (Fig. 10) below 90% of the vehicle load capacity.

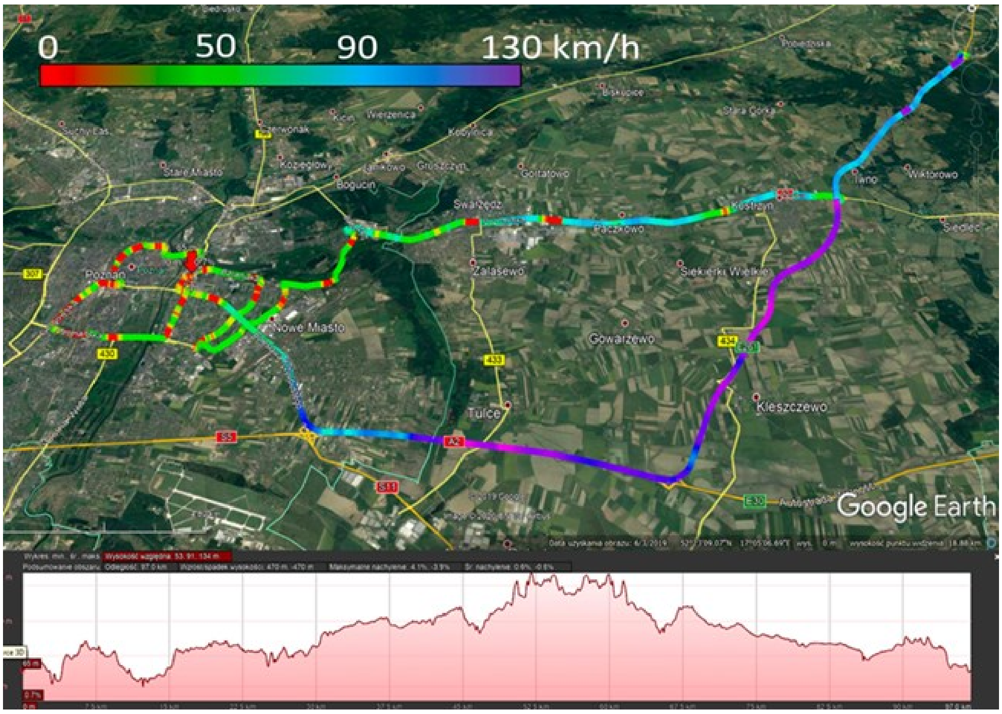

Fig. 9. RDE test road with altitude profile [1]

Detailed guidelines for each phase of the test additionally specify:

a) in the urban phase:
   - share ranging from 29% to 44% in the global test distance,
   - minimum length of the distance 16 km,
   - maximum vehicle speed 60 km/h,
   - average vehicle speed from 15 to 40 km/h,
   - downtime from 6% to 30% of the total urban phase time.

b) in the extra-urban phase:
   - share ranging from 29% to 44% in the global test distance,
   - minimum length of the distance 16 km,
   - vehicle speed from 60 km/h to 90 km/h,

c) in the motorway part:
   - share ranging from 29% to 44% in the global test distance,
   - minimum length of the distance 16 km,
   - vehicle speed above 90 km/h,
   - maintaining a speed of over 100 km/h for a minimum of 300 s,
   - permissible exceeding the maximum speed in the test, i.e., 145 km/h must not last more than 3% of the total stage time (up to 160 km/h).

4. Research objects

Vehicle A (Fig. 11) is equipped with a SI engine and meets the Euro 6d emission standard. SI-powered passenger cars accounted for 38% of new cars registered in the EU in 2022. Detailed technical data are presented below (Table 3).

Fig. 10. Vehicle equipped with Semtech DS measuring equipment [1]

Fig. 11. Vehicles A, B and C with test equipment [2]

Fig. 12. Vehicle D with test apparatus [3]

Fig. 13. Vehicle E in preparation for test [4]

Table 3. Technical characteristics of vehicles [1-4]

