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Comparison of Noise Emissions in Cars with Electric and Conventional Drive

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Abstract

Currently, great importance is attached to the issue of environmental protection, also in the context of the impact of transport on the environment. Limited fossil resources, climate change and global warming are driving the automotive industry towards more efficient and sustainable solutions. These problems force car manufacturers to use new technologies and alternative driving systems. Examples of such vehicles include electric cars (EVs) and hybrid cars (HEVs or PHEVs). The impact of using these means of transport on the emission of pollutants other than exhaust gases is an important issue. An example of such emissions is noise. Conventionally powered cars produce noise from their combustion engines and exhaust systems. All vehicles, whether conventionally or alternatively powered, emit noise as a result of the interaction between the tires and the road surface, as well as the air flowing over the body (aerodynamic noise). Superficially, it seems that electric cars produce less noise. This article measures noise outside passing electric, conventional and hybrid vehicles. Measurements were taken at speeds of 20 km/h, 50 km/h, and 80 km/h, and the results were presented in graphical form. The aim of this research is to investigate whether vehicles with hybrid and electric drives produce less noise than those with conventional drives.

Keywords: electric vehicles, electromobility, noise emission, noise measurements, safety

1. Introduction

Currently, great importance is attached to the issue of environmental protection, also in the context of the impact of transport on the environment. Limited fossil resources, climate change and global warming are driving the automotive industry towards more efficient and sustainable solutions. These problems are prompting car manufacturers to adopt new technologies and alternative propulsion systems. Examples of such vehicles are electric cars (EVs). The impact of operating these means of transport on the emission of pollutants other than exhaust fumes is significant (Cebulska, 2021). Noise is an example of such an emission. The growing number of motor vehicles in use prompts us to address this topic, particularly as the number of vehicles

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with alternative drives, i.e., hybrid and fully electric, is gradually increasing. There are clear indications that noise emissions are lower for alternatively powered vehicles (Fic, 2019). In light of unanswered questions on this subject, it seems necessary to consider the issue of pollutant emissions from the use of means of car transport. It is believed that the main source of noise is not the engine, but rather the noise from running tires and airflow (Kwiatkiewicz et al., 2020).

2. Noise emission

Traffic noise, next to exhaust emissions, is considered the most bothersome type of pollution resulting from vehicle operation. As in the case of exhaust emissions, noise emissions are determined by appropriate standards. Noise measurements are taken under both laboratory and field conditions (Fiebieg, 2020). Noise is sounds, usually of excessive intensity, occurring at a given place or time. The noise level is determined based on sound pressure. Sound pressure determines the time-varying deviation from the average value of static pressure prevailing in a given place, which occurs during the propagation of an acoustic wave (Nader, 2016). The unit of sound pressure is Pascal [Pa]. The decibel scale is used to compare noise magnitudes that vary linearly over a wide range, i.e., the sensitivity range of the human ear. The decibel scale describes the ratio of two measured quantities – sound intensity to the reference level (Harazin & Grzesik, 1998).

Due to the properties of human hearing, i.e., sounds of the same level but different spectra are heard differently, the signal is processed by weighting (correction) filters with standardized characteristics. Shaping the signal measured using weighting filters is called frequency weighting. Correction curve A is most often used in measurements. This curve is intended to adjust the decibel scale to the characteristics of the human ear at low sound pressure levels. It is most often used in noise measurements (Nader, 2004).

The sound level is the sound pressure level corrected according to the A-weighting curve. This curve is intended to adapt the decibel scale to the characteristics of the human ear at low sound pressure levels. It is most often used in noise measurements. We perceive very low and very high frequency sounds more intensely than sounds in the frequency range from 800 Hz to 7 kHz. Equalization curve B applies to average sound pressure levels. The C equalization curve corresponds to the ear's response to sounds with high sound pressure levels. Curve D is used to measure aircraft noise, while L is an unweighted (flat) curve (Przysucha & Batko, 2014).

