A concise analysis of global experience in the field of environmental labelling of road vehicles with an emphasis on differentiating access to low-emission zones is given. The main principles of the introduction and application of a unified system of environmental labelling of road vehicles are highlighted with an emphasis on tools to stimulate the maintenance of the environmental properties inherent in the design. On the basis of simulation, forecasts of a decrease in the average specific reduced emissions of harmful substances by a fleet of vehicles of different categories are given in accordance with different control scenarios. Through the introduction of the proposed environment zones of various levels, the fundamental possibilities are shown to achieve a decrease in the level of total specific reduced emissions approximately: up to 40–65 % of the current level within dense urban development covering large territories ("red" environment zones of level V with the maximum permissible level of reduced emissions of 251 g/km (g/tkm) and, accordingly, limiting the active operation of at least vehicles that meet the requirements of "Euro-0" and below); 4–5 times in very polluted and densely populated areas ("yellow" environment zones of level IV, with restrictions for cars with engines with positive ignition of the level "Euro-2" and below, and cars with diesel engines "Euro-4" and below); by an order of magnitude in especially sensitive designated areas ("green" environment zones of level III with the maximum permissible level of reduced emissions of 63 g/km (g/tkm) with unlimited access for cars with engines with positive ignition of the "Euro-4" level and above, passenger cars with diesel engines of "Euro-6d" level up to 8 years, trucks and buses of "Euro-6" level up to 15 years old)

Keywords: emissions of pollutants, environmental labelling of vehicles, environment zones, environmental management

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REQUIREMENTS FOR A UNIFIED SYSTEM OF ROAD VEHICLES ENVIRONMENTAL LABELLING AND LOW EMISSION ZONES

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1. Introduction

Environmental labelling of vehicles is an essential part of green marketing and the management of low-emission zones. The environmental properties and appropriate labelling of vehicles are viewed by many governments as a tool to reward consumers in favor of environmentally friendly technologies. The auto industry sees this as an important part of the marketing battle for the buyer. Environmental labelling in the form of "emission stickers" (stickers on the windshield) or other media allows differentiating access to settlements in order to reduce air pollution, traffic noise and traffic jams.

Various access restriction schemes (ARS) in general, including low-emission zones (LEZ) in particular, increasingly dominate European traffic [1, 2]. In early 2020, many different ARS forms were created in 24 European countries. Hundreds of European cities already have entry rules for vehicles differentiated by environmental class, age, type,

purpose and other properties. In 2018 there were about 260 LEZ [3]. For example, in Germany in 2018 there were about 60 LEZ (Umweltzone), and other cities are considering the possibility of LEZ implementation. By the end of 2017, France had 28 LEZ [3].

There are no common European standards or even informal rules for establishing ARS and separate LEZ requirements or even requirements for environmental labelling of vehicles in order to differentiate access [4]. Each state establishes restrictions on its territory, together with schemes for the identification and labelling of vehicles, always individually [5, 6]. Even not all European countries have a common national LEZ structure, and the existing national frameworks differ significantly [3].

The macroeconomic basis for the dissemination of the ARS implementation process is, but is not limited to, externalities associated with air pollution problems. In total, outdoor air pollution causes 310,000 premature deaths in Europe every year, more than the number of deaths caused by road traffic accidents. According to estimates [7], harm to human health from air pollution costs the European economy from 427 to 790 billion EUR per year. Exhaust gas emissions from road transport were directly associated with approximately 39,000 annual premature deaths in the European Union in 2015 [8]. Traffic jams also have a significant impact on the economy, costing almost 100 billion EUR, or 1 % of EU GDP annually [8]. Estimates [8] indicate that noise contributed at least in 2011: 900,000 additional hypertension cases, 43,000 additional hospitalizations, 10,000 premature deaths annually. Based on the data [8], in terms of economic impact, traffic noise can cost the EU about 36 billion EUR annually. Less traffic through ARS operations and well-planned streets in urban areas can result in fewer accidents as a side effect. Many cities consider the tourist area a more attractive place to spend money, if there are also no traffic jams, loud noise and excessive pollution [8].

A significant number of countries associate the level of vehicle taxation directly or indirectly with their environmental properties. This area is characterized by an extraordinary variety of approaches [9].

There is a need for a systematic analysis of global experience in this area as a baseline for the informed implementation of more efficient low-emission zones. There is also a lack of information on the ground to justify and determine reasonable levels of environment zones and the corresponding requirements for road vehicles in terms of ingredient pollution.

So, the above indicates the relevance of research on the development of a unified system of environmental labelling of vehicles and environmental zones with the definition of the basic requirements for its implementation.

2. Literature review and problem statement

Below is a brief analysis of global experience in vehicle environmental labelling, with a focus on the implementation of environmental zones.

LEZs are known as areas where ARS is based predominantly on the environmental performance of vehicles, and either an outright ban on entry for certain categories is being considered, or a choice where more polluting vehicles must pay more [10].

Other ARS properties for city vehicles may include, for example, a permit that is required to enter an area at a specific time of day. These ARSs are known as Traffic Restrictions, Permit Schemes or ZTLs in Italy [7].

ARS with Dynamic Access Rules are also 'Extreme Pollution Schemes', where regulation is dependent on predicted or measured air quality to stay within legal limits. Such schemes can use many different types of rules, including temporary LEZs, lower speed limits, advice not to drive, and even cheaper public transport tickets. The schemes can be combined [7].

While the ZCRs in France are permanent zones, the ZPAs are weather dependent and only apply on days when NO_x or PM is expected to be high [11].

Research [1] on the Regulation on Vehicle Access to Urban Areas gives the following list of basic urban ARS topologies:

1) based on border crossing;

2) fee is charged for driving within the area;

3) "toll rings" to regulate access to almost the entire city

4) "point" based on the prohibition to move through bridge, etc.;

5) access pricing scheme based on distance or time.

