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NOISE EMISSIONS: WHAT TO EXPECT FROM ELECTRIC VEHICLES COMPARED TO COMBUSTION VEHICLES?

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In the next few years, the number of electric vehicles will increase significantly. Electric vehicles are generally considered to be quieter than combustion vehicles because they generate virtually no engine noise. But the rolling noise of the tyres, which increases at higher speeds, is also important when considering noise. Factors like tire width and empty weight play an important role in the rolling noise. How these factors influence the effective noise emissions of electric vehicles compared to combustion vehicles has not yet been investigated but is of great interest to public authorities in the field of noise protection. This study has been conducted in collaboration with the cantons of Aargau and Basel-Land and aims to provide results on the noise emissions of different electric vehicles at different driving speeds, road surfaces and driving situations. In this study, the noise emissions of a total of 14 electric and combustion vehicles were recorded by means of pass-by measurements during a two-day measurement campaign. The measurements were carried out on a conventional pavement and a low-noise pavement (ACMR 8 / SDA 4). The vehicles were selected to cover all vehicle categories ranging from small cars to vans. To allow comparisons, for each electric vehicle an internal combustion vehicle of a similar type was selected. The measurements showed that electric vehicles are quieter than combustion vehicles during “acceleration” and "stop & go" driving situations. At constant driving speeds, the differences in noise emissions are smaller. Furthermore, it was found that the noise reduction potential of electric vehicles is greater on the quieter SDA 4 road surface than on the ACMR 8 road surface. The change from combustion vehicles to electric vehicles holds great potential for noise reduction in inner-city areas where acceleration or stopping is frequent.

Keywords: electric vehicles, combustion vehicles, noise protection, road noise, low-noise pavements

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1. Introduction

E-mobility is gaining in importance worldwide. Accordingly, the number of electric vehicles (EVs) will steadily grow and EVs will increasingly replace cars with combustion engines (CVs) in the future [1]. In line with this, the EU Environment Council decided in June 2022 that from 2035, it won't be possible to register new vehicles with internal combustion engines in the EU anymore [2].

EVs are known to have numerous positive effects on the environment. In addition to that, EVs are also generally considered to be quieter than vehicles with combustion engines, as they produce virtually no engine noise [3]. But the overall noise emissions of vehicles don't only come from engine noise: tyre-road noise is another decisive factor in the overall noise emissions of vehicles, at high speeds, aerodynamic noise also plays an increasing role. Tyre-road noise itself is determined by factors such as vehicle weight, tyre width, tyre type, tyre tread, rubber compounds and the pavement. Although of great interest to authorities in the field of noise control, little research has been done on how these factors affect the effective noise emission of electric vehicles compared to internal combustion vehicles. Systematic comparisons between electric vehicles and combustion vehicles still hardly exist today.

To fill this gap, in this study we compare the general noise emissions of electric vehicles with those of combustion vehicles under simplified assumptions. In particular, we investigate if and how noise reduction differs between EVs and CVs on a conventional pavement and on a low-noise pavement.

2. Theory and methodology

In this chapter, a short theoretical background about the car noise emissions is presented, followed by the acoustic measurement setup performed in this study.

2.1 Theoretical background

Noise emissions from vehicles have different physical generation mechanisms and are commonly divided into the following three noise components [4]:

- Propulsion noise → engine, gearbox and exhaust noises
- Tyre-road noise → noise, generated while the tyre rolls along the pavement
- Aerodynamic noise → noise created around the chassis of the car due to turbulence while moving through air

Aerodynamic noise only plays a role at high speeds. Since in this study only speeds of 20 – 60 km/h are considered and since the corresponding vehicles have approximately the same chassis, this noise component can be neglected for the comparison of EVs with CVs within the scope of this study.

Because an electric motor is much quieter than an internal combustion engine and because an electric vehicle does not require an exhaust, the propulsion noise component of an EV is much quieter than of a CV. This is the main reason why EV are generally considered quieter.