Sound level is not a physical quantity, and the decibel is not a unit of measurement. Due to the frequency ranges, infrasonic noise with infrasonic frequencies from 2 Hz to 16 Hz and audible frequencies up to 50 Hz, audible noise in the frequency range from 16 Hz to 16 kHz and ultrasonic noise with frequencies from 10 kHz to 100 kHz are distinguished. The ear is most sensitive to frequencies between 2 kHz and 5 kHz (Augystyńska & Zawieska, 1999).

Frequency weighting involves shaping the measured signal using weighting filters that adapt the device's characteristics to match those of the human ear. These quantities include:

- sound pressure level;
- maximum and equivalent sound level A and peak sound level C; level of noise exposure during an eight-hour working day (Gronowicz, 2004).

Noise can be classified based on the balanced sound level value, measured using an A-weighted filter (Nader, 2016):

- below 35 dB(A) – not harmful, but bothersome;
- 35–70 dB(A) – negatively affects the nervous system, decreases efficiency, makes rest difficult;
- 70–80 dB(A) – headaches and permanent hearing loss;
- 85–130 dB(A) – numerous hearing damage and disorders of the circulatory and nervous systems;
- 130–150 dB(A) – permanent hearing damage, causes vibrations of internal organs, which may result in their damage;
- above 150 dB(A) – in addition to the above-mentioned disorders, it may cause nausea, balance and limb movement disorders, and even mental illnesses such as anxiety or depression.

The perception of noise is subjective and depends on the immunity of the nervous system, mental state, duration of exposure and type of noise. Noise occurring in means of transport has a negative effect on the hearing organ and the central nervous system, causing "acoustic trauma" that triggers the body's defense reactions, which are manifested by changes in breathing and heart rate, increased blood pressure, changes in circulation, and disruption of intestinal peristalsis. Prolonged exposure to high noise levels exceeding the levels considered safe may lead to deterioration or even loss of hearing and neurotic diseases. This noise may cause hearing impairment without anatomical damage, resulting in a decrease in hearing acuity or damage to the anatomical structures of the hearing organ, e.g. perforations or defects in the eardrum, leading to hearing impairment and even deafness (Gronowicz, 2004).

Infrasound is perceived not only by the hearing organ, but also by mechanoreceptors, similarly to low-frequency vibrations. Their impact may result in ear pain, pressure changes, cardiac disturbances and resonance vibrations. Ultrasound affects the body in a mechanical way, similar to infrasound and thermal form. They harm the nervous system, metabolic processes, and circulatory system disorders. Impulse noise is particularly harmful because it is unsteady noise, consisting of one or more sound events with a duration of approximately one second, and hearing damage depends on the peak acoustic level (Tsoi Ka et al., 2023).

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3. Electric vehicles as a source of noise

Road noise is created as a result of operating the driving unit, the exhaust system, airflow while driving, and noise resulting from the interaction of the tire with the road surface and the air flowing around the car while driving. Vehicles moving at a given speed are characterized by different acoustic power, so noise is a function of the number of vehicles, their type and the road on which they travel (Yehchen et al., 2020).

Conventionally powered cars produce noise from their combustion engines and exhaust systems. Electric cars do not have an internal combustion engine, and therefore, no intake or exhaust system. Consequently, the noise is primarily caused by variable electromagnetic forces that accompany the conversion of electrical energy into mechanical energy (Cebulska & Hadrys, 2023). These include friction noise from the rotor, bearings, brushes, and slip ring, as well as airflow through the rotating rotor, along with electromagnetic noise. The operation of the drive system and transmission also generates noise. At speeds up to 20 km/h, the main source of noise in electric vehicles is the AVAS system. All vehicles with conventional and alternative drive emit noise as a result of the interaction between the tires with the road surface and the air flowing around the body (aerodynamic noise) (Sandberg & Goubert & Mioduszewski, 2010).