Toll road infrastructure has advantages as it covers the cost of operating the LEZ and is a source of investment in the city's transport network and better transport alternatives, vital to success [12].

In London, the ULEZ pay rate will be 12.50 GBP for cars, vans and motorcycles and £ 100 for trucks and buses [3]. Fines for illegal entry into LEZ can be high and range from 80 to 2,700 EUR [2].

LEZ can apply restrictions in heavy vehicles, light vehicles, motorcycles or any combination of vehicle types [8].

Vehicle regulation in LEZ is based mainly on the age of the vehicle (year of first registration) and, accordingly, the "Euro class" [3]. Since the "Euro-class" or vehicle age cannot adequately reflect environmental damage, some cities are introducing stricter regulations, focusing primarily on diesel vehicles.

London ULEZ standards are among the strictest for LEZ based on road prices [12], and are in effect 24 hours a day, every day of the year, including weekends and holidays except Christmas [13, 14].

LEZ measures are applied either manually using windshield stickers, as in Berlin, Stuttgart, Paris, or with camera systems using license plate recognition, as in Amsterdam, Brussels, or using radio frequency identification (RFID) [8].

In all LEZs there are some possibilities for exemption from requirements (exceptions) for certain types of vehicles, discussed, in particular, in [3].

Low Emission Zones (LEZs) are considered to be the main tool for the management of local toxic air pollution [10]. Well-designed LEZs can reduce peak and average total emissions and may have helped meet the annual average limits required by legislation. However, the actual efficiency of LEZ fluctuates over a wide range, from brought about by a significant decrease in pollution [6, 15–17], moderate [18, 19], to a rather slight decrease [20] and to absent effects [21], for reasons described below.

Fig. 1 shows the average particulate number (PN) per day of the week in the 30–200 nm size range observed in Dresden in 2010–2014 [6]. A significant effect has been proven with the LEZ implementation.

The potential socio-economic consequences of LEZ are summarized in [23]. Appropriate policy measures should take into account at least such potential negative consequences of LEZ [23]:

– disproportionate impact on expensive "specialized" vehicles, e.g. buses, specialized trucks;

– greater relative influence on smaller companies;

– largest relative influence on trucking, wholesale trade, manufacturing sector and small construction companies;

– in general, high potential business costs for companies, which can negatively affect the attractiveness of LEZ.

It is very important that the LEZ scheme contains a balanced set of benefits, including families with low income, people with disabilities (people with disabilities). LEZ must be complemented by affordable alternatives, including more attractive, convenient and comfortable forms of public transport, attractive walking and cycling infrastructure.

The work [16] provides an overview of the most famous cities that have set a course for various forms of Zero Emission Zones (ZEZ), which provide access only to the so-called "forms of zero emission mobility", covering all types of wheeled vehicles.

Looking ahead, LEZs should be gradually developed into Zero Emission Zones (ZEZs). This means the electrification of all types of road transport, as well as the introduction of convenient and attractive urban infrastructure for walking and cycling.

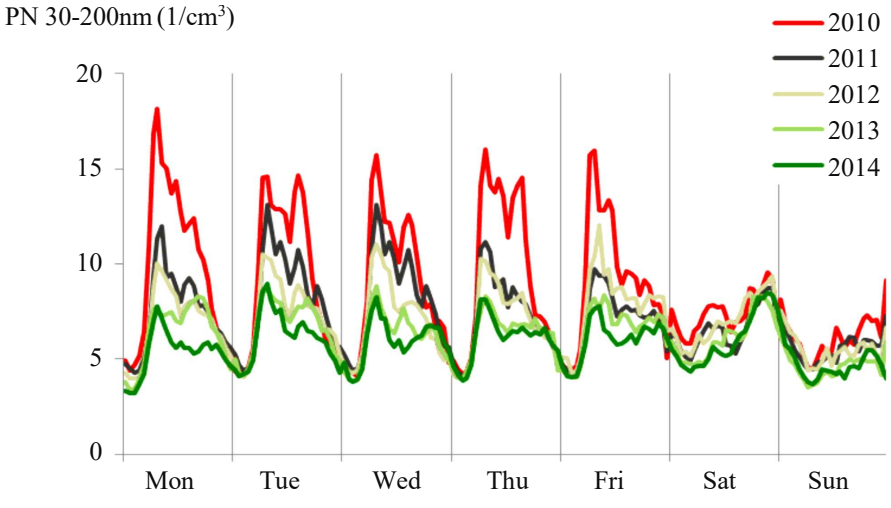

Fig. 1. Average values of the particulate number (PN) per day of the week in the size range 30–200 nm, which were observed in the air of Dresden during 2010–2014 [6]

The impact of LEZ on air quality depends on many factors, in particular [6]:

– established emission standards;

– effectiveness of LEZ use (control);

– types of vehicles covered;

– LEZ geographical boundaries;

– vehicle fleet structures for LEZ implementation;

– importance (contribution) of various sources of pollution in this city;

– how extreme the city's air quality problems are.

Based on the analysis of available sources, the following hypothesis can be determined about what are the key factors that lead to LEZ failures or their low effectiveness in many cases.

Unsuccessful Euro emission standards have undermined LEZ reputation in the past [3].

The excess of real emissions of standard values is an important problem, especially in Europe, where dieselization of the passenger car fleet is much higher than in other regions of the world.

The data [24] show that there has been no significant progress in the transition from Euro 4 to Euro 6 for conventional passenger cars.

Thus, overestimation of the efficiency of emission standards leads to overestimation of the initially predicted effects of many LEZ schemes. Moreover, the initial environmental performance of vehicles tends to deteriorate with age and accumulated mileage.

