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Fuel consumption and CO_2 emission analysis of hybrid and conventional vehicles in urban driving conditions

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Hybrid vehicles are a good solution for a smooth transition towards electromobility. The aim of this paper is to examine the relationship between route parameters and fuel consumption and emissions of harmful exhaust components of vehicles with a conventional and hybrid drive system. As a result of simulation tests, values for fuel consumption and CO_2 emissions for HEV and ICEV vehicles were obtained in 28 trips in urban conditions. The average fuel consumption achieved by the hybrid was 53% lower than that of a conventional vehicle. When analysing the average value of CO_2 emissions, the hybrid showed a 54% lower value than a conventional vehicle. Using statistical methods, the relationship between the route parameters and the operational parameters of the vehicle was determined. It has been shown that the route parameters strongly correlate with the fuel consumption and CO_2 emissions of a conventional vehicle. In the case of hybrid vehicles, there was a weaker relationship between these parameters.

Key words: *hybrid vehicle, conventional vehicle, emission, fuel consumption, CO_2*

1. Introduction

Hybrid vehicles are competitive with conventional vehicles. They are becoming an increasingly popular choice among drivers due to their lower fuel consumption and lower emissions. The European Automobile Manufacturers' Association (ACEA) has prepared a report on the number of newly registered hybrid vehicles in the European Union. In 2022, the number of registered HEVs (Hybrid Electric Vehicles) amounted to 2,089,653 units, which is 8.6% more than in the previous year. In Poland, the number of newly registered HEVs increased by 5.1% [46].

The dynamic growth of the market of vehicles with alternative drives is observed. The reason is the tightening of exhaust emission standards. Since 1992, the European emission standard has regulated the emission levels of nitrogen oxides (NO_x), hydrocarbons (HC), carbon oxides (CO) and particulate matter (PM) for most vehicles, passenger cars, trucks and buses. Vehicles that do not meet emission requirements cannot be sold in the EU.

The standard in force since 2015 is Euro 6 (referred to as Euro 6b) [10]. It assumes the emission level that cannot be exceeded by motor vehicles sold after 2015 (Table 1). This standard has been amended several times. The change to the Euro 6c standard was related to the introduction of the WLTP (Worldwide Harmonized Light-duty Test Procedure) replacing the outdated NEDC (New European Driving Cycle). The Euro 6d-temp standard was a transitional variant, preparing for the new method of measuring exhaust emissions in the Euro 6d standard. Its introduction was intended to reduce the differences in exhaust emissions between laboratory and road tests.

Table 1. Euro 6 emissions standards

	Emissions, g/km							
Type of vehicle	CO	THC	NMHC	NH_3	NO_x	$HC+NO_x$	PM	Brake PM_{10}
Diesel	0.50	–	–	–	0.80	0.170	0.0045	–
Petrol	1.0	0.10	0.068	–	0.06	–	0.0045	–

Currently, the introduction of the Euro 7 has been announced [9]. The new emission standard aims to unify the restrictions related to the emission of harmful exhaust components. The proposed emission values of individual exhaust gas components are presented in Table 2. The Euro 7 standard additionally defines the values of pollutants that were not regulated before, e.g. nitrous oxide.

Table 2. Euro 7 emissions standards

	Emissions, g/km							
Type of vehicle	CO	THC	NMHC	NH_3	NO_x	$HC+NO_x$	PM	Brake PM_{10}
Diesel Petrol	0.50	0.10	0.068	0.02	0.060	–	0.0045	0.007

The authors of the paper [33] presented the methodology related to the preparation of vehicles to meet the emission values set out in Euro 7. It was shown that driving conditions have a large impact on emissions and can reduce the efficiency of some filtering devices. The methods of reducing the emission of harmful exhaust components include: modification of exhaust gas treatment devices, optimization of the engine operating temperature, and modifications in the field of vehicle electronic systems.