The literature shows that the noise in cars with an electric engine is lower up to 20 km/h. At speeds above 30 km/h, the difference in noise impact compared to cars with a conventional hard drive disappears. This is because the main noise sources are road tire noise and aerodynamic noise. Modern combustion engines are not loud, so they may be inaudible when driving due to jammed tires. Another important aspect is the soundproofing of the car, which depends on the vehicle's class (Yoshinaga & Namikawa, 2009).

Due to the low noise level in electric cars at speeds up to 20 km/h, these vehicles are equipped with the AVAS system. This system emits sounds to inform passersby about the approaching vehicle. AVAS automatically produces a sound at minimum vehicle speeds, from start up to approximately 20 km/h, and when reversing. If the vehicle is equipped with an internal combustion engine and is operated within the speed range specified above, the AVAS shall not produce sound. For vehicles equipped with a reversing audible alarm, the AVAS is not required to produce a sound when the vehicle is in reverse. The sound level produced by the system shall not exceed the approximate sound level of an M1 vehicle equipped with an internal combustion engine and operating under the same conditions. It is mandatory equipment for every electric and hybrid car sold in the European Union from July 1, 2021. This regulation is governed by Regulation No. 540/2014 of the European Parliament and of the Council on requirements for the acoustic vehicle information system for the purposes of EU vehicle type-approval of June 26 2017 (UE 2017/1576. Journal of Laws 239, 2017).

4. Apparatus and subject of research

Noise measurements were carried out using a Bruel & Kjaer 2250 Light sound intensity meter (fig. 1). Meets the requirements of the following standards: IEC 61672-1 (2002 – 05) class 1, IEC 60651 (1979) with amendment 1 (1993 – 02) and 2 (2000 – 10) type 1, IEC 60804 (2000 – 10) type 1. Values such as LAeq, LAFmax, LCeq, LCpeak were measured. The meter and technical data are presented below (Table 1).

Figure 1. Sound intensity meter – Bruel & Kjaer 2250 Light. Adopted from: https://www.bksv.com/en/instruments/handheld/sound-level-meters/2250-series/type-2250-l. Accessed: March 30, 2024.

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Table 1. Technical parameters of the sound intensity meter – Bruel & Kjaer 2250 Light

Characteristic	Value
Measuring frequency range	5.6 Hz – 20 kHz with standard ½" type 4950 free-field pre-polarized microphone with a sensitivity of 50 mV/Pa
Measurement range	16.4 – 140.0 dB(A); 43.0 – 142.8 dB(C) peak value
Dynamic range	120 dB
Frequency correction characteristics	A, B, C, Z
Time constants	F, S, I
The total self-noise of the analyzer	16.4 dB(A)

Source: B&K Sound and Vibration Measurement. Adopted from: https://www.bksv.com/en/instruments/handheld/sound-level-meters/2250-series/type-2250-l. Accessed: March 30, 2024.

Three vehicles were used during the tests. The first of these was the Dacia Spring electric car (Vehicle 1). The second vehicle is a Dacia Sandero with a 1.0 Tce petrol engine (Vehicle 2). The third vehicle is the Toyota C-HR hybrid car (Vehicle 3). Dacia Spring (Vehicle 1) and Dacia Sandero (Vehicle 2) are the cheapest cars currently available on the European market. Since Dacia does not offer a hybrid car, the Toyota C-HR (Vehicle 3) was used for the research as one of the cheaper hybrid cars with similar dimensions. The vehicles are shown below (Figures 2–4).

Figure 2. Vehicle 1 – Dacia Spring electric car and electric engine. Source: the authors' own research.

Figure 3. Vehicle 2 – Dacia Sandero conventional car and internal combustion engine. Source: the authors' own research.

Figure 4. Vehicle 3 – Toyota C-HR hybrid car and two engines (electric and internal combustion). Source: the authors' own research.

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5. Research

Before proceeding with the noise tests from the outside of the vehicle, background measurements were taken. The temperature during the measurements was approximately 10 °C, in wind-free and rain-free conditions. The measurements were presented as the arithmetic mean of the collected results, discarding the lowest and highest values. The results are presented in Table 2.

