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Environmental Sustainability of the Vehicle Fleet Change in Public City Transport of Selected City in Central Europe

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Abstract: Diesel is the most used fuel for buses and other urban transport vehicles in European countries. This paper deals with impacts on emissions production from the operation of the urban public transport fleet after its renewal. To what extent can the renewal of the urban public transport fleet in the city of Žilina contribute to increasing environmental sustainability in the way of reducing air pollution? The vehicle fleet change has partially consisted of vehicle traction system transition-diesel buses were substituted by hybrid driven (HEV) and electric driven buses (BEV). How can the direct and indirect emissions from the operation of vehicles be calculated? These were the posed research questions. The research aimed to propose a methodology for the calculation of direct and indirect emissions. Indirect emissions values (WtT—Well-to-Tank) for different types of fuels and tractions were obtained based on regression functions. These WtT emission factors together with the existing TtW (Tank-to-Wheels) emission factors (direct emissions) can be used for the assessment of environmental impacts of specific types of vehicles concerning energy source, fuel, or powertrain and type of operation. Direct pollutants such as CO, NO_x and PM were calculated with the use of simulation methodology of HBEFA (Handbook of Emission Factors for Road Transport) software. The calculated CO_2 savings for the period 2019–2023 about fleet renewal in absolute terms are EUR 1.3 million tons compared to the operation of the original fleet while maintaining the same driving performance. The renewal of the vehicle fleet secured by vehicle traction transition can be a way to reduce the energy intensity and environmental impacts of public transport in Žilina.

Keywords: public transport; vehicle fleet change; vehicle traction transition; electric vehicles; direct and indirect emissions; environmental sustainability

1. Introduction and Literature Review

The Europe 2020 strategy for smart, sustainable and inclusive growth sets out five headline targets, which determine the position where Europe should be in 2020. One of these targets is related to climate and energy. Member States have committed to reduce their greenhouse gas emissions by 20% by 2020, to increase the share of renewable energy sources in the EU energy mix to 20% and to achieve the 20% energy efficiency improvement. The EU is currently on the right track to achieve two of the above targets, but it will not be able to meet the energy efficiency target without further action [1].

Air protection is one of the areas where the EU is highly active because of the need to ensure cleaner air. Air pollution can significantly harm human health and the environment. Annually, up to 400,000 premature deaths in the EU are caused by poor air quality [2]. Action is being taken at EU and national level as well as through active cooperation at international conventions level. The aim is to improve air quality by controlling emissions of pollutants into the atmosphere improving fuel quality and integrating environmental protection requirements into other sectors e.g., transport, energy [2]. The transition to a competitive low carbon economy means that the EU should be prepared to ensure that by 2050 it will reduce its internal emissions by 80% compared to 1990. The European Commission has carried out an extensive model analysis with various possible scenarios showing how these objectives could be met. This analysis of different scenarios shows that in terms of cost-effectiveness it would be optimal to achieve an internal reduction of emissions of 40% by 2030 compared to the level in 1990 and of 60% by 2040. The reduction of emissions are of 25%. In this way, there would be an annual reduction of approx. 1% in the first decade by 2020, compared to the 1990 level. In the second decade from 2020 to 2030, there would be a reduction of 1.5% and in the last two decades by 2050, there would be a reduction of 2%. It is envisaged that with the greater availability of more cost-effective technologies also in the transport sector, efforts will be intensified.

One of the objectives of the White Paper Roadmap to a Single European Transport Area: Creation of a competitive resource-efficient transport system to make a significant contribution to achieving the 60% greenhouse gas emission reduction target; halve the use of "conventionally fueled" cars in urban transport by 2030; phase them out in cities by 2050; achieve the introduction of essentially CO_2-free city logistics in major urban centers by 2030 [3].

Urban public transport with extensive fleets of city buses as well as taxis and lorries used in urban logistics are particularly well suited for the introduction of alternative propulsion systems and fuels. This could make a significant contribution to reducing the intensity of carbon oxides in urban transport and at the same prepare the conditions for testing new technologies and the opportunity for their timely introduction to the market.

The Slovak Republic, as an EU Member State, has also joined these targets in the area of reducing greenhouse gas emissions.

The objective described in the Public Transport Development Strategy is to increase the attractiveness of public passenger transport through the modernization and reconstruction of public transport infrastructure, including the provision of ecological and low-floor vehicle fleet [4,5]. The specific objective "Increasing the attractiveness and accessibility of public passenger transport through the renewal of public transport vehicles (urban public transport)" has been set. The deployment of low-floor and energy-efficient vehicles in urban public transport will not only increase the accessibility of urban public transport for disabled passengers, as well as passenger comfort and time savings, but it will also reduce energy consumption and the related costs. The condition for supporting the renewal of vehicles in urban public transport is the existence of a comprehensive strategic plan for sustainable development of transport in individual cities (transport master plan, plans of sustainable urban mobility) and implementation of measures to ensure the preference of urban public transport on the routes for which they will be designed and the building of Integrated Transport Systems [6–8].

Results to be achieved by this:

- increasing the attractiveness of public passenger transport,
- improving the quality of services provided by urban public transport in large agglomerations (travel time savings, expanding the range of services, increasing comfort and reliability, etc.) [9],
- increasing accessibility of urban public transport vehicles,
- reduction of negative impacts on the environment (reduction of noise, emissions of CO_2, NO_2 and PM_{10}, vibrations, etc.),
- reducing the morbidity of the population and increasing the standard of living of the population's life expectancy,
- increasing the share of public passenger transport in the division of transport work.

The reduction of the costs of operation of urban public transport vehicles and energy is also expected [10,11]. The other member states of the European Union have also adopted strategies to reduce emissions in passenger transport [12].

Air pollution from transport and its impacts can be monitored by measurement, modelled on the basis of suitable simulation models based on historical data and calculated on the basis of suitable emission calculators and emission factors.

Suna, S. et al. [13] deal with the analysis of past and future trends in the area of emissions from transport in a selected Chinese city for the period 2000 to 2030.

There are studies focusing on research into the reduction of emissions by the management of traffic flow and optimization of the operation of vehicles in order to limit the stopping of vehicles in the traffic flow. Such research in the field of bus transport (Arti Choudhary, Sharad Gokhale, 2019) confirmed a significant reduction of emissions [14].

Changes in passenger behavior can have a major impact on reducing energy consumption and the associated reduction of greenhouse gas emissions. Research into energy consumption trends and greenhouse gas emissions up to 2050 at the national level in China was published by Li, P. et al., 2018 [15].

Impacts of transport on the environment, especially on air pollution, are greatest in large agglomerations. They are connected with economic development, increasing incomes of the population and the associated increase in the degree of automobilization. Impacts on air pollution are often multiplied by insufficient road infrastructure and the associated rise of congestions. Traffic congestions, deteriorating air conditions, and a negative impact on the population are also becoming a problem for smaller cities such as Žilina, if city bypasses are not completed. Research on the development of the number of passenger cars and pollutant emissions in the conditions of Romania in the Lasi metropolitan area was conducted and published by Rosu Lucian, Istrate Marinela and Banica Alexandru, 2018 [16]. They carried out the research with a use of a questionnaire survey, statistical data and a simulation model. The results indicate that the metropolitan area is confronted with a significant expansion that leads to high levels of various emissions of air pollutants from the massive use of passenger cars in the peri-urban area. The number of premature deaths due to environmental pollution in cities can also be reduced by promoting public transport which can substitute some part of the driving passenger cars and decrease the emissions production [17]. Within the frame of local impacts on the environment, scientists investigate a mutual relationship or more precisely a dependence between emissions of individual pollutants and parameters of traffic flow such as its structure, age of vehicles in it, traffic flow intensity (Catalano, M. et al., 2016) [18], taking into account a maximum peak load and considering options for reducing pollution at local (street) level, e.g., in Turkey, Istanbul (Elbir, T. et al., 2010) [19].

The methods of reducing pollutant emissions also involve the operation of more environmentally acceptable types of fuels and renewal of the vehicle fleet with more modern vehicles. For example, Kuranc, A. et al., 2017 [20] deal with the issue of fleet renewal in the agricultural sector.

A specific area of production of emissions from transport and transport services are greenhouse gas emissions. Transport is one of the largest greenhouse gas (GHG) producers. The amount of emissions produced can be expressed as the equivalent of carbon dioxide (CO_2) emissions, which is the amount of CO_2 emissions that represents the same global warming potential as the actual greenhouse gas mix-carbon dioxide (CO_2), methane (CH4) and nitrous oxide (N_2O) (Stojanovic et al., 2012) [21].