A number of studies provide examples of implemented construction modifications to passenger car powertrains that have resulted in reduced vehicle emissions. For example, the study [7] investigated the effect of a three-way catalyst on exhaust emissions. So far, unregulated components, e.g. NH_3 or N_2O, and presented in the Euro 7 standard, have also been included. It has been shown that the emission level of these components is related to the temperature of the catalyst. A way to control the emission of these components may be to optimize the temperature of the catalytic converter after starting the engine. In paper [8], the authors decided to create a control model for an electrically heated catalyst. Appropriate adjustment of the exhaust aftertreatment system can reduce the amount of NO_x emitted. The proposed strategy of predictive catalyst control allowed them to reduce their average emissions by 50% and in exceptional situations – even by 70%. This allows it to meet the expected Euro 7 standards.

Another method that will significantly reduce emissions is the cooperation of the internal combustion engine with the electric drive system [24, 45]. This solution is otherwise called a hybrid drive system. The paper [22] presents a model of a passenger car (segment C), in which a 1.6 Euro 6d-temp diesel engine cooperated with an electric drive system. The results of the simulation tests confirmed that both in the standard WLTP and in the RDE (real-life drive cycle) the hybrid achieved lower fuel consumption and CO_2 emissions, up to 50% in urban conditions. The authors of papers [14, 17, 22] indicate that hybridization in diesel vehicles is necessary to achieve the level of CO_2 emissions assumed in the new standards.

Vehicles with a hybrid drive system, unlike electric cars, do not have a limited range. Thanks to the electric drive that supports the internal combustion engine, hybrids achieve lower fuel consumption and lower emissions.

The adoption of hybrid vehicles by customers is the subject of many research studies [1, 18, 26]. According to the authors of the paper [44], the most important factor in the adoption of hybrid vehicles is the sense of control over one's own resources. The study found that the most influential determinant of the intention to buy hybrid cars is the feeling that people have better control over their financial assets. Environmental awareness turned out to be the second most important factor influencing the intention to buy a hybrid car. This finding confirms that people's knowledge of the environmental impact of transport carbon emissions will strengthen their intention to buy a hybrid car. Government incentives can significantly increase the acceptance of hybrid vehicles by potential buyers. The study [21] showed that the impact of the purchase price, operating costs, and environmental impact has an impact on the willingness to purchase HEVs by the surveyed group. About 37% of the 150 surveyed people declare their willingness to buy a vehicle with a hybrid drive in the future.

Hybrid vehicles have become the subject of many scientific studies. Especially often the authors decide to compare the level of operational parameters of HEV and ICEV (Internal Combustion Engine Vehicle). For example, in the paper [31], the authors examined the impact of vehicle load and its power on fuel consumption and emission of harmful exhaust components. A 100 kg increase in vehicle weight has been shown to increase fuel consumption by 0.4 dm^3/100 km for HEV and 0.7 dm^3/100 km for ICEV. The use of a linear regression model made it possible to compare the same vehicle models with different drives. The difference in fuel consumption ranged from 2.7 to 3.25 dm^3/100 km.

The authors [2] studied the emission of a conventional vehicle and two models of hybrid vehicles. The results indicate that Euro 3 hybrid vehicles achieved lower emission values than a Euro 4 conventional vehicle. In [16] it was shown that two different hybrids emit significantly less CO_2 than conventional vehicles. HEVs also reported lower fuel consumption, ranging from 40 to 60%. In a study [28], HEV and ICEV vehicle emissions were compared in real road conditions. In the test runs in urban conditions, the vehicles were equipped with exhaust gas analysers. It has been shown that the CO and NO_x emissions of a hybrid vehicle are several times lower than those of a conventional vehicle. The inverse relation concerned the emission of particulate matter. The HEV vehicle, as a result of intermittent operation of the internal combustion engine, emitted more than two times more PMx. The research results presented in [11, 13, 42] also confirm that hybrids have lower fuel consumption and lower emission levels than conventional vehicles in various driving conditions.

