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Electric Cars - Noise Simulation of AVAS Effects

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Abstract
Besides their environmental impact on e.g. air pollution, electric cars are often expected to bring a noticable reduction in noise emissions. Even for speeds on urban roads, the noise contribution of the tyres (i.e. rolling noise) is dominant. