Indicator Method for Determining the Emissivity of Road Transport Means from the Point of Supplied Energy

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Abstract: Recently, many activities have been undertaken to reduce the negative impact of transport on the environment, e.g., using propulsion sources and consumed energy. Electric and hybrid vehicles are becoming more and more popular. Methods of measuring the emissivity of the means of transport as well as devices for determining measurements are being developed. This work presents an indicator method (IM) for determining the emissivity of road transport, while omitting the use of quite complicated and expensive research equipment. For typical road vehicles, it is possible to determine the emissivity means of transport, taking into account statistical data. The values of the indicators selected, based on statistical data analysis, were verified by comparing their values with the results of the actual emissivity of air pollutants. As part of the research work, the emissivity values of selected means of transport in a distribution company were determined using the IM method. The results were compared with the actual emissivity measurements. The method of indicative determination of emissivity makes it possible to estimate the initial emissivity level, knowing the type of vehicle and the distance performed as part of the transport work. Thanks to a simple and uncomplicated method, delivery planning can become more sustainable, and the selection of less emissive means of transport can contribute to reducing the negative impact of transportation on the environment.

Keywords: transport emissivity; air pollutants; road transport; propellants

1. Introduction

Air pollution caused by human activity related to raw material acquisition, manufacturing, operation, and decommissioning of transport means represents a significant share of the total anthropogenic pollution emitted into the natural environment. Legislative measures to reduce pollution from fuel combustion have been planned for many years and will continue to be planned in the European Union, which took on the role of world leader in environmental protection in the Lisbon Strategy in 2000. The issues of air pollutant emissions are thoroughly defined by standards and protocols, e.g., sUNI EN ISO 140 67:2018 [1], UNI EN ISO 14064:2019 [2] (parts 1, 2, and 3), and The Greenhouse Gas Protocol of 2004. Documents mentioned above define the principles, requirements, and guidelines for quantifying and reporting the product's carbon footprint, consistent with international standards for life cycle assessment. This paper presents an indicator method intended to determine the estimated emissivity of road transport means for the preliminary estimation of main air pollutant components in vehicles operating in freight and passenger transport. The paper's research objective was to determine the indicators of main air pollutant emissions by using publicly available statistical data. The research thesis assumes finding a correlation between the values of indicators determined based on statistical data with indicators determined based on real studies of the emissivity of transport means in real driving emission (RDE) tests. The research question is whether it is possible to determine the emissivity of vehicles using statistical emissivity indicators while ensuring the adequate

accuracy of results compared to real studies. The statistical emissivity indicator values for various vehicle types determined in the paper were verified through their comparison with emissivity results obtained during the real field measurements carried out as part of a diploma paper and based on the results of literature studies.

2. Transport Ecology and Sustainable Development

In 2021 alone, nearly 87% of all freight transported in Poland was carried by road, and the transport work conducted by road exceeded 83%. It is also noteworthy that over the last 20 years, road transport work has been steadily increasing compared to that of, for example, rail transport, with rail transport having been at a comparable, constant level for many years [3]. Transport work conducted by road has a significant impact on the environment. Numerous environmentally friendly initiatives are being undertaken to encourage passengers to use collective or public transport [4]. The field of freight transport organisation is experiencing the development of environmentally friendly technologies, and transport means using new fuels, e.g., hydrogen, electric, or hybrid drive units. The emission standards for road transport vehicles in Europe have been rigorously tightened over the past 20 years [5]. A sustainable transport initiative assuming more minor pollutant emissions into the environment is also currently being developed, and the concept of transport ecology is becoming popular [6,7]. There is a growing awareness of optimal transport organisation, especially in urban areas. Methods that enable the determination of emissivity, the so-called carbon footprint, of transport means are also becoming more important [8]. Transport processes are being increasingly modelled considering new environmental trends in transport. Regarding the promoted zero-emissions transport, transport ecology aims to achieve and maintain sustainable development. A systemic view on human transport activity and the relations with basic biological, chemical, and physical systems is being proposed. The creation of environmental awareness contributes to keeping transport activity at a sustainable level, leading to further evolution in economics and technology, among other things. However, it is necessary to remember that transport and transport infrastructure negatively impact, on the environment and surroundings [9]. To ensure the sustainable development of transport, it is necessary to take into consideration the social aspects that contribute to the satisfaction of transport needs and its public utility. The natural environment is endangered by pollution introduced directly to one of its three essential elements, i.e., the atmosphere, surface water, and soil. Transport activity is mainly associated with primary pollutant emissions into the air, generation of pollutants related to any consumables and components worn during the use of transport means, and the so-called secondary emissions.

In terms of the emissivity of transport means, it is assumed that Europe will become the first climate-neutral continent in the world by 2050. In order to make this objective achievable, it is necessary to work towards sustainable transformation also in the area of transport. One of the proposed solutions is to use renewable energy [10]. It has many potential advantages, including reduced greenhouse gas emissions, energy supply diversification, and reduced dependence on the fossil fuel markets (especially diesel and gas). The development of renewable energy sources can also stimulate employment growth by creating jobs in the new green technologies sector. The economic branch of transport is currently emitting approx. 22% of greenhouse gases in the European Union [11], most of which, over 70%, is emitted by road transport (Figure 1) and passenger vehicles (Figure 2). Rail transport is the least emissive.
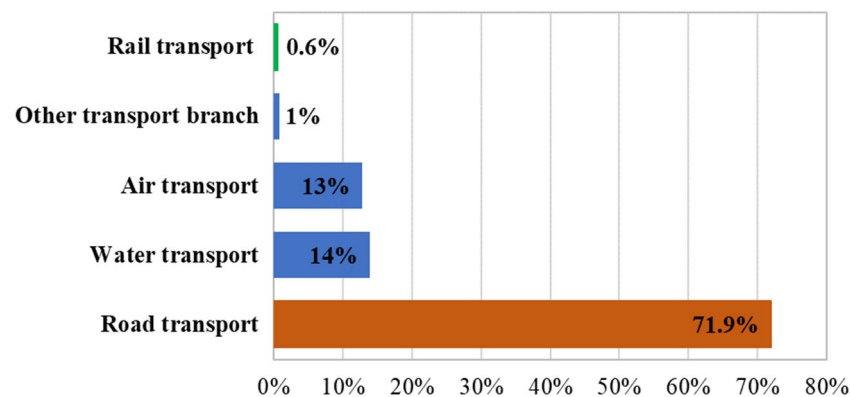
Figure 1. Share of particular transport branches in air pollutant emissions based on [11].
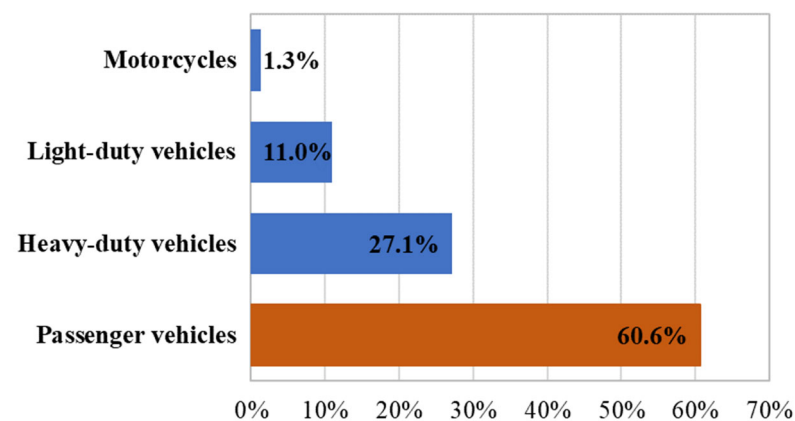
Figure 2. Share of particular road transport means in air pollutant emissions based on [11].

It is necessary to note the Sustainable and Smart Mobility Strategy adopted in December 2020, which fits the action plan for a sustainable economy. The objective of the actions planned for the coming years is mainly to change the way people and goods are transported, to combine various transport branches within a single transit, and to promote environmentally friendly solutions for entrepreneurs. Funding for investment, rolling stock and infrastructure modernisation will be increased, and solutions to increase resilience to future economic shocks will be promoted.

3. Research Problem

The paper focuses on the issue of developing a method intended for the estimation of emissivity indicators for road transport means because road transport plays a crucial role in freight and passenger transport in Poland. The research problem identification involved an analysis of the existing methods of calculating the emissivity of transport means along with an analysis of the IT tools offered in an open format, including the COPERT programme coordinated by the European Environment Agency [12]. The selection of the method by which air pollutant emissions in transport can be calculated depends on the specific processes responsible for emissions generation, the importance and share of the analysed pollutants in total emissions, the scale of the contribution of a particular installation or, for example, the transport branch in the total pollutant emissions as well as environmental fees and the effect of a particular pollutant type on ambient air. The methods of calculating emissivity can be based on periodical measurements, unit measurements, process balances, and on statistical or literature data [13].