	Vehicle A	Vehicle B	Vehicle C	Vehicle D	Vehicle E
Brand and model	Mercedes-Benz C200	Volkswagen Caddy	Toyota Prius	Skoda Rapid	Subaru Impreza
Engine	SI, Turbo, R4	CI Turbo, R4	SI + EV, R4	SI, Turbo, R4	SI, L4
Engine displacement	1497 cm3	1968 ^{cm3}	1798 ^{cm3}	1197 cm3	1994 cm3
Max. power	135 kW	75 kW	90 kW	63 kW	118 kW
Maximum torque	280 Nm	280 Nm	142 Nm	160 Nm	186 Nm
Transmission box	AT9	MT6	CVT	MT5	MT5
Weight	1430 kg	1584 kg	1415 kg	1155 kg	1440 kg
Emission class	Euro 6d	Euro 6d	Euro 6d	Euro 5	Euro 4
Mileage	200 000 km	200 000 km	200 000 km	132 000 km	350 000 km

Vehicle B (Fig. 11) is equipped with a CI engine and meets the Euro 6d emission standard. CI-powered passenger cars accounted for 17% of new cars registered in the EU in 2022. Detailed technical data are presented in the table (Table 3).

Vehicle C (Fig. 11) is equipped with a SI engine with a hybrid system and meets the Euro 6d emission standard. PHEV passenger cars accounted for 8.5% of new cars registered in the EU in 2022. Detailed technical data are presented in the table (Table 3).

Vehicle D (Fig. 12) is equipped with an SI engine and meets the Euro 5 emission standard. Detailed technical characteristics are presented in the table (Table 3). The tested vehicle may enter the Warsaw SCT until 2032. In the course of the tests, the vehicle was retrofitted with a GPF particulate filter.

Vehicle E (Fig. 13) is equipped with an SI engine and meets the Euro 4 emission standard. SI-powered passenger cars accounted for 38% of new cars registered in the EU in 2022. Detailed technical characteristics are presented in the table (Table 3). The tested vehicle may enter the Warsaw SCT until 2032. The vehicle is equipped with an LPG system, but the measurements were carried out on a petrol-fueled engine.

Selected research objects constitute a representative cross-section of the automotive market in the European Union. Vehicles A, B and C meet the highest emission standards and none of the low-emission zones assumes the time of exclusion of these cars. Vehicles D and E have already been planned for exclusion in the most restrictive low-emission zone, i.e., the Warsaw SCT. In each of the other discussed zones, these vehicles are not to be banned.

5. EMISSIONS OVERVIEW

The RDE study is divided into 3 phases: urban, extra-urban and motorway. Distance and test rides guidelines are intended to reflect the actual conditions of operation of the vehicle. Detailed results for each vehicle are presented below.

Table 4. Results of CO emission measurements

	Vehicle A [1]	Vehicle B [2]	Vehicle C [3]	Vehicle D [4]	Vehicle E [5]
Urban	0.484	0.114	0.08	0.13	2.1748
Suburban	no data	0.075	0.069	0.18	0.61223
Motorway	no data	0.082	0.034	0.4	3.30445
Medium	**0.281**	**0.09**	**0.061**	**0.24**	**1.92648**

Table 5. Results of NO_x emission measurements

	Vehicle A [1]	Vehicle B [2]	Vehicle C [3]	Vehicle D [4]	Vehicle E [5]
Urban	0.0263	0428	0.0063	0.038	0.03886
Suburban	no data	0.0137	0.0092	0.015	0.01995
Motorway	no data	0.0035	0.0096	0.009	0.03701
Medium	**0.0166**	**0.0219**	**0.0084**	**0.021**	**0.03107**

Table 6. PM Emission Measurement Results

	Vehicle A [1]	Vehicle B [2]	Vehicle C [3]	Vehicle D [4]	Vehicle E [5]
Urban	7.50E+10	6.20E +10	1.00E+12	2.50E+13	no data
Suburban	no data	2.80E+10	1.10E+11	2.10E+13	no data
Motorway	no data	5.40E+10	3.10E+10	1.60E+13	no data
Medium	**4.00E+10**	**4.80E+10**	**4.00E+11**	**2.30E+13**	**no data**

Excessive carbon monoxide emission by Vehicle E (Table 3.) indicates excessive exhaustion of the vehicle with a mileage of approx. 350 000 km The obtained emission results exceed almost twice the permissible standard for Euro 4, i.e., 1 g/km The remaining results are within the requirements of the Euro 6 standard.

The obtained results of nitrogen oxides emissions by all of the tested vehicles meet the permissible standard for Euro 6, i.e., 0.06 g/km for SI engines and 0.08 g/km for CI engines.

