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Assessment of Petrol and Natural Gas Vehicle Carbon Oxides Emissions in the Laboratory and On-Road Tests

Kazimierz Lejda [1,*], Artur Jaworski [1], Maksymilian Mądziel [1], Krzysztof Balawender [1], Adam Ustrzycki [1] and Danylo Savostin-Kosiak [2]

1 Faculty of Mechanical Engineering and Aeronautics, Rzeszow University of Technology, 35-959 Rzeszów, Poland; ajaworsk@prz.edu.pl (A.J.); mmadziel@prz.edu.pl (M.M.); kbalawen@prz.edu.pl (K.B.); austrzyc@prz.edu.pl (A.U.)
2 Department of Motor Vehicle Maintenance and Service, Faculty of Automotive and Mechanical Engineering, National Transport University, 02000 Kyiv, Ukraine; daniel_s@ukr.net
* Correspondence: klejda@prz.edu.pl; Tel.: +48-178651597

Abstract: The problem of global warming and the related climate change requires solutions to reduce greenhouse gas emissions, in particular CO_2. As a result, newly manufactured cars consume less fuel and emit lower amounts of CO_2. In terms of exhaust emissions and fuel consumption, old cars are significantly inferior to the more recent models. In Poland, for instance, the average age of passenger cars is approximately 13 years. Therefore, apart from developing new solutions in the cars produced today, it is important to focus on measures that enable the reduction in CO_2 emissions in older vehicles. These methods include the adaptation of used cars to run on gaseous fuels. Natural gas is a hydrocarbon fuel that is particularly preferred in terms of CO_2 emissions. The article presents the results of research of carbon oxides emission (CO, CO_2) in the exhaust gas of a passenger car fueled by petrol and natural gas. The emissions were measured under the conditions of the New European Driving Cycle (NEDC) test and in real road tests. The test results confirm that compared to petrol, a CNG vehicle allows for a significant reduction in CO_2 and CO emissions in a car that is several years old, especially in urban traffic conditions.

Keywords: vehicles emission; CNG; carbon oxides; on-road tests; portable emissions measurement systems (PEMS)

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1. Introduction

Transport generates 25% of total greenhouse gas emissions and is estimated to be the second largest source of the same after the energy sector [1–8]. In terms of these emissions, as much as 95% of CO_2 is generated by road transport, of which 61% is emissions from passenger vehicles [9–12]. The emission of CO is similarly a significant threat to the environment and the health of society. Carbon monoxide is emitted as a product of incomplete combustion of carbon fuels (e.g., petrol, diesel) [13,14]. These fuels are the main source of vehicle power and it is estimated that their combustion contributes to the emission of about 89% of CO emissions from anthropogenic sources in developed countries [15]. Carbon monoxide plays a fundamental role in regulating the amount of OH in the troposphere and is indirectly related to climate change [16]. This is due to the chemical impact of CO on CH_4, CO_2 and O_3 [13].

Increased awareness of the threat posed by CO_2 emissions contributed to the introduction of regulations regarding its emissions from passenger vehicles. The European Union has set a greenhouse gas reduction target of 60% compared to 1990 levels [17]. Data from the European Environmental Agency (EEA) for 2015 [18] confirm that vehicles produced in 2014 achieved the target of 130 g/km CO_2 emissions, while the average emissions were 123.4 g/km. In 2015, the average emissions for the produced vehicles fell to the level of 120.7 g/km of CO_2. However, these were data for emissions from homologation procedures for the New European Driving Cycle (NEDC), which, compared to road data, significantly lowered the average values of emissions [19–27]. The differences in CO_2 emissions for the NEDC and the road test reached 30–40% [28–30]. Therefore, it can be assumed that the NEDC procedures, which cover CO_2 emissions, among others, meant that the manufacturers then sought to optimize the fuel consumption of the vehicle based on the test conditions themselves, and did not introduce actual improvements in vehicles that would minimize these emissions [31–38]. For 2019, the average CO_2 emission was 122.4 g/km, which meets the required CO_2 emission target of 130 g/km and at the same time is above the value effective from 2020 on and amounting to 95 g/km of CO_2 emissions [39]. Therefore, vehicle manufacturers are working on engineering improvements to engines and vehicles to reduce the emission of harmful exhaust components to a minimum. One of the solutions used is to fuel automobiles with alternative fuels, e.g., hydrogen, natural gas (CNG—compressed natural gas), liquefied petroleum gas (LPG), ethanol, methanol and others [40,41].

Natural gas is the preferred alternative fuel used to power internal combustion engines. The reduced proportion of carbon to hydrogen in the molecule of this fuel, with a high calorific value per unit of mass, allows the reduction in CO_2 emissions. Moreover, the research results presented in the literature show a reduction in the emission of other gaseous pollutants and solid particles in relation to fueling with petrol [42,43] or diesel oil [16,17]. However, when a vehicle is fueled with natural gas, NOx emissions can be significantly higher under heavy load conditions compared to petrol. This may be due to the higher exhaust gas temperature and a different conversion rate of pollutants in the exhaust gases by the catalytic reactor, which was developed to fuel the engine with petrol [44]. Considering the problem of global warming and the related efforts to reduce greenhouse gas emissions, including CO_2, natural gas propulsion seems to be a very beneficial alternative. However, this fuel contains mainly methane which, although not classified as a toxic exhaust gas component, is nonetheless harmful to the atmosphere as one of the major greenhouse gases [45–47].

Due to the efforts to reduce CO_2 emissions, it is beneficial to adapt car engines to run on gaseous fuels such as LPG and CNG [48–51]. This may include not merely fitting CNG fuel supply systems in factory, but also adapting existing cars, including those with lower EURO emission standards, which constitute the largest share in terms of the age structure of passenger cars in e.g., Poland (Figure 1). Older cars (Euro 2, Euro 3, Euro 4) have much higher CO_2 emissions compared to modern ones. It is therefore important to carry out tests for these types of vehicles that are characterized by relatively high mileage in order to analyze the emission of gaseous pollutants in the exhaust gas.

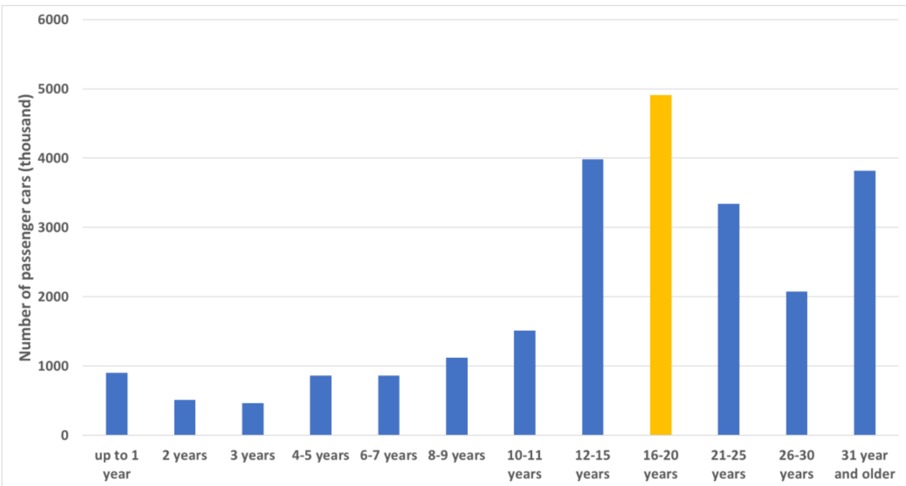

Figure 1. Passenger cars in Poland by age groups in 2019 (based on [52]).