Pollution in road transport is mainly generated by fuel combustion, and non-fume emissions, e.g., brake pad wear, tyre wear, a secondary dusting of sediments and particles present on the roadway, etc. The pollution level in road transport is affected by the length and distribution of the road infrastructure, fuel type and quality, engine features and

maintenance, traffic congestion, as well as the vehicle type and the manner of operation. The impact of transport on the surroundings is based on the evaluation of transport activity external effects. External costs are usually associated with the negative effects of transport on the surroundings. In terms of environmental impact, the external costs of transport with the most significant effects on human functioning include air pollution, climate change, and noise. Passenger vehicles contribute to the highest share of air pollutant emissions (Figure 3). Light-duty or heavy-duty vehicles are responsible for nearly 40% of pollutant emissions [14]. The research subject is also motivated by the systematic increase in transport work conducted by road transport and the persistently high share of conventional fuels used to power the vehicles operated in road transport. The structure of air pollutants based on the fuel used is presented in the following figure:
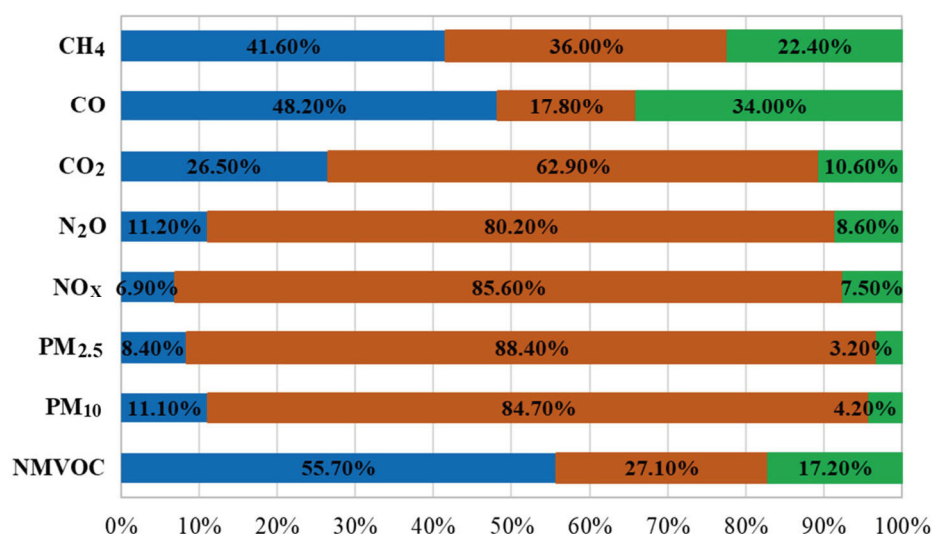

Figure 3. The structure of air pollutants depends on the fuel used, based on [14].

Diesel is a fuel type that has a particularly negative impact on the environment. Diesel vehicles generate over 80% of all pollutants regarding particulate matter and nitrogen oxides and are responsible for as much as 60% of carbon dioxide emissions. At this point, it is necessary to specify the national energy mix—fossil fuels constitute nearly 80% of all sources of electricity production in Poland. This is also important in terms of the development of low-emission vehicles, especially electric vehicles. These vehicles are emission-free at the place of their operation, especially in urban areas, while their emissions are transferred to the site of electricity production. Methods of evaluating pollutant emissions in road transport described in the literature may also include field tests encompassing road traffic measurements on a selected road section, especially in urban areas [15]. In such cases, the level of pollutant emissions is affected by traffic freedom, traffic intensity, the structure of the vehicles driven on the analysed section, as well as the fuel type and its unit consumption, among other things. The traffic freedom indicator determines the changes in traffic conditions with consideration of the feelings of drivers and other road users. It is assumed that there are six main classes of traffic freedom: class A describes free traffic with great freedom of choosing one's driving speed, while class E describes uneven traffic in which the traffic intensity corresponds to the road's capacity. By determining the average daily traffic on a given day, the structure of moving vehicles with the division to diesel or petrol vehicles and the available data determining the consumption of fuels per 100 km of distance travelled, and by using literature studies, it is possible to attempt to determine the emissivity indicators for transport means [16]. However, the emission values determined by using these indicators, while only being approximate, will also reflect the real traffic conditions on the analysed road sections in the analysed day periods [17].

Studies are being carried out with the purpose of evaluating energy consumption and exhaust emissions by vehicles with different drive units during real operation. Many authors propose solutions intended to reduce pollutant emissions in terms of designing new engines and the percentage determination of decreasing emissions by transport means, among others, due to the implementation of new technical solutions that reduce pollutant emissions and fuel consumption [18]. The literature contains numerous elaborations that point to real vehicle emissivity in real operating conditions [19]. In particular, the real leading air pollutant emission indicators are analysed in comparison to the values declared by vehicle manufacturers and exhaust emission standards. However, the analyses of the emissivity of pollutants generated by vehicles can differ substantially depending on testing conditions, which may be affected by ambient temperature, natural topography, and road conditions, among others [19]. Methods based on the measurements of the real emissivity of transport means are characterised by the highest accuracy, however, they are only micro-scale tests, and it is difficult to generalise them for a greater population of transport means moving on a selected road section. Emissivity tests can be carried out for various vehicle types, in various traffic conditions, in different natural topographies, and using selected fuels. The literature presents interesting comparative results of emissivity studies carried out on various transport means utilising, e.g., electric, hybrid or conventional drive units [20]. Clear progress in emissivity reduction is being made in hybrid vehicles, but electric vehicles, especially those powered by renewable sources, appear to be the most promising option [20,21]. Furthermore, emissivity remains a study subject in terms of measuring the emissions of transport means at intersections and locations with increased traffic congestion. The most common conclusion from such analyses is that appropriate spatial planning and road designing that ensure the least number of stops favours the reduction of the emissivity of transport means [22]. Particularly in urban traffic conditions, the combination of good practices in the spatial designing of roads and the promotion of vehicles powered by, for example, natural gas and the adaptation of conventional vehicles powered by gas [23], may contribute substantially to the reduction of air pollutants. The introduction of new power sources for vehicles intended for passenger transport in urban areas also contributes to the reduction of air pollutants, taking into consideration such factors as road inclination, street crowding, fuel consumption, or passenger load [24] and route height difference [25], among others. Research is being carried out on gas and particulate matter components emitted by commercial vehicles used in urban distribution, especially in terms of the impact of the transported load's size on emissivity [26]. The results of studies on the increased emissions of air pollutants in urban traffic conditions confirm the impact of traffic congestion and street crowding on this phenomenon [27]. The increase in pollutant emissions in urban areas is caused by the increased numbers of traffic jams as well as increased acceleration and deceleration frequencies. One possible solution to reduce emissions used in conventional vehicles, e.g., intended for load distribution in urban areas and diesel, may be the use of various types of bio-components (including heavy alcohols), the combustion of which significantly reduces air pollutant emissions.

As mentioned in EU strategic documents, diesel vehicles will be used at least until 2050 [28]. The results of transport means emissivity are also affected by the conditions and type of the tests carried out. In addition to RDE tests [29,30], which are considered to be the most accurate tests for the emissivity of transport means, exhaust emissions can also be measured behind a moving vehicle. In this case, it is necessary to maintain an adequate distance and take into account the dispersion of exhaust components [31]. Due to the significant role of transport ecology and the increasing demand to reduce transport's negative impact on the environment, researchers are also carrying out studies of air pollutant emissions in heavy-duty vehicles [32]. However, the working conditions and the vehicle load are important when carrying out emissivity tests on heavy-duty commercial vehicles. It is necessary to compare the emissivity results obtained during laboratory testing with real emissivity tests [33]. Air pollutant emissions are also affected by factors related to the operating temperature of the engine and exhaust system components,

as demonstrated in ref. [34]. The literature has described many issues related to emissions from urban transport. At present, municipal energy services are being promoted to consider the operation of the coal system and to ensure the protection of the urban system [35]. Pro-ecological means of transport and individual ecological transport means are being promoted [36]. Numerous factors disrupting the development in individual cities are being identified, e.g., uncontrolled development of cities, commuting to work of people meeting outside the city [37]. The emissivity of the means of transport is affected by land development [38], time of day, road profile, and traffic arrangement [39]. The proposed method is an innovative approach to estimating the emission of primary air pollutants. It can be developed by considering other factors that significantly impact the multiplicity of pollutant emissions, such as the age of vehicles, mileage, and general technical condition.

4. Indicator Method (IM) for Determining the Emissivity of Transport Means

Road transport contributes significantly to environmental degradation through the extensive use of internal combustion engines that emit exhaust fumes into the atmosphere. Considerations on the emission of pollutants in transport in the literature are often limited to greenhouse gas emissions only, such as carbon dioxide (CO_2), methane (CH_4), nitrogen oxides (NO) or nitrous oxide (N_2O). However, all harmful compounds affect the soil, water, air, flora, fauna, landscape, or humans directly and indirectly. One of the most commonly used methods of determining transport means emissivity is RDE testing, but this requires the use of expensive measuring equipment and carrying out time-consuming field tests. With this in mind, the indicator method for determining transport means emissivity was developed, which also allows us to determine the indicators of long-term external costs arising from air pollutant emissions. In 2018, a methodology for estimating air pollutant emissions was published by Statistics Poland, but this method did not determine the unit values of particular air pollutants emitted by specific road transport means [40]. The data source for the above methodology was the information from the database of the Ministry of Digital Affairs based on vehicle odometer readings collected in the Central Vehicle Register (CEP), indicating the amount of transport work conducted, vehicle types by age groups, the fuel used, engine capacities, and the gross vehicle weight. Statistics Poland's methodology for estimating air pollutant emissions utilised the General Road Traffic Measurement 2015 results. As part of the research work on defining the indicator method, the basic types of air pollution monitored at the level of Statistics Poland were taken into account. For this reason, issues related to pollutants such as PM1 or black carbon have been omitted. For electric vehicles, the emissivity indicators were determined based on the report developed by the National Centre for Emissions Management (KOBIZE) [41]. In the indicator method, the emissivity of particular vehicle types can be determined for passenger vehicles, light-duty vehicles, and heavy-duty vehicles utilising different types of fuels and engines with various capacities. Passenger vehicles were classified into categories from V1 to V7. Light-duty and heavy-duty vehicles were categorised from T1 to T4. The indicator method enables the estimation of the emissivity of electric transport means. In this case, the quantity is determined as a measure of the emission generated at the electricity production location. Electric vehicles were classified into categories from E1 to E6.

Publicly available statistical data and results of research projects made available by Statistics Poland, the General Directorate for National Roads and Motorways and KOBIZE [38] were used to develop indicator tables demonstrating the emission of types of transport means classified in Table 1 in the unit of pollutant emission per one kilometre travelled. Table 2 presents the indicators of emissivity of conventional vehicles with reference to basic air pollutant types, i.e., methane, carbon oxide and dioxide, nitrogen oxides and dioxides, suspended dust and non-methane volatile organic compounds.

Table 1. Classification of transport means.