However, because the electric battery is quite heavy, other studies have found electric vehicles to be about 200-300 kg heavier than their corresponding combustion vehicle [5]. An increased vehicle weight might lead to an increased tyre-road noise [6]. Furthermore, heavier vehicles and vehicles with high torque generally need larger tyres which also contributes to higher noise emissions. These factors suggest, that in scenarios where tyre-road noise is dominating the propulsion noise, electric vehicles may produce more noise emissions than their internal combustion counterparts.

In addition to the three noise components already mentioned, there is another source of noise in electric vehicles: Acoustic Vehicle Alerting System (AVAS). The purpose of the AVAS system is to create audible signals for electric vehicles at low speeds, with the aim of enhancing the safety of pedestrians and other vulnerable road users. Sound from AVAS is not investigated in this study.

2.2 Measurement setting

To collect the noise emission data, pass-by measurements were performed. Pass-by measurements are standardized and well suited for close-range emission measurements [7]. The measurements were conducted on a low-noise pavement (SDA 4, semi dense asphalt) and a conventional pavement (ACMR 8, asphalt concrete mixture – rough):

- Conventional pavement → pavement age = 14 years; acoustic pavement performance = -1.8 dB(A)
- Low-noise pavement → pavement age = six years; acoustic pavement performance = -6.8 dB(A)

The acoustic pavement performance corresponds to the reference pavement of Swiss StL86+ model with a mixed traffic of 8 % heavy vehicles. The given values indicate the noise reduction compared to a dense AC11/SMA11 pavement with an age of around 5-10 years. Both measurement sites have a rural character with low background noise and meet the requirements of ISO/EN 11819-1 on the measurement location [7]. Acoustic disturbances such as other sources of noise or reflections from buildings and walls were not present. Furthermore, the roads were completely closed during the measurements so that disturbing noise from other vehicles could be avoided.

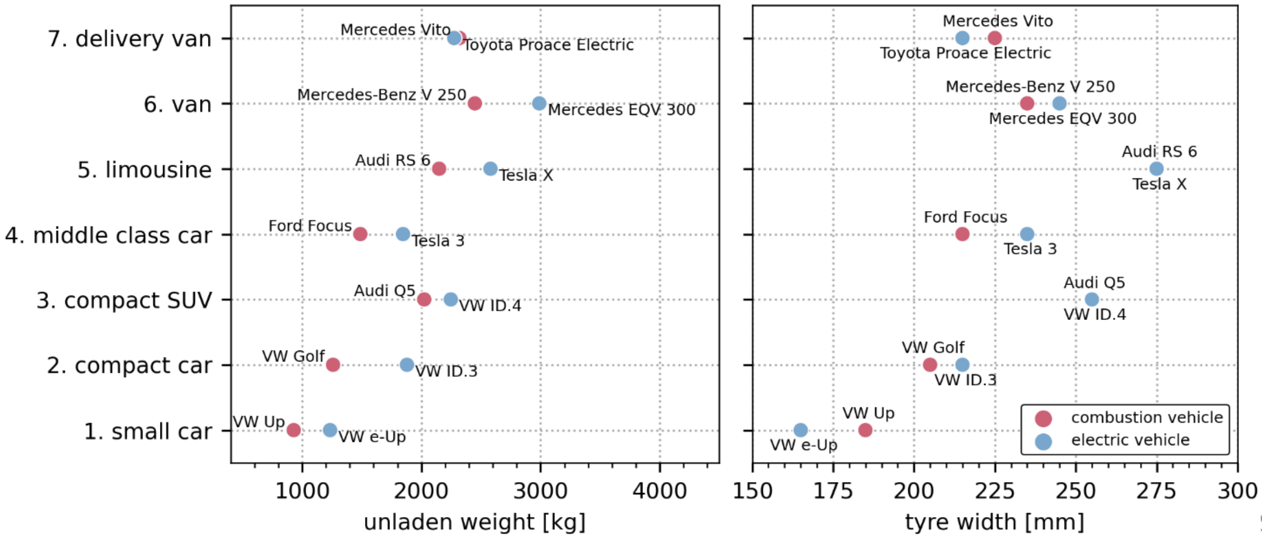

Figure 1: Selected electric vehicles and their counterparts with combustion engines, broken down by category, unladen weight and tyre width.