Relatively old vehicles, even those meeting "high" environmental standards, in actual use due to malfunctioning or deterioration of emission control systems, can generate huge emissions. Even a small proportion of these huge pollutants in the total traffic flow plays a decisive role in total emissions. This will neutralize any initiatives to increase the share of "clean" transport, including purely electric transport.

Procedures required by EU directives 2014/45 and 2014/47 cannot reveal many malfunctions of emission control systems during actual driving. In addition, on-board diagnostic systems are largely discredited, leading to massive non-compliance with emission standards, [25].

Even a small number of vehicles that heavily pollute the air can completely discredit the effectiveness of the restrictions imposed by LEZ. EU Directive 2015/413 regulates the cross-border exchange of information on traffic offenses related to road safety and [26] proposes to include offenses related to LEZ.

The European Commission White Paper "A Roadmap to a Single European Transport Area – Towards a Competitive and Efficient (in terms of resource efficiency) transport system", was adopted on 28 March 2011 The section on urban mobility states "Develop an approved basis for toll charges urban roads and access restriction schemes and their application, including a legal and proven operational and technical base, covers vehicles and infrastructure" [27].

Reference [28] offers the following recommendations for national frameworks:

– development of a system of requirements for vehicles. For example, the development of a sticker system that is used in Germany and France;

– general list of exemptions, with the possibility of some local adaptations;

– choice of option (ban versus the possibility of paying a commission);

– if automatic number-plate recognition (ANPR) is to be used, preparation of the necessary national databases;

– if modernization is allowed, development of national standards for the classification of various modernization technologies;

– national road signs for LEZ;

– determination of daily zone entry fees and penalties for non-compliance.

The growing spread of traffic restrictions creates a European "patchwork quilt" in which transport is becoming more expensive [3] and inconvenient through diversified and conflicting regulations.

An attempt to establish some specific general approaches and although voluntary standards for the planning and implementation of LEZ are outlined in [29].

A detailed analysis of different labelling systems is presented in [30–33] and in many other sources. In a global context, the diversity and incompatibility of the various labelling systems are extraordinary.

Sources [30, 31, 34–39] and many others provide evidence that CO_2 labelling is not effective enough if it is stagnated solely for environmental marketing purposes. This does not provide enough incentive for the auto industry to develop and produce much more energy efficient vehicles with a lower carbon footprint.

The impact of environmental labelling of cars on consumer behavior and "green shopping" has been studied in [16, 34, 39–41] and many other sources. It has been shown that the potential for such influence is very limited unless a strong financial background is involved in the decision-making process.

Green marketing in the automotive industry has been analyzed nationally and internationally in many studies, in particular [42–49], which confirm the existence of a "chasm" between recognition of the problem and "green" consumption.

Environmental stickers are used, in particular, in Germany [50], Austria [51], France [52], Great Britain [53], as well as in Belgium, Denmark, Italy, Hungary, Spain, Norway, Sweden [54]. The presented approaches are incompatible with each other both in the "ecological" differentiation of the fleet, and in the form of data presentation.

Road tolls in European countries [55, 56] are a widespread economic instrument. Road tolls and an overview of the Eurovignet Directive are given in [57].

Distance and differentiated from the "Euro-class" payment for tolls on autobahns and main roads are widespread in Europe. As a smart and fair approach, road tolls need to be differentiated with respect to road wear and environmental performance in order to facilitate and support the renewal of the existing fleet.

In [58], a general concept of EU type labelling is proposed, classifies four main consequences – noise, gas emissions, fuel consumption and damage to infrastructure. It is believed that tolls and access for trucks should be related to the size of their ecological footprint (footprint) classified on the eco label.

In [59], various vehicle labelling systems are evaluated and discussed in relation to the criteria for environmentally friendly vehicles. It presents a view of environmental labelling as part of a system aimed at informing consumers about the environmental impact of goods and services, which are called environmental product information schemes (EPIS).

In addition, [59] proposed to include in the future also:

– strict emission limits during cold start at low ambient temperatures;

– a life cycle perspective for CO_2 emissions including production, use and recycling;

– strict limits on acoustic noise emissions from vehicles.

It is concluded in [59] that successful labelling should, in particular:

– be simple and straightforward;

– show significant differences between the best and worst vehicles;

– be able to complement and link national tax incentives or local incentives, such as entry into environment zones and free parking.

In [60], it is proposed to systematically set goals and standardized indicators for sustainable transport.

The ACEEE vehicle environmental rating methodology [61] is based on the principles of life cycle assessment and environmental economics in the US market. A full life cycle assessment (LCA) has been studied to conduct a comprehensive environmental impact assessment for electric vehicles (EVs) and vehicles with internal combustion engines (ICE) [24, 62].

However, [63] confirms the high complexity of the implementation of approaches based on LCA, in the absence of output data.

Toxicity weighting can be seen as a valid, accurate and reliable way to estimate the cumulative toxicity and prioritize emission reduction strategies when the number of pollutants is large, such as in the case of road vehicles. Toxicity weighting is applied using the US Environmental Protection Agency's Risk-Screening Environmental Indicators (RSEI) [64]. The various aggregation functions of pollutants are part of many air quality indexing (or air pollution indexing) systems around the world [65]. Analysis of toxicity weighted emissions is an approach also used in [66].

However, a review [65] of various approaches to air quality indexing and toxicity weighting methods shows that no standard methodology is currently widely accepted.

[67] provides an overview of four environmental rating methodologies for road vehicles, covering Greenscore in the US, Ecoscore in Belgium, VCD Green Vehicle List in Germany and the Australian Green Vehicle Guide. A significant disadvantage of the mentioned methodologies is that the effect of pollutant emissions is weakened by taking into account "standard" values (emission limit values) instead of real emission values. In addition, the list of pollutants is too limited. Weighting the various exposure categories is highly subjective and cannot be considered entirely justified.