Lizbetin et al. (2018) also address the issue of GHG emissions in the road haulage area [22]. GHG emissions influence the ozone layer and share to the greenhouse effect that causes global warming problems that are closely related to weather changes and extreme weather events. It needs to be pointed out discrepancies associated with FAME biofuels (Fatty Acid Methyl Esters) in particular the fact that, although their use produces nearly zero GHG emissions, their production is highly energy intensive. Article by Ivkovic et al. (2018) is concentrating on the production of GHG emissions in the field of long distance transport of persons, especially in road and air transport [23]. The aim of authors research was to develop and select a suitable method for modeling the estimation of GHG costs in the road and air transport sector in Serbia, as well as to apply a method aimed at special calculation by type of transport.

In addition to monitoring and measurement, the amount of emissions generated from transport can also be determined by the application of suitable energy and emission calculators, most of which are based on the use of emission factors of individual types of pollutants for specific groups of vehicles and the operational fuel consumption is used as input for the calculation. In particular, for the calculation of greenhouse gas emissions, emission factors and methodology according to European Standard EN 16258:2012 methodology for calculation and declaration of energy consumption and GHG emissions of transport services (freight and passengers) can be used. In this way, it is possible to compare the amount of emissions produced by the different modes of transport according to the approach (the well-to-wheels and tank-to-wheels principles), for example, Petro and Konečný (2017), Skrúcaný et al. [24,25]. Using the emission factors prescribed by the standard, for example, the comparisons of greenhouse gas emissions or energy consumption of several modes of transport are becoming more objective [26]. Ľupták, V. et al., (2019) published a case study focused on a comparative analysis of environmental impact assessment (greenhouse gases according to EN 16258: 2012 standard) of two modes of transport-railway and bus transport in the field of passenger transport [27]. Hlatká, M. et al. (2018) also used that standard and published a study that compares the production of greenhouse gas emissions on a particular transport route in passenger transport with the use of bus transport and a combination of air transport with bus transport [28].

The problem of emission calculators is the fact that they consider emission factors for a period of several years without updating them whereby with the use of electrical energy there is a year-on-year change in the energy mix from its production and thus also a change in the amount of indirect emissions (well-to-tank). Petro et al. (2019) point to this problem and propose a structure of a dynamic calculator that would update the amount of emissions from electrical energy production on a year-on-year basis. Several scientific studies and articles refer to the use of EN 16258 standard, which was adopted in 2012 [29,30].

Keskisaari, V. et al. (2017) assessed the links between the urban structure and socio-economic and demographic variables in a published study, and also considered the lifestyle of the population, in relation to the production of greenhouse gas emissions from land transport in Helsinki, Finland. The aim of this study was to identify and improve our understanding of the latent ways of modality that guide the possibilities of daily travel of people and the resulting greenhouse gas production [31]. In their study in Finland, Ottelin, J. et al. (2014) found, inter alia, that in the metropolitan region there is a relation between ownership of cars and the use of air transport in the middle-income group of the population. The main political implication of their study was that air transport needs to be included in the assessment of greenhouse gas emissions (as confirmed by other studies) and strategies focused on the reduction of greenhouse gas emissions related to the transport behavior of the population [32].

Emissions from transport are also affected by the system of regular emission controls [33]. Milosavljevic, B. et al. (2015) [34] dealt with a dispersion of pollutants from transport in urban space and emission factors.

Blaž, J et al. (2019) [35] focused on the issue of the use of hybrid-drive buses in public passenger transport and Napoli, G. et al. (2017) [36] studied the development of a fuel cell hybrid electric powertrain. Lebkowski, A. (2019) analyzed various configurations of hybrid power systems, consisting only of batteries, combinations of batteries and supercapacitors, and only supercapacitors. For these configurations, mathematical models were developed. These models were used in the research on energy consumption and carbon dioxide emissions using a city bus with a length of 12 m [37]. These are procedures that can be used to refine the presented methodology for calculating emissions from the operation of hybrid buses (16 buses in urban public transport of Žilina) and to optimize their deployment according to the characteristics of public transport lines.

Kivekas, K. et al. (2018) [38] dealt with the issue of deployment of electric buses in urban public transport. The environmental effects of electromobility in urban public transport in Gdansk, Poland were addressed by Pietrzak, K. et al. (2020) [39]. The methodology applied in this paper is focused on the evaluation of the gradual replacement of diesel buses by electric buses. In terms of the evaluation electricity production, the methodology is based on the current state of the energy mix of electricity production, which is mainly based on production in coal-fired thermal power plants. The consumption of fuel and electricity is estimated, so it can distort the results.

Csiszár, C. et al. (2019) proposed a method of locating of charging stations for electric vehicles, where they pointed out that in terms of effectiveness the most suitable locations are P + R (park and ride) car parks where transport by passenger car is combined with public passenger transport [40]. After modifications, their location method can also be used for the selection of places for partial charging of electric buses during their operation on public transport lines in order to increase their range and thus the efficiency of operation and benefit for the city's air.

In the paper focused on the use of hydrogen as a renewable energy source, Ozawa et al. (2017) in their methodology also considered the WtT greenhouse gas emissions in the supply chain [41]. Khan (2017) dealt with the same issue of the calculation of indirect emissions, but only greenhouse gases. For WtT emissions, he also considered greenhouse gas emissions in the transport and distribution of fuels [42].

Many scientific works deal with problems of vehicle operation emissions and ways to decrease environmental impacts of transport on air pollution. The gap is that scientific works give just comprehensive and general results of vehicle operation and its impact on air pollution. These results are unusable for a real specific region with taking in to account all conditions affecting the final environmental impact.

Each vehicle fleet is different, the depth of renewal is a very varying factor, each region is different, electricity production is different—these and many other factors are influencing the real environmental impact of the vehicle fleet renewal in real conditions of chosen region.

These facts are reasons why the primary research questions were stated:

- To what extent can a change of vehicle fleet of urban public transport in a small regional city of Žilina with a population of 82,931 (as of 31 December 2019) contribute to meeting the objectives of reducing the impact of transport on energy intensity and air pollution?
- How can the direct and indirect emissions from the operation of vehicles be calculated?

This paper continues by sections. "Materials and Methods" described materials and methods used in the research and some results are firstly represented. Deeper results interpretation and following discussion can be found in the chapter "Results and Discussion". Concluded remarks to the results and their discussion are stated in the section "Conclusion".

2. Materials and Methods

2.1. Methodology of Calculation and Declaration of Direct and Indirect Emissions from Transport Services of Public Transport

The members of the author team have been working on the proposal of the calculation methodology and the calculation of WtT and TtW emissions of pollutants from transport and transport services since 2006 (the results in the field of CO_2 emissions production were published, for example [43,44]. The published studies were also focused on the comparison of environmental impacts from the operation of bus and trolleybus transport in a particular city. For the calculation of TtW emissions, the emission limits of buses were used. The efficiency of transforming the energy of fuel (diesel) into the required power was considered using the Sankey diagram. The energy value of used diesel and its consumption by public transport buses was taken into account.

Gradually, the authors modified and applied the methodology. It is improving with regard to the changes of values of emission factors, the adoption of the standard EN 16258 in 2012, the availability of results of certified measurements of direct emissions from road transport vehicles (HBEFA—Handbook of Emission Factors for Road Transport), the availability of statistical data on production and pollutant emissions from the power industry and the petrochemical industry.

The method of calculation regards both direct and indirect emissions of harmful substances produced by the operation of a vehicle in public passenger transport. This approach is more objective compared to considering only direct emissions of exhaust gases of a vehicle.

Emissions from transport services represent the sum of direct and indirect emissions. The indirect emissions from transport operation taken into account come from:

- the production of electricity necessary for the production of fuel in a refinery,
- the production of fuel in a refinery.

The direct emissions are related to the fuel consumption of a vehicle during providing transport services.

The structure of considered direct and indirect emissions is demonstrated in Figure. 1. An (in block diagram) version of this picture can be found in the appendix section in Figure A1. The extended version in Figure A1 includes contains the sequence of steps for the calculation of total emissions, which the inputs and outputs of these steps are identified.