Fuel Type	Vehicle Description	Vehicle Type
petrol	passenger vehicles below 1400 cm^3	V1
petrol	passenger vehicles 1400–1999 cm^3	V2
petrol	passenger vehicles 2000 and more	V3
diesel	passenger vehicles below 1400 cm^3	V4
diesel	passenger vehicles 1400–1999 cm^3	V5
diesel	passenger vehicles 2000 and more	V6
LPG	LPG passenger vehicles	V7
petrol	light-duty vehicles, GVW < 3.5 t	T1
diesel	light-duty vehicles, GVW < 3.5 t	T2
diesel	heavy-duty vehicles, GVW 3.5–12 t	T3
diesel	heavy-duty vehicles, GVW > 12 t	T4
diesel	buses	B
petrol	motorcycles	M
electricity	passenger vehicles with a capacity of up to 0.15 kWh/km	E1
electricity	passenger vehicles with a capacity of up to 0.17 kWh/km	E2
electricity	passenger vehicles with a capacity of up to 20.5 kWh/km	E3
electricity	light-duty vehicles with a capacity of up to 0.18 kWh/km GVW < 3.5 t	E4
electricity	heavy-duty vehicles with a capacity of up to 0.27 kWh/km, GVW 3.5–12 t	E5
electricity	heavy-duty vehicles with a capacity of up to 1.33 kWh/km, GVW > 12 t	E6

Table 2. Emissivity indicators for conventional vehicles.

Vehicle Type	CH$_4$	CO	CO$_2$	N$_2$O	NO$_x$	PM$_{2.5}$	PM$_{10}$	NMVOC
V1	0.0038	0.5097	71.7926	0.0008	0.0724	0.0036	0.0055	0.0587
V2	0.0056	0.5070	83.7738	0.0011	0.1273	0.0037	0.0057	0.0594
V3	0.0070	0.5626	104.2086	0.0011	0.1736	0.0037	0.0057	0.0712
V4	0.0001	0.0061	29.6577	0.0019	0.1414	0.0066	0.0076	0.0011
V5	0.0006	0.0127	44.6658	0.0020	0.1952	0.0119	0.0131	0.0025
V6	0.0007	0.0161	60.7634	0.0019	0.1997	0.0132	0.0144	0.0052
V7	0.0055	0.9956	56.3022	0.0014	0.1947	0.0026	0.0040	0.0359
T1	0.0037	0.7613	82.9933	0.0018	0.0993	0.0040	0.0062	0.0268
T2	0.0003	0.1215	74.6871	0.0010	0.3498	0.0242	0.0260	0.0160
T3	0.0035	0.2172	83.8480	0.0039	1.0056	0.0303	0.0333	0.0621
T4	0.0132	0.5843	352.0844	0.0151	2.2247	0.0584	0.0700	0.0678
B	0.0097	0.2779	154.7508	0.0040	1.3161	0.0304	0.0339	0.0468
M	0.0169	2.1477	22.8067	0.0004	0.0392	0.0062	0.0067	0.3070

The presented pollutant emission indicators concern passenger or light-duty vehicles divided up by their main fuel types, i.e., diesel, petrol, and LPG. Their values make it possible to determine the emissivity of transport means in terms of the transports carried out and are similar in nature. In terms of CH$_4$ methane emissions, the emission indicator values increase along with the increasing capacities of petrol and diesel engines. The methane emissions generated by LPG vehicles are comparable to those of V2 type petrol

vehicles with cubic capacities of 1400–1999 cm^3. However, the highest methane emissivity indicators were obtained for T3 type heavy-duty vehicles, the gross vehicle weight of which exceeded 12 t, as well as buses and motorcycles. Carbon oxide emission indicators are similar for petrol vehicles, regardless of their cubic capacity, i.e., V1, V2, and V3. The situation is similar for V3, V4, and V6 type diesel vehicles. The highest emission values were recorded for motorcycles and V7 type vehicles.

Calculation of air pollutant emissions for conventional vehicles indicated in Table 1 is carried out using the statistical values of the indicators presented in Table 2 and in Figures 4–11, as well as the length of the road connecting the points of dispatch and collection of cargo or passengers covered by the types of vehicles, by the following equations:

$$E_{CH_4} = l(i,j) \times W_{1,k} \tag{1}$$

$$E_{CO} = l(i,j) \times W_{2,k} \tag{2}$$

$$E_{CO_2} = l(i,j) \times W_{3,k} \tag{3}$$

$$E_{NO_2} = l(i,j) \times W_{4,k} \tag{4}$$

$$E_{NO_X} = l(i,j) \times W_{5,k} \tag{5}$$

$$E_{PM_{2.5}} = l(i,j) \times W_{6,k} \tag{6}$$

$$E_{PM_{10}} = l(i,j) \times W_{7,k} \tag{7}$$

$$E_{NMVOC} = l(i,j) \times W_{8,k} \tag{8}$$

$$E_T = E_{CH_4} + E_{CO} + E_{CO_2} E_{NO_2} + E_{NO_X} + E_{PM_{2.5}} + E_{PM_{10}} + E_{NMVOC} \tag{9}$$

where individual symbols mean:

E_T—the total emission of air pollutants generated by the k-th vehicle type,
$l(i,j)$—the length of connecting the i-th sending point with the *j*-th receiving point,
$W_{1,k}$—CH$_4$ emission factor—taken from Table 2, for the k-th vehicle type,
$W_{2,k}$—CO emission factor—taken from Table 2, for the k-th vehicle type,
$W_{3,k}$—CO$_2$ emission factor—taken from Table 2, for the k-th vehicle type,
$W_{4,k}$—NO$_2$ emission factor—taken from Table 2, for the k-th vehicle type,
$W_{5,k}$—NO$_X$ emission factor—taken from Table 2, for the k-th vehicle type,
$W_{6,k}$—PM$_{2.5}$ emission factor—taken from Table 2, for the k-th vehicle type,
$W_{7,k}$—PM$_{10}$ emission factor—taken from Table 2, for the k-th vehicle type,
$W_{8,k}$—NMVOC emission factor—taken from Table 2, for the k-th vehicle type.

In contrast, carbon dioxide emission indicators increase along with increasing gross vehicle weight in each vehicle type group. The highest carbon dioxide emissions were recorded for T4 vehicles and buses. Carbon dioxide emissions of T4 type vehicles are over three times higher than those of the V3 type, and T1 and T2 type vehicles. The highest carbon dioxide emissivity indicators were recorded for T4 heavy-duty vehicles. In terms of nitrogen oxide and dioxide emissions, the values are clearly the highest for light-duty and heavy-duty vehicles. Particulate matter emissions in particular vehicle types increase in different engine cubic capacities. The exceptions are petrol vehicles, the PM$_{2.5}$ and PM$_{10}$ emissions which in V1, V2, and V3 type vehicles are very similar and do not increase along with an increasing engine cubic capacity. The highest particulate matter emissivity was recorded in T4 type vehicles.
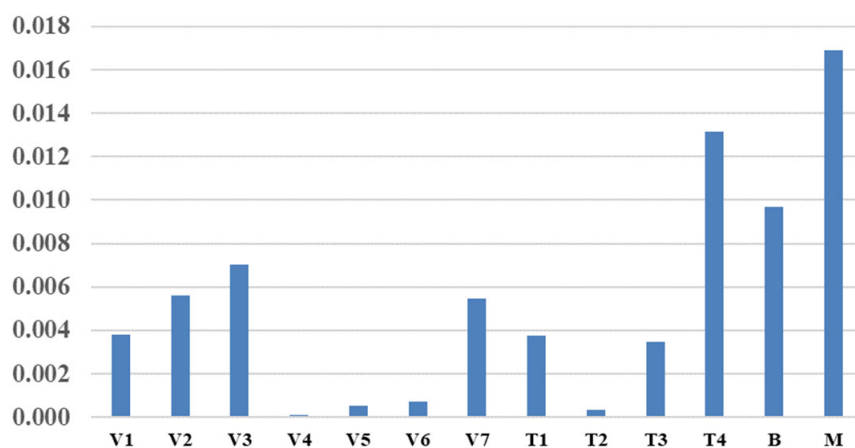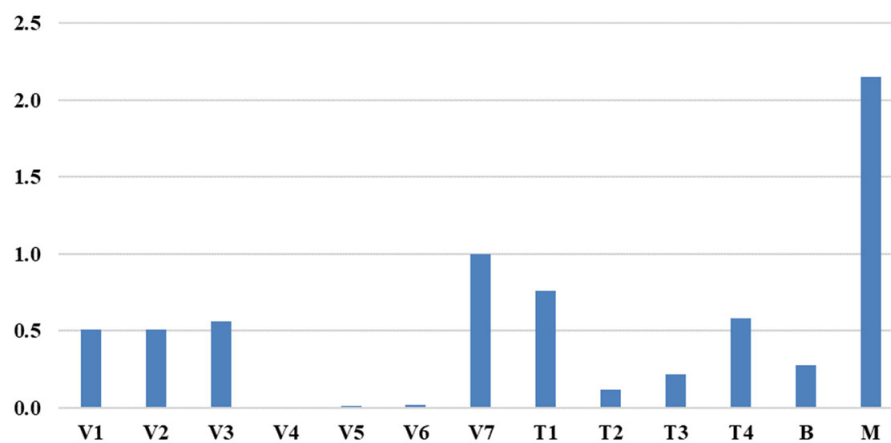
Figure 4. Indicators of methane emissions CH_4 (g/km).

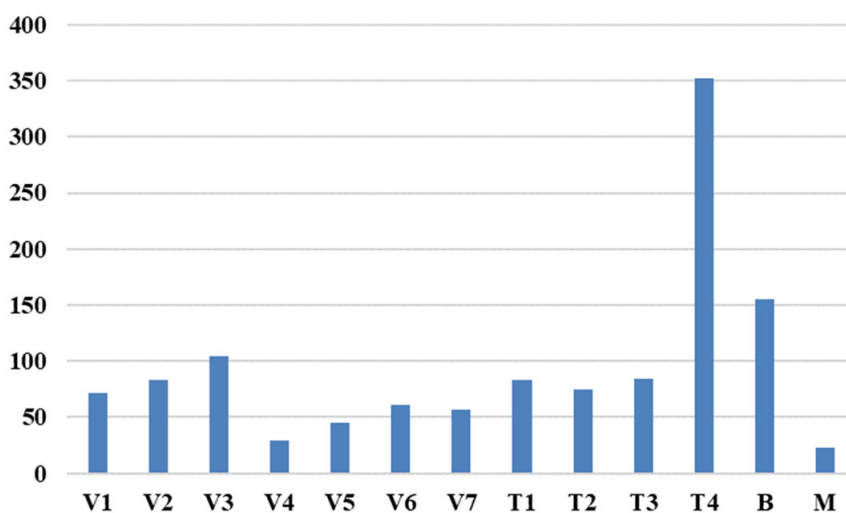**Figure 5.** Indicators of carbon oxide emissions CO (g/km).