In many papers, comparisons can be found between vehicles with different powertrain variants in terms of emissions or fuel consumption [23, 25]. In paper [27], fuel consumption was compared between an ICEV vehicle and two hybrid vehicles (Toyota Yaris Hybrid and Toyota Prius). The results showed that the higher the vehicle speed, the lower the fuel economy. A comparison of the two HEV versions showed that the Toyota Prius consumes 17% less fuel thanks to a more efficient electrical energy recovery system. In the publication [40], the emissions of a full hybrid and a plug-in hybrid were compared. It has been shown that low temperature increases exhaust emissions. However, there were no differences in the emission of regulated exhaust gas components of both vehicles when using a different fuel mixture. On the other hand, the lower SOC value increased the differences in the case of a PHEV (Plug-in Hybrid Electric Vehicle). The authors [41] analysed the operation of the hybrid drive in terms of energy consumption and braking strategy. It has been shown that energy recovery is approx. 2.3 kWh, which contributes to significant fuel savings. In addition, the use of methods to optimize the operation of the internal combustion engine and the electric machine may contribute to meeting the assumptions of the Euro 7 standard.

A comparison of emission values recorded under real traffic conditions and in relation to standardised driving cycles can be found in various studies. In papers [35, 36], the emission of a vehicle with a hybrid drive that met the Euro 6d standard was examined. The vehicle's emissions complied with the applicable exhaust emission standard. Tests in laboratory conditions showed lower values of CO and NO_x emissions than in real tests. Of the unregulated components, only N_2O met the required level. In [12], a Euro 6 hybrid vehicle was examined in the context of CO_2 emission in the NEDC and WLTP cycles at different levels and engine start temperatures. It was shown that in WLTP, the vehicle's energy consumption increased by 50% and CO_2 emissions by 30%. In addition, the difference between cold and warm start in WLTP is 4%, while for NEDC, it is 10%.

The publication [19] presents comparisons of the emission of harmful exhaust gas components and the HEV and ICEV fuel consumption in the RDE and laboratory cycles. The results showed that HEV has lower fuel consumption in the range of 23–49% compared to ICEV, and its efficiency is the highest in the city. In addition, the analysis also showed that the vehicles emitted less harmful exhaust components than the Euro 6 standard. The start-stop hybrid generated higher HC or CO values as a result of frequent stops and low exhaust gas temperatures.

Many papers show the level of CO_2 emission in real-world driving conditions. The results of tests carried out in real traffic conditions confirm that driving conditions effect the level of emissions for both HEV and ICEV [3, 6, 43]. The paper [36] compared the carbon dioxide emissions of hybrid and conventional vehicles on different types of roads. It has been shown that the highest CO_2 emission occurs in urban traffic for both vehicle types. The lowest emission value occurs on suburban and highway roads. On all types of roads hybrids emit less CO_2 than conventional vehicles, the difference can be up to 50% [29]. As the results of research presented in [31] show, the use of hybrid vehicles may increase by 3% per 1 km.

As mentioned before, driving conditions are crucial for both conventional and hybrid vehicle efficiency. In [39], the impact of ambient temperature on the emission of vehicles meeting the Euro 6 standard was examined. It was revealed that the emission values of THC, CO, NO_x, SPN and NH_3 were higher at –7ºC than at 23ºC. CO_2 and N_2O emission values were higher at temperatures below 0°C. The results of the study [15] show that the use of a plug-in hybrid vehicle on the motorway generates high emission values, which may even exceed the limit in the Euro 6 standard. The problem of increased emissions is also the cold start of the engine. The implemented route has a large impact on the fuel consumption and emissions of vehicles equipped with an internal combustion engine. The intensity of traffic and the location of road infrastructure elements (i.e. traffic lights, intersections, roundabouts) force frequent acceleration, braking and stopping, and thus affect the smoothness of driving.

The purpose of this paper is to compare the values of fuel consumption and CO_2 emissions of passenger cars equipped with a conventional drive and a hybrid drive. For simulation tests, speed profiles from 28 trips recorded in real conditions were used. The relationship between travel time and average travel speed and the values of fuel consumption and CO_2 emissions were analysed.