To compare electric vehicles with combustion vehicles, 7 electric vehicles of different categories, ranging from small cars to delivery vans, were selected. Based on this selection, the corresponding vehicle counterparts with internal combustion engines were then searched for (see Figure 1). When selecting the vehicles, the pairing was chosen as best as possible, however, there were limitations in selection and availability. For example, a *VW E-Golf* would have been preferable as a counterpart to the *VW Golf*, instead of the *VW ID.3*. As can be seen in Figure 1, all EVs (except for category 7 "delivery van") have a higher empty weight than the corresponding CVs due to their heavy batteries. In terms of tyre width, there is no systematic difference between the two vehicle types. The vehicles were driven by different drivers. Despite precise instructions, minor differences in personal driving behaviour are expected.

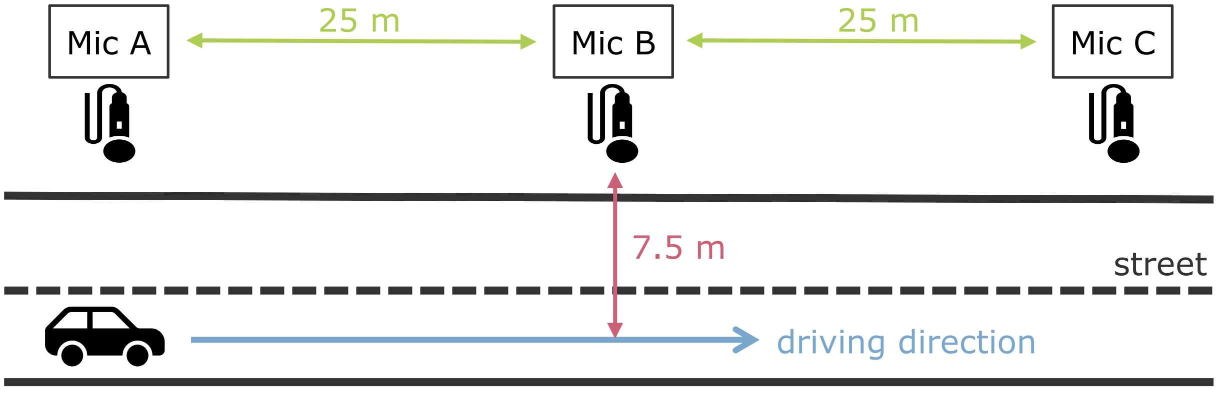

Figure 2: Schematic representation of the measurement setup.

Figure 2 shows the measurement setup schematically. Three microphones A, B & C were placed at a distance of 25 m from each other and 7.5 m from the centre of the opposite lane. During a pass-by, the maximum sound level ($L_{A,\,F,\,max}$) as well as the equivalent sound level ($L_{A,\,eq}$) were recorded. The measurements were taken on the 8th and 14th of June 2022 in fine weather and dry conditions.

2.3 Driving scenarios

The following three inner-city driving scenarios were simulated with all vehicles on both pavement surfaces.

2.3.1 Constant driving speed

The vehicles passed the three microphones at a constant driving speed of 20, 30, 40, 50 and 60 km/h. Due to time constraints of the whole measurement setup, only one measurement per vehicle could be carried out at the speeds of 20, 30 and 60 km/h. At speeds of 40 and 50 km/h, the measurements were carried out twice.

2.3.2 Acceleration

The vehicles drove at 20 km/h to the first microphone "A" and then accelerated to 40 km/h and 60 km/h to microphones "B" and "C" respectively. These measurements were repeated five times with each vehicle.

2.3.3 Stop & Go

At about 30 km/h, the vehicles drove past the first microphone "A", then slowed down and came to a complete stop at the level of the second microphone "B". They then accelerated again and passed microphone "C" at a speed of about 40 km/h. These "stop & go" scenarios were repeated five times with each vehicle. The "stop & go" scenario bears similarities to the "acceleration" scenario, but it includes an extra element of deceleration.