The permissible road emission of the number of PM is 6E+12, which means that Vehicle D does not meet the Euro 6 standard only in this aspect. During the tests on this vehicle, it was proposed to retrofit the GPF, which resulted in a reduction of PM emissions by 87% to the level of 2.9E+12. This value would qualify the tested vehicle to meet the Euro 6 emission standard. Among the three vehicles approved to the Euro 6d standard, the result differing from the others was obtained by Vehicle C – the reason for such a situation is the failure to use a particulate matter filter in the tested PHEV vehicle [2]. Vehicles A and B were equipped with GPF and DPF filters, respectively.

The blue color (Fig. 14) indicates the graphical interpretation of the carbon emission results of the vehicles in question. It is worth noting that a vehicle complying with the Euro 6d standard with an SI engine with more power generates more CO than a vehicle approved with the Euro 5 standard.

The green color (Fig. 15) indicates the graphical interpretation of the results of NOx emissions obtained for the discussed vehicles. A vehicle with a PHEV drive is noticeably lower than the others.

The graphical interpretation of the particulate matter emission results of the discussed vehicles is marked in green (Fig. 15). The graph uses a logarithmic scale – PM emission by vehicle D is many times greater than the others.

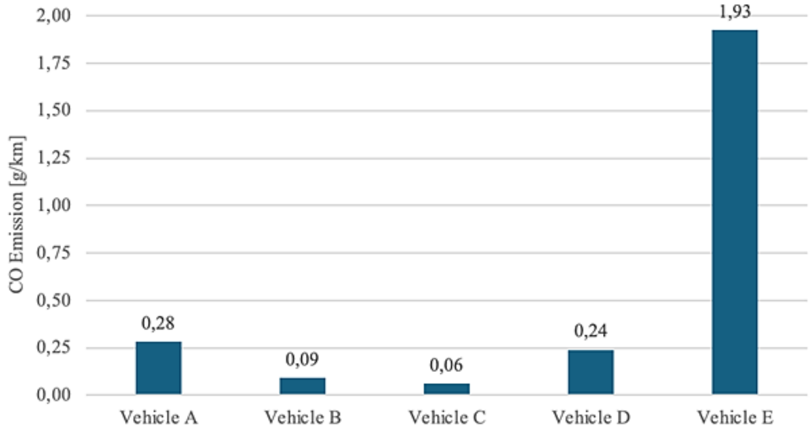

Fig. 14. CO Emission [g/km]

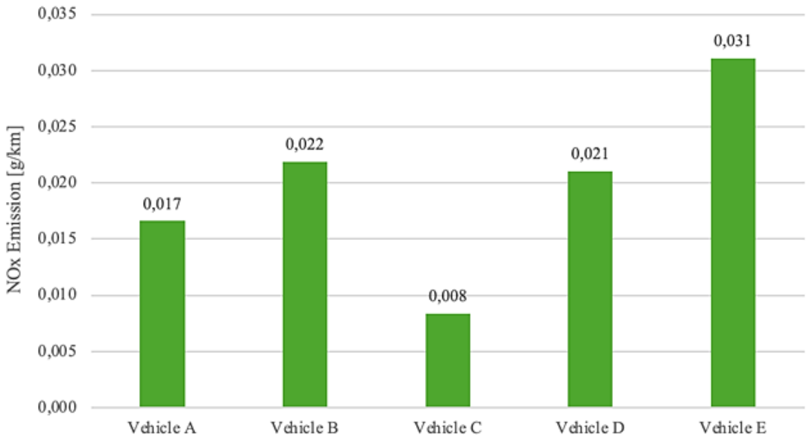

Fig. 15. NO_x emission [g/km]

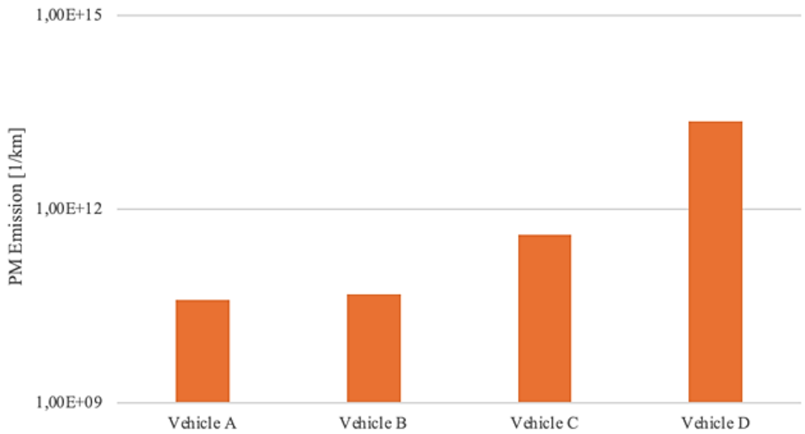

Fig. 16. PM emission [1/km]