Table 2. Background noise measurement

	L_{Aeq}, dB	L_{AFmax}, dB	L_{Ceq}, dB	L_{Cpeak}, dB
Background	32.62±3.01	34.84±3.09	48.2±0.5	59.28±1.7

Source: the authors' own research.

The outdoor noise measurements were conducted on a flat asphalt surface in a closed road environment under controlled conditions. No other vehicles were passing in the area during the measurements. The measurements were taken on Sunday between 4:00 p.m. and 7:00 p.m., with a reduced background noise level. Ten measurements were taken while vehicles were passing at speeds of 20 km/h, 50 km/h, and 80 km/h at a distance of 2 m. The temperature during the measurements was approximately 10 °C with wind-free and rain-free conditions. The driving speed was constant, and the measurement section was approximately five meters in length. The measurements were presented as an arithmetic mean of the collected results, excluding the lowest and highest values. The measurements were presented as an arithmetic mean of the collected results, excluding the lowest and highest values. Figure 5 illustrates the measurements performed. The results are presented in Tables 3, 4, 5 and shown in Figures 6, 7, 8.

During the tests, the following values were measured:

- L_{Aeq} – the equivalent average sound level corrected according to the frequency response A, expressed in decibels (dB);
- L_{AFmax} – the maximum effective value of the sound level corrected according to the frequency response, expressed in decibels (dB);
- L_{Ceq} – the equivalent average sound level corrected according to the frequency response C, expressed in decibels (dB);
- L_{Cpeak} – the maximum instantaneous value (peak) of the sound level (also called peak) corrected according to the frequency response C, expressed in decibels (dB).

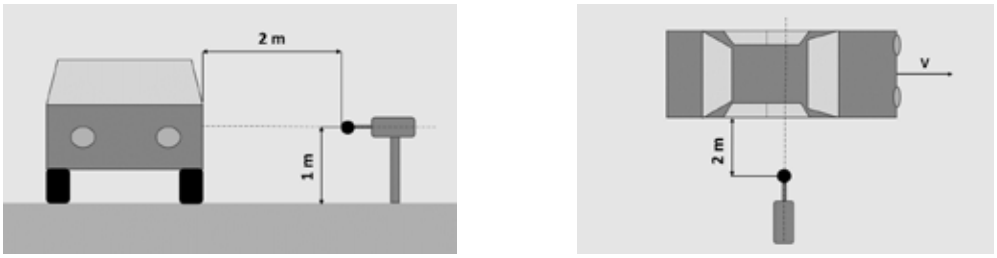

Figure 5. External noise measurement scheme. Source: the authors' own work.

a. Noise measurement at a speed of 20 km/h

Table 3. Sound intensity from outside vehicles at a speed of 20 km/h

Sound Intensity	Vehicle 1 – conventional drive	Vehicle 2 – electric drive	Vehicle 3 – hybrid drive
L_{Aeq}, dB	55.38	56.7	58.42
L_{AFmax}, dB	55.09	58.36	61.81
L_{Ceq}, dB	70.02	61.11	68.7
L_{Cpeak}, dB	80.81	73.86	81.96

Source: the authors' own research.

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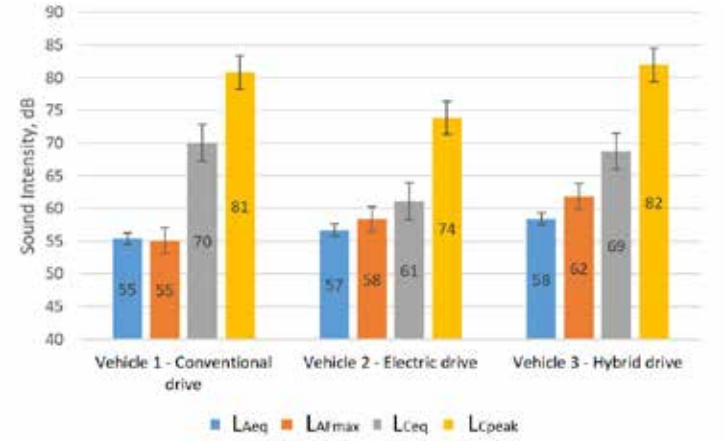

Figure 6. Sound intensity emitted by passing tested vehicles at a speed of 20 km/h. Source: the authors' own study.