2. Methodology

2.1. Logging of vehicle movement parameters under real conditions

First, velocity profiles were recorded for trips in urban conditions. It was assumed that the length of each run was 5 km. The registration was carried out twice a day: at noon and during the afternoon rush hour. The measurements were carried out using the Kistler Data Logger GPS sensor, the measurement vehicle was a Hyundai Kona (Fig. 1). The SOC (State of Charge) value of each trip was the same and amounted to 95%. The following parameters were recorded: time, instantaneous speed, instantaneous acceleration, distance traveled and instantaneous geographic location.

Data from each run was logged in separate files. The data was then verified and edited appropriately so that it could be entered as input into the simulation program. The collected vehicle dynamic parameters from each run were subjected to further statistical analysis.

Fig. 1. Measurement apparatus and test vehicle

2.2. Simulation tests

Simulation tests were carried out in the AVL Cruise program. The collected speed profiles were used as input data, reflecting the parameters of the route and the driving style of the driver. The program adapts models of vehicles with conventional drive (ICEV) and hybrid drive (HEV). Table 3 presents a summary of selected technical parameters of the analysed vehicles.

Table 3. Selected technical parameters of the analysed vehicles

		ICEV	HEV
Vehicle	Mass, kg	1600	1600
	Frontal area, m^2	1.72	1.75
	Drag coefficient	0.33	0.33
Internal combustion engine	Engine displacement, cm^3	1200	1497
	Number of cylinders	4	4
	Max speed, 1/min	6000	4700
	Idle speed, 1/min	850	945
	Maximum torque, Nm	90	–
	Inertia moment, $kg \cdot m^2$	0.1055	0.18
PSM Electric motor	Maximum power, kW	–	50
	Max speed, 1/min	–	6000
NiMH Battery	Battery capacity, kWh	–	1.31
	Initial state of charge, %	–	60
	Nominal voltage, V	–	7.2

As a result of the simulation, CO_2 emissions and vehicle fuel consumption values were obtained for each trip. The results were then subjected to further statistical analysis.

2.3. Data analysis

The aim of the study was to assess the impact of the route on the operational parameters of the vehicle. In the measurements of real traffic conditions, velocity profiles as a function of time were obtained. On their basis, the parameters reflecting the driving conditions were selected. The following were used for further analysis: travel time, average velocity during the trip, and the share of stopping time in the travel time. Two parameters were selected to assess vehicle efficiency: fuel consumption and CO_2 emissions. The impact of route parameters on fuel consumption and CO_2 emissions of hybrid and conventional vehicles was examined using correlation analysis.

3. Results

3.1. Analysis of vehicle movement parameters during trips

During the tests in real driving conditions, 28 trips were made. Each of the trips ran in the city, measuring about 5 km. The velocity profile of one randomly selected trip is shown in Fig. 2. The time of travel, the average velocity in each trip and the percentage of stopping time during each trip were statistically analysed.

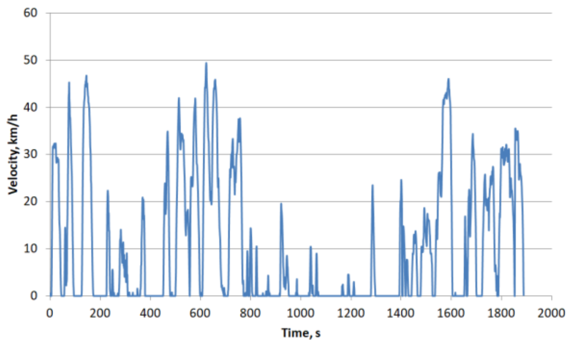

Fig. 2. Recorded velocity profile of a randomly selected trip

Selected statistical parameters of the analysed trips are shown in Table 4. The shortest of the recorded trips was 574 s (about 10 min), while the longest was 1890 s (31.5 min). The mean travel time of the analysed 5 km sections under urban conditions was 962 s (about 16 min). On average, the travel time values deviate from the arithmetic mean by ±346 s (about 6 min).