Table 7. Average emission of harmful substances from the RDE test

	Vehicle A [1]	Vehicle B [2]	Vehicle C [3]	Vehicle D [4]	Vehicle E [5]
CO Emission [g/km]	0.281	0.09	**0.061**	0.24	1.92648
NO_x emission [g/km]	0.0166	0.0219	**0.0084**	0.021	0.03107
PM emission [1/km]	**4.00E+10**	4.80E+10	4.00E+11	2.30E+13	no data

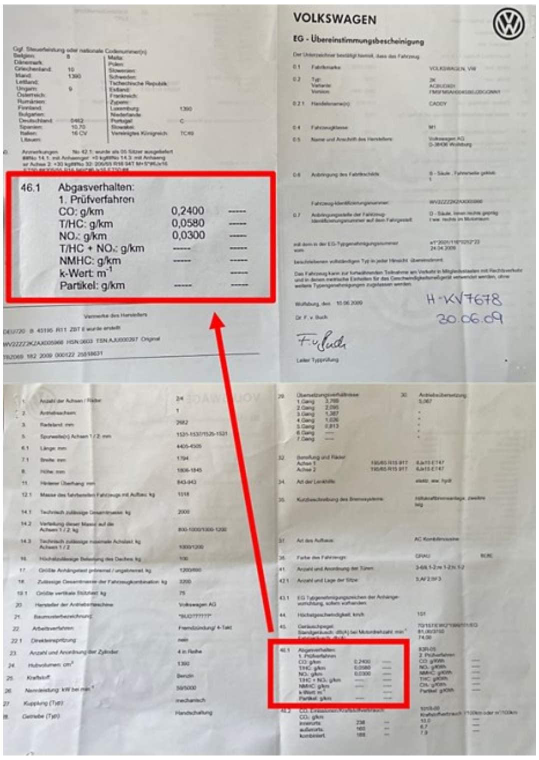

Fig. 17. Volkswagen Caddy Approval Certificate

Above is a summary of all harmful substances measured in selected RDE tests (Table 6). In view of RDE tests, it should be noted that the car emitting the least pollutants is Vehicle C, which is worse compared to other presented vehicles only in terms of PM emissions, which, as noted earlier, is a consequence of the lack of use of GPF in the exhaust aftertreatment system. Considering the above, the emission level of Vehicle C, which is a hybrid car of the PHEV type, may seem surprisingly low – however, this is due to the appropriate selection of operating parameters of the combustion engine, which, assisted by an electric motor, can work on a lean mixture or at a lower pressure in the combustion chamber, which creates unfavorable conditions for the formation of carbon and nitrogen oxides in the combustion process.

6. EURO BACKWARD COMPLIANCE

Vehicle manufacturers often produce vehicles that are ready to meet its requirements before the introduction of the next exhaust emission standard. An example of a vehicle from the transitional period is the Volkswagen Caddy produced in 2009 equipped with a SI engine with a capacity of 1390 cm^3. As the manufacturer informs in the extract from the approval certificate (Fig. 17), the vehicle met its requirements in terms of the amount of carbon monoxide, hydrocarbons and nitrogen oxides emitted two years before the Euro 5 emission standard came into force. There is no information on the amount and mass of particulate matter emitted to qualify the vehicle for the Euro 5 standard, because the Euro 4 and older standards did not specify any requirements in this regard. A solution that would allow for longer operation of the vehicle in question, among others, in the area of the Warsaw SCT, would be to create the possibility of measuring emissions of substances missing in the vehicle approval by an authorized body and retroactively recognizing the vehicle as compliant with a newer standard.