3. Results & Discussion

In this chapter, the results of the noise emission measurements from all three driving scenarios are presented and discussed respectively. For simplicity, we focus on the $L_{A,\,F,\,max}$-measured values on low-noise pavement. Differences between $L_{A,\,F,\,max}$ values are generally more pronounced and allow easier comparisons. However, the aggregated results of the L_{eq} measurements and the results of the conventional pavement are shown in the summary table in chapter 3.4.

3.1 Constant driving speed

Figure 3 shows the measured $L_{A,\,F,\,max}$ values (transparent) and the mean values calculated from them (opaque) per vehicle category and speed for the constant driving speed scenario on the low-noise pavement. The values from the three microphones (A-C) are hereby treated equally.

As expected, noise emission increases with increasing speed but also with increasing category number (increasing empty weight, see Figure 1). At speeds of 20 and 30 km/h, there is a greater scatter in the data than at higher speeds. This can be related to a higher sensitivity of noise emissions at lower speeds, e. g. due to a smaller deviation of the driven speed from the target speed.

Certain EVs are quieter than their corresponding CVs at all measured speeds (e. g. category 3: *VW ID.4* vs. *Audi Q5*; category 5: *Tesla X* vs. *Audi RS 6* and category 7: *Toyota Proace Electric* vs. *Mercedes Vito*), but the reverse situation is also observable (e. g. category 2: *VW ID.3* vs. *VW Golf* and category 4 (except for 20 km/h): *Tesla 3* vs. *Ford Focus*).

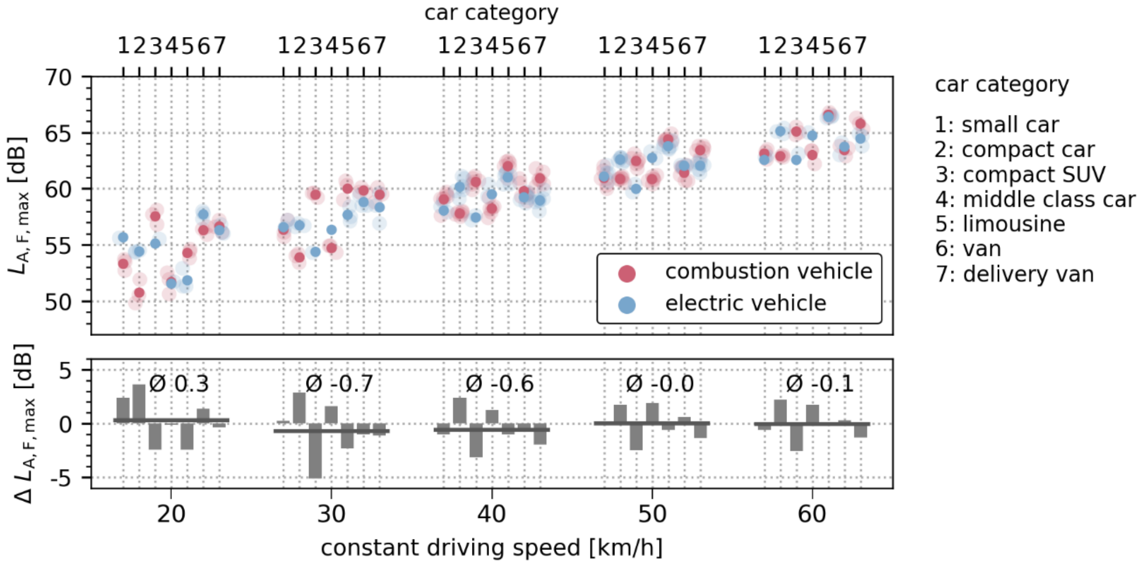

Figure 3: $L_{A, F, max}$-noise emissions of CVs and EVs on the low-noise pavement for the constant driving speed scenario. The transparent dots represent the measurements for each run and microphone position (raw values) and the opaque dots show the mean values per car category and driving speed derived from them. The bar chart below shows the difference (EV – CV) in mean values per car category and speed.