Table 4. Summary of selected statistical parameters of trips

	Mean	SD	Median	Min	Max
Travel time, s	962	346	881	574	1890
Average velocity, km/h	21.19	6.13	21	10	31.80
Share of stopping time in the travel time, %	25.01	11.97	22.90	7.14	48.54

Another parameter is the average velocity of the trip. This parameter reflects the movement smoothness. The lower the average velocity, the higher the traffic density for the duration of the trip, resulting in a higher share of stopping time. Among the analysed trips, the highest average speed was 31.8 km/h and the lowest was 10 km/h. The mean value of this parameter was 21.19 km/h. The standard deviation (SD) was 6.13 km/h. Figure 3 shows box plots of travel time, average speed, and the share of stopping time in total travel time.

The parameter reflecting the smoothness of the trip is also the share of stops during the drive. On average, the share of stops during the trip was 25%. In one of the analysed trips, the vehicle spent more than half of the duration of the entire run at a standstill due to heavy traffic.

3.2. Analysis of vehicle movement parameters during trips

On the basis of the recorded speed profiles, simulation tests of vehicles with conventional and hybrid drives were carried out. A summary of selected statistical measures of fuel consumption of the analysed vehicles is presented in Table 5. Figure 4 shows box plots of fuel consumption

Table 5. Selected statistical measures of fuel consumption (kg)

Vehicle	Mean	SD	Median	Min	Max
ICEV	0.37	0.11	0.35	0.25	0.67
HEV	0.17	0.04	0.16	0.13	0.24

The lowest vehicle fuel consumption recorded in the runs was 0.25 kg, and the highest was 0.67 kg. The mean value of fuel consumption was 0.37 kg. The fuel consumption values of a vehicle with a conventional drive in the analysed trips are strongly differentiated, as evidenced by the high value of the standard deviation – 0.11 kg.

On selected trips, the difference between the maximum and minimum fuel consumption recorded by the hybrid vehicle was 0.11 kg. The mean fuel consumption of this vehicle in the analysed journeys was 0.17 kg, the SD was 0.04 kg.

Then, the fuel consumption values were analysed in detail for the following stages of motion: idling, acceleration phase, driving at constant speed and deceleration. Table 6 and Table 7 present statistical measures of fuel consumption at the indicated stages of movement by the analysed vehicles. Figure 5 shows box plots of the fuel consumption values of the analysed vehicles