Previous works, which investigated the impact of the use of CNG fueling a vehicle on CO emissions was only limited to tests on the RDE road [53–55] or to bench tests on an engine dynamometer [56] and was limited to a selected vehicle structure, e.g., Euro 6 vehicles [54], Euro 5 waste trucks [57], taxi cars [58], buses and enhanced environmentally friendly vehicles (EEVs) [59]. There are still a few studies that would deal with the emissions of older CNG-adapted vehicles in such a wide range of tests as presented in this paper, i.e., including both chassis dynamometer and on-road tests. Carrying out such tests is crucial, especially for countries with an aging vehicle structure. Indicating that the number of emissions that can be reduced using CNG could contribute to the implementation of a policy of adapting older petrol-powered vehicles to this type of solution. Moreover, a small number of works deal with the issue of CO_2 emissions to the extent that is presented in this work, e.g., the authors of the paper [53] present the results of CO_2 emissions for a passenger car meeting the Euro 6 standard, but they are limited only to aggregated emission levels and they do not present the emission results during the test period. In the literature has been also indicated some problems are connected with CNG fueling. There can be some issues connected with the emission of ammonia which contributes to particle pollution [60,61]. It has been also been noted that CNG vehicles can emit more NOx emission comparing to petrol vehicles [62]. The cost of installation of the CNG fueling system to the cars that have not been equipped with this system by the vehicle manufacturer is also very high. Another problem is the loss of space inside the car which is a disadvantage if the user cares about the cargo space in the trunk. One of the main problems connected with the refueling station is the availability of those with CNG. In Poland, there is approximately 30 refueling stations with CNG fuel [63]. This state of affairs contributes to a very limited use of CNG-fueled vehicles due to the low availability of this fuel.

According to the above issues, the authors conducted a comparative study of the impact of natural gas supply on the emission of pollutants in the exhaust gas for a selected passenger car. The aim of this study was to present the comparative results for both laboratory and road tests. The tests were carried out on the basis of a chassis dynamometer and the portable emission measurement system (PEMS). Aggregated and instantaneous data were included in the analysis of the results in order to investigate the different emission parameters under varying driving conditions. The purpose of the research was not to show the emission values in relation to the EU regulation, but to present actual, real-world emission results for a representative passenger vehicle. This work is one of the few that contains a complete picture of the comparative emissions for petrol and CNG both for the NEDC test and for the on-road emission from PEMS, which is a high value for further analysis. Apart from the aggregated emission levels, in g/km, the exact emission location along the route was also assessed.

2. Description of the Research Methodology

The tests were carried out on a passenger car, the technical data of which are presented in Table 1. The car's engine was powered by commercial petrol and natural gas, the parameters of which are shown in Table 2. The bench tests were carried out in the Automotive Emissions Laboratory of the Rzeszow University of Technology. The laboratory was equipped with an AVL chassis dynamometer integrated into a climatic chamber. A detailed description of the test stand can be found in [9]. The bench tests were carried out under hot start conditions for the engine coolant temperature of 85 ± 2 °C. The cold test phase was omitted due to the fact that the engine runs on petrol after the cold start. Switching to natural gas supply takes place after reaching the appropriate temperature conditions specified in the CNG controller. The tests were carried out for the NEDC cycle, under the ambient temperature conditions in the climate chamber of 20 ± 1 °C. Two tests were carried out with petrol and with natural gas. The research results show the mean values from two measurements.

Table 1. Technical data of the tested vehicle.

Parameter	Data
Year of production	2001
Emission standard	Euro 3
Engine capacity (cm^3)	2435
Compression ratio	10:1
Engine working principle	Positive ignition/4 stroke
Fuel type	Petrol/CNG
Maximum net power (kW)/at (rpm)	103/4500
Maximum engine torque (Nm)/at (rpm)	220/3750
Odometer (km × 1000)	265
Transmission type/number of gears	Manual/5
Fuel system—petrol	Multi-point indirect injection
Fuel system—CNG	Multi-point gaseous phase indirect injection
Aftertreatment system	TWC
Kerb weight (kg)	1660

Table 2. Properties of tested fuels, where MON = motor octane number; and RON = research octane number.

Parameter	CNG	Petrol
Higher calorific value	11.239 kWh/m^3	47,300 kJ/kg
Lower calorific value	10.137 kWh/m^3 49,180 kJ/kg	44,000 kJ/kg
Density under reference conditions (kg/m^3)	0.742	0.74
Air–fuel ratio (AFR) for stoichiometric mixture (mass)	17.2	14.6
Octane number MON (RON)	105 (110)	85 (95)
Boiling temperature (°C)	40–210	−161
Natural gas composition at a CNG refueling station in Rzeszow (% by volume):		
Methane (%)	97.012	-
N_2 (%)	0.587	-
CO_2 (%)	0.166	-
Ethane (%)	1.581	-
Propane (%)	0.481	-
I-Butane (%)	0.073	-
N-Butane (%)	0.069	-
I-Pentane (%)	0.014	-
N-Pentane (%)	0.009	-
C6+ (%)	0.007	-

Figure 2 shows the view of the vehicle on the test stand. The tested vehicle has an indirect, multi-point CNG fueling system which is not factory-fitted and has been adapted to the car.

Road pollutant emission measurements were carried out using the Horiba OBS-2200 (Horiba, Kyoto, Japan) portable emission measurement system (Table 3). The view of the car with the measuring equipment installed is shown in Figure 3. The tests were carried out on an urban, rural and motorway route, as shown in Figure 4. Road tests were carried out on a sunny day, with an ambient temperature of 30 ± 1 °C. Basic parameters of the test route are shown in Table 4.

Figure 2. View of the vehicle on the test stand.

Table 3. Selected technical parameters of the PEMS Horiba OBS-2200.

Data	Principle	Accuracy
CO	NDIR—non-dispersive infrared method; range 0–10%	±2.5%
CO_2	NDIR—non-dispersive infrared method; range 0–5 vol% to 0–20 vol%	±2.5%
THC	FID—flame ionization detection method; range 0–10,000 ppm	±2.5%
NOx	CLD—chemi-luminescence detection method, range 0–100 to 0–3000 ppm	±2.5%
Frequency counter	1 Hz	±2.5%
Warm-up time	Within 1 h	-
Exhaust flow	Pitot tube mass exhaust flow	Within ±1.5% of full scale or within ±2.5% of readings (whichever larger)

Figure 3. View of the test road (blue line).

Figure 4. View of the tested vehicle with the portable emission measurement system (PEMS) system.

Table 4. Specifications of the on-road emission test.