An alternative solution, in the case of excessive particulate emissions, as in the case discussed in the study [3], is the retrofitting of the GPF particulate filter, which allowed to reduce the actual PM emission by 90% by increasing the vehicle exhaust gas purity from Euro 5 to Euro 6. Currently, Polish law does not provide any benefits for the user related to this type of vehicle improvement.

7. Emissions of impacted vehicles

Unlike foreign low-emission zones, Polish clean transport zones do not allow the entry of vehicles that meet the requirements of a given exhaust emission standard before its coming into force. In order to enter, for example, the Warsaw SCT, a vehicle must meet the Euro standard assigned to a given stage or be manufactured in the year of its introduction and later. In the case of cars sold as new in the European Union, the conditions related to the emission standard and the year of production can be used interchangeably, otherwise the situation is different with vehicles that have never been approved to meet the Euro standards, i.e., those coming from outside the European Union market.

Imports of passenger cars from the United States in 2019-2021 amounted to about 100,000 units [28], and due to the high costs associated with the import process, it should be assumed that these were relatively new cars, and thus allowed to enter SCT. Below is a list (Table 7) of vehicles with SI engines that were registered for the first time after 2014 and are currently entitled to unlimited entry to the Warsaw SCT with the previously mentioned Volkswagen Caddy from 2009, which will lose the possibility of entering this zone in 2032 (2030 for 2008 and older, 2028 for 2004).

The emissions declared by the manufacturer come from the approval certificate (Fig. 17), the values marked with an asterisk have been converted from the US federal standard according to the following formula:

$$\frac{g}{mi} \div 1,6 = \frac{g}{km} \quad (1)$$

The determined value (X) refers to the sum of NO_x emissions and non-methane volatile organic compounds, but their proportion has not been determined, which in comparison makes the sum the maximum permissible NO_x emission value. The increase in emission limits between Tier 2 and Tier 3 is due to the extension imposed on manufacturers of the period during which a vehicle must maintain emissions from 50,000 miles to 150,000 miles. However, in the context of vehicle approval and entry into service in SCT, this is not relevant at present.

Based on the following information, it should be noted that the federal exhaust emission standards in the USA used to this day are less restrictive than the Euro 4 standard in terms of CO and NO_x emissions, but the third level of regulation in force since 2017 imposes quite large restrictions on manufacturers regarding the mass of particulate matter emitted by the vehicle.

Table 7. Average emission of harmful substances from the RDE test

	Vehicle F [25]	Vehicle G [25]	Vehicle H [26]	Vehicle I [27]
Primary market	E	E	USA	USA
Engine type	SI	SI	SI	SI
Year of manufacturing	2009	2015	2015	2023
Approval emission standard	Euro 4	Euro 5	Federal Tier 2 Bin 8	Federal Tier 3 Bin 160
Warsaw terms of entry SCT	by 2032	unlimited	unlimited	unlimited
Permissible / Declared Emission				
CO [g/km]	1.00 / 0.24	1.00 / -	2.125* / -	2.625* / -
NO_x [g/km]	0.08 / 0.03	0.06 / -	0.0875* / -	0.1*^{X} / -
PM [1/km]	- / no data	0.005 / -	- / -	0.002* / -

Fig. 18. Examples of vehicles conforming to standards [29-32]

Vehicle F corresponds to the Volkswagen Caddy (Fig. 18a), but its drive system with similar parameters was also installed in other vehicles from the VAG group, e.g., Volkswagen Polo, Golf, Seat Leon or Skoda Fabia - all of these vehicles equipped with a naturally aspirated SI engine with a capacity of 1390cm3 will lose the possibility of entering the Warsaw SCT in the years 2028 - 2032.

The G vehicle represents passenger cars with the SI engine available for sale in the EU in the years 2014 - 2015, regardless of the engine parameters, including Mercedes Benz G65 AMG (Fig. 18b), BMW 760Li or Lexus RC F.

Vehicle H corresponds to LDVs (light-duty vehicles) of Group 8 in the Federal Tier 2 Emissions Regulation produced up to 2017. These include, among others: Ford F250 (Fig. 18c), Ford F350, GMC Savana, Chevrolet Express.

Vehicle I correspond to LDVs (light-duty vehicles) of group "160" in the Federal Tier 3 Emissions Regulation produced after 2017. These include, among others: Chevrolet Camaro, Dodge Challenger Demon 170 (Fig. 18d), Chrysler 300, Dodge Durango and Jeep Wrangler.