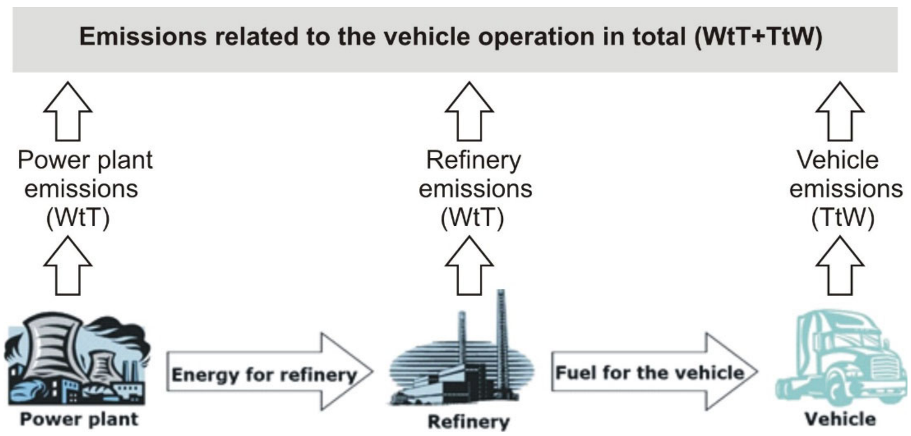

Figure 1. The chain of emissions production in transport with the use of fossil fuels (direct TtW and indirect WtT emissions).

An extended (in block scheme format) version of this picture can be found in the Appendix The extended version in annex include contains the sequence of steps for the calculation of total emissions, which the inputs and outputs of these steps are identified

To assess the impact of the operation of vehicles of a particular transport system on the environment, it is necessary to set values of emission factors for the used type of fuel or for the electricity. In the conditions of the Slovak Republic, we consider Slovenské Elektrárne as a producer and the historical development of the amount of electricity and the related harmful substances produced by this producer. For diesel, it is necessary to identify emission factors related to its production (indirect emissions related to diesel consumption). It is based on the amounts of produced diesel fuel and emissions of harmful substances by the Slovnaft refinery, which is the monopoly producer of diesel fuel in the Slovak Republic.

2.1.1. Indirect Emissions Related to the Production of Harmful Substances (Well-to-Tank Approach, WtT)

Step 1: Indirect emissions from the production of electricity necessary for the refinery (as a producer of fuels, WtT).

Step 1 consists of two consecutive sub-steps:

- From the calculation of emission factors related to electricity production,
- From the calculation of the amount of indirect emissions from electricity consumption in the production of diesel fuel,

Step 1.1 Emission factors for the production of electricity

Based on the application of Equation (1), there were identified the emission factors of specific harmful substances from electricity production in the period 2005–2017 in the Slovak Republic. The values of the emission factors (EF) are listed in Table 1. The time series of the emission factors are used to define one-criterion regression functions of specific harmful substances emissions from electricity production in the Slovak Republic.

$$EF = \frac{QS}{QE} \text{ [g/kWh]} \quad (1)$$

where:

QS—produced amount of specific harmful substance [g]

QE—produced amount of electricity [kWh]

Table 1. Emission factors for the production of electricity in the Slovak Republic in g/kWh.

Harmful substance	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
CO_2	158.711	154.446	154.830	146.332	136.490	117.961	119.477	113.333	102.392	97.149	113.341	107.209	109.812
PM	0.367	0.239	0.028	0.022	0.022	0.015	0.018	0.013	0.012	0.012	0.024	0.008	0.005
SO_2	1.484	1.335	1.252	1.289	1.342	1.449	1.615	1.333	1.201	0.996	2.112	0.297	0.330
NO_x	0.324	0.258	0.247	0.204	0.213	0.178	0.195	0.161	0.132	0.134	0.174	0.088	0.083
CO	0.037	0.041	0.045	0.044	0.033	0.031	0.034	0.030	0.028	0.028	0.032	0.053	0.044

Source: processed by the authors from the annual reports of the Slovenská Energetika.

Figures 2 and 3 illustrate the one-criterion regression functions defining the development of the emission factors in the production of electricity in the Slovak Republic in 2005–2017. The functions are completed with the values of the coefficients of determination of the given models. The specific types of functions were proposed not only according to the values of the coefficients of determination but also according to the logical interpretability and the possibility to use the functions for the estimate of the emission factors in the future.

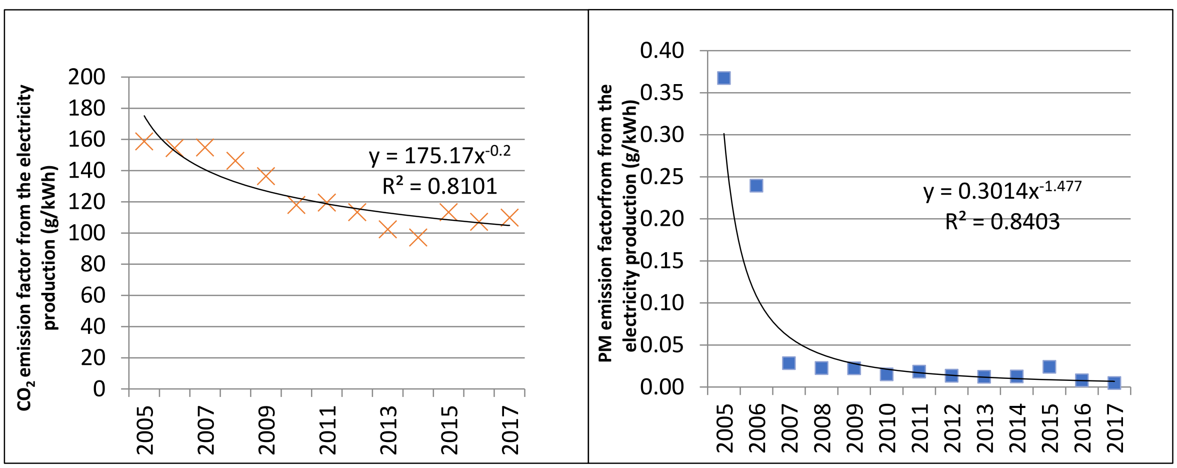

Figure 2. The chain of CO_2 (**left**) and PM (**right**) emissions production in transport with the use of fossil fuels (direct and indirect emissions).

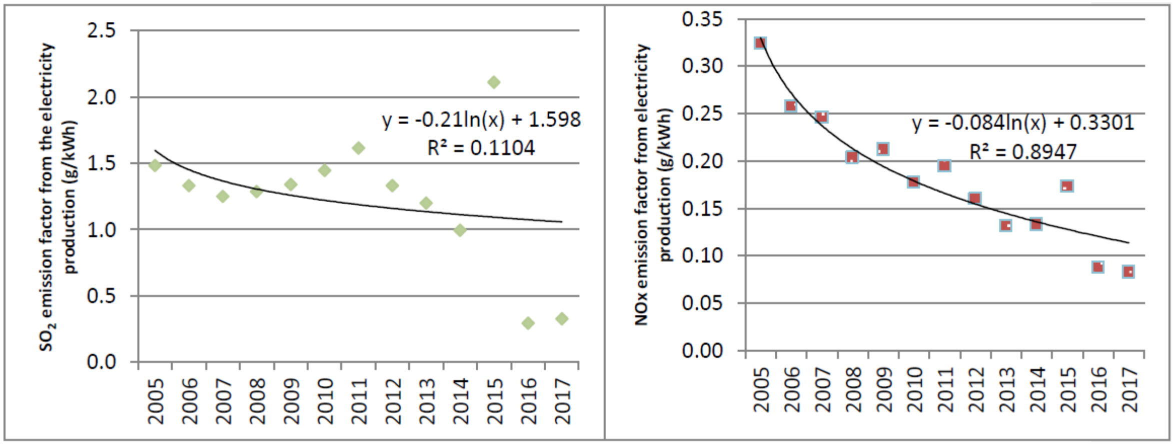

Figure 3. The development of the course of SO_2 (**left**) and NO_x (**right**) emission factor in the production of electricity in the period 2005–2017 in the Slovak Republic.

Table 2 illustrates trend equations together with the R^2 coefficient of determination. Based on these functions, it is possible to calculate the development of each harmful substance in the coming years separately. Table 2 also contains the values of emission factors of the selected harmful substances from the electricity production in the Slovak Republic in the years 2018 and 2019 calculated following the one-criterion regression functions. The regression functions can be updated on the basis of the updated time series of the values of electricity production and the related harmful substances emissions. In this way, it is possible to ensure the timeliness of the used emission factors in the calculation of harmful substances emissions.

Table 2. Emission factors for the production of electricity in the Slovak Republic.