Parameter	Petrol	CNG
Total distance covered (km)	32.9	32.9
Urban portion distance (km)	11.0	11.0
Rural portion distance (km)	10.1	10.1
Motorway portion distance (km)	11.8	11.8
Average speed (km/h)	49.6	58.0
Urban portion average speed (km/h)	27.5	33.8
Rural portion average speed (km/h)	74.1	76.4
Motorway portion average speed (km/h)	101	108.5
Lowest route altitude (m)	225	228
Highest route altitude (m)	273	273
Route time (sec)	2390	2042

3. Results and Discussion

3.1. Results of the Bench Tests of CO_2 and CO Emission

The average CO_2 and CO emission values obtained during the bench tests for a car fueled with petrol and natural gas are presented in Table 5. Table 5 shows a comparison of the relative CO_2 and CO emissions for the tested fuels. It can be concluded that the average CO_2 emission for the test car fueled with natural gas was lower by approximately 23% than for petrol, both for the entire NEDC test and for the individual components (UDC and EUDC).

Table 5. Average emission results for New European Driving Cycle (NEDC) test (standard deviation values are given in brackets).

Pollutant	Phase	Emission Results (g/km) Fuel Type: Petrol	Emission Results (g/km) Fuel Type: CNG	Difference of Emissions for CNG Compared to Petrol (%)
CO	UDC	3.119 (0.213)	1.056 (0.043)	33.8
	EUDC	1.57 (0.057)	0.384 (0.071)	24.4
	NEDC	2.145 (0.115)	0.633 (0.06)	29.5
CO_2	UDC	280.3 (4.85)	214.7 (8.19)	76.6
	EUDC	196.9 (4.55)	152.6 (4.14)	77.5
	NEDC	227.9 (4.55)	175.6 (5.63)	77

It can be concluded that the average CO emission from natural gas for the studied car during the NEDC test was lower by approximately 70% compared to fueling the vehicle with petrol. For the UDC phase, the average CO emission from natural gas was lower by approximately 66%, and for the EUDC phase by approximately 75%.

Figure 5 shows a comparison of changes in CO_2 emission between petrol and CNG fuels during the NEDC test. Higher instantaneous emission values for fueling with petrol are evident. The CO_2 emission values depend on the rolling resistance that occurs during acceleration as well as at higher speeds. The maximum emission values during petrol fueling reached approximately 11 (g/s), and for fueling with natural gas—up to approximately 8.5 (g/s).

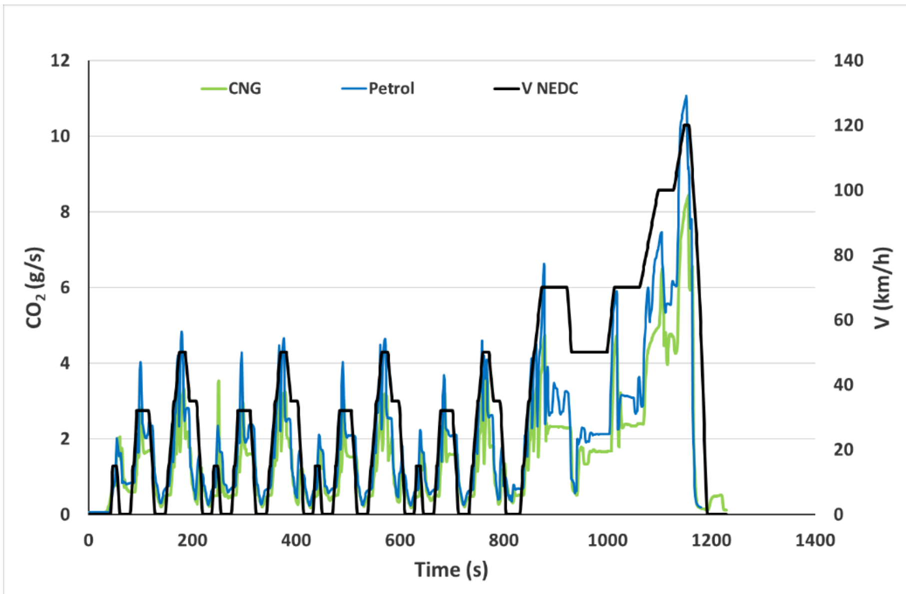

Figure 5. Comparison of CO_2 emission between petrol and CNG propulsion in NEDC test.

Figure 6 shows a comparison of CO emission changes between petrol and CNG fueling during the NEDC test. Significantly higher values of instantaneous emission are visible for petrol propulsion compared to CNG, especially during acceleration. The maximum values of CO emission for petrol propulsion reached approximately 0.18 (g/s), whereas for natural gas they were approaching approximately 0.05 (g/s).

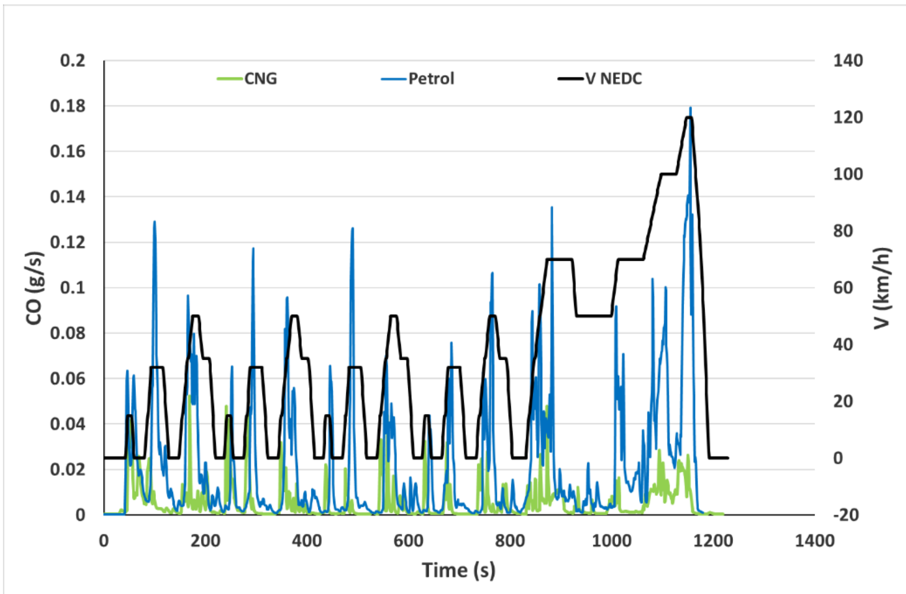

Figure 6. Comparison of CO emission between petrol and CNG propulsion in NEDC test.

The relation between CO_2 and CO emission for petrol fuel are also visible in Figures 7 and 8, which illustrate the cumulative emission values. As for the cumulative CO_2 emission (Figure 7), its values increase in proportion to the test time, both for petrol and CNG propulsion. The diagram of the cumulative CO emission (Figure 8) shows a greater increase in instantaneous emission when vehicle was fueled with petrol in relation to fueling with CNG, corresponding to the periods of increased load during acceleration.