It must be mentioned that – due to the small vehicle sample and the low number of measurement repetitions – the data basis is rather small. Thus, no clear statements can yet be derived from the measurement data concerning the differences in noise emissions between EVs and CVs. Nevertheless, it seems that at constant driving speeds, other factors such as empty weight or tyre specifications play a more significant role than the type of propulsion.

If all differences of the mean values per category and speed are statistically examined together, no significant difference between electric vehicles and combustion vehicles with regard to the noise emission is found, regardless of the road surface (see Table 1 on page 7).

3.2 Acceleration

Figure 4 shows the measured $L_{A, F, max}$ values (transparent) and the mean values calculated from them (opaque) per vehicle category and microphone position for the “acceleration” scenario on the low-noise pavement. Due to the fivefold repetition of the measurement runs per vehicle, the data quality in this scenario and in the “stop & go” scenario is higher than in the constant speed scenario where only one (20, 30 & 60 km/h) or two (40 & 50 km/h) measurement runs were made.

The figure shows that the EVs in each category are between -2.1 dB (category 4) and -13.1 dB (category 5) quieter than the corresponding CVs. The only exception here is category 2, compact car (*VW ID.3* vs. *VW Golf*), where the difference is on average +0.4 dB.

In this study, only the mean differences between EVs and CVs are evaluated at the three microphone positions. The absolute $L_{A, F, max}$ values are not of interest and will not be discussed further.

Noise emissions no longer increase with the ascending category number in this scenario. For example, the *Audi RS 6* (category 5, limousine) with its powerful engine shows the highest noise emissions and is on average 13.1 dB louder than the corresponding EV counterpart *Tesla X*.

Comparing all mean differences per category and microphone position together, it can be seen that the EVs of the sample are on average -5.2 dB quieter than the CVs (see Table 1 on page 7). This difference is statistically significant with a p-value (Wilcoxon signed-rank test) of 0.0001.

In contrast to the constant driving speed scenario, the type of propulsion (EV or CV) plays a decisive role in the “acceleration” scenario.

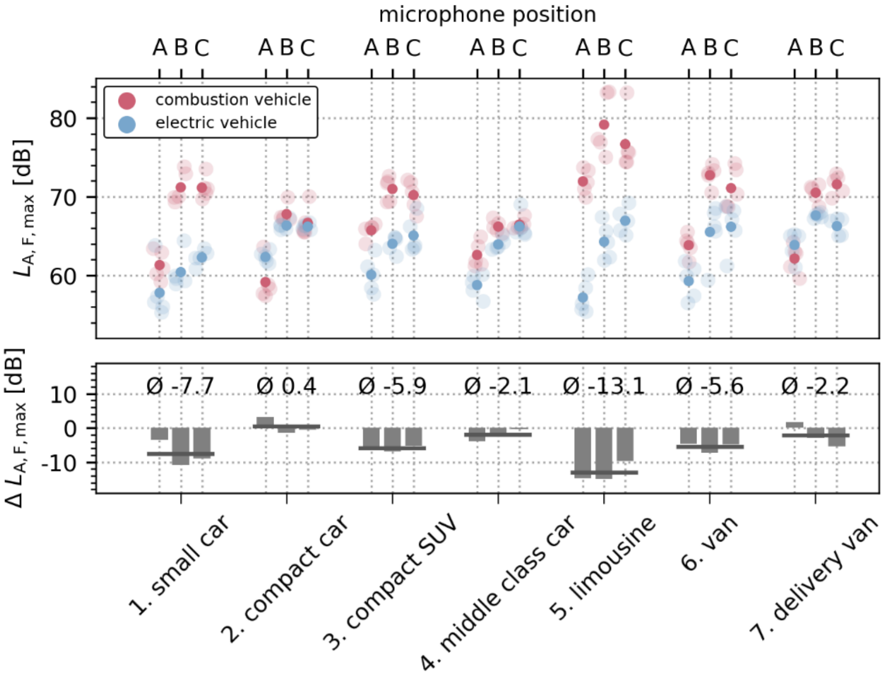

Figure 4: $L_{A,\,F,\,max}$-noise emissions of CVs and EVs on the low-noise pavement for the "acceleration" scenario. The transparent dots represent the measurements for each run and microphone position (raw values) and the opaque dots show the mean values per car category and microphone position. The bar chart below shows the difference (EV – CV) in mean values per car category and microphone position.