Harmful substance	Equasions	R^2	2018	2019
CO_2	$Y = 175.17.x^{-0.2}$	0.8101	103.33 g/kWh	101.92 g/kWh
PM	$Y = 0.3014 \cdot x^{-1.477}$	0.8403	0.00611 g/kWh	0.00552 g/kWh
SO_2	$Y = 1.9268 \cdot x^{-0.325}$	0.1823	0.817 g/kWh	0.799 g/kWh
NO_x	$Y = 0.3781 \cdot x^{-0.455}$	0.7641	0.114 g/kWh	0.110 g/kWh
CO	$Y = 0.0395 \cdot x^{-0.049}$	0.0329	0.035 g/kWh	0.035 g/kWh

Step 1.2 The calculation of harmful substances emissions related to the use of electricity in a refinery (per 1 L of diesel fuel)

Below is the calculation of the values of specific harmful substances that originate from the production of electricity necessary for the production of 1 L of diesel fuel (ESN). Table 2 lists all the values of specific harmful substances during the reporting period. The calculation was based on the Equation (2).

$$ESN = ESE \cdot SEVN \text{ [g/l]} \tag{2}$$

where:

ESE—specific harmful substance emissions from a power plant in the production of diesel fuel [g/Wh];

$SEVN$—consumption of electricity per production of 1 liter of diesel fuel [Wh/l]

The specific amount of indirect pollutant emissions produced from the operation of the bus related to the electricity consumption in the production of diesel is calculated as the product of the values of indirect emissions per 1 L of diesel from Table 3 and the consumption of diesel in the monitored period.

Table 3. The values of indirect emissions from electricity consumption in the production of 1000 L of diesel fuel.

Harmful substance	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
CO_2	77.133	75.061	75.247	71.117	66.334	57.329	58.066	55.080	49.763	47.214	55.084	52.104	53.369	50.218
PM	0.178	0.116	0.014	0.011	0.011	0.007	0.009	0.006	0.006	0.006	0.012	0.004	0.002	0.003
SO_2	0.721	0.649	0.608	0.626	0.652	0.704	0.785	0.648	0.584	0.484	1.027	0.145	0.161	0.397
NO_x	0.158	0.125	0.120	0.099	0.103	0.086	0.095	0.078	0.064	0.065	0.084	0,043	0.040	0.055
CO	0.018	0.020	0.022	0.021	0.016	0.015	0.016	0.015	0.013	0.014	0.015	0,026	0.022	0.017

We do not consider petrol as fuel since the bus transport vehicles in the Slovak Republic do not use this fuel.

Step 2: Indirect emissions of the refinery from the production of diesel fuel (WtT)

The calculation is based on the production of diesel fuel and the related emissions produced by the Slovnaft refinery as a monopoly producer of diesel fuel in the Slovak Republic. We used the available data of the refinery from 2014 to 2017. Based on the Equation (3), the amounts of specific harmful substances per 1 kg of the produced diesel fuel (*ERN*) were calculated. The values are listed in Table 4.

$$ERN = \frac{QES}{QN} \text{ [g/kg]} \quad (3)$$

where:

QES—the amount of emissions of specific harmful substance [g],

QN—the amount of produced diesel fuel [kg].

Table 4 presents the results of the calculations of the amounts of specific harmful substances emissions per 1 kg of diesel fuel produced by the Slovnaft refinery in the Slovak Republic. This year 4,312,900 tons of diesel fuel were produced which resulted in producing 1,814,547 tons of CO_2.

Table 4. Harmful substances calculated in grams per 1 kg of produced diesel fuel.

Type of Emission	2014	2015	2016	2017
CO_2 (g)	420.725	430.185	458.548	452.776
SO_2 (g)	0.483109	0.414994	0.581073	0.683114
CO (g)	0.102530	0.105744	0.095237	0.098991
PM (g)	0.014886	0.013200	0.016660	0.019399
NO_x (g)	0.333581	0.328416	0.428931	0.432166

Calculation of CO_2 emissions per 1 L of produced diesel fuel:

As the diesel fuel consumption in road transport is tracked and reported in units per liter, it is necessary to transform the emission factors of indirect emissions from units of kg of emissions per kg of diesel fuel to the units of kg of emissions per liter of diesel fuel. The density of diesel fuel at 15 °C is 0.82 to 0.86 kg/dm^3, the median is 0.84 kg/dm^3.

The volume of 1 kg of diesel fuel

$$V = \frac{m}{\rho} = \frac{1 \text{ kg}}{0.84 \text{ kg/dm}^3} = 1.19 \text{ dm}^3 = 1.19 \text{ l} \quad (4)$$

where:

V—volume [dm^3],

m—mass [kg],

ρ—density [kg/dm^3].

CO_2 emissions per 1 L of produced diesel fuel in 2014:

$$ECO_2 = \frac{420.725\ \text{kg}}{1.19\ \text{l}} = 0.353551\frac{\text{kg}}{\text{l}} = 353.551\ \text{g}\ \text{CO}_2\ \text{on 1 L of produced diesel fuel} \quad (5)$$

The same calculation method as for CO_2 is used according to Equation (5) also for the conversion of other emissions, the results for all types of emissions per 1 L of diesel produced in the period from 2014 to 2017 are shown in Table 5.

Table 5. Calculated harmful substances per 1 L of produced diesel fuel.

Type of Emission	2014	2015	2016	2017
CO_2 (g/L)	353.551	361.500	385.335	380.484
SO_2 (g/L)	0.405974	0.348734	0.488297	0.574045
CO (g/L)	0.086159	0.08886	0.080031	0.083186
PM (g/L)	0.012509	0.011093	0.014	0.016301
NO_x (g/L)	0.28032	0.27598	0.360446	0.363165

The specific amount of indirect pollutant emissions produced from the operation of the bus related to the production of diesel by the refinery is calculated as the product of the indirect emission values per 1 L of diesel from Table 5 and the consumption of diesel by bus in the monitored period.

2.1.2. Direct Emissions from Transport Services

Direct emissions from the operation of a vehicle are related to the fuel consumption of the vehicle during its operation, direct emissions from traffic operation are also referred to as "tank-to-wheel" (TtW).

To calculate the amount of emissions it is possible to use computer programs called emission calculators. There is a wide range of emission calculators on the market, from free versions to prepaid applications. Using them, it is possible to calculate the influence of a vehicle operation during transport on the environment. In other words, they can calculate only direct emissions from vehicle exhaust. As regards indirect emissions, emission calculators can express only the emissions of harmful substance which is equivalent to CO_2 according to the standard EN 16258. Among such emission calculators, there are EcoTransit, Map&Guide or the calculator of DHL company. This principle uses the emission factor for calculating the amount of CO_2 according to the amount of consumed fuel. This methodology is simple and does not take in to account the differences in the fuel production in different regions.

The indirect emissions from the operation of diesel buses and trolleybuses like CO_2, CO, NOx and PM were estimated according to our proposed methodology as presented in this section. Emission factors for the production of diesel fuel are listed in Tables 4 and 5.

HBEFA database was used to get results about direct emissions production of the diesel buses fleet. Any measurements of the exhaust emissions were not done during the operation. The real fleet operation data were available as inputs, like fuel consumption from all vehicles, driven distances, elevation profiles of lines, number of passengers, reached velocities (speed profiles). According to this data and the vehicle technical data were set the amounts of direct emissions with considering and comparing the real fuel consumption and the HBEFA calculated fuel consumption.

Table 6 presents indirect emissions values (WtT) in 2017 for different types of fuels, which were obtained from the research based on regression functions. The WtT emission factors together with the existing TtW emission factors can be used for objectively evaluating the environmental impact of specific types of vehicles with respect to their fuel and type of transport.

Table 6. Emission factors (EF) of direct and indirect harmful substances emissions for different types of fuel or electricity in 2017 in the Slovak Republic.

Diesel—the Amount of Emissions (g/l)			Electricity—the Amount of Emissions (g/kWh)		
Type of Harmful Substance	**WtT**	**TtW**	**Type of Harmful Substance**	**WtT**	**TtW**
CO_2	380.537	*	CO_2	109.81	0
PM	0.016302	*	PM	0.0046	0
SO_2	0.574161	*	SO_2	0.330	0
NO_x	0.36324	*	NOx	0.083	0
CO	0.083222	*	CO	0.044	0

* TtW—The amount of direct emissions from diesel fuel and petrol depends on the specific type of vehicle and its consumption. To calculate the emissions, it is possible to use a suitable calculator of direct emissions using the emission factors obtained from the certified measurements, e.g., Map&Guide or EcoTransit.

3. Results and Discussion

This section of the paper deals with the application of the proposed methodology of the emission calculation, and it also presents the comparison of the amount of direct and indirect harmful substances emissions produced by the fleet of vehicles of the public city transport company in Žilina between 2012 and 2019. The result is the assessment of the change of the fleet of vehicles for newer types of vehicles, which meet stricter emission limits. Such a change can significantly influence the decrease of the direct and indirect emissions produced in the transport operation. The input data represent the number of vehicles, their emission limits, average fuel consumption or electricity consumption, and the number of kilometers made during the operation period. The city transport company uses various types of vehicles, such as diesel buses, trolleybuses, hybrid engine vehicles and electric vehicles. The provided data on the daily composition of the vehicles cover a work day, a vacation day and a weekend day.