In works [68, 69], the total toxicity is calculated as the sum of known pollutants multiplied by the coefficient of relative toxicity in comparison with carbon monoxide as a well-known poison. The toxicity coefficients are based on a comparison of the maximum permissible concentrations of pollutants in the air and are taken as the ratio of the maximum permissible concentrations of carbon monoxide in the pollutant being considered.

In [70, 71], a unified classification of environment zones (EZ) and a unified classification of the environment hazard level (EHL) were developed. This classification takes into account the emissions of 64 known pollutants, establishing the cumulative toxicity compliance of petrol-powered and diesel-powered passenger cars (PC), light commercial vehicles (LDV) and heavy-duty vehicles (HDV).

The approach described in [70, 71] can be proposed as a basis for the development of a unified system of environmental labelling of vehicles in terms of ingredient pollution.

The following conclusions can be drawn from the above analysis. Environmental labelling and ecolabels, already introduced on the European continent, represent a wide variety of approaches. The regulation in this area in

different countries is very different and incompatible, and the experience gained is very mixed.

More and more national governments are considering introducing environmental labelling of vehicles or a unified national system for regulating access restriction schemes. More and more local communities want to introduce low emission zones. But national governments and city administrations face the challenge of high uncertainty and many unknowns along the way.

In addition, the growing proliferation of many conflicting approaches and options for restricting traffic creates a European "patchwork quilt" with which transport is becoming more expensive and inconvenient.

The problem of preventing fragmentation of requirements in different territories and ensuring a continuous (uninterrupted) transport system with more efficient regulation in the above areas is very urgent and needs to be addressed. The solution to this problem obviously requires the development and implementation of a unified international system of environmental labelling of vehicles and environmental zones.

Proposals for the concept of implementation of state policy in the field of labelling and regulation of the essential environmental properties of wheeled vehicles, as well as terms and definitions in this area, were set forth in [72]. It formulated a general ideology for the formation of a unified system of environmental labelling of vehicles and environmental zones. But [72] did not provide a generalized analysis of the world experience, which provides the initial data and general considerations for the effective implementation of new environment zones in cities on the basis of a unified system. Therefore, from the point of view of the identified problem, an appropriate analysis is required. There is also a need to isolate the basic principles of introducing a unified system of environmental labelling of vehicles in operation from this concept and supplement them with individual elements for more efficient implementation in a practical plane. In addition, reasonable, with a predictable impact on the quality of atmospheric air, the level of environment zones and the corresponding requirements for road vehicles should be determined, it is advisable to implement in cities.

3. The aim and objectives of research

The aim of research is to determine the basic requirements for a unified system of environmental labelling of vehicles with an emphasis on differentiating access conditions to low-emission zones (environment zones), which will make it possible, in particular, to significantly improve the quality of atmospheric air in cities. In the future, the introduction of a unified international system of environmental labelling of vehicles and, accordingly, unified requirements for environment zones should allow avoiding fragmentation and obtaining a continuous (uninterrupted) and more convenient transport system with more effective regulation in the field of differentiation of conditions for transport access to infrastructure.

To achieve the aim, the following objectives are set:

– to define the basic principles for the implementation and practical use of a unified system of environmental labelling of vehicles, based on world experience in the field of environmental labelling of vehicles with an emphasis on differentiating access to low-emission zones;

– to determine the reasonable level of environment zones, on the basis of forecasting, a decrease in the average specific emissions of pollutants by the fleet under different scenarios of regulation, and the corresponding requirements for road vehicles, it is advisable to differentially introduce in cities.

4. Basic principles of implementation and practical use of the unified system of environmental labelling of vehicles

The initial data for the development of the basic principles for the implementation and practical use of a unified system of environmental labelling of vehicles is an analysis of world experience in environmental labelling of vehicles and schemes for regulating access to infrastructure, proposals for a concept for the implementation of state policy in the field of labelling and regulation of essential environmental properties of wheeled vehicles presented in [72], which, in turn, are based on:

– a conceptual understanding of the data structure of vehicle environmental labelling needed to manage vehicle access to infrastructure and sustain environmental marketing;

– taking into account positive and negative experiences on the ground, relevant determinants, driving factors, and related issues.

The above justifies the selection of at least the following basic principles for the introduction of a unified system of environmental labelling of vehicles in terms of operation:

1. The essential environmental properties of a wheeled vehicle in operation should be used in labelling and regulation at various levels should include:

– current hazard level of ingredient contamination;

– type of motor fuel or other source of energy;

– type of the source of propulsion;

– indicators of energy efficiency;

– averaged specific emissions of carbon dioxide;

– level of acoustic noise (sound pressure) when the vehicle is moving;

– factors of intensity of road surface wear and formation of wear products of pneumatic tires and road surface.

2. The above essential ecological properties of wheeled vehicles in operation should be used:

a) for consumers to make a familiar and informed choice in favor of environmentally friendly and energy-efficient designs for wheeled vehicles (on the basis of communicating adopted and prospective fiscal and other incentive measures). Such measures should include advantages in the use of infrastructure facilities, preferential terms of access to environment zones, parking spaces and other facilities;

b) as a basis for a fiscal policy of "hard" stimulation of consumers' purchase of environmentally friendly vehicle designs (together with data on the environmental properties of the vehicle and replaceable structural elements related to their production and disposal);

c) to differentiate the conditions of access to the infrastructure of vehicles in operation, in terms of pronounced local environmental damage (that is, with the exception of

indicators of energy efficiency and average specific emissions of carbon dioxide);

d) when holding tenders for the transportation of passengers and goods, depending on specific local conditions, the nature of environmental problems, and the corresponding priorities (the significance of individual environmental properties of vehicles in certain operating conditions).

3. The above measures of state regulation must be complemented by the establishment of progressive environmental requirements (maximum permissible emissions) for vehicles that first enter the market for the purpose of free circulation.