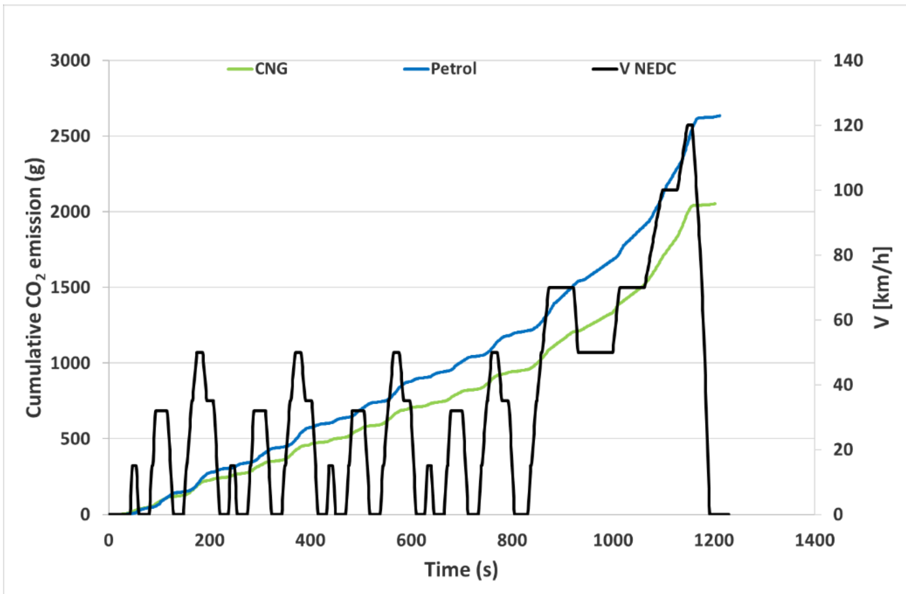

Figure 7. Cumulative CO_2 emission of a vehicle fueled with petrol and CNG for the NEDC test.

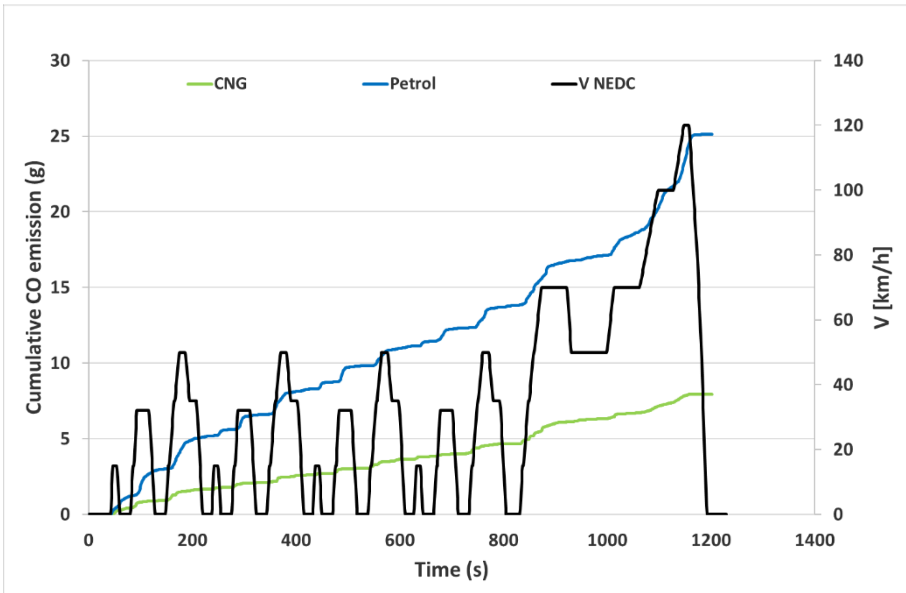

Figure 8. Cumulative CO emissions of a vehicle fueled with petrol and CNG for the NEDC test.

3.2. On-Road Test Results of CO_2 and CO Emission

The results of CO_2 emission tests under road conditions are shown in Figure 9. On urban, rural as well as motorway sections, CO_2 emission is higher with petrol propulsion compared to natural gas. The highest average CO_2 emission, amounting to approximately 389 g/km, was obtained with petrol propulsion in urban conditions. When running on CNG, the CO_2 emission value was lower for the urban section by approximately 135 g/km. The lowest difference in average CO_2 emission (approximately 51 g/km) was obtained for the rural portion of the test route. For motorway driving, the difference in CO_2 emission was approximately 72 g/km. The average emission for the entire on-road test with CNG propulsion was approximately 187 g/km, whereas for petrol it was approximately 273 g/km.

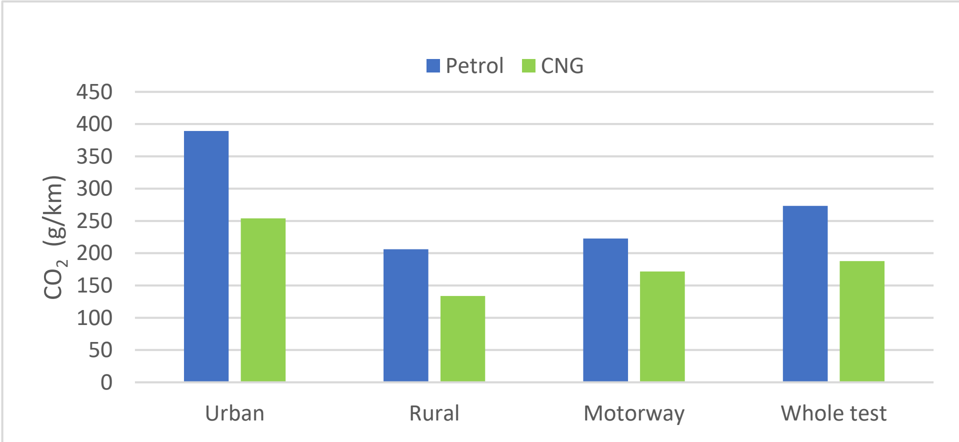

Figure 9. Average CO_2 emission for on-road test.

Figure 10 shows the results of the average CO emission. The impact of fueling with natural gas on the reduction in the emission of this component is evident. A particularly large difference in CO emission was seen on the urban portion of the test, amounting to approximately 3.0 g/km. For the entire on-road test, the average CO emission with petrol fueling was around 2.1 g/km, while for petrol—around 0.7 g/km.

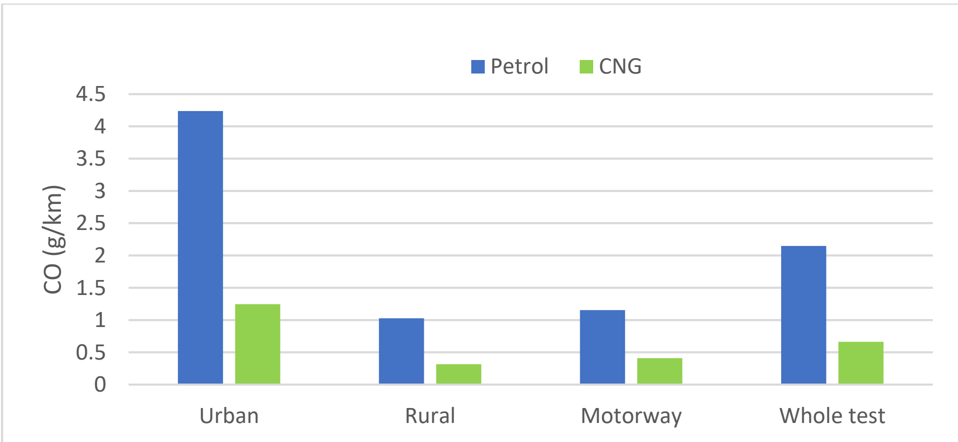

Figure 10. Average CO emission for on-road test.