In the results, we dealt with the values of CO_2, CO, NOx and PM emissions which were produced directly during the vehicle operation and indirectly during the production of electricity necessary for the refinery. Direct CO_2 emissions are calculated with the use of the formulas presented in the standard EN 16,258. Other direct pollutants such as CO, NOx and PM are calculated with the use of HBEFA simulation methodology.

General relations for the calculation of direct emissions for a particular vehicle:

The amount of CO_2 according to the standard EN 16258

$$QCO_2 = CS \cdot g_t \text{ [kg]} \tag{6}$$

where:

CS—total fuel consumption [liters],

g_t—tank-to-wheels factor of greenhouse gases for the fuel used (e.g., for diesel fuel, g_t = 2.67 kgCO_2/l)

Simulation of direct emissions production using HBEFA 3.3 database.

General emissions models are suitable primary for calculation of emissions in air quality studies, and the framework of integrated assessment studies. Models deliver the factors of emissions and the methodology usable for estimating total and partial emissions at a fleet or unit vehicle level. The most widespread models in the EU include COPERT, HBEFA and VERSIT+ [45–47].

The HBEFA database application estimates the emission factors of several pollutants per vehicle category, selected EURO standard, year of fleet operation or production and for a wide variety of traffic situations [46,48]. The traffic scenarios are mainly represented by four parameters: region type (rural, urban), road type, actual speed limit and traffic flow density (free flow, heavy, saturated, and stop and go) [49].

HBEFA (Handbook of Emission Factors for Road Transport), provides emission factors for vehicle categories like: PC (passenger car), LDV (light duty vehicles), HDV (heavy-duty vehicles), buses, motorcycles. The HBEFA allows users to choose different emission factors (EFs). Values of these EFs are influenced by more vehicle variables such as weight, size, type, engine cylinder capacity, fuel type consumed of the vehicle (gasoline, diesel, others), principle of exhaust treatment technology (with or without catalytic converter), driving style (acceleration and speed) and road longitude slope [50,51].

Output data are results of previous measurement real vehicles from selectable categories in laboratory conditions on vehicle dynamometers and in real driving tests.

Based on the above, HBEFA software was chosen as the most suitable simulation software to simulate the amount of emissions produced by vehicles. It provides sufficiently accurate data and allows the user to select the accurate values of factors according to immediate conditions of vehicle operation. The advantage of this software is possible to get partial results of vehicle fuel consumption and emissions production per each route section according to every change of driving parameters (velocity, slope, ambient temperature, etc.). We used HBEFA such like a database, not a software at all—it is possible to compare short sections, not only whole evaluated route or line and then we can simulate and adjust the input data to real vehicle operation.

The input parameters for the simulation and selection of precise conditions of the vehicle operation were the composition of the vehicle fleet, emission limits of vehicles, speed profile of vehicles operated on lines within the city of Žilina, vertical alignments of the lines, average air temperature reached during the measurement period, and the most important—average fuel consumption (diesel) during the selected spring month.

The measurement period was April (most representative season of the average air temperature and other ambient conditions affecting the vehicle energy consumption). This is a sufficiently long period of time to obtain an accurate long-term fuel consumption. This was one of the input data, on the basis of which the exact value of the pollutants produced by the vehicle was selected. The HBEFA software provides an interval of the resulting values of the production of emissions. From this interval, the values were selected on the basis of the actual fuel consumption of the bus.

The calculation of the rate of emission production was made for a diesel-powered bus, with engines with selected emission limits (see below), with a total weight of 18 t, with a longitudinal slope of the line +/− 2%, on city expressways, service and collector roads with an average speed of vehicle of 24.57–37.3 km/h. The results of the simulation are shown in Table 9. The gradual renewal of the outdated vehicle fleet of the transport enterprise of the City of Zilina, which provides urban public transport in the territory of the regional city of Žilina, started only after 2012 (see Table 7). In 2012, only four Irisbus buses of the EURO 4 emission class were operated in Žilina. On the other hand, seven buses of the outdated concept Karosa B 732 met only the EURO 1 emission class and six Karosa B 732 buses met the EURO 2 emission standard. In 2019, all buses met the highest emission class EURO 6. These are mainly 16 Iveco Urbanway 12 Hybrid buses and 14 Solaris Urbino 12 4th generation buses, which were first put into operation in the Slovak Republic in urban public transport in Žilina.

Table 7. Vehicle fleet before the renewal (2012).

Vehicles 2012				
Make and Type of Vehicle	**Emission Class EURO**	**Consumption (diesel/el—l/100 km; kWh/100 km)**	**Number (Vehicle)**	**Capacity (Persons)**
		Buses		
Karosa B952	EURO 3	30.43	17	100
Renault PS09D1 City bus	EURO 3	33.88	3	100
Karosa B 932	EURO 2	33.74	6	95
Karosa B732	EURO 1	33.33	7	95
Irisbus Citelis Line	EURO 4	44.47	1	96
Irisbus Citelis	EURO 4	34.27	3	117
Total (average-consumption)	-	35.02	37	3682
		Trolleybuses		
Škoda 15 Tr	-	217.21	29	150
Škoda 14Tr	-	141.69	13	82
Total (average-consumption)	-	179.45	42	5416
Total buses+trolleybuses	-	-	79	9098

Trolleybuses were renewed to a smaller extent. The biggest renewal, mainly with the help of the EU Structural Funds started in 2016 and was completed in April 2019 with the acquisition of two Škoda Perun electric buses and Škoda Solaris trolleybuses (see Table 8).

Table 8. Parameters reflecting the state of the vehicle fleet after the fleet renewal (2019).

Vehicles 2019				
Make and Type of Vehicle	**Emission Class EURO**	**Consumption (diesel/el—l/100 km; kWh/100 km)**	**Number (Vehicle)**	**Capacity (Persons)**
		Buses		
Solaris Urbino 12 (IV. generation)	EURO 6	36.27	14	98
Solaris Urbino 12 (III. generation)	EURO 6	36.7	5	98
Iveco Urbanway 12 Hybrid	EURO 6	29.73	16	80
Škoda Perun (electro)	-	195.3	2	73
Total (average-consumption)	-	34.23	37	3,288
		Trolleybuses		
Škoda 31Tr SOR	-	205.43	8	166
Škoda 30Tr SOR	-	139.05	7	94
Škoda 27Tr Solaris	-	202.31	18	131
Škoda 26Tr Solaris	-	139.03	9	91
Total (average-consumption)	-	176.224	42	5163
Total buses+trolleybuses	-	-	79	8451

Tables 7 and 8 present a comparison of selected parameters of vehicles of the Transport Enterprise of the City of Žilina in 2012 and 2019. The number of buses and trolleybuses did not change but the capacity (occupancy) of buses slightly decreased. The total average diesel consumption decreased by 0.79 l/100 km, from 35.02 l/100 km in April 2012 to 34.23 l/100 km in April 2019.

The renewal of the Žilina public transport fleet was completed at the beginning of 2019. In April 2019, new vehicles were already deployed in the real operation of the Žilina public transport and it was possible to find out the necessary data from their operation for the research. Due to the fact that public transport is operated according to the timetable during working days with differences over Saturdays, Sundays and public holidays, which was taken into account in the calculations according to the number of these days in 2019 and the same procedure was used for 2012 for vehicles used at that time. Two diesel buses were replaced by electric buses. The fuel consumption of buses was determined in 2012 in the transport enterprise of the City of Žilina by internal calculations on the basis of internal guidelines from data on the amount of diesel refueled and the km performed on individual buses. Each vehicle and each driver currently has an ID card, after insertion of which the stand allows to start refueling diesel. Each refueling is electronically recorded in the registration system. The actual mileage is recorded from the daily vehicle performance record and then the calculations of the average consumption for each vehicle are performed separately. An example of a worksheets of these calculations can be found in Table S2 (Supplementary Materials) and Table S3 (Supplementary Materials) in the Supplement. The authors of the paper are planning to measure the consumption of fuel in real traffic using measuring equipment in the urban public transport Žilina on a selected type of diesel and hybrid bus, as well as on a gas bus, but in another transport company. It will be a new research project funded by SPP (Slovenský plynárenský priemysel—Slovak Gas Industry), a.s.