The study of the external noise of the test vehicles passing by at a speed of 20 km/h revealed that the noise level LAeq was lower in the case of Vehicle 1 (55 dB(A)), whereas in Vehicle 2, it was 57 dB(A). In Vehicle 3, it is 58 dB(A). This is due to the fact that at a speed of 20 km/h in electric and hybrid cars, the noise is emitted by the AVAS system. The difference in noise was not large, because the AVAS system is supposed to emit noise of a similar volume to the noise of the combustion engine. In the case of the maximum instantaneous sound value L_{Cpeak}, the lowest value was recorded in Vehicle 2, and it was 74 dB(C). In the case of Vehicle 1 and Vehicle 3, the values were similar and amounted to 81 dB(C) and 82 dB(C), respectively. The standard deviation was small for the equivalent average sound level L_{Aeq} values, whereas for the instantaneous peak values L_{Cpeak}, it was larger due to the instantaneous, various sounds caused by the operation of the combustion engine or the AVAS system.

b. Noise measurement at a speed of 50 km/h

Table 4. Sound intensity from outside vehicles at a speed of 50 km/h

Sound Intensity	Vehicle 1 – conventional drive	Vehicle 2 – electric drive	Vehicle 3 – hybrid drive
L_{Aeq}, dB	62.89	61.71	67.66
L_{AFmax}, dB	67.35	64.2	71.3
L_{Ceq}, dB	69.18	65.79	75.04
L_{Cpeak}, dB	82.48	79.06	96.21

Source: the authors' own research.

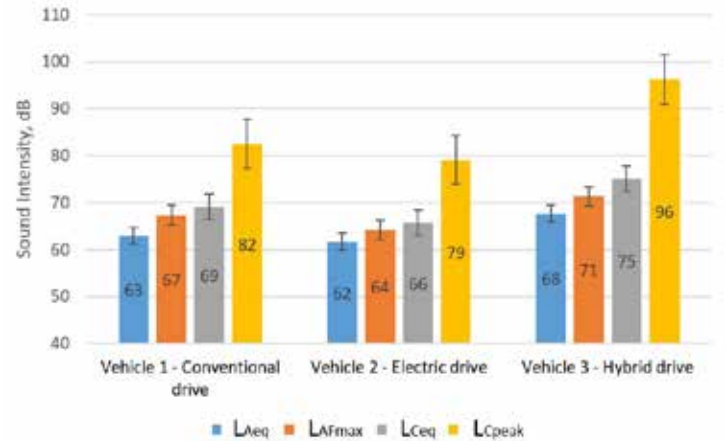

Figure 7. Sound intensity emitted by passing tested vehicles at a speed of 50 km/h. Source: the authors' own study.

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At a speed of 50 km/h, the noise level L_{Aeq} for Vehicle 1 and Vehicle 2 was very similar and amounted to 62 dB(A) for the conventional drive and 63 dB(A) for the electric drive. In the case of Vehicle 3, the noise emission was 68 dB(A) for the hybrid drive. In the case of the maximum instantaneous sound value, L_{Cpeak}, the lowest value was recorded in Vehicle 2, at 79 dB(C). In Vehicle 1, it was 82 dB(C). However, the highest peak value was recorded in Vehicle 3 (96 dB(C)). The highest external noise emission from the hybrid drive may result from the fact that the vehicle used both the combustion engine and the electric engine when driving at this speed, which could translate into greater noise from both of these power sources. The standard deviation was small for the equivalent mean sound level L_{Aeq} values, whereas for the instantaneous peak values L_{Cpeak}, it was larger due to the instantaneous, miscellaneous sounds caused by the operation of the drive units, tires and aerodynamic noise.

c. Noise measurement at a speed of 80 km/h

Table 5. Sound intensity from outside vehicles at a speed of 80 km/h

Sound Intensity	Vehicle 1 – conventional drive	Vehicle 2 – electric drive	Vehicle 3 – hybrid drive
L_{Aeq}, dB	70.25	71.91	70.89
L_{AFmax}, dB	73.34	75.65	73.86
L_{Ceq}, dB	74.85	72.87	84.56
L_{Cpeak}, dB	88.12	87.75	97.62

Source: the authors' own research.