The results of the instantaneous CO_2 and CO emissions obtained during the road tests with petrol propulsion are shown in Figures 11 and 12, while for natural gas propulsion—in Figures 13 and 14. The values of CO_2 emissions (Figures 11 and 13) were similar to the results obtained in laboratory tests and are dependent on the resistance to motion and its increase during acceleration, as well as the increasing speed. The maximum values of CO_2 emission were higher for petrol propulsion (Figure 11) and were reaching approximately 12 g/s. For natural gas propulsion (Figure 13), the maximum values of CO_2 emission were approximately 8 g/s. Moreover, the CO emission (Figures 12 and 14) for petrol propulsion would temporarily reach higher values than with natural gas, amounting to approximately 0.3 g/s.

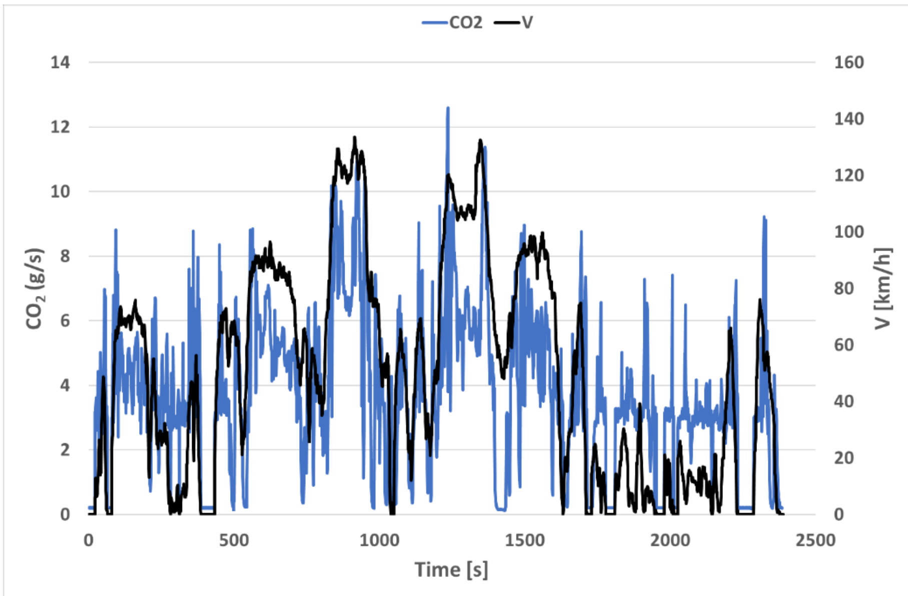

Figure 11. CO_2 emission versus vehicle speed in on-road test, petrol propulsion.

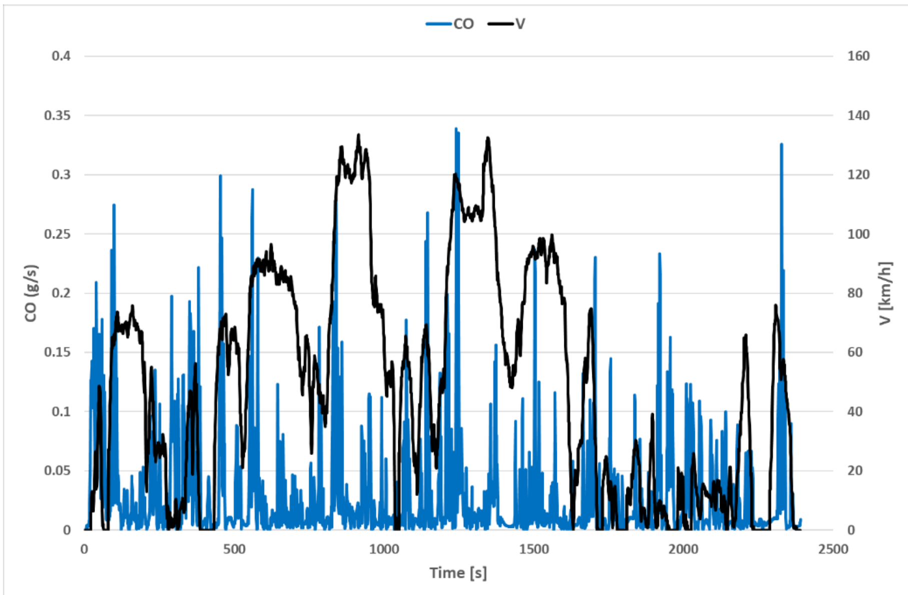

Figure 12. CO emission versus vehicle speed in on-road test, petrol propulsion.

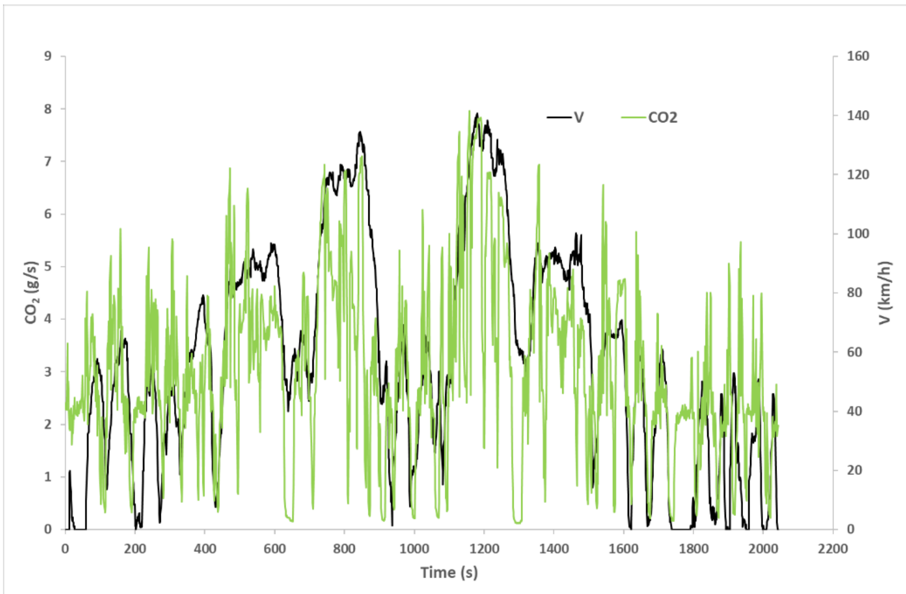

Figure 13. CO_2 emission versus vehicle speed in on-road test, CNG propulsion.