The electricity consumption of trolleybuses decreased from 179.45 kWh/100 km to 176.224 kWh/100 km. The overall average decrease in the energy intensity of the vehicle fleet is approximately 2%. The renewal of the vehicle fleet was also possible on the basis of the establishment of the organization Integrated Transport of the Žilina Region (Integrovaná doprava Žilinského kraja, s.r.o) and the start of work on the integrated transport system of public passenger transport in the Žilina Region [52].

More detailed outputs of the calculation of WtT and TtW emissions from the operation of the urban public transport vehicle fleet in the city of Žilina in 2012 and 2019 according to the proposed methodology in Section 2 are for CO_2 in Table S1 (Supplementary Materials) in the Supplement. Given that the total driving performance of vehicles remained unchanged in that period, it was possible to calculate a comparison of the production of direct and indirect emissions from vehicle operations in 2012) and 2019 (Table 9).

Table 9. Outputs from the calculation of direct and indirect emissions in 2012 and in 2019.

Summary Table with Emissions Production Comparison Before and After Renewal-Emission Produced at Working Day											
Year	**Type of Vehicle**	**Number of Vehicles in Circulation (pcs)**	**Number of Kilometer Performed (km)**	**Direct Emissions (kg)**				**Indirect Emissions (kg)**			
				CO_2	**CO**	**NO_x**	**PM**	**CO_2**	**CO**	**NO_x**	**PM**
2012	Bus	31	5890	5,056.632	4.992	44.686	0.502	884.217	0.221	0.835	0.049
	trolleybus	30	5889	0.000	0.000	0.000	0.000	1,288.967	0.347	1.826	0.152
	Total	61	11,779	5,056.632	4.992	44.686	0.502	2,173.184	0.568	2.661	0.201
2019	Bus	31	5607	4,540.718	1.063	3.107	0.026	883.243	0.234	0.817	0.038
	electric bus	2	269	0.000	0.000	0.000	0.000	53.941	0.068	0.236	0.011
	trolleybus	29	5855	0.000	0.000	0.000	0.000	1,071.991	0.368	1157	0.058
	Total	62	11,731	4,540.718	1.063	3.107	0.026	2,009.175	0.670	2.210	0.107

In 2012, no hybrid buses or electric buses were deployed.

When comparing the values of emissions from Table 9, a significant decrease (on average up to 88% depending on the emission constituent, see Supplement Table S1 (Supplementary Materials)) of emissions is evident in 2019. The main reason is that in this year the transport enterprise of the City of Žilina operated all vehicles with the Euro VI emission limit. In contrast, in 2012 vehicles with lower emission limits such as Euro I, II, III and IV were deployed. Another crucial factor, especially for the reduction of CO_2 production is the combustion of diesel with a 7% biocomponent, while in 2012, diesel was refueled without a biocomponent. Thanks to the biocomponent in diesel, it was possible to significantly reduce CO_2 emissions while reducing the average consumption of vehicles by only less than 1 l/100 km. The deployment of electric buses that replaced the original diesel buses also contributes to the overall improvement of the CO_2 production for the entire vehicle fleet.

In Figure 4, the total savings in CO_2 production in 2019 (completely renewed vehicle fleet) up to 2023 are calculated. The graph illustrates the difference between the CO_2 production of the renewed vehicle fleet compared to the state before the complete renewal. It is important to mention the growing difference in CO_2 production if the vehicles of the original fleet would operate in the next five years. Over that period, in terms of renewal of vehicle fleet, CO_2 emissions in absolute terms will be reduced by more than 1.3 million tons compared to the operation of the original vehicle fleet, while maintaining the same driving performance as in the current period.

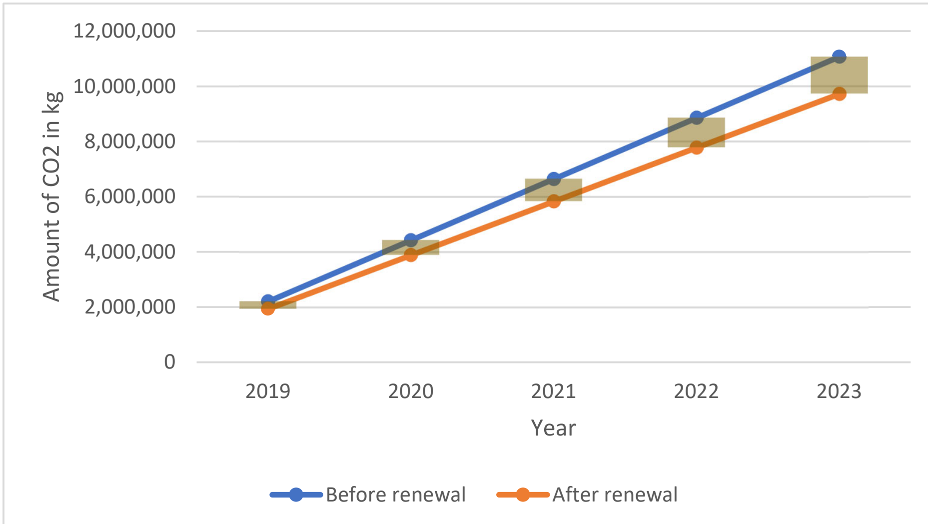

Figure 4. Cumulated annual CO_2 production before and after the renewal of the vehicle fleet.

It is also necessary to point out the planned shutdown of the Nováky Thermal Power Plant in Zemianske Kostoľany in 2023, which should have a positive impact on the energy mix in the Slovak Republic and by analogy also on indirect emissions from electricity generation.

Figure 5 shows the absolute savings in CO_2 production over the years 2019–2023 compared to the base period (before the renewal of vehicle fleet), when annual CO_2 production (including indirect emissions) amounted to more than 2.2 million tons of CO_2. After the renewal of the vehicle fleet, annual production (including indirect emissions) represents more than 1.9 million tons of CO_2. This represents an annual savings of almost 270,000 tons of CO_2. An important fact is an increase in savings (cumulation can be seen in the first and second graph) over the years compared to the base period (before the renewal of vehicle fleet). These are values that will significantly contribute to the improvement of air quality in the city of Žilina.

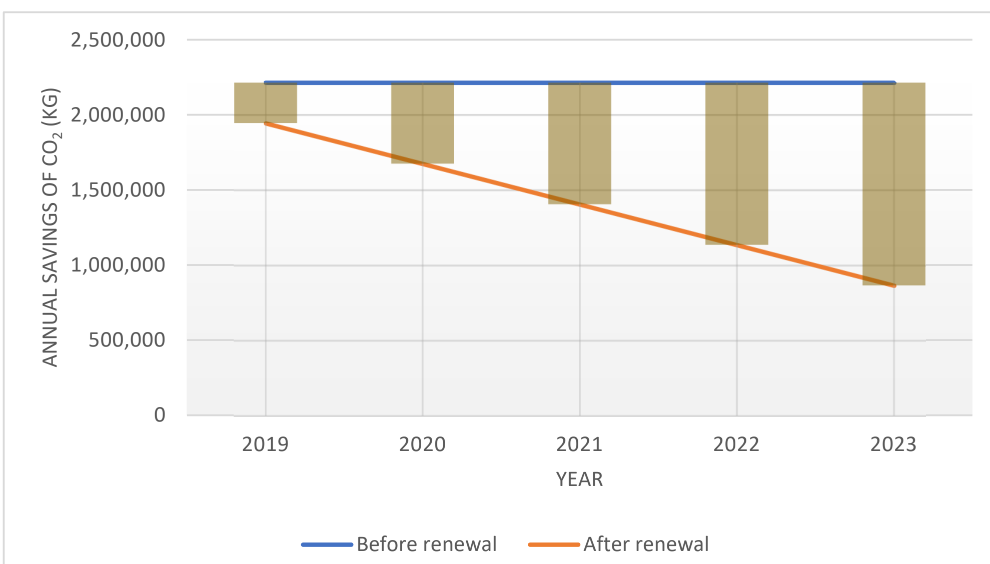

Figure 5. Absolute CO_2 savings over the years 2019–2023.