4. The designation of zones for regulated use of infrastructure (environment zones) and other means of access control and payment for use should be coordinated with the environment labelling system of vehicles. That is, road signs to indicate the conditions of access to environmental zones and stickers for environmental labelling of vehicles should have a unified and consistent design. This should include color and other labellings that reflect the class of the environmental area and, accordingly, the severity of the minimum vehicle emissions requirements. The labelling must include significant environmental properties.

5. The use of the polluter pays principle, according to which the costs of society related to measures to prevent, control and reduce pollution are borne by the polluter.

6. The hazard level of ingredient contamination should be automatically reviewed taking into account the age of the vehicle using default values.

7. Labelling and the corresponding regulation should be combined with the implementation of measures to maintain the environmental properties of the vehicle laid down by the manufacturer during the entire period of its operation.

8. Progressive should be simultaneously introduced, in accordance with the development of technology, technology and measures:

a) effective periodic monitoring of wheeled vehicles for serviceability, determining the operability of the main structural elements responsible for the level of emissions of pollutants into the air and the level of acoustic noise (sound pressure);

b) selective roadside instrumental control of the level of pollutant emissions and the level of acoustic noise.

9. The hazard level of ingredient contamination should be subject to revision during periodic vehicle inspection or selective roadside instrumental emission control. Technically faulty vehicles should be assigned a lower level according to the established procedure in order to display large emissions, in order to limit their access to densely populated areas and damage to the population.

10. Indicators of the normalized level of acoustic noise can also be subject to revision during monitoring.

11. The vehicle manufacturer should have the right to determine, establish and prove a different degree of deterioration in the properties of the transport medium. Operational emission control programs and efficient systems to support the fleet in operation should be in place.) This can be seen as a powerful incentive for activities to keep vehicle emissions within established limits throughout the life of the vehicle.

12. Responsibility for:

– violation of certain rules for environmental labelling wheeled vehicles, their admission to infrastructure facilities and payment for the use of infrastructure facilities;

– the use of vehicles that do not meet the established requirements for roadworthiness.

In the above principles, the emphasis is placed on supplementing the proposals set out in [72] with elements according to No. 9–11, which are important from the point of view of effective regulation in this area.

This means that an effective system for assessing the usability of vehicles should be built, into which the functions of adjusting their current environmental properties will be integrated. These "dynamic" properties should include at least the ingredient contamination hazard and acoustic noise levels. Depending on the results of scheduled periodic or selective instrumental control, such "dynamic" labelling should limit the access of environmentally hazardous equipment to crowded places.

Element 11 is very important. It should stimulate manufacturers to "accompany" vehicles throughout the entire service life and ensure the safety of the essential environmental properties incorporated into their design, which they met at the time of production.

Representation of the developed [70, 71] unified system of environment zones corresponding to the dynamic hazard levels, and the corresponding cumulative emissions are shown in Fig. 2 in a slightly modified form.

The color designation of environment zones on road signs and the designation of the hazard level of vehicles on their labelling are consistent with each other in this system, as shown in Fig. 2. The visual representation of the gamma of color designation of environment zones on road signs and designation of the hazard level of vehicles, proposed in [70–72], was not previously given. It is convenient for organizing and controlling access. The designation of the ordinal number of the level of environmental hazard and, accordingly, the level of cumulative emissions should be used for the purpose of differentiated payments for access to environment zones and the like.

Environment Zone	I						II			III			IV			V			VI									
EHL, #	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
RE, g/km (g/tkm)	5	6	8	10	13	16	20	25	32	40	50	63	79	100	126	158	199	251	316	398	501	630	793	999	1258	1583	1994	2510

Fig. 2. Representation of a unified system of environment zones, dynamic levels of hazard (Environmental Hazard Level (EHL)), and their corresponding combined emissions (Reduced Emissions (RE)) in g/km and g/tkm

5. Determination of reasonable levels of requirements for vehicles in environment zones

The introduction of an environment zone requires the establishment of a minimum level of environmental requirements for road vehicles (RV), for which no restrictions will apply. Important baseline information for making informed decisions by local administrations is, in particular:

– data on the ecological structure of the fleet involved in road traffic;

– data on specific operational emissions of RV of various groups, which can be differentiated;

– "contribution" of RV of various groups to the total pollution, taking into account the structure of the fleet;

– predicted decrease in average specific emissions from the fleet in environment zones under different control scenarios (based on modeling results).

Based on the data of the State Enterprise "State Road Transport Research Institute" ("DergavtotransNIIproect", Ukraine) and expert assessments, as an example, the data on the approximate ecological structure of the active part of the RV fleet in Ukraine as of the end of 2020 were reproduced (reconstructed). Using data from [70, 71] on the dynamic level environmental hazard, for each RV group, the share in the total emissions of the entire fleet was calculated, and the reduction in specific emissions under different regulation scenarios.

The structure of the fleet and emissions of RV of various categories are shown below in the Tables 1–5 and Fig. 3–5.

Tables 1–5 and Fig. 3–5, the following notation is used:

– *S* (%) – share (**%**) in the active part of the RV fleet (ecological structure);

– *EHL* (g/km) – Environment Hazard Level (EHL);

– *RE* (%) – share in the total emissions of the entire active part of the fleet;

– *G* (%) – share (**%**) in the total emissions of the sum of the above and the lowest environmental levels of RV;

– *R* (%) – a decrease in specific emissions with a simple exclusion from the road traffic in the environment zone of the above and the lower ecological levels of RV (in **%** of the pollution level in 2020);

– *RC* (%) – a decrease in specific emissions, subject to the exclusion of the stated and lower environmental levels of RV from the road traffic in the environment zone (in **%** of the 2020 pollution level), And taking into account the "compensation" of traffic volumes of RV of the highest environmental levels;

– *PC* (*G*) – passenger cars with positive ignition engines;

– *PC* (*D*) – passenger cars with diesel engines;

– *EV* – electric vehicles;

– *HDV* – heavy-duty commercial vehicles;

– *Bus* – buses.