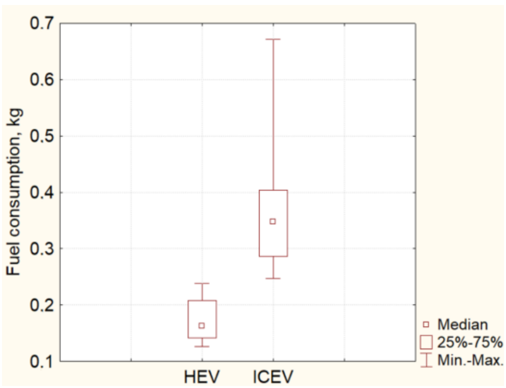

Fig. 4. Box plots of fuel consumption

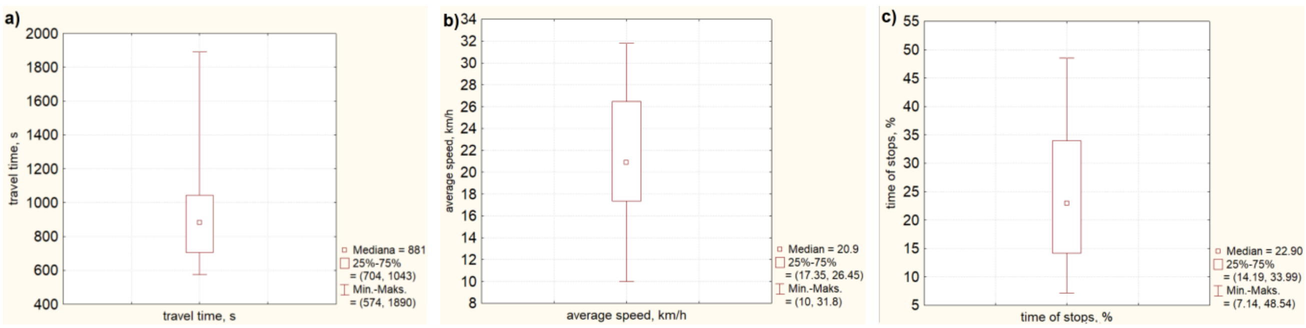

Fig. 3. Box plots of (a) travel time, (b) average speed of the analysed trips, (c) share of stopping time

Table 6. Selected statistical measures of fuel consumption (kg) of the conventional vehicle at various stages of movement

Movement stage	Mean	SD	Median	Min	Max
Idling	0.10	0.08	0.07	0.01	0.31
Acceleration	0.20	0.03	0.19	0.15	0.27
Driving with constant speed	0.03	0.01	0.03	0.02	0.04
Deceleration	0.05	0.01	0.05	0.03	0.09

Table 7. Selected statistical measures of fuel consumption (kg) of the hybrid vehicle at various stages of movement

Movement stage	Mean	SD	Median	Min	Max
Idling	0.00	0.00	0.00	0.00	0.00
Acceleration	0.13	0.02	0.12	0.09	0.17
Driving with constant speed	0.01	0.00	0.01	0.01	0.02
Deceleration	0.03	0.01	0.03	0.02	0.08

Taking into account fuel consumption in particular stages of motion, it can be seen that both for the hybrid and the conventional vehicle, the highest values were noted during acceleration. The lowest fuel consumption was recorded while driving at a constant speed. For a conventionally powered vehicle, high levels of fuel consumption occur when idling. The hybrid vehicle recorded no fuel consumption while idling. The highest fuel consumption occurred during acceleration. The mean fuel consumption for acceleration is 0.13 kg.

Comparing the fuel consumption of both vehicles in each of the movement phases, it can be seen that the conventional vehicle shows higher values in each driving phase. The fuel consumption level recorded by the conventional vehicle was higher than that of the hybrid by 35% during acceleration, 67% during steady speed and 0.4% during braking, respectively.

Table 8 presents a summary of selected statistical measures of CO_2 emissions of the analysed vehicles.

Table 8. Selected statistical measures of CO_2 emission (kg)

Vehicle	Mean	SD	Median	Min	Max
ICEV	1.18	0.34	1.10	0.78	2.12
HEV	0.54	0.11	0.51	0.40	0.75

The difference between the maximum and minimum CO_2 emissions recorded by a conventional vehicle in the analysed trips was 1.34 kg. The average CO_2 emission was 1.18 kg. The CO_2 emission values obtained in the analysed runs are strongly differentiated, which is expressed by the value of the standard deviation. The mean CO_2 emission of the hybrid in the analysed trips amounted to 0.54 kg. The spread of recorded emission values was 0.35 kg. On average, CO_2 emissions deviate from the arithmetic mean by ±0.11 kg. The box plots of CO_2 emissions for both vehicles is shown in Fig. 6.