Vehicles from groups G, H and I currently have unlimited access to the Warsaw and Krakow SCT.

8. Clean transport zones in Poland

The RDE test allows for the measurement of road emissions, and more specifically only the emissions of combustion products in the engine. Until now, the applicable exhaust emission standards regulated only the compounds emitted by the vehicle as a result of the conversion of chemical energy into mechanical energy using an internal combustion engine. The next Euro 7 standard, which will come into force in July 2030 [22], will also apply to particulate matter emitted as a result of wear of brake pads and tires.

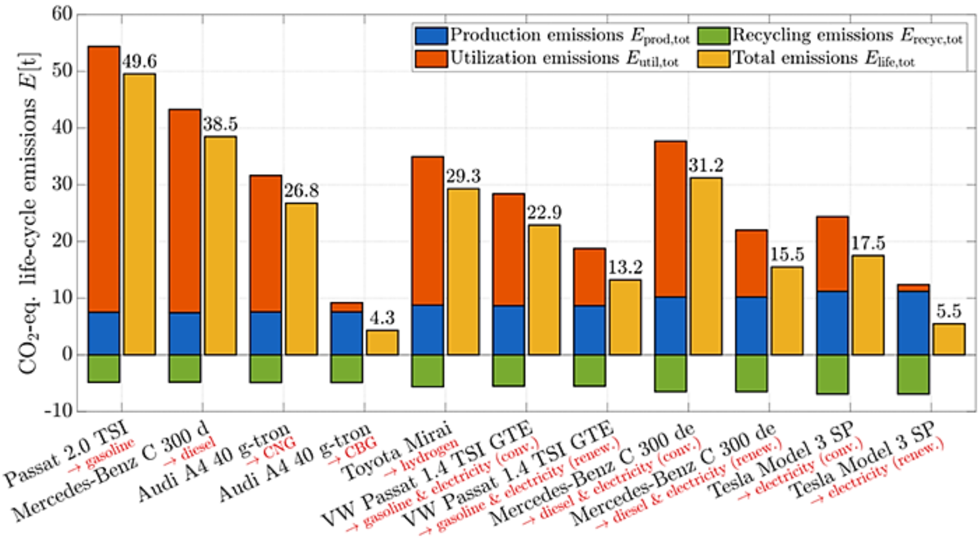

Fig. 19. Total vehicle emissions by power type [6]

Fig. 20. Audi A4 g-tron [6]

The issue of total emissions refers to harmful substances emitted into the atmosphere at each stage of the vehicle's life, from production, through operation – including the production of energy supplied to the vehicle, to disposal or recycling. The authors of the study [6], the results of which are presented below (Fig. 19), compared the total emission of vehicles with comparable technical parameters, but with different sources of propulsion. In addition, for hybrid and electric vehicles, a difference in emissions was shown due to the source of electricity - conv. (average emission per one kWh in Europe) and renew. (energy from renewable sources). The study also compared a hydrogen-powered vehicle as a way to obtain the use of non-renewable energy (gray hydrogen).

The study proved that the lowest CO_2 emissions come from a vehicle powered by biogas, which ultimately turned out to be more than 20% less harmful to the environment than an electric vehicle powered by renewable energy sources. The obtained results also highlight the problem of the origin of fuels - Toyota Mirai powered by gray hydrogen will emit more greenhouse gases over its life cycle than a plug-in hybrid combined with the SI engine.

As a significant aspect of the study, it should be noted that the authors adopted vehicle recycling as a negative CO_2 emission, arguing that it is possible to reuse parts and materials. The Audi A4 g-tron (Fig. 20.) with the possibility of methane supply in any form was considered the most environmentally neutral in the study [6] (with biogas supply).

9. Suggested solutions

- Allowing the legislator to apply for a change to the assigned Euro standard if the amount of substances emitted by the vehicle actually qualifies it to meet a higher standard.
- Determining, as part of the regulations on clean transport zones, the rules promoting drivers who choose environmentally friendly solutions, e.g., allowing vehicles with lower emission standards as part of carpooling, i.e., when 3 or more people travel in such a vehicle.
- Extension of periodic technical tests with an exhaust emission measurement procedure aimed at eliminating vehicles with excessive emissions caused by poor technical condition of vehicles.
- Creating an infrastructure that tests the emissions of individual vehicles in real time, e.g., based on a network of emission gates located in the border of the low-emission zone, allowing for the ongoing elimination of vehicles with excessive emissions related to poor technical condition.
- Increasing the popularity of improving the purity of exhaust gases of vehicles already in operation by, for example, government support for the retrofitting of particulate filters, which would translate into the possibility of longer vehicle maintenance on the road, and thus not emitting pollutants related to the production of new vehicles.