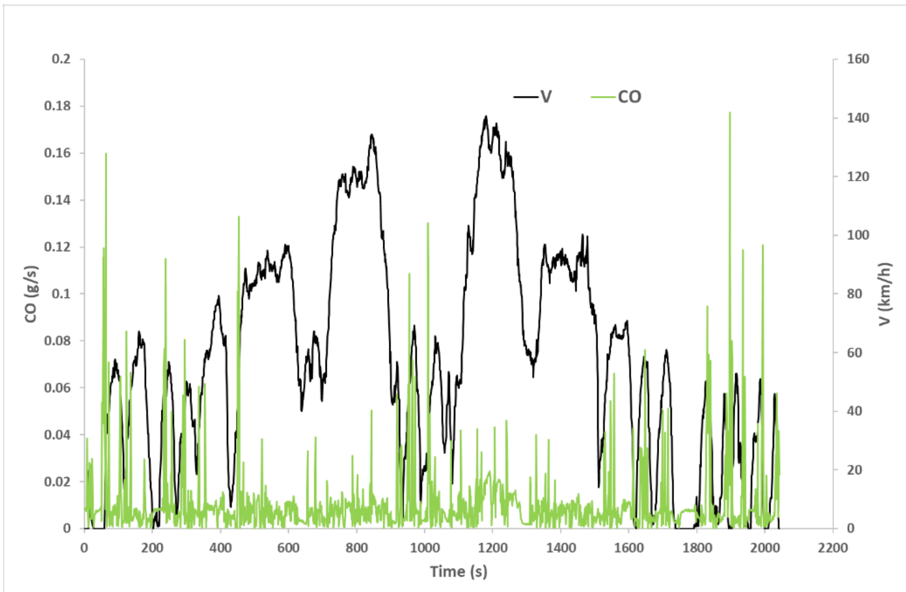

Figure 14. CO emission versus vehicle speed in on-road test, CNG propulsion.

Figures 15–18 show the changes in the cumulative emission values of the pollutants under study versus time. The values of cumulative CO_2 emission in the entire on-road test, when the vehicle was fueled with petrol (Figure 15) and then natural gas (Figure 17), show a large difference in emission (approximately 2800 g). These values are also related to varying traffic conditions and average speeds. The cumulative CO emissions are similar (Figures 16 and 18). When the vehicle was fueled with CNG, the emission value for the entire test was approximately 22 g, whereas with petrol propulsion it amounted to approximately 70 g.

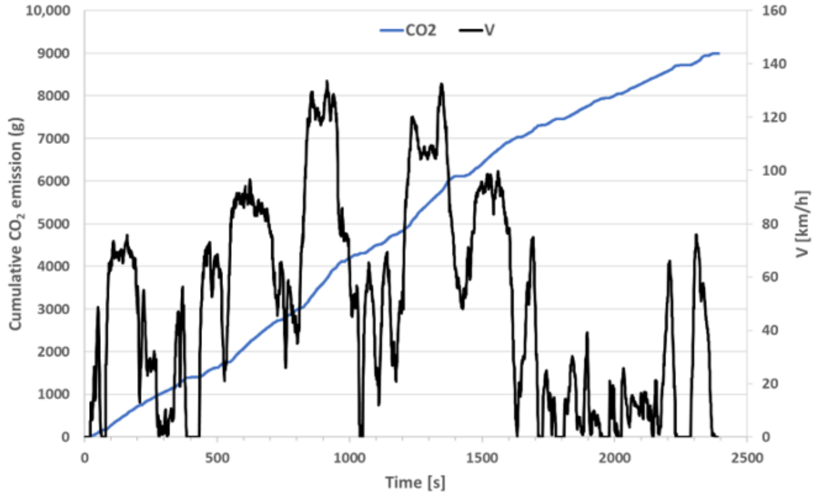

Figure 15. Cumulative CO_2 emission versus vehicle speed in on-road test, petrol propulsion.

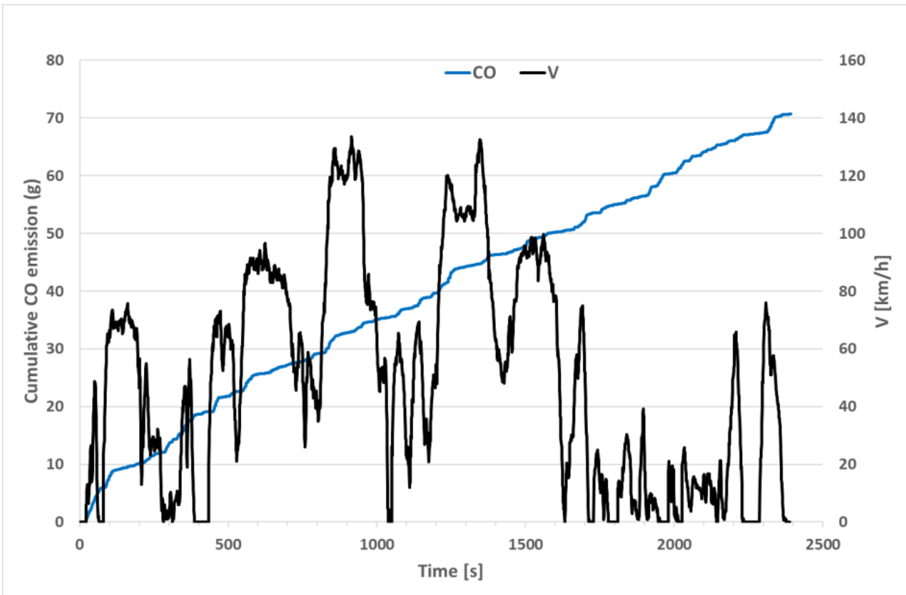

Figure 16. Cumulative CO emission versus vehicle speed in on-road test, petrol propulsion.

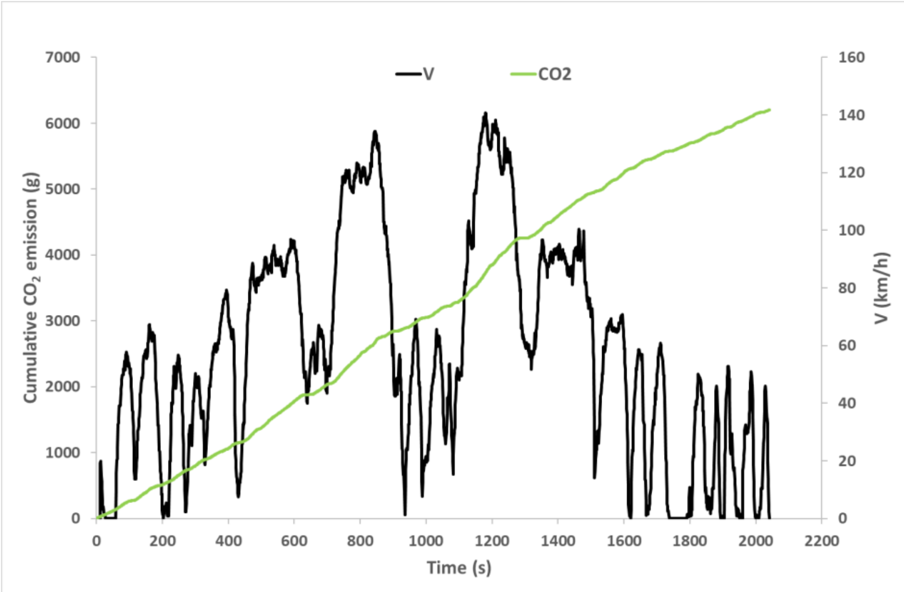

Figure 17. Cumulative CO_2 emission versus vehicle speed in on-road test, CNG propulsion.