3.3 Stop & Go

The following Figure 5 shows the measured $L_{A,\,F,\,max}$ values (transparent) and the mean values calculated from them (opaque) per vehicle category and microphone position for the "stop & go" scenario on the low-noise pavement.

The "stop & go" scenario is more complex than the previous two scenarios, as it is a combination of constant driving speed and acceleration phase. Further, when accelerating from a complete stop, individual driving behaviour (e.g. changing gears) plays a greater role than in the previous scenarios.

The measured values in this scenario show the same tendency as in the "acceleration" scenario, but the differences between EVs and CVs are less pronounced, due to the factors mentioned above. Interestingly, in the categories number 5 (limousine) and 7 (delivery van) the electric vehicles were significantly quieter than their corresponding combustion vehicle.

At the microphone position "C", where the vehicles are in the acceleration process, a consistent picture emerges across all categories. Similar to the "acceleration" scenario, the EVs are all quieter compared to their CV counterparts.

Comparing again all mean differences per category and microphone position together, it can be seen that the EVs of the sample are on average -3.4 dB quieter than the CVs. This difference is statistically significant with a p-value (Wilcoxon signed-rank test) of 0.0011.

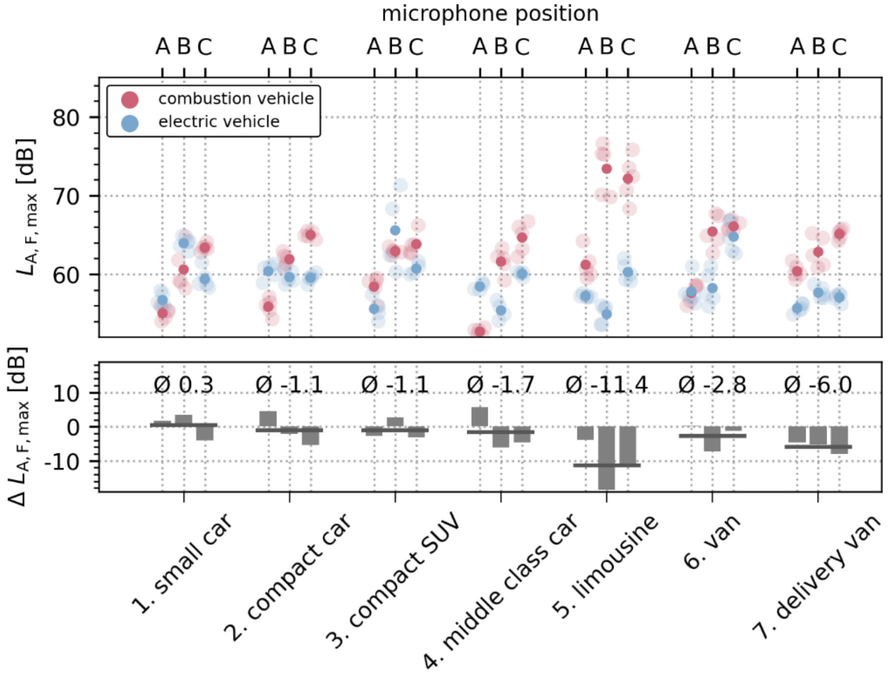

Figure 5: $L_{A, F, max}$-noise emissions of CVs and EVs on the low-noise pavement for the "stop & go" scenario. The transparent dots represent the measurements for each run and microphone position (raw values) and the opaque dots show the mean values per car category and microphone position. The bar chart below shows the difference (EV – CV) in mean values per car category and microphone position.