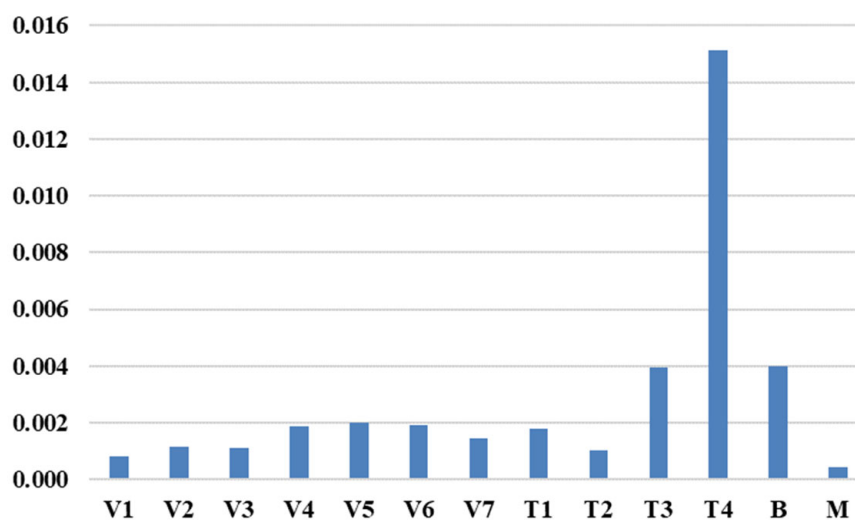**Figure 6.** Indicators of carbon dioxide emissions CO_2 (g/km).

Figure 7. Indicators of nitrogen emissions N_2O (g/km).
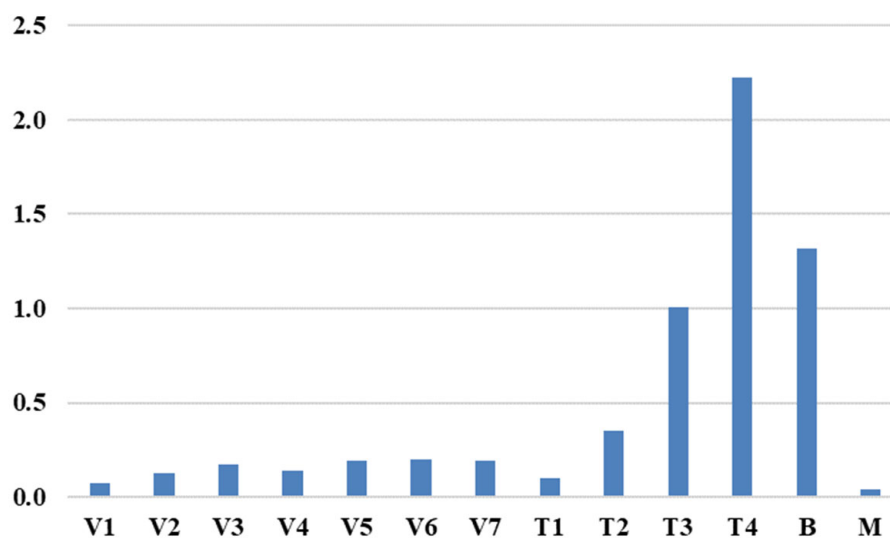
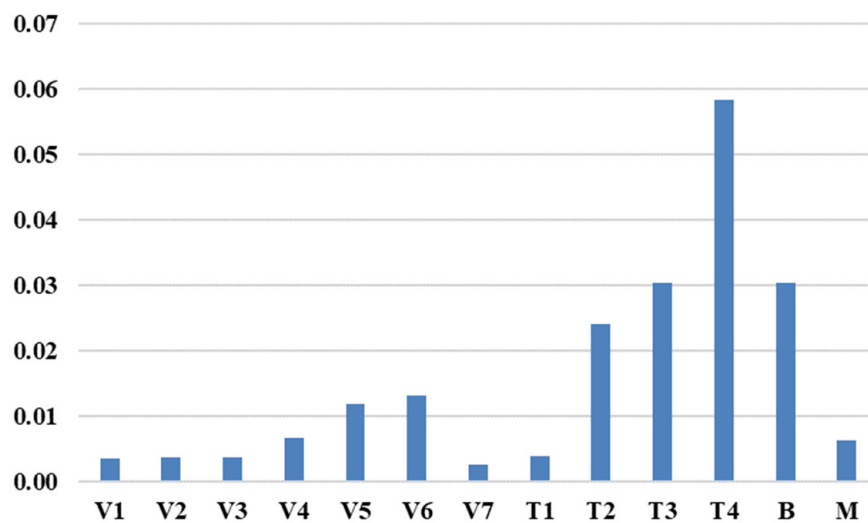

Figure 8. Indicators of nitrogen oxide emissions NO_x (g/km).

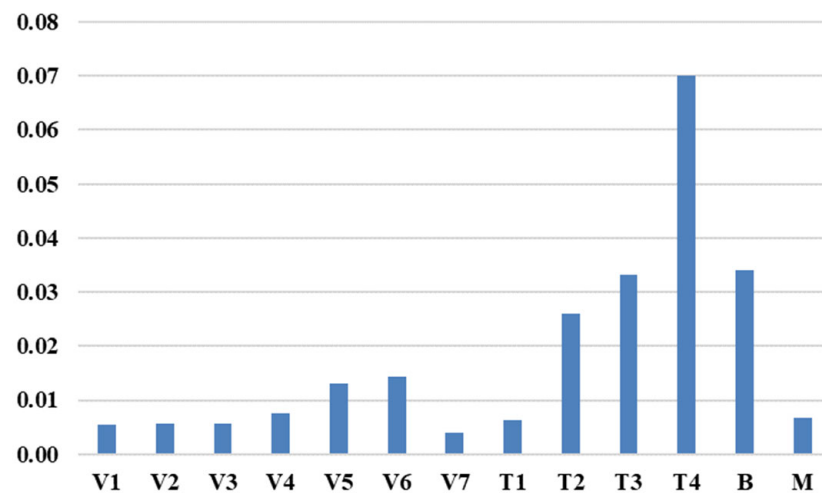**Figure 9.** Indicators of particulate matter emissions $PM_{2.5}$ (g/km).

Figure 10. Indicators of particulate matter emissions PM_{10} (g/km).
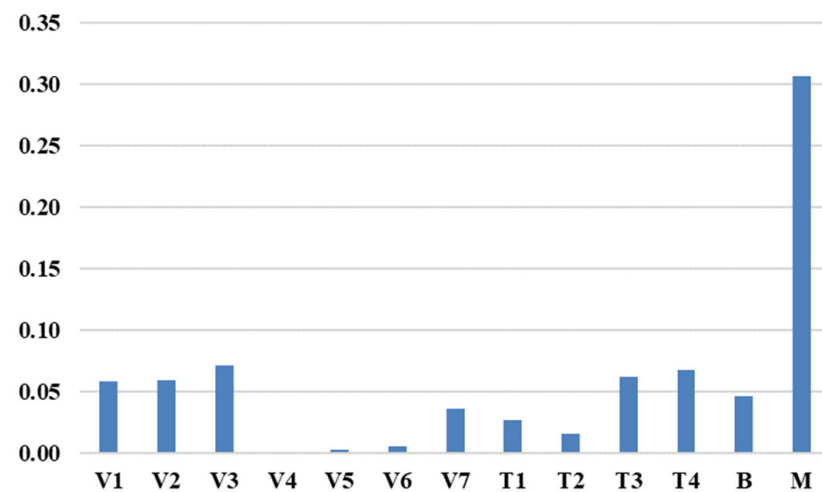

Figure 11. Indicators of non-methane volatile organic compound emissions NMVOC (g/km).

The analysis of statistical data made available by the National Centre for Emissions Management involved the determination of electric vehicle emissivity in terms of emissions generated at the electricity production location [41]. This led to the development of indicator tables intended for calculating the estimated emissivity of electric transport means in terms of the primary air pollutants, e.g., carbon oxide and dioxide, sulphur dioxide, nitrogen oxides, and total dust. The indicator values were determined with reference to 1 kWh of energy consumed by the vehicle (Figures 12–16). The emissivity of electric vehicles can be determined based on the electric engine's type and power. It must be noted that electric vehicle emissions mainly occur at the electricity production location; in order to limit this phenomenon, it is recommended to promote electricity production from renewable energy sources.

Table 3. Emissivity indicators for electric vehicles.

Vehicle Type	CO_2	SO_2	NO_x	CO	Total Dust
E1	108.190	0.0789	0.0809	0.0315	0.0040
E2	119.358	0.0870	0.0893	0.0347	0.0044
E3	143.090	0.1043	0.1070	0.0416	0.0053

Table 3. *Cont.*

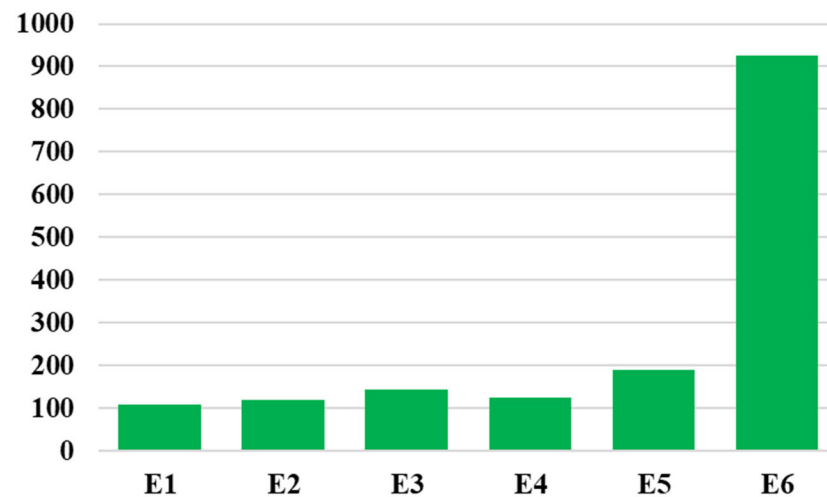| Vehicle Type	CO_2	SO_2	NO_x	CO	Total Dust
E4	125.64	0.0920	0.0940	0.0370	0.0050
E5	188.54	0.1370	0.1410	0.0550	0.0070
E6	924.85	0.6740	0.6920	0.2690	0.0340

Figure 12. Indicators of carbon dioxide emissions in electric vehicles CO_2 (g/km). $W_{5,k}$ —PM emission factor—taken from Table 3, for the k-th vehicle type.