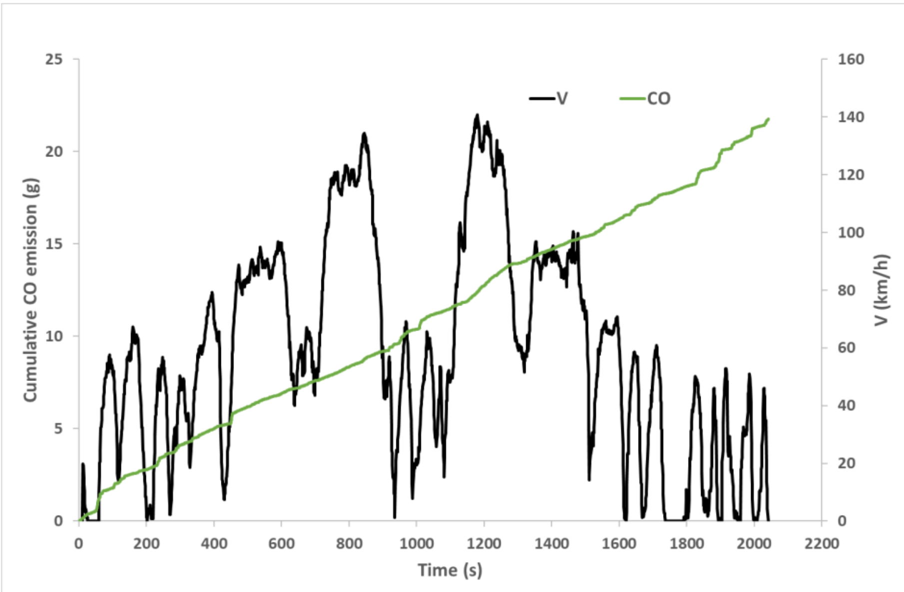

Figure 18. Cumulative CO emission versus vehicle speed in on-road test, CNG propulsion.

Comparing the results obtained in the laboratory and road tests (Figures 19 and 20), higher CO_2 values (by approximately 20% when running on petrol and by approximately 13% when running on CNG) obtained during the road tests are observed. Meanwhile, the average CO emission obtained during the road tests was similar to that obtained in the NEDC test.

The differences in CO_2 emissions are related to the more favorable composition of natural gas (lower carbon/hydrogen ratio). In the case of CO emissions, the control of the mixture composition plays an important role, which in the case of natural gas supply is associated with the reduction in the instantaneous dose of fuel under dynamic load changes, resulting in the depletion of the mixture composition. Comparing CO_2 and CO emissions when running on different fuels, it is clear that for tests under stationary conditions, more unambiguous results are obtained. This is due to the fact that the car engine is subjected to the same loads during the same driving cycle. In road conditions, each route is unique, especially in urban driving conditions [53–55]. Therefore, it should be borne in mind that the differences in the values of pollutant emissions and fuel consumption by the car engine while running on petrol and CNG are additionally related to different road conditions.

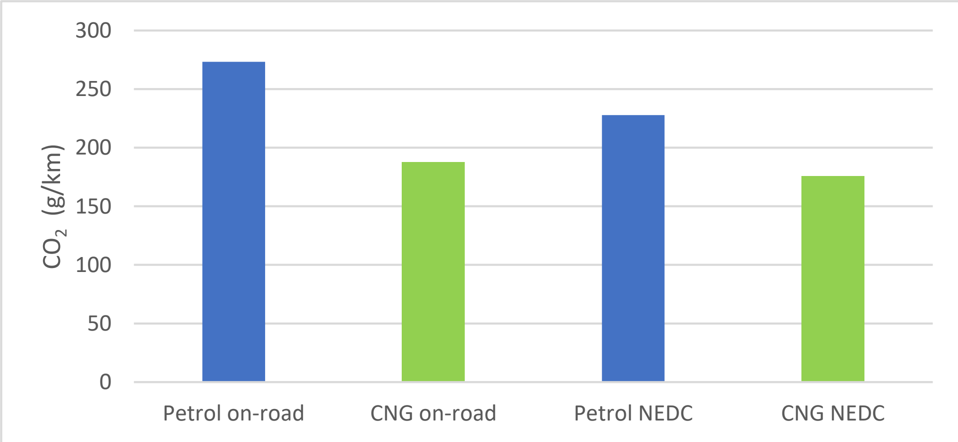

Figure 19. Comparison of CO_2 emission between vehicles fueled with petrol and CNG in the on-road and NEDC tests.

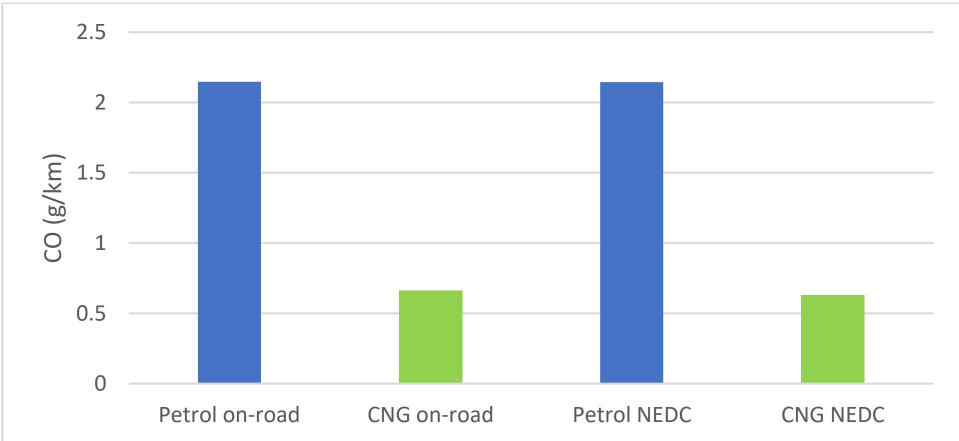

Figure 20. Comparison of CO emission between vehicle fueled with petrol and CNG in the on-road and NEDC tests.

3.3. Results of Fuel Consumption

Fuel consumption *FC* was determined on the carbon balance [64], according to the Formula (1) for petrol and according to Formula (2) for CNG:

$$FC = \frac{0.1155}{s_{Cycle}}\left(0.865 \cdot HC_{MASS} + \frac{M_C}{M_{CO}} \cdot CO_{MASS} + \frac{M_C}{M_{CO2}} \cdot CO2_{MASS}\right)\left(\frac{\text{kg}}{100\ \text{km}}\right) \quad (1)$$

$$FC = \frac{0.1335}{s_{Cycle}}\left(0.749 \cdot HC_{MASS} + \frac{M_C}{M_{CO}} \cdot CO_{MASS} + \frac{M_C}{M_{CO2}} \cdot CO2_{MASS}\right)\left(\frac{\text{kg}}{100\ \text{km}}\right) \quad (2)$$

where: HC_{MASS} is hydrocarbons mass emission (g), M_C is carbon atomic mass (g), M_{CO} is carbon monoxide molecular mass (g), CO_{MASS} is carbon monoxide mass emission (g), M_{CO_2} is carbon dioxide molecular mass (g), $CO2_{MASS}$ is carbon dioxide mass emission (g) and s_{Cycle} is the distance of test cycle (km).