According to the reconstructed data on the ecological structure *S* (%) of the active part of the *RV* fleet in Ukraine (Fig. 3), and the level of the *RV* environmental hazard determined in [70, 71], *RE* share (%) in the total emissions of the entire active part of the fleet is calculated (Fig. 4). The share of *G* (%) in the total emissions of the sum of the above and the lowest environmental levels of *RV* and the corresponding decrease in specific emissions *R* (in % of the current pollution level) are calculated without taking into account the "compensation" of traffic volumes. Shown in Fig. 5 *RC* reduction (%) of specific emissions through the exclusion from road traffic in the environment zone of the stated and lower environmental levels of *RV* is calculated on the assumption of "compensation" of traffic volumes evenly distributed among *RV* of higher environmental levels (that is, constant total traffic volumes).

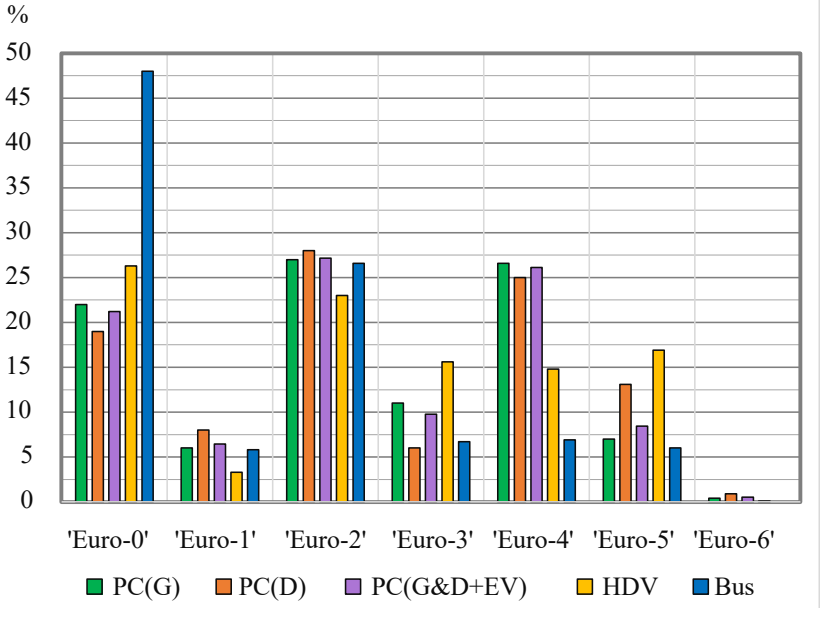

Fig. 3. Reproducible data on the ecological structure (%) of the active part of the RV fleet in Ukraine

Table 1

Fleet structure and emissions from vehicles with positive ignition engines

Standard	*S* (%)	*EHL* (g/km)	*RE* (%)	*G* (%)	*R* (%)	*RC* (%)
"Euro-0"	22	1,258	69.4	69.4	30.6	39.2
"Euro-1"	6	501	7.54	76.9	23.1	29.2
"Euro-2"	27	251	16.99	93.9	6.1	12.5
"Euro-3"	11	79	2.18	96.1	3.9	9.8
"Euro-4"	26.6	50	3.33	99.4	0.6	7.2
"Euro-5"	7	32	0.56	99.97	0.03	6.3
"Euro-6"	0.4	25	0.03	100	–	–

Table 2

Fleet structure and emissions from diesel vehicles

Standard	*S* (%)	*EHL* (g/km)	*RE* (%)	*G* (%)	*R* (%)	*RC* (%)
"Euro-0"	19	1,583	54.8	54.8	45.2	55.3
"Euro-1"	8	630	9.19	64.0	36.0	47.0
"Euro-2"	28	398	20.3	84.3	15.7	33.7
"Euro-3"	6	316	3.46	87.8	12.2	27.2
"Euro-4"	25	199	9.07	96.9	3.1	19.2
"Euro-5"	13.1	126	3.01	99.87	0.13	14.4
"Euro-6"	0.9	79	0.13	100	–	–

Table 3

Fleet structure and emissions by all passenger cars and electric vehicles

Standard	*S* (%)	*RE* (%)	*G* (%)	*R* (%)	*RC* (%)
"Euro-0"	21.2	65.0	65.0	35.0	43.1
"Euro-1"	6.5	8.0	73.0	27.0	33.5
"Euro-2"	27.2	18.0	91.0	9.0	17.6
"Euro-3"	9.8	2.6	93.6	6.4	14.0
"Euro-4"	26.1	5.1	98.6	1.4	10.1
"Euro-5"	8.4	1.3	99.9	0.06	8.2
"Euro-6"	0.5	0.1	100	0	1.1
EV	0.3	0.004	100	–	–

Table 4

Fleet structure and emissions from heavy-duty commercial vehicles

Standard	*S* (%)	*EHL* (g/tkm)	*RE* (%)	*G* (%)	*R* (%)	*RC* (%)
"Euro-0"	26.3	1583	53.2	53.2	46.8	63.6
"Euro-1"	3.3	1258	5.31	58.5	41.5	54.7
"Euro-2"	23	793	23.3	81.8	18.2	34.1
"Euro-3"	15.6	501	9.99	91.8	8.2	21.2
"Euro-4"	14.8	251	4.75	96.6	3.4	13.9
"Euro-5"	16.9	158	3.41	99.99	0.01	5.1
"Euro-6"	0.1	40	0.01	100	–	–