Figure 13. Indicators of sulphur dioxide emissions in electric vehicles SO_2 (g/km).

The ability to carry out comparative analyses of emissions generated by electric and conventional vehicles is limited due to the extent of the data collected by KOBIZE and the different nature of the pollutants monitored at electricity production locations compared to pollutant emissions generated by conventional vehicles. However, the indicators that can be compared are carbon dioxide, carbon oxide, and nitrogen oxides. In addition, it is possible to determine the sulphur dioxide emission indicator for electric vehicles based on statistical data. This is due to the fact that most electricity in Poland is produced from fossil fuels, which are rich in sulphur compounds. The pollutant emission indicators for electric vehicles refer to passenger or light-duty and heavy-duty vehicles and are derived directly from statistical data analysis. The emission indicators of E1, E2, and E3 type electric vehicles, referring to sulphur dioxide, carbon oxide, carbon dioxide, and nitrogen oxides, increase along with increasing electric engine capacities. The situation is similar for E4

and E5 type light-duty electric vehicles, whereas, in E6 light-duty vehicles, the emissivity indicators increase substantially.

Figure 14. Indicators of nitrogen dioxide emissions in electric vehicles NO_x (g/km).
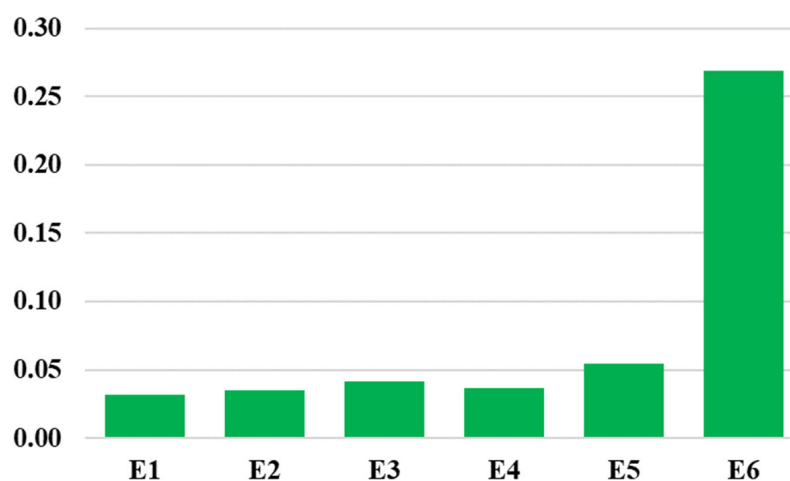

Figure 15. Indicators of carbon oxide emissions in electric vehicles CO (g/km).

Figure 16. Indicators of total dust emissions in electric vehicles total dust (g/km).

Calculation of air pollutant emissions for electric vehicles indicated in Table 1 is carried out using the statistical values of the indicators presented in Table 3, as well as the length

of the road connecting the points of dispatch and collection of cargo or passengers covered by the types of electric vehicles, by the following equations:

$$EV_{CO_2} = l(i,j) \times W_{1,k} \tag{10}$$

$$EV_{SO_2} = l(i,j) \times W_{2,k} \tag{11}$$

$$EV_{CO} = l(i,j) \times W_{3,k} \tag{12}$$

$$EV_{NO_X} = l(i,j) \times W_{4,k} \tag{13}$$

$$EV_{PM} = l(i,j) \times W_{5,k} \tag{14}$$

$$E_{TV} = EV_{CO_2} + EV_{SO_2} + EV_{CO} + EV_{NO_X} + E_{VPM} \tag{15}$$

where individual symbols mean:

E_{TV}—the total emission of air pollutants generated by the k-th electric vehicle type,

$l(i,j)$—the length of connecting the *i*-th sending point with the *j*-th receiving point,

$W_{1,k}$—CO_2 emission factor—taken from Table 3, for the k-th vehicle type,

$W_{2,k}$—SO_2 emission factor—taken from Table 3, for the k-th vehicle type,

$W_{3,k}$—CO emission factor—taken from Table 3, for the k-th vehicle type,

$W_{4,k}$—NO_X emission factor—taken from Table 3, for the k-th vehicle type,

5. Verification of the Indicator Method for Emissivity Evaluation

The indicator values provided in Tables 2 and 3 were verified by comparison with real air pollutant emissivity values based on real measurements carried out on selected passenger and light-duty vehicle types [26,42]. The basic technical parameters of test vehicles are presented in Table 4. The emissivity measurements evolve along with the development of air pollutant emission standards. Dynamic road conditions were not taken into account in laboratory tests, hence the tests did not fully reflect the reality. For this reason, researchers started to carry out exhaust emission measurements in real traffic conditions. RDE tests were introduced by the Regulation of the European Union no. 2016/646 [43]. The results of the T2 vehicle's real emissivity were taken from literature data [26]. Tests were also carried out for a hybrid engine vehicle. Due to the lack of specific emission indicator values for hybrid vehicles, RDE test results allowed conductance of a comparative analysis of the emission indicators achieved by petrol and diesel vehicles with those of hybrid engine vehicles. The hybrid vehicle tested in terms of real emissivity was equipped with a petrol engine and an electric engine. The test vehicles were characterised by the Euro 6 pollutant emission standard (V3 and V6), while the light-duty vehicle was equipped with a diesel engine that met the Euro 5 standard (T2).

Table 4. Basic technical parameters of test vehicles.

Vehicle Feature/Type	V3	V6	HYBRID	T2
engine type	Petrol engine	Diesel engine	Petrol and electric engines	Diesel engine
engine cubic capacity	1984 cm^3	1968 cm^3	1798 cm^3	1968 cm^3
vehicle mass	1349 kg	1651 kg	1536 kg	1660 kg
emission standard	Euro 6	Euro 6	Euro 6 d-Temp	Euro 5
declared CO_2 emissions	139 g/km	119 g/km	80 g/km	162 g/km

Table 4. *Cont.*

Vehicle Feature/Type	V3	V6	HYBRID	T2
fuel consumption	7.3 L/100 km	6.8 L/100 km	5.0 L/100 km	9.0 L/100 km
vehicle type	V3	V6	-	T2
Vehicle brand	Volkswagen Golf	Volkswagen Arteon	Toyota Prius	Volkswagen Transporter