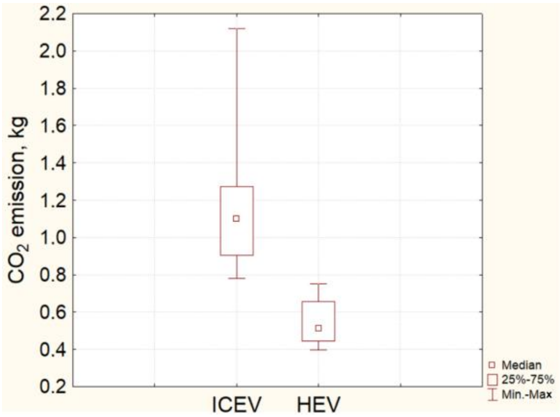

Fig. 6. Box plots of CO_2 emission

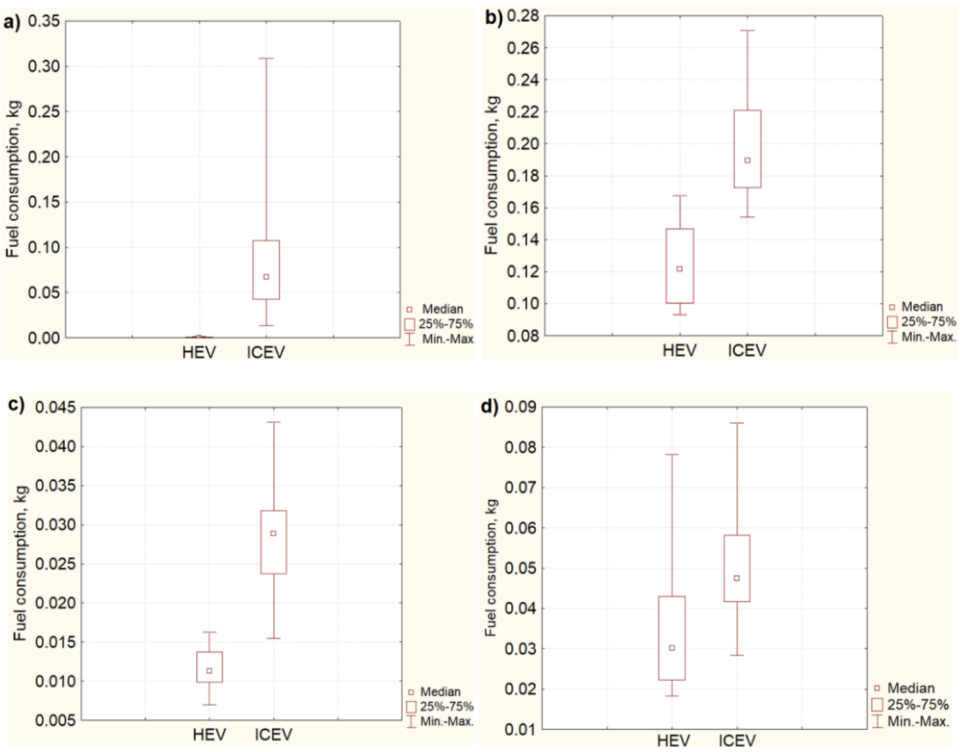

Fig. 5. Box plots of ICEV and HEV fuel consumption in various stages of motion: (a) idling, (b) acceleration, (c) constant speed driving, (d) deceleration

3.3. Evaluation of the impact of route parameters on the fuel consumption and CO_2 emissions of the analysed vehicles

Next, the relationships between the route parameters and the operational parameters of the conventional vehicle were studied. It can be seen that there are strong correlations between fuel consumption and CO_2 emissions and travel time. Similarly, there is a strong correlation between fuel consumption and CO_2 emissions and average speed during the trip (Table 9 and Table 10). A strong correlation was noted for the time share of a stop versus the values of fuel consumption and CO_2 emissions.

Table 9. Correlation coefficients of route parameters and fuel consumption of the analysed vehicles ($p < 0.05$)

	Travel time, s	Average velocity, km/h	Stopping time, %
ICEV	0.94	–0.85	0.73
HEV	0.55	–0.59	0.21

Table 10. Correlation coefficients of route parameters and CO_2 emissions of the analysed vehicles ($p < 0.05$)

	Travel time, s	Average velocity, km/h	Stopping time, %
ICEV	0.94	–0.85	0.73
HEV	0.55	–0.59	0.21

Considering the operational parameters of the hybrid, a moderate relationship was observed between the parameters selected for the route and the level of fuel consumption and CO_2 emissions trip (Table 9 and Table 10). A weak relationship exists between the share of stopping time in the total trip and the values of fuel consumption and CO_2 emissions.