Figures 4 and 5 take into account the savings in CO_2 emissions in connection with the operation of the renewed vehicle fleet in urban public transport Žilina on the basis of data valid in 2019 without considering changes, the impact of which is currently difficult to predict. The real development of CO_2 emissions savings will depend on several factors, such as the rate of increase in the share of energy from renewable sources in the energy mix. The completion of Unit 3 in 2020 and Unit 4 in 2021 of the nuclear power plant in Mochovce in the Slovak Republic will allow the gradual shutdown of thermal power plants. Based on the information of Slovenské elektrárne, a.s. the capacity of each unit should be 471 MWe. One unit of the power plant will cover 13% of the electricity consumption of the Slovak Republic. According to current calculations, the annual production of completed units will save more than seven million tons of CO_2 emissions. We can then assume the progressive development of CO_2 savings. Changes related to electricity generation may affect the course of CO_2 savings in future years, as the amount of CO_2 savings calculated in Figure 6 does not take into account changes in electricity generation in the following years. An increase in the number of transported passengers is expected, as well as the introduction of an integrated transport system and the transition to a periodic timetable will bring changes in driving performance. The aim of the graphic representation in Figures 4 and 5 is not to predict the real development of emissions production in individual years, but to point out the cumulative nature of the development of savings in emissions production.

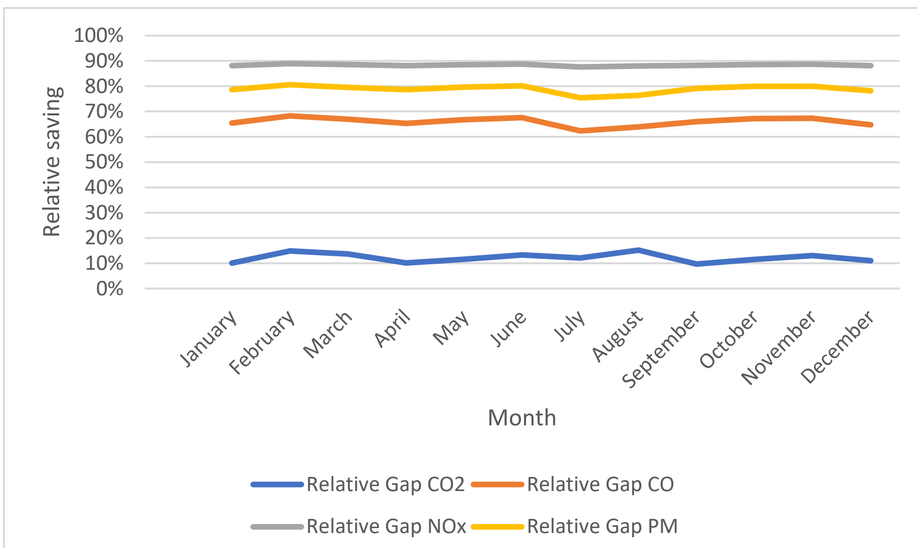

Figure 6. Relative savings in the harmful substances production of public transport in 2019 compared to 2012.

Savings in CO_2 production are not the only or greatest benefit in reducing emissions production. The reduction of production of emissions of toxic gases CO and NO_x as well as PM particles has a significantly higher positive impact on human health. Relative savings of the individual components of harmful substances during the calendar year are expressed in Figure 6. The total average savings in CO production are 66%, savings for NO_x gases are up to 88%. PM production decreased by an average of 79% due to vehicle fleet renewal. The absolute savings in the individual months of the calendar year are shown in Figure 7. In addition to the savings in PM production, it is important to pay attention to another fact—the amount of produced particulate matter after the vehicle fleet renewal is less dependent on the change of driving performance which vary from month to month depending on the number of holidays and working days. This is caused by the fact that individual vehicles produce very small amounts of particulate matter. With an increase in driving performance, the change in the total production of particulate matter is smaller than in the case of an increase in the driving performance of the vehicle fleet whose individual vehicles have a higher rate of PM production. This fact is particularly positive for the future, when increasing supply (by analogy with increasing driving performance) in public passenger transport may not result in a dramatic increase in pollutant production. This means that it is possible to provide the public with better transport services with a low negative impact on the health of the population.

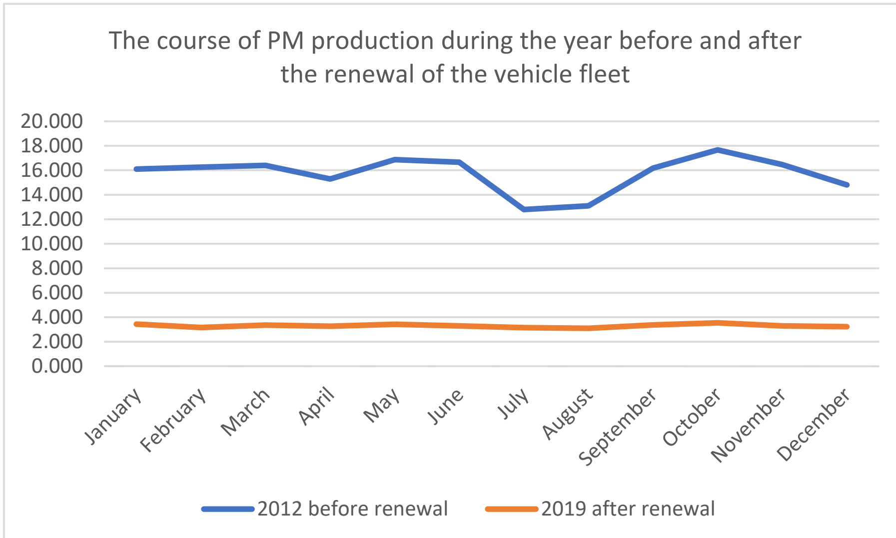

Figure 7. Comparison of PM production during the year before (2012) and after fleet renewal.

The proposed methodology for the calculation of direct and indirect emissions is the result of own research. The values of indirect emissions (WtT) for various types of fuels were obtained by research based on regression functions. These WtT emission factors, together with existing TtW emission factors (direct emissions) can be used for a more objective assessment of the environmental impacts of specific types of vehicles with respect to their fuel as well as the mode of transport.

Many scientific studies were solved in this problem of emissions intensity of transport. Most of them were mentioned in the section Introduction and Literature review. Problematic of urban transport and its impact on the environment and the point of view of used fuel or traction Methodology of this studies often use simulation software to estimate or calculate the energy consumption and emissions production [53], or the results are considering just some prognosis and common vehicle environmental impact declared by producers [54]. These two paths are used mostly just for the calculation of TtW emissions and other detailed statistical data must be used to reach realistic values of WtW approach [55–57]. The academic novelty of this manuscript is the connection of: 1. Data from real vehicle operation characteristics (mainly fuel and energy consumption), 2. Scientific evaluation of WtT emissions from fuel and energy production (statistical data and prognosis), 3. Estimating the production of TtW vehicle emissions by using simulation software. Using these different methods brings a unique result taking in to account holistic approaches from whole problematics in one scientific work.

The methodology and approach used are unique on two levels. Firstly, the existing emission calculators and related standards (EN 16258) in the field of calculation of direct and indirect emissions consider emission factors of indirect greenhouse gas emissions. The proposed methodology and performed calculations also take into account indirect emissions of other pollutants (CO, NO_x, PM). This makes the approach to the calculation of direct and indirect emissions more comprehensive. Secondly, the emission factors of indirect emissions from electricity production determined on the basis of regression functions can be dynamically updated on an annual basis depending on the statistical data from electricity industry. The calculated indirect emissions using updated emission factors respect the structure of the energy mix and current emissions from electricity industry in the conditions of the Slovak Republic. The methodology considers the energy self-sufficiency of the Slovak Republic, after 2020 the Slovak Republic will be an exporter of electricity.

The weakness of our proposed methodology is the fact that it does not consider the amount, origin and emission intensity of imported electricity. Nowadays Slovakia trades electricity with neighboring countries according to current price and consumption. All neighbors, except of for Austria, produce more carbon intensive electricity than Slovakia. Studies dealing with carbon intensity of electricity production declare that the county of origin of the electricity plays a different role in the final carbon intensity of EV operation [37].

As a result, electric driven vehicles can produce more secondary actual emissions than the methodology estimates. This weakness can be removed after considering the data about electricity production and distribution from the countries of its origin. Application of this methodology will reach higher accuracy after 2020 when Slovakia becomes a pure electricity exporting country.

Indirect emissions (WtT) related to the distribution and storage of fuels are only taken into account in the calculation of indirect greenhouse gas emissions. Emission factors according to EN 16,258 were used. For example, in the paper focused on the use of hydrogen as a renewable energy source, Ozawa et al. (2017) in the methodology considered also WtT greenhouse gas emissions in the supply chain [41]. Khan (2017) dealt with the same issue of the calculation of indirect emissions, but only greenhouse gases. For WtT emissions, he also considered greenhouse gas emissions from the transport and distribution of fuels [42].