The emissivity tests on V3, V6, and hybrid type passenger vehicles were carried out during RDE tests in the Poznań urban area with the use of test equipment placed inside the vehicle and in the trunk, i.e., the SEMTECH DS gaseous exhaust components analyser and the EEPS 3090 mass spectrometer for measuring particulate matter. The vehicles, along with the measuring equipment were prepared accordingly prior to testing, i.e., they were exposed to a 20 °C temperature without external climate exposure. The gaseous exhaust components were measured with the analyser. An exhaust fume collection system, in which the exhaust fumes moved at a temperature of 191 °C to prevent water condensation, was mounted between the exhaust analyser and the vehicle's exhaust system. After the exhaust fumes were fed to the analyser through a special filter, the particulate matter was separated, and the exhaust fumes were fed into the flame ionisation detector (FID), in which the concentration of hydrocarbons was measured. Then, the exhaust fumes were cooled down to a temperature of 4 °C and moved to the non-dispersive ultraviolet radiation (NDUV) analyser in which the concentration of nitrogen oxides was determined. The exhaust fumes mixture was then fed into the non-dispersive infrared radiation (NDIR) analyser to measure the concentration of carbon oxide and dioxide. Finally, the SEMTECH DS device measured the oxygen concentration using an electro-chemical analyser. Additionally, the separated particulate matter was fed into the second TSI analyser (particulate matter counter). However, in the case of the particulate matter results, the test featured a comparative analysis of the statistically determined emissivity with literature data used to calculate the generated particulate matter mass based on the given vehicle's fuel consumption per 100 km [42]. Each vehicle travelled 100 km distance during the tests. During the verification of the IM indicator method, it was assumed that each vehicle type travels a distance of 100 km. The list of results of the vehicles' total emissivity determined using the IM and RDE methods is presented in Figures 17–20. The comparison was provided for four primary air pollutants, i.e., CO, CO_2, PM, and NO_X. In addition, conventional vehicles' emission (V3, V6, T2) and hybrid vehicle performance were compared with an electric vehicle's emission performance. A Nissan Leaf vehicle (E2) with a power consumption up to 0.17 kWh/km was selected for the comparative analysis.
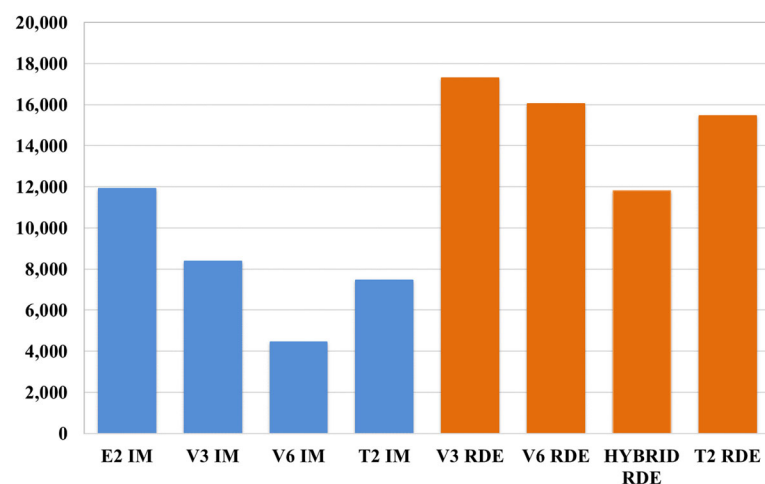
Figure 17. Comparison of the carbon dioxide emissions in the IM and RDE methods, CO_2 (g/km).
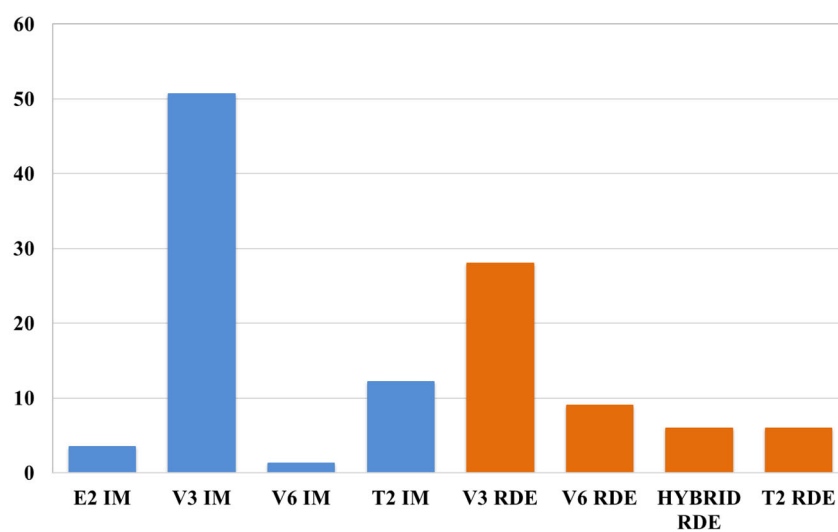
Figure 18. Comparison of the carbon oxide emissions in the IM and RDE methods, CO (g/km).
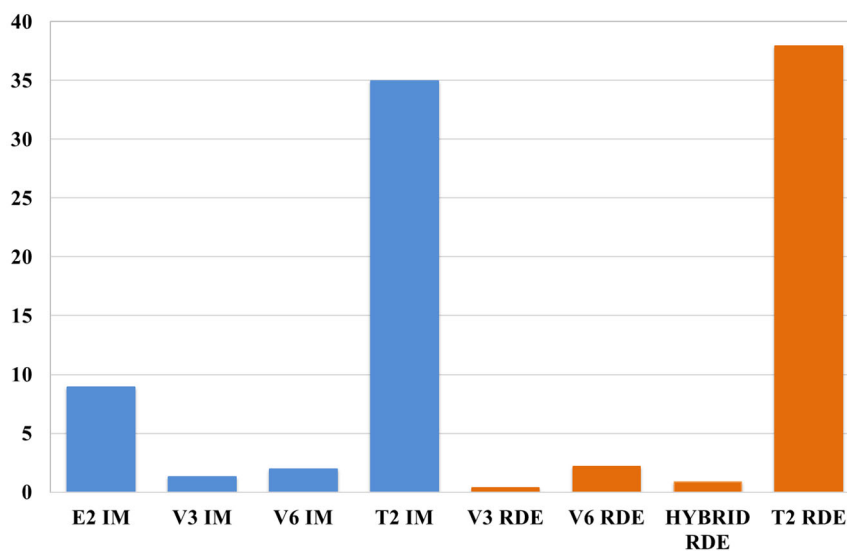

Figure 19. Comparison of the nitrogen oxide emissions in the IM and RDE methods, NO_x (g/km).
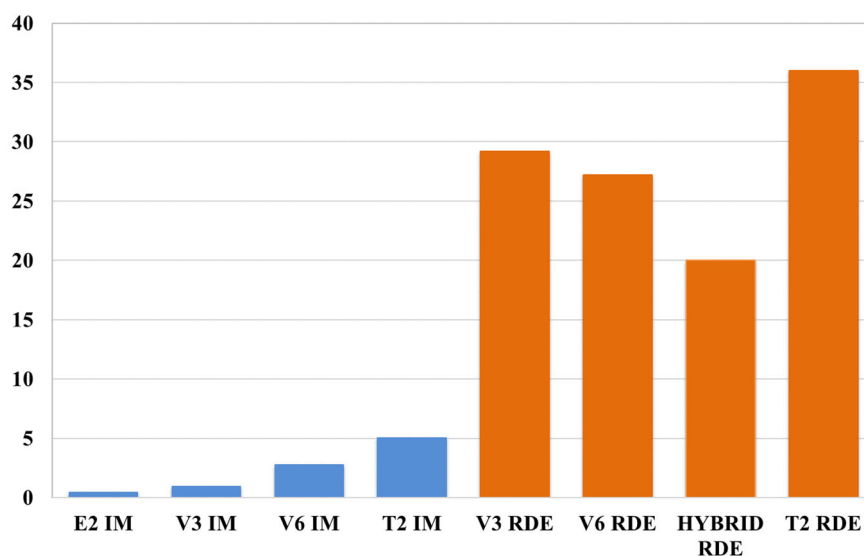

Figure 20. Comparison of the particulate matter emissions in the IM and RDE methods, PM (g/km).

The IM method's carbon dioxide emissions turned out to be lower than those obtained in the RDE tests for each of the analysed vehicle types. The emissions determined by the IM method for V3 and T2 type vehicles were twice as high as the values obtained in the RDE tests, while the emissivity of the V6 type vehicle was three times higher. However, it is noteworthy that the proportions of the obtained emission results and trends were maintained. The emissivity of the V3 petrol vehicles is higher in both methods than that of the V6 diesel vehicles. On the other hand, the emissivity of the T2 light-duty vehicles is lower than that of the V3 petrol vehicles but higher than the emissivity of the V6 vehicles. The smallest difference between the emissivity obtained in the IM method and the RDE tests was recorded when hybrid vehicle results were compared. In terms of carbon oxide emissions, the pollutant emission values determined by the IM method for the V3 and T2 vehicles turned out to be higher by almost half than those obtained in the RDE tests for both vehicle types. For the V6 type vehicle, the air pollutant emissions determined by the IM method were over three times lower than pollutant emissions obtained in the RDE tests. The measured carbon oxide emissions of the hybrid vehicle were not substantially lower than those of other vehicle types.

As a result of the comparative analyses, it can be seen that carbon dioxide emission in the RDE tests is higher, on average, by 100% than the emission value calculated based on the indicator method. Concerning carbon oxide emissions, the emissions of the V3 and T2 vehicles in road tests are lower by nearly 50% compared to the emission value calculated under the indicator method. The reverse situation is observed for the V6 vehicle. Regarding nitrogen oxide emissions, the emission results obtained using the indicator method and RDE tests do not show significant differences. The values of total dust emissions using the indicator method are over nine times lower than the results obtained in RDE tests. Very similar results were obtained for nitrogen oxides, and the emission values determined using the IM method were almost twice as low as those obtained in the RDE tests. The highest differences in results were recorded for particulate matter emissions. The comparative analysis of the PM emissions in the IM method was carried out based on the calculation of the generated pollutant and particulate matter mass in relation to the fuel consumption.

The adopted emission values in the article for electric vehicles are appropriate for the Polish energy system, in which nearly 80% of electricity is produced from fossil fuels. It can therefore be concluded that the emission of electric vehicles occurs at the place of electricity production. Notably, the emission does not occur at the location of vehicle operation, which is essential for implementing transport in urban areas. Electric vehicles (E2) were subjected to a comparative analysis with the number of pollutant emissions recorded in road tests to verify the indicator method. The carbon dioxide emissions of electric vehicles are comparable to the CO_2 emissions of hybrid vehicles (Hybrid RDE). The carbon oxide emissions of electric vehicles are 40% lower than the average emission value obtained in RDE tests for all tested vehicles. On the other hand, the emission of nitrogen oxides from electric vehicles is higher by about 20% than the average emissions recorded in road tests for all tested vehicles. PM emissions for electric vehicles do not differ significantly from the emission results for other types of vehicles in the IM method.

The above analyses enabled the determination of corrective factors for air pollutant emissions determined by the IM method for the V3, V6, and T2 vehicle types covered in the RDE tests. The values of the corrective factors are presented in Table 5. The corrective factors increase or decrease the original emission value calculated by the IM method and allow the determination of approximate air pollutant emissions. The indicators highlighted in italics in Table 5 require a reduction in the emissivity determined by the IM method, while other values require an increase in the emissivity determined by this method.

The above corrective factors and RDE test results demonstrate the results of tests and observations carried out for three vehicle types. The differences in the obtained results might have been different had the test vehicle population been more numerous. It is advisable to carry out extended RDE tests for all vehicle types set out in Table 1 in order to verify the IM method's usefulness for the complete set of vehicle types.

Table 5. Correction factors.