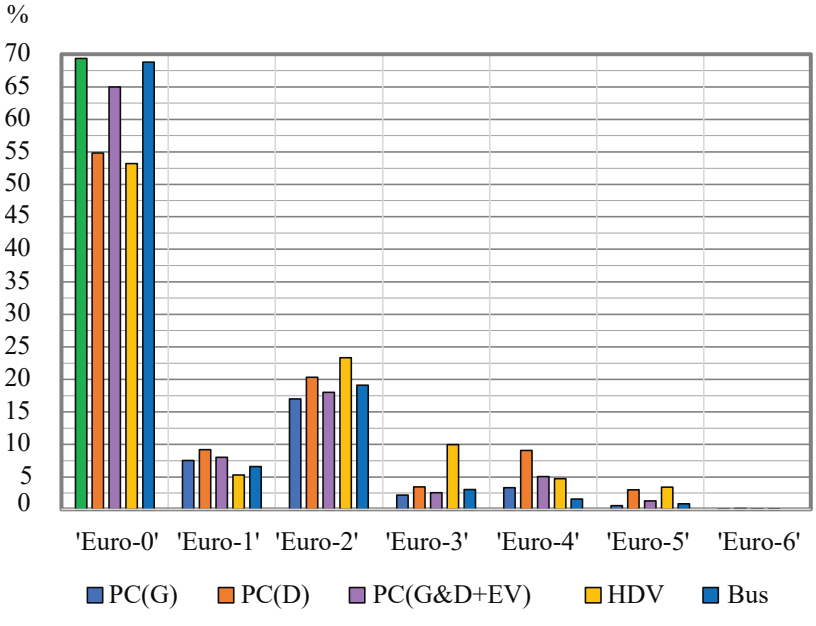

Fig. 4. Calculated contribution (%) to the total combined specific emissions of pollutants in Ukraine by RV of different "Euro" levels

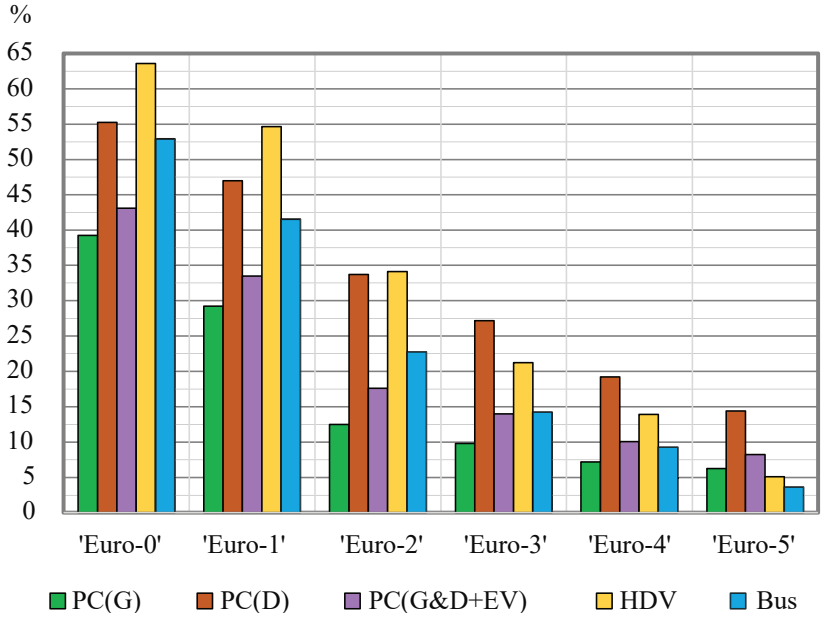

Fig. 5. The reduction of total aggregate specific emissions of pollutants (in % of the level of 2020, taking into account the structure of the active part of the fleet in Ukraine) is calculated in the case of excluding access to the environment zone of RV of the mentioned and lower "Euro" levels

Table 5

Fleet structure and bus emissions

Standard	*S* (%)	*EHL* (g/tkm)	*RE* (%)	*G* (%)	*R* (%)	*RC* (%)
"Euro-0"	48	1583	68.8	68.8	31.2	52.9
"Euro-1"	5.8	1258	6.61	75.4	24.6	41.6
"Euro-2"	26.6	793	19.1	94.5	5.5	22.8
"Euro-3"	6.7	501	3.04	97.6	2.4	14.2
"Euro-4"	6.9	251	1.57	99.1	0.9	9.3
"Euro-5"	6	158	0.86	100	0	3.6
"Euro-6"	0	40	0.00	100	–	–

6. Discussion of the results of determining the basic requirements for a unified environmental labelling system

The above analysis of world experience in the field of the research substantiates the feasibility of developing and implementing a unified system of environmental labelling of vehicles and schemes for regulating access to infrastructure.

The main principles of the implementation and use of a unified system of environmental labelling of vehicles are highlighted in the article, based, in particular, on:

– the proposals set forth in [72], with their addition with elements of building an effective system for assessing the suitability of vehicles for operation, and encouraging automakers to maintain essential environmental properties incorporated in the design of RV during the entire period of operation;

– key factors leading to positive or negative results of previously introduced environment zones in different cities, relevant determinants, driving factors, as well as related issues;

– using the concept of calculating the consolidated level of environmental hazard of vehicles in terms of ingredient pollution, set forth in [70, 71].

Requirements for RV, it is advisable to differentially introduce in environment zones in cities, justifiably by predicting a decrease in the average specific emissions of pollutants by the fleet under different

scenarios of regulation. The data given in the Tables 1–5 and Fig. 3–5, clearly prove the feasibility of limiting active operation in cities at least RV that meets the requirements of "Euro-0" and below. This will make it possible to achieve a decrease in the level of total specific RC emissions to approximately 40–65 % of the current level (Fig. 5), depending on the RV category. In practice, this means the massive establishment of "red" environment zones of level V (zones of wide coverage) with a maximum allowable level of cumulative emissions of 251 g/km (g/tkm), as shown in Fig. 2, and in [71].