In the calculation of other pollutants, indirect emissions related to the distribution of fuels and their storage were not considered in our methodology (except for greenhouse gases). This can be considered a shortcoming of the above procedure. The reason is the unavailability of relevant information and data from distribution companies. In the future, we would like to focus our research on this part of the methodology for calculation of indirect emissions in cooperation with fuel manufacturers and distribution companies in the Slovak Republic. The determinants of the values of indirect emission factors from the distribution of fuels are the location of production and storage of fuels, the location of petrol stations, used trucks for distribution as well as transport routes and their level of optimization.

The results are based on the average fuel consumption of buses and the average electricity consumption of trolleybuses and electric buses, which affects the accuracy of the results. Elements like traffic conditions, age of vehicles, number of passengers on board, etc. were not considered in the estimation directly but they were included in the average vehicle fuel/electricity consumption per investigated time period. The final amount of consumed fuel/energy reflected all vehicle operation conditions. So the obtained results can be different from the short time point of view in the comparison of actual emission production. If we consider that bus lines, driving performance and number of passengers, average vehicle speed and ambient conditions, the results from 2012 and 2019 should be suitable for determination of the vehicle fleet renewal on the air pollution.

The above outputs do not take into account the fact that the consumption and content of pollutants in exhaust gases especially of buses with conventional internal combustion engines can change after several years of urban operation. Therefore, the authors of the paper prepared measurements of direct emissions from the operation of buses of urban public transport in the city of Žilina. They are connected with the research into the emission impact of introducing the preference of public passenger transport vehicles at controlled junctions [58,59].

The results of calculations of the impacts of the complex renewal of the public transport vehicle fleet in the city of Žilina on the basis of the developed methodology need to be verified by long-term continuous measurement of air quality in places near urban public transport lines. In this area, it is possible to use the experience of the city of Umeå in Sweden. It takes a number of measures every year to improve air quality not only in the field of public passenger transport. It evaluates the effectiveness of these measures based on the results of air quality measurements and other indicators such as the road cleaning system, increasing use of urban public transport, etc. [60]. A procedure was proposed to evaluate the impacts of the operation of the entire urban public transport fleet for a calendar year. The procedure is based on the actual mileage of specific vehicles operating on urban public transport lines on weekdays, weekends and public holidays and thus provides a tool for assessment of further changes in the structure of the vehicle fleet in future years. It is also possible to examine how the change in the deployment of specific vehicles, for example with different consumption of diesel or electricity, will affect the impacts on air quality in the city. The possibilities of specifying the outputs are through the measurement and control of fuel consumption and electricity consumption in real operation on specific lines where urban public transport vehicles are deployed.

In terms of evaluation of benefits of renewal of vehicle fleet in urban public transport for a modern vehicle fleet equipped with air conditioning, information system and Wi-Fi connection, it is necessary to investigate whether it will also have the effect of increasing the number of passengers and the demand for public passenger transport. This is another direction of research that the authors are planning to address in the next period, given that they already have experience in this field [61].

Increase in the use of public passenger transport, especially in large cities, may in the future influence the changes in the work system, for example by an increase in work from home that does not generate any traffic or change of behavior of young people in cities with reliable public passenger transport where owning a car is not a necessity [7].

4. Conclusions

On the basis of the research outcomes presented in this paper, we recommend that the EU should continue to support the renewal of the urban public transport vehicle fleet in smaller cities. This support can significantly help reduce the negative impacts of urban public transport on the environment. Other synergy effects are in improving the quality of public passenger transport and increasing its use. This has positive impacts on the change in the ratio of the division of transport work between public passenger transport and individual car transport.

According to the EU White Paper on Transport, urban public transport is suitable for the introduction of alternative propulsion systems and fuels, given the large vehicle fleets of city buses. On 5 March 2020, the Government of the Slovak Republic approved the National program for reduction of pollutant emissions for the Slovak Republic pursuant to Article 6 of Directive 2016/2284 of the European Parliament and of the Council on the reduction of national emissions of certain atmospheric pollutants. It includes support for increasing the share of public passenger transport, in particular for electric drive, more massive support for electric vehicles and the introduction of low-emission zones in cities. According to the approved low-carbon strategy of the development of the Slovak Republic by 2030 with a 2050 perspective, carbon neutrality will not be achieved without significant support of public passenger transport, for example by measures to support the development of rail transport (trams and trolleybuses), bus public transport powered by alternative fuels (bio CNG electrification, liquid fuels, hydrogen), etc. It is important that local governments and public administrations support the development of mobility using alternative energy sources. They thus create a positive example and impact on the ecological behavior of the population. Given the size of vehicle fleets and mileage, the nationwide greening of vehicle fleets can also contribute to meeting global climate change targets. There are more ways how to meet the emission targets till 2030 or 2050 but the most effective are for example transition of energy sources used in transport (alternative drive systems, alternative fuels), driving vehicles with higher energy efficiency (new and effective vehicles), higher usage of vehicle / transport system capacity (higher occupancy of vehicles, eliminate "empty" drives).

The paper did not cover all the impacts of the renewal of vehicle fleet in urban public transport but it was focused on the design of the methodology and its application to the operation of vehicles for the production of direct and indirect emissions. It is also necessary to deal with the issue of long-term financing of public passenger transport if the EU Structural Funds are reduced so that the impacts of the operation of public passenger transport on the environment continue to decrease. Although the renewal of the public passenger transport fleet is associated with other indirect emissions related to the production of new vehicles, we did not consider the indirect emissions related to the production of new vehicles. The renewal of vehicle fleets also pursues other objectives, not only the reduction of emissions from transport but is also connected with an increase in the accessibility of public passenger transport for people with reduced mobility, the quality of services provided in public transport and also safety. More modern vehicles are equipped with several active and passive safety systems which can have an impact on reducing accidents and thus also contribute to the protection of human health and life.

Supplementary Materials: The following are available online at www.mdpi.com/1996-1073/13/15/3869/s1: Table S1: Comparison of harmful substances produced before and after fleet renewal; Table S2: Worksheets for calculation harmful substances-2012; Table S3: Worksheets for calculation harmful substances-2019.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

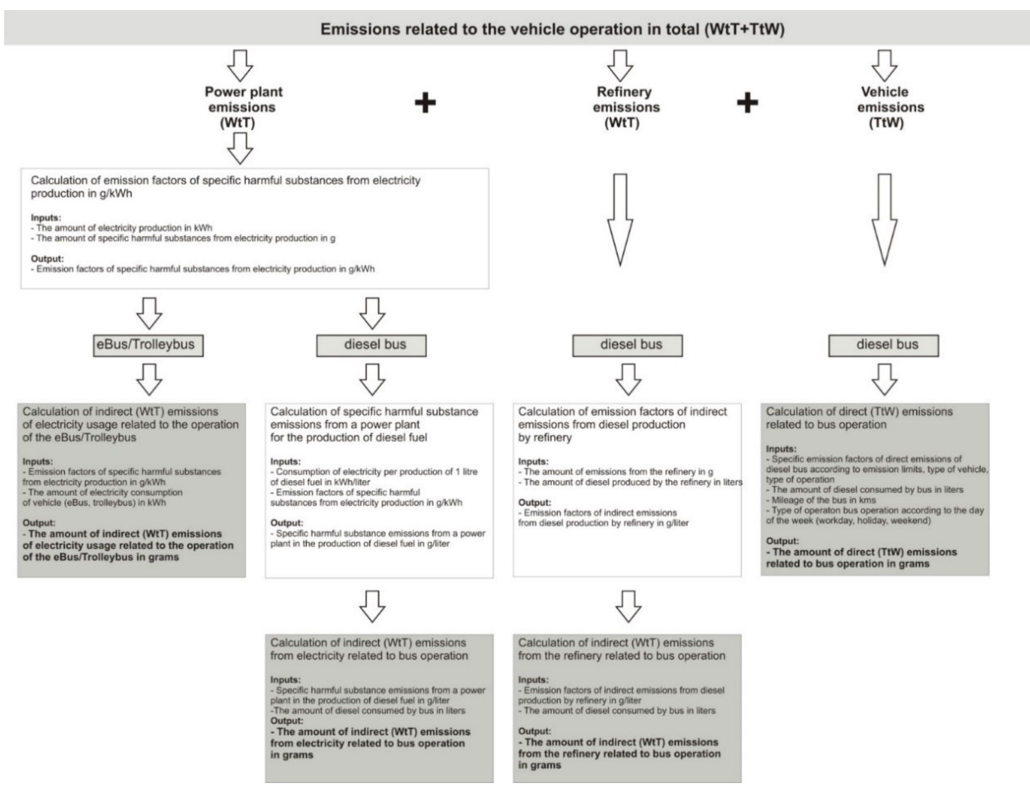

Figure A1. Emissions related to the vehicle operation in total (WtT + TtW).

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