4. Discussion

Based on the results of the simulation tests, it can be concluded that the hybrid has lower fuel consumption and lower CO_2 emissions than a conventional vehicle. The analysed values of nitrogen dioxide emissions and fuel consumption were obtained on the basis of real velocity profiles of 28 trips made in urban conditions. The mean fuel consumption achieved by the hybrid was 53% lower compared to a conventional vehicle. The maximum value noted in by ICEV was 64% higher than that obtained by HEV. The hybrid vehicle also showed the lowest carbon dioxide emissions in selected trips. When analysing the average value of CO_2 emissions, the hybrid showed 54% lower than the conventional vehicle.

The results of simulation tests presented in the paper confirm that the use of a hybrid drive system in vehicles can significantly reduce the level of CO_2 emissions and fuel consumption. The papers cited in the Introduction section confirm that hybrids have lower emissions and lower fuel consumption levels not only in urban conditions, but also in highway and suburban driving conditions.

Based on the results of the correlation analysis, it can be seen that the operating parameters of a conventional vehicle are fully affected by the analysed route. Correlation studies have confirmed a strong relationship between travel time and average travel speed on fuel consumption and CO_2 emissions. Urban driving at different times of the day has different traffic flows, so it affects the vehicle's fuel consumption and, thus its emissions. The longer the travel time, the higher the values of these parameters. Lower traffic density, reducing average driving speed, results in higher fuel consumption and emissions. This is confirmed by the results of tests conducted in real world traffic conditions, which can be found in publications [4, 5, 37].

Operational parameters of hybrid vehicles are less dependent on the performed route. The correlation analyses showed a moderate impact of travel time and average travel speed on fuel consumption and CO_2 emissions. The results of real-world studies presented in papers [20, 30, 34] confirm the effectiveness of hybrid propulsion especially in urban conditions. The internal combustion engine, supported by the electric drive, works in its optimal operating range, so its operation is not significantly affected by the conditions of the route. This results in lower emissions and fuel consumption.

5. Conclusions

The purpose of this study was to examine the values of CO_2 emissions and fuel consumption for vehicles with conventional and hybrid drives. In the first part, speed profiles were collected during 28 trips in urban conditions. The recorded speed profiles were used as input data for the simulation program, reflecting the route profile. As a result of simulation tests, the values of fuel consumption and CO_2 emissions of a hybrid and a conventional vehicle were obtained. Based on the simulation results, it can be concluded that the hybrid vehicle showed the lowest fuel consumption and CO_2 emissions. Then, the impact of the route on the operating parameters of the analyzed vehicles was analyzed.

The results of the correlation study showed that the route has a strong impact on the fuel consumption and CO_2 emissions of a conventional vehicle. Studies have shown a correlation of 0.94 for driving time – 0.85 for average speed and 0.73 for stopping time.

In the case of a hybrid vehicle, these dependencies are much smaller (less than 0.60). A moderate relationship was demonstrated.

Fuel consumption at various stages of vehicle movement was also analyzed. The results showed that a conventional vehicle consumes more fuel at each stage of motion. During acceleration alone, the ICEV recorded an average of 67% higher fuel consumption than the HEV. When idling, no fuel consumption was recorded for the hybrid vehicle.

This paper shows a comparison of fuel consumption and CO_2 emissions of vehicles with conventional and hybrid drive in urban driving conditions. It is evident that hybrid drive vehicles indisputably have lower fuel consumption values, which also translates into economic benefits as well as a reduction of harmful impact on the environment. Hybrid vehicles may therefore compete with conventional vehicles in the future. However, it is necessary to reduce the cost of its purchase.

Nomenclature

ACEA European Automobile Manufacturers' Association
CO carbon oxide
CO_2 carbon dioxide
HEV hybrid electric vehicle
ICEV internal combustion engine vehicle
NEDC New European Driving Cycle
NO_x nitrogen oxide
PM particulate matter
RDE Real Driving Emissions
WLTP Worldwide Harmonized Light-duty Test Procedure

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