Vehicle Type	CO$_2$	CO	NO$_X$	PM
	[g/100 km]			
V3 IM	1.07	*0.45*	*0.73*	30.26
V6 IM	2.68	3.61	1.19	8.85
T2 IM	0.92	*0.51*	0.96	6.17

6. Example of Calculation

The research work involved an analysis of the emissivity of various transport means that carried out transport work in specific, real-life transport relations. Real transport plans of a distribution company located in the Mazowieckie Voivodeship and emissivity indicators determined by the aforementioned MI method were used in the analysis. The emissivity of three vehicle types, i.e., V3, V6, and T2, assigned to different vehicle groups depending on the fuel type used, were analysed by using the monthly real total distance travelled by vehicles. The analysis was carried out for indicator values determined by the IM method and taking into account the corrective factors. The analysis results are presented in Figures 21–24.
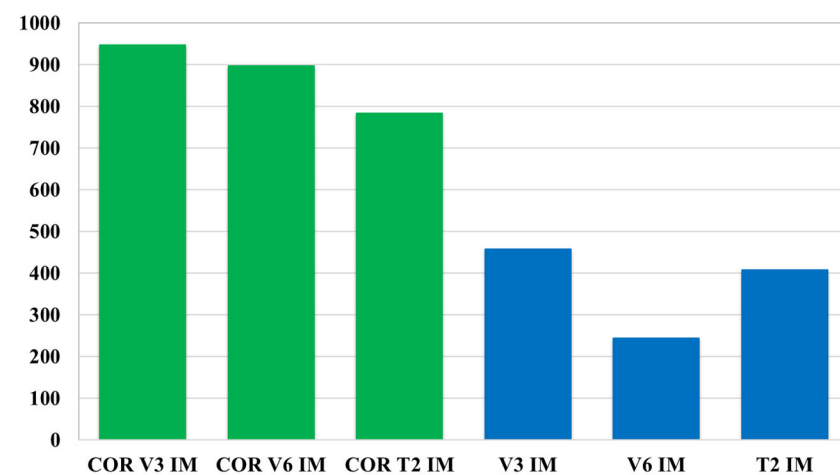
Figure 21. Carbon dioxide emissions before and after correction CO$_2$ (kg).
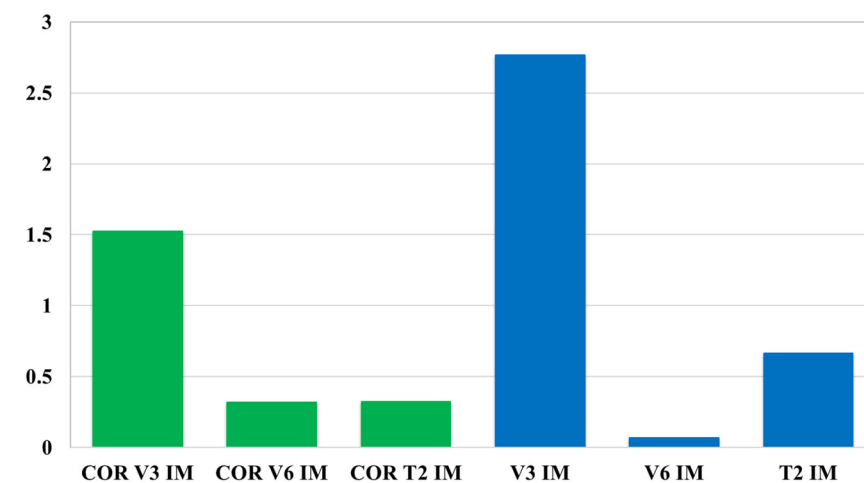
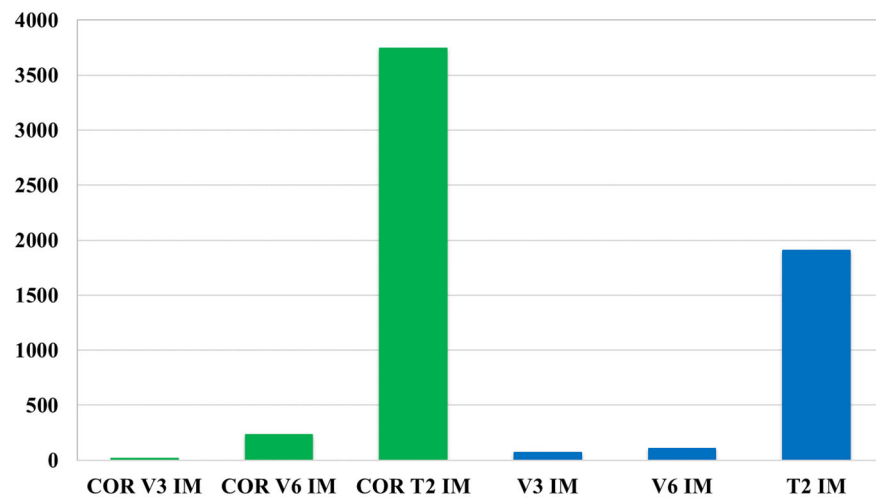**Figure 22.** Carbon oxide emissions before and after correction CO (kg).

Figure 23. Nitrogen oxide emissions before and after correction NO_x (g).
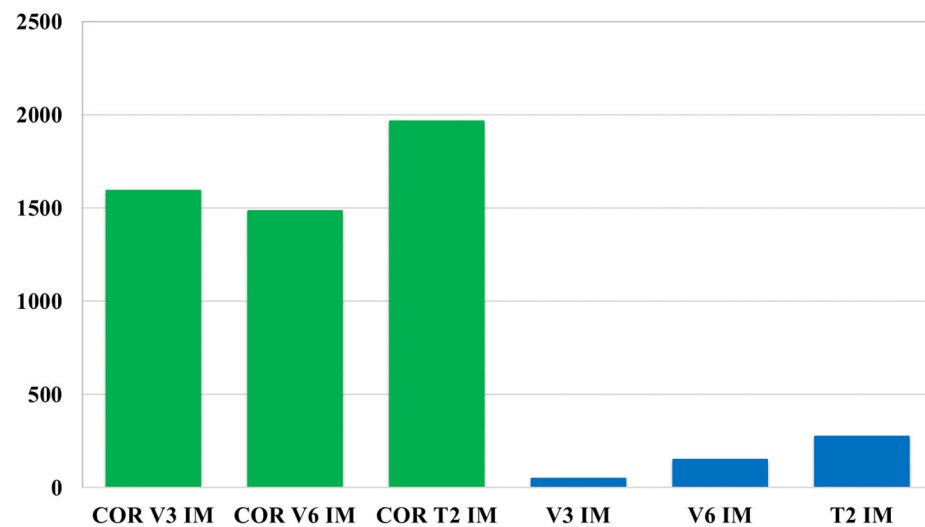

Figure 24. Particulate matter emissions before and after correction PM (g).

Knowing the total real distance travelled by given transport means in the transport company, it is possible to determine the emissivity of main air pollutants by using the corrected IM method.

7. Conclusions

Based on statistical data and taking into account the corrective factors, the IM indicator enables the determination of the emissivity of primary air pollutants generated by various types of transport means. The method allows emissivity results for given vehicle types to be obtained quickly and in a manner comparable to RDE tests. Freight transport organisation, e.g., in urban areas that optimises the delivery process in terms of costs can be combined with the calculation of the emissivity of transport means and the external costs generated. In this way, delivery planning can become more sustainable, and the selection of transport means with lower emissivity can contribute to reducing the transport's negative impact on the surroundings. The results obtained make it possible to illustrate the emissivity of main air pollutants by the most common road transport means used for freight and passenger transport. However, a complete verification of the IM method required carrying out RDE tests for all vehicle types set out in Table 1.

As was mentioned above, the proposed method is an innovative approach to estimating the emission of primary air pollutants. It can be developed by considering other factors

that significantly impact the multiplicity of pollutant emissions, such as the age of vehicles, mileage, and general technical condition.

In the coming years, an increase in the prices of propellants is assumed at the levels observed over the last five years. The rise in gasoline, diesel oil, and gas prices from 2017 to 2022 amounted to nearly 50%. Regarding electricity, the price increases were lower and amounted to over 20% over the last five years. Assuming the same growth dynamics in the subsequent five-year periods, a scenario of increases in the prices of propellants in 2027 and 2032 is possible. In 2007–2017, petrol prices increased by nearly 8%, diesel prices by almost 15%, and electricity prices by 30%. The smallest increase in prices was recorded for LPG. Nevertheless, the situation in the last five years had a significant impact on the rise in the price of propellants. Despite the end of restrictions resulting from the pandemic, no significant decrease in fuel prices has been observed. The prices of the propellants forecast included the pandemic period, which turned out to be an exceptional situation. However, the situation in Ukraine is equally unique and challenging to predict. Considering the abovementioned, in the following years, using low-emission vehicles and producing electric energy from renewable sources will be developed. It has a good relationship with reducing the emission of primary air pollutants from transport activity. Indicator methods can support the design of urban areas and transport planning regarding environmental aspects.

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References

1. *Standard ISO 140 67:2018*; Greenhouse Gases—Carbon Footprint of Products - Quantification Requirements and Guidance. ISO: Geneva, Switzerland, 2018.
2. *Standard ISO 14064:2019*; Greenhouse Gases—Part 1 (Specification and Guidelines for Quantifying and Reporting Greenhouse Gas Emissions and Removals at the Organization Level), Part 2 (Specification and Guidelines for Quantifying, Monitoring and Reporting Emission Reductions and Increasing Removals of Greenhouse Gases at the Project Level) and Part 3 (Specification and Guidance for the Verification and Validation of Greenhouse Gas Claims). ISO: Geneva, Switzerland, 2019.
3. Zych-Lewandowska, M.; Jakubowski, B.; Reda, K.; Sikora, K. Rail for Climate-Climate for Rail. In *Transport Policy and Ecology*; Prokolej Foundation—Summary Report; Pro Kolej Foundation: Warszawa, Poland, 2021.
4. Jacyna, M.; Żochowska, R.; Sobota, A.; Wasiak, M. Scenario analyses of exhaust emissions reduction through the introduction of electric vehicles into the city. *Energies* **2021**, *14*, 2030. [CrossRef]
5. European Union Law. Available online: https://eur-lex.europa.eu/ (accessed on 14 March 2023).
6. Jacyna, M.; Wasiak, M.; Lewczuk, K.; Kłodawski, M. Simulation model of transport system of Poland as a tool for developing sustainable transport. *Arch. Transp.* **2014**, *31*, 23–35. [CrossRef]
7. Gołda, I.J.; Gołębiowski, P.; Izdebski, M.; Kłodawski, M.; Jachimowski, R.; Szczepański, E. The evaluation of the sustainable transport system development with the scenario analyses procedure. *J. Vibroeng.* **2017**, *19*, 5627–5638. [CrossRef]
8. Sitnik, L.J. Operational energy footprint of vehicle. *Combust. Engines* **2021**, *60*, 37–40. [CrossRef]
9. Zych-Lewandowska, M.; Domagała, J.; Klepacki, B. *Negatywne Efekty Zewnętrzne Transportu w Teoriach Ekonomicznych Oraz Metody ich Szacowania [Negative External Effects of Transport in Economic Theories and Methods of Their Estimation]*; SGGW Publishing House: Warszawa, Poland, 2020.
10. European Parliament. Available online: https://www.europarl.europa.eu/news/pl/headlines/society/20190926STO62270/czym-jest-neutralnosc-emisyjna-i-jak-mozemy-ja-osiagnac-do-2050-r (accessed on 16 March 2023).
11. European Environment Agency. Available online: https://www.eea.europa.eu/signals/signals-2022/infographics/what-are-the-sources-of/view (accessed on 27 March 2023).