The results of the average fuel consumption for tests are presented in Figures 21 and 22. Fuel consumption values, similarly to CO_2 and CO emissions, were lower for CNG propulsion in relation to petrol. It is also related to the higher mass calorific value of natural gas. In the case of road tests (Figure 21), it should be borne in mind that fuel consumption depends on the vehicle's traffic conditions. During urban driving, the largest differences in the value of average mass fuel consumption occur, amounting to approximately 30%, while for motorway driving, these differences were the lowest and amounted to approximately 12%. This value is similar to the percentage difference between the calorific value of CNG and petrol. The comparative assessment of fuel consumption is therefore more favorable for the NEDC test (Figure 22), when the car was subjected to the same loads resulting from the same test cycle. In this case, the difference in the value of petrol consumption compared to CNG for the individual test phases was approximately 12%. Thus, energy consumption for both fuels was at a similar level.

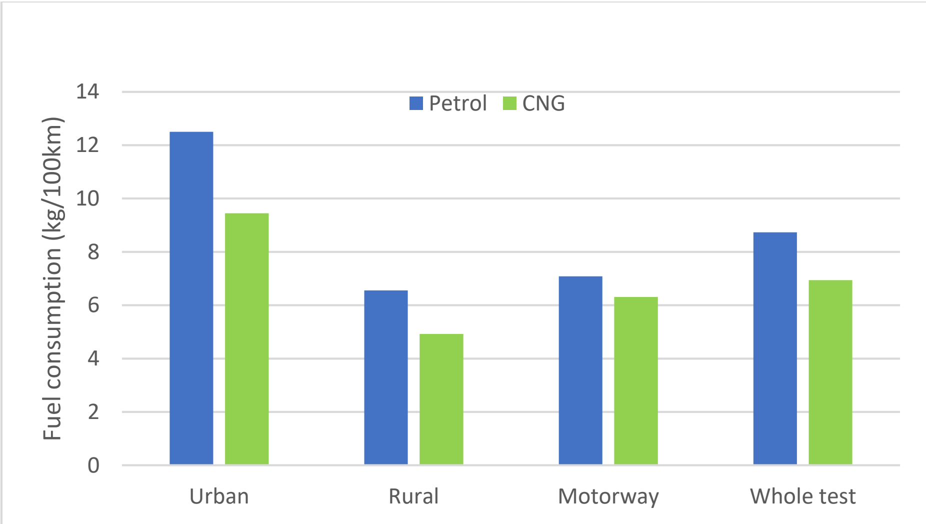

Figure 21. Comparison of the fuel consumption between the vehicle fueled with petrol and CNG in the on-road test.

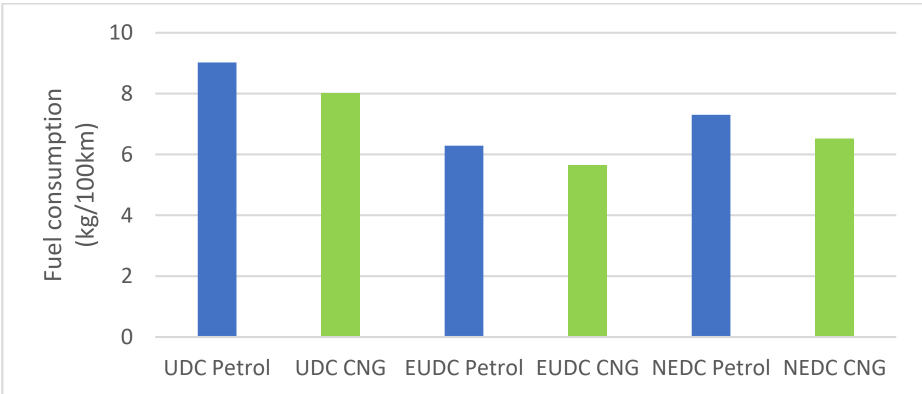

Figure 22. Comparison of fuel consumption between the vehicle fueled with petrol and CNG in the NEDC test.

4. Conclusions

Based on the research, the following conclusions can be drawn:

- The conducted research confirms that adapting the engines of older cars with a Euro 3 emission class to run on natural gas allows for a significant reduction in CO_2 and CO emissions.
- In relation to a petrol-fueled vehicle during laboratory tests, the CO_2 emission for the natural gas supply was lower by approximately 23%.
- The reduction in CO emission with the use of natural gas in laboratory tests was approximately 70% in relation to petrol fueling.

- The average CO_2 emission obtained in the on-road road tests was lower for natural gas-fueled vehicle by approximately 30% than for fueling with petrol.
- The average CO emission obtained in road tests was approximately three times higher when the vehicle was fueled with petrol as compared to natural gas.
- It should be borne in mind that the traffic flow for the on-road emission test with petrol supply was worse than for the test with natural gas supply.
- The research results show that, in order to reduce CO_2 emissions, it is beneficial to adapt older cars to natural gas supply, which are characterized by relatively high fuel consumption and greenhouse gas emissions, compared to newly manufactured cars.
- As the results of tests for exhaust gas pollutant emissions and fuel consumption depend on the test cycle, during the comparative assessment of the influence of the fuel type on these parameters, it is beneficial to carry out not only road tests, but also on the chassis dyno test with repeated load conditions.
- The data collected during the research can be used to prepare a model of CO_2 and CO emissions for passenger vehicles in the future, but there is still a need to collect more real emission measures for other types of vehicles that meet other exhaust emission standards. It is particularly important for countries where the number of CNG-fueled vehicles is increasing, while the generally used national emission models, e.g., COPERT [65,66], and models for the regional scale, e.g., Enviver Versit + [67,68], do not contain enough data for this type of calculation. This is particularly important for shaping the transport policy of a given region, which is characterized by a different structure of vehicles compared to, for example, European models, where there is a different share of vehicles powered by different fuels.

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Abbreviations

CLD	Chemi-luminescence detection
CH_4	Methane
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
ECE 15	Segment of Urban Driving Cycle
EEA	European Environmental Agency
EEV	Enhanced environmentally friendly vehicle
EU	European Union
EUDC	Extra Urban Driving Cycle
FID	Flame ionization detector
HC	Hydrocarbons
LPG	liquefied petroleum gas
NDIR	Non-dispersive infrared
NEDC	New European Driving Cycle

NOx	Nitrogen oxides
O_3	Ozone
OH	Hydroxyl
PEMS	Portable emissions measurement systems
RDE	Real driving emissions
THC	Total hydrocarbons
TWC	Three-way catalytic converter
UDC	Urban Driving Cycle

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