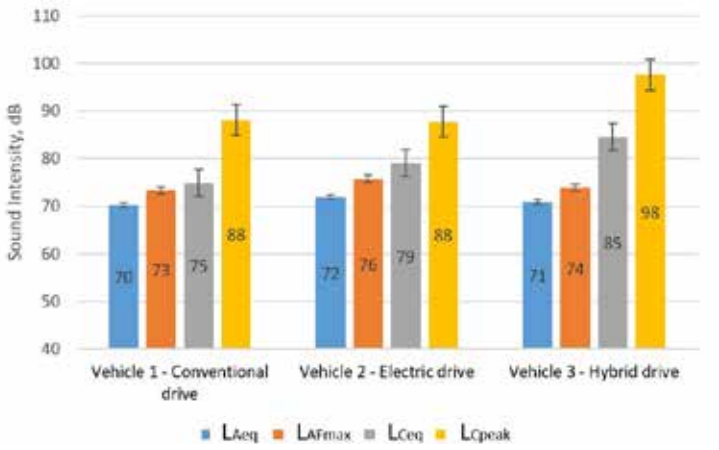

Figure 8. Sound intensity emitted by passing vehicles at a speed of 80 km/h. Source: the authors' own study.

Similar measurement results were recorded at a speed of 70 km/h. A lower noise level was recorded for Vehicle 1 (70 dB(A)), while for Vehicle 2 it was 2 dB higher (72 dB(A)). In the hybrid vehicle (Vehicle 3), the noise level was between the two previously mentioned drives and amounted to 71 dB(A). The test results indicate that tire noise and aerodynamic noise dominate. In the case of the maximum instantaneous sound value, L_{Cpeak}, the same value was recorded for Vehicles 1 and 2, amounting to 88 dB(C). In the vehicle with a hybrid drive (Vehicle 3), this value was 10 dB higher, amounting to 98 dB(C). This may be due to the fact that Vehicle 3 used both drives (electric and hybrid) while driving and had the largest tires and bodywork. The standard deviation was very small for the equivalent mean sound level L_{Aeq} values, whereas for the instantaneous peak values L_{Cpeak}, it was larger due to the instantaneous, miscellaneous sounds caused by the operation of the drive units, tires and aerodynamic noise.

6. Conclusions

Noise measurements taken outside the vehicles showed that the noise emitted by passing vehicles, when measured at the same speeds, was similar. Modern petrol engines emit low noise levels, which are drowned out by the tires while driving. The main sources of noise are tire and road noise, and aerodynamic noise. At low speeds in an electric car, the meter recorded the sound from

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the AVAS system. At higher speeds, tire noise from the road dominates, so there is no difference in noise emission depending on the type of drive used. This means that the noise emissions of electric and hybrid cars on highways will not be reduced compared to cars powered solely by combustion engines. Tire noise depends on the type and size of the tire. It can be argued that noise in the case of electric vehicles may be potentially higher due to the fact that electric vehicles have a greater mass, primarily due to the use of batteries. New vehicles are often equipped with larger and wider tires. Another problem is the fact that the market mainly offers SUVs, which have worse aerodynamic properties than smaller vehicles. Aerodynamic noise depends on the vehicle size and body type. The cars subject to the research had all-season tires with a noise level of 71 dB declared by the manufacturer. To reduce noise, the type of tires, road surface, and aerodynamics of the vehicles should be adjusted.

Declaration of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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