12. Emisia, Conscious of Transport's Impact. Available online: https://www.emisia.com/utilities/copert/ (accessed on 21 February 2023).

13. Agarwal, A.K.; Mustafi, N.N. Real-world automotive emissions: Monitoring methodologies, and control measures. *Renew. Sustain. Energy Rev.* **2021**, *137*, 110624. [CrossRef]

14. European Parliament. Available online: https://www.europarl.europa.eu/news/pl/headlines/society/20190313STO31218/emisje-co2-z-samochodow-fakty-i-liczby-infografiki (accessed on 21 February 2023).

15. Spławińska, M. Ocena szacowania średniego dobowego ruchu (SDR) wykorzystującego wskaźniki przeliczeniowe [Evaluation of the average daily traffic (ADT) estimation with the use of conversion factors]. *Drogownictwo* **2010**, *7–8*, 267–272.

16. Chłopek, Z. *Ekologiczne Aspekty Motoryzacji i Bezpieczeństwo Ruchu Drogowego [Environmentally Friendly Aspects of the Automotive Industry and Road Traffic Safety]*; SIM Publishing House: Boston, MA, USA, 2012.

17. Merkisz, J.; Pielecha, J.; Nowak, M.; Andrzejewski, M.; Molik, P. Emisja zanieczyszczeń ze środków transportu podczas przejazdu wybranym odcinkiem infrastruktury drogowej [Pollutant emissions by transport means driven on a selected road infrastructure section]. *Logistyka* **2014**, *3*, 4302–4310.

18. Skobiej, K.; Pielecha, J. Analysis of the Exhaust Emissions of Hybrid Vehicles for the Current and Future RDE Driving Cycle. *Energies* **2022**, *15*, 8691. [CrossRef]

19. Suarez-Bertoa, R.; Valverde, V.; Clairotte, M.; Pavlovic, J.; Giechaskiel, B.; Franco, V.; Astorga, C. On-road emissions of passenger cars beyond the boundary conditions of the real-driving emissions test. *Environ. Res.* **2019**, *176*, 108572. [CrossRef]

20. Pielecha, J.; Skobiej, K.; Kurtyka, K. Exhaust emissions and energy consumption analysis of conventional, hybrid, and electric vehicles in real driving cycles. *Energies* **2020**, *13*, 6423. [CrossRef]

21. Sitnik, L.J.; Ivanov, Z.D.; Sroka, Z.J. Energy demand assessment for long term operation of hybrid electric vehicles. In *IOP Conference Series: Materials Science and Engineering*; IOP Publishing: Bristol, UK, 2020; Volume 1002, p. 012026.

22. Mądziel, M.; Campisi, T.; Jaworski, A.; Tesoriere, G. The development of strategies to reduce exhaust emissions from passenger cars in Rzeszow city—Poland. a preliminary assessment of the results produced by the increase of e-fleet. *Energies* **2021**, *14*, 1046. [CrossRef]

23. Lejda, K.; Jaworski, A.; Mądziel, M.; Balawender, K.; Ustrzycki, A.; Savostin-Kosiak, D. Assessment of petrol and natural gas vehicle carbon oxides emissions in the laboratory and on-road tests. *Energies* **2021**, *14*, 1631. [CrossRef]

24. Rosero, F.; Fonseca, N.; López, J.M.; Casanova, J. Effects of passenger load, road grade, and congestion level on real-world fuel consumption and emissions from compressed natural gas and diesel urban buses. *Appl. Energy* **2021**, *282*, 116195. [CrossRef]

25. Wang, H.; Ge, Y.; Hao, L.; Xu, X.; Tan, J.; Li, J.; Yang, R. The real driving emission characteristics of light-duty diesel vehicle at various altitudes. *Atmos. Environ.* **2018**, *191*, 126–131. [CrossRef]

26. Nowak, M.; Rymaniak, Ł.; Fuć, P.; Andrzejewski, M.; Daszkiewicz, P. Badania emisji składników gazowych i cząstek stałych lekkiego pojazdu dostawczego w rzeczywistych warunkach eksploatacji. [Testing the emissions of gaseous components and particulate matter by a light-duty commercial vehicle in real operating conditions]. *Autobusy Tech. Eksploat. Syst. Transp. [Buses Technol. Oper. Transp. Syst.]* **2017**, *18*, 327–331.

27. Sokolnicka, B.; Fuć, P.; Szymlet, N.; Siedlecki, M.; Grzeszczyk, R. Harmful exhaust components and particles mass and number emission during the actual drive of a passenger car in accordance with the RDE procedure. *Combust. Engines* **2019**, *58*, 198–202. [CrossRef]

28. Sitnik, L.J.; Sroka, Z.J.; Andrych-Zalewska, M. The Impact on Emissions When an Engine Is Run on Fuel with a High Heavy Alcohol Content. *Energies* **2020**, *14*, 41. [CrossRef]

29. Costagliola, M.A.; Costabile, M.; Prati, M.V. Impact of road grade on real driving emissions from two Euro 5 diesel vehicles. *Appl. Energy* **2018**, *231*, 586–593. [CrossRef]

30. Triantafyllopoulos, G.; Katsaounis, D.; Karamitros, D.; Ntziachristos, L.; Samaras, Z. Experimental assessment of the potential to decrease diesel NOx emissions beyond minimum requirements for Euro 6 Real Drive Emissions (RDE) compliance. *Sci. Total Environ.* **2018**, *618*, 1400–1407. [CrossRef]

31. Rymaniak, Ł.; Kamińska, M.; Szymlet, N.; Grzeszczyk, R. Analysis of harmful exhaust gas concentrations in cloud behind a vehicle with a spark ignition engine. *Energies* **2021**, *14*, 1769. [CrossRef]

32. Mendoza-Villafuerte, P.; Suarez-Bertoa, R.; Giechaskiel, B.; Riccobono, F.; Bulgheroni, C.; Astorga, C.; Perujo, A. NOx, NH$_3$, N$_2$O and PN real driving emissions from a Euro VI heavy-duty vehicle. Impact of regulatory on-road test conditions on emissions. *Sci. Total Environ.* **2017**, *609*, 546–555. [CrossRef]

33. Fontaras, G.; Zacharof, N.G.; Ciuffo, B. Fuel consumption and CO$_2$ emissions from passenger cars in Europe–Laboratory versus real-world emissions. *Prog. Energy Combust. Sci.* **2017**, *60*, 97–131. [CrossRef]

34. Zhai, Z.; Xu, J.; Zhang, M.; Wang, A.; Hatzopoulou, M. Quantifying start emissions and impact of reducing cold and warm starts for gasoline and hybrid vehicles. *Atmos. Pollut. Res.* **2023**, *14*, 101646. [CrossRef]

35. Davoudi, S.; Sturzaker, J. Urban form, policy packaging, and sustainable urban metabolism. *Resour. Conserv. Recycl.* **2017**, *120*, 55–64. [CrossRef]

36. Battistini, R.; Nalin, A.; Simone, A.; Lantieri, C.; Vignali, V. How to do University Student Cyclists Ride? The Case of the University of Bologna. *Appl. Sci.* **2022**, *12*, 11569. [CrossRef]

37. Lu, D.N.; He, H.D.; Zhao, H.M.; Lu, K.F.; Peng, Z.R.; Li, J. Quantification of traffic-related carbon emission on elevated roads through on-road measurement. *Environ. Res.* **2023**, *231*, 116200. [CrossRef] [PubMed]

38. Frey, H.C.; Zhang, K.; Rouphail, N.M. Fuel use and emissions comparisons for alternative routes, time of day, road grade, and vehicles based on in-use measurements. *Environ. Sci. Technol.* **2008**, *42*, 2483–2489. [CrossRef]

39. Sharma, A.; Massey, D.D.; Taneja, A. A study of the horizontal distribution pattern of particulate and gaseous pollutants based on ambient monitoring near a busy highway. *Urban Clim.* **2018**, *24*, 643–656. [CrossRef]

40. Wegner, M.; Andrychowska, A.; Bawelska, A.; Bącela, K. *Opracowanie Metodyki i Oszacowanie Kosztów Zewnętrznych Emisji Zanieczyszczeń do Powietrza [Establishment of Methodology and Estimation of the External Costs of Air Pollutant Emissions by Road Transport Means at the National Level–Statistics Poland's Report]*; Statistics Poland's Centre for Statistical Research and Education: Warsaw, Poland, 2018.

41. Report on CO2, SO2, NOX, CO and Total Dust Emissivity Indicators for Electricity Based on Information Contained in the National Database of the Emissions of Greenhouse Gases and other Substances in 2021. Available online: https://www.kobize.pl/uploads/materialy/materialy_do_pobrania/wskazniki_emisyjnosci/Wska%C5%BAniki_emisyjno%C5%9Bci_dla_energii_elektrycznej_grudzie%C5%84_2022.pdf (accessed on 5 May 2023).

42. Pielecha, P. Analiza Porównawcza Emisji Spalin na Przykładzie Wybranych Pojazdów Osobowych w Rzeczywistych Warunkach Ruchu Drogowego [Comparative Analysis of Exhaust Fume Emissions Based on the Example of Selected Passenger Vehicles in Real Road Traffic Conditions]. Bachelor's Thesis, Faculty of Transport of the Warsaw University of Technology, Warsaw, Poland, 2023.

43. Regulation of the Commission (EU) no. 2016/427 of 10 March 2016 amending Regulation (EC) no. 692/2008 as Regards Emissions from Light Passenger and Commercial Vehicles. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32016R0427 (accessed on 5 May 2023).