A significant (on average, approximately 4–5 times) reduction in specific emissions in very polluted and densely populated areas (in designated environment zones) can be achieved by introducing at least "yellow" environment zones of level IV. This level covers the *RV* categories by Euro class and age, as shown in [71]. In practice, this may include restrictions for passenger cars with positive-ignition engines of the "Euro-2" level and below, and diesel vehicles with diesel engines "Euro-4" and below (Fig. 5). If restrictions were introduced for all diesel vehicles of the "Euro-2" level and below without taking into account the type of fuel, this would lead to the level of RC emissions (Fig. 5): 17.6 % (Table 3) of the current level on average for cars "PC (G&D + EV)" vehicles, taking into account the structure of their fleet; 22.8 % (Table 5) for Bus and 34.1 % (Table 4) for HDV.

The implementation of "green" environment zones of the level of radiation sources with the maximum permissible level of cumulative emissions of 63 g/km (g/tkm) and, accordingly, the maximum level of environmental hazard No. 11 (Fig. 2 and [71]) can theoretically reduce local reduced emissions by order (Fig. 5). This means that such zones will have unrestricted access: cars with engines with positive ignition of "Euro-4" level and above; cars with diesels of "Euro-6d" level up to 8 years old inclusive; freight transport and buses of the "Euro-6" level under the age of 15 years inclusive [71].

The introduction of "blue" (level II) and "white" (level I, including electric vehicles) environment zones of short range (central parts of cities, etc.) (Fig. 2 and [71]) currently requires additional justification. This should include, in particular, modeling the spatial dispersion of pollutants and their concentrations in the air, taking into account the existing background pollution of the area.

These results contribute to solving the problem of preventing fragmentation of requirements for environmental labelling and schemes for restricting transport access in different territories and ensuring a continuous (uninterrupted) transport system with more efficient regulation. It consists in extended proposals on the basic principles of introducing a unified environmental labelling system for *RV* in operation and justification based on simulation of reasonable requirements for *RV* in accordance with differentiated and standardized levels of environment zones. In practical terms, the results obtained already now provide important input data for local administrations in terms of the predicted consequences of possible regulatory decisions and their justification.

The peculiarity of those presented in this study is also in predicting the consequences of the introduction of environment zones according to different scenarios of regulation, based on the level of the combined hazard of ingredient pollution of RV and taking into account the structure of the fleet.

The proposed approach allows for the regulation of *RV* produced under incompatible environmental standards [73, 74] of various markets in a single, unified coordinate system [70–72]. This is very important considering the processes of further international harmonization, avoiding barriers and increasing the efficiency of the transport complex.

A significant limitation of this study is that it does not take into account the problem of violation by individual drivers (owners) of the established requirements for the *RV* technical condition, the current environmental labelling, and the conditions for admission to environment zones. The influence of these factors on the overall level of pollution and the development of a set of measures should be the subject of separate studies.

Further development of the proposed system of environmental labelling of vehicles in terms of ingredient pollution is also carried out, in particular, in the following areas:

– expanding the differentiation of standard values of hazard levels in accordance with the types of motor fuel (taking into account biofuels and conversion to use liquefied petroleum gas) and other factors;

– development of methods, technologies and equipment for improving the instrumental control of emissions during periodic and selective assessment of the suitability for operation (with a corresponding adjustment of the current hazard class).

7. Conclusions

1. Based on the analysis of the world experience of environmental labelling and the introduction of low-emission zones, the main principles of the implementation of a unified system of environmental labelling of vehicles are highlighted. These principles include 7 types of significant environmental properties of vehicles and principles of regulation based on them with an emphasis on operation. In terms of ingredient pollution, a unified system is presented that contains 5 levels of environment zones: "white", "blue", "green", "yellow", and "red". These 5 levels of environment zones cover "zero" and 17 of the following standardized hazard levels within the limits of their respective cumulative total emissions of toxic substances from 5 to 251 g/km (g/tkm). The above principles emphasize the elements that are important from the point of view of effective regulation in this area in practical terms. Namely, the creation of an effective system for assessing the suitability of vehicles, which will integrate the functions of adjusting their current environmental properties. These "dynamic" properties should include at least the ingredient contamination hazard and acoustic noise levels. Periodic and selective instrumental control with "dynamic" labelling of the current environmental properties should limit the access of environmentally hazardous equipment to crowded places. Attention is also focused on encouraging automakers to "accompany" vehicles throughout the entire service life and to ensure the safety of the essential environmental properties inherent in their design, which they met at the time of production.

2. The information necessary are reproduced (reconstructed) to justify and determine the appropriate levels of environmental zones and the corresponding requirements for road vehicles. In particular, these are data on the ecological structure of the active part of the fleet data on the aggregate specific operational emissions of RV of various groups and their "contribution" to the total pollution, taking into account the structure of the fleet. Forecasts of a

decrease in the average specific emissions from the fleet in environment zones were obtained for different scenarios of regulation. These forecasts substantiate the advisability of limiting further active operation in cities of road vehicles of a certain level of environmental hazard, depending on the breadth of coverage of territories. The results provide fundamentally new opportunities for the introduction of more efficient schemes for regulating the access of vehicles to contaminated areas of cities, which is confirmed by the results of calculations for reducing emissions. By introducing the proposed environment zones of various levels, it is shown the fundamental possibilities to achieve a decrease in the level of total specific cumulative emissions approximately: at the level of 40–65 % of the current level within the dense urban development, covering large territories ("red" environment zones of level V); 4–5 times in highly polluted and densely populated areas ("yellow" environment zones of level IV); by an order of magnitude in highly sensitive designated areas ("green" environment zones of level III).

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