3.4 Summary of all three scenarios

The above-mentioned mean differences between EVs and CVs per scenario are summarised in Table 1 for both noise levels $L_{A, F, max}$ and L_{eq}. The mean value per scenario corresponds to the average value over all categories, speeds and microphone positions. These mean values represent a strong simplification of the measured data. No weighting of the individual vehicle categories was carried out. Furthermore, the 95 % confidence interval of the mean noise emission value is given. The p-values of significance are given below the table. All values for the constant velocity scenario are not statistically significant.

Table 1: Mean difference values (EV - CV) and the corresponding 95 % confidence interval of $L_{A,F,max}$ and $L_{A,eq}$ for the three scenarios. All seven car categories are considered together and without weighting.

	Δ $L_{A,F,max}$ (EV – CV) [dB]				**Δ $L_{A,eq}$ (EV – CV) [dB]**			
	conventional pavement		**low-noise pavement**		**conventional pavement**		**low-noise pavement**	
scenario	**mean**	**ci (95 %)**	**mean**	**ci (95 %)**	**mean**	**ci (95 %)**	**mean**	**ci (95 %)**
1. constant velocity	+0.6	[0.0, 1.3]	-0.2	[-0.9, 0.5]	+0.2	[-0.4, 0.8]	-0.2	[-1.1, 0.4]
2. acceleration	-2.1**	[-3.6, -0.4]	-5.2***	[-7.3, -2.9]	-1.5**	[-2.7, -0.3]	-4.4***	[-6.0, -2.5]
3. stop & go	-2.1*	[-4.3, -0.2]	-3.4**	[-5.4, -0.7]	-1.3*	[-2.6, -0.1]	-2.9**	[-4.3, -1.1]

* p-value < 0.05, ** p-value < 0.01, *** p-value < 0.001

In the previous chapters, only the measured values of the maximum sound level were presented and discussed for the sake of simplicity. When looking at the equivalent sound levels, the picture is similar to the $L_{A, F, max}$ values, but the numerical differences between the EVs and CVs are slightly smaller.

Up to this subchapter, only the noise emission measurements on the low-noise pavement have been presented. Table 1, however, also shows the results of the conventional pavement. The comparison of the two pavements shows that the noise reduction is significantly greater on the low-noise pavement than on the conventional pavement.

For the typical inner-city scenarios “acceleration” and “stop & go”, the differences between EVs and CVs are on average around -2.1 and -5.2 dB for $L_{A,\,F,\,max}$ and -1.3 and -4.4 dB for $L_{A,\,eq}$, depending on the pavement type. These results correspond with the results of a similar study conducted in the Netherlands in 2012 [8].

4. Conclusions

Our limited vehicle comparison showed that the EVs used in this study are quieter than their CV counterparts for the typical inner-city scenarios “acceleration” and “stop & go”. For the $L_{A,\,F,\,max}$ sound level, a reduction between 2 and 5 dB was measured, for L_{eq}, the reduction is between 1.5 and 4.5 dB.

Interestingly, our study shows that the effect of EV's is greater on low-noise pavements than on conventional ones. This can be explained by the reduced rolling noise which leads to a bigger influence of the propulsion noise component, causing the main difference in noise emissions between EVs and CVs.

At constant speed, however, the electric vehicles used in this study did not show any systematic differences in noise emissions compared to the corresponding combustion vehicles. Due to the small sample size in the present study, the results should be verified in future work.

Overall, the study has shown that with an increasing number of EVs, the potential for reducing road noise in inner-city situations is significantly greater if low-noise pavements are used instead of conventional pavements. Using low-noise pavements – a widely pursued noise reduction strategy by authorities today – will thus gain even more importance in the future.

This study has limitations and further research is needed. It is recommended to investigate a larger sample size and improved pairing of selected vehicles. Besides, other vehicle types e.g. heavy trucks, as well as the impact of AVAS should be included. For the prediction of the statistical effects of a fully electrified vehicle fleet on noise emission, simulations can be used to represent the weight of different types of vehicles. Additionally, measuring noise emissions at higher speeds, such as on highways, would be of interest.

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