Summary and recommendations for further research

Low-emission zones, called clean transport zones in Poland, introduced in Warsaw and Cracow were designed in a fairly ambitious European scale – Warsaw in terms of restrictiveness, and Małopolska in terms of the area it will cover. Many Polish cities will be faced with the task of establishing their own zones in connection with the assumptions of the KPO. Local government officials will have to decide which vehicles they want to limit, because as shown in the study - the emissivity of vehicles is diverse, and the older Euro standard does not always mean that the vehicle is unfit for use. This fact seems to be understood by those responsible for low-emission zones in the world, e.g. Umweltzone with a fairly liberal approach to emission standards (Euro 1 - SI, Euro 4 - CI) or ULEZ allowing backward compatibility with the requirements of the zone.

The measurement of emissions in road tests using the RDE method carried out on 5 different vehicles showed that even among vehicles meeting the latest Euro 6 emission standard, the discrepancy in emissions of harmful substances can be very large, and sometimes larger than a vehicle meeting the Euro 5 standard. A very high emission was demonstrated by a vehicle that meets Euro 4 standard, while with a high degree of probability the results were influenced by the high mileage of the vehicle and the interventions made in the fuel system.

Among the vehicles already in operation, the year of production and the Euro standard are not a method that allows to clearly determine the fitness or unfitness of the vehicle for use and the level of actual emissions, as shown by the approval certificate or retrofitting of the GPF filter. One of the solutions that could eliminate environmentally harmful vehicles is the establishment of an institution responsible for actual emission measurements and classification of vehicles into appropriate classes, taking into account their technical condition and introduced modifications.

The issue that requires additional regulation are cars imported from outside the EU, because the solutions proposed in the SCT adopted so far do not focus on them precisely enough.

Among the tested vehicles, a PHEV car deserves a distinction, the emission of harmful substances of which was noticeably lower, despite the less complicated

SI engine system, the support of which by the electric motor allowed to obtain the most effective working conditions.

In the emission settlement of means of transport, it should be remembered that the combustion products in the engine are only one of the components of the total environmental impact of the vehicle during its total lifetime. Keeping vehicles on the road for as long as possible means that pollution related to the production of more cars, batteries for electric vehicles or hydrogen tanks for fuel cell vehicles does not enter the atmosphere. Great emphasis should also be placed on the method of obtaining fuel, because zero-emission drives can have a comparable negative impact on the environment if dirty energy is used to produce it.

The research and observations described in the work do not fully cover the issue of assessing the actual level of emissions of harmful substances at various stages of vehicle operation. The conclusions of the study motivate for further research, especially in connection with the obligation to establish further clean transport zones in subsequent Polish cities, in the field of:

– development of the process of effective testing of vehicle emissions in the course of periodic technical tests,
– testing actual emissions in city centers using a network of connected emission gates,
– assessment of the effectiveness of retrofitting of systems reducing vehicle emissions during operation.

OCENA RZECZYWISTEJ EMISJI POJAZDÓW W KONTEKŚCIE STREF NISKOEMISYJNYCH

W roku 2024 na terenie pierwszych Polskich miast powołane do życia zostały Strefy Czystego Transportu ograniczające prawo wjazdu do centrów największych aglomeracji pojazdom niespełniającym najnowszych norm emisji spalin. Rozwiązanie to ma na celu zarówno przeciwdziałanie zanieczyszczaniu powietrza w okolicy największych skupisk ludzkich, ale także ograniczenie ruchu samochodów w centrach największych miast. Niedoskonałość klucza selekcji pojazdów polega na ograniczeniu się do spełnienia odpowiedniej normy EURO, która może nie określać jednoznacznie rzeczywistej emisji. Celem pracy jest określenie metodologii efektywnego porównywania wyników całkowitej emisji spalin pojazdów.

Słowa kluczowe: strefy czystego transportu, emisja spalin, samochody osobowe, zanieczyszczenie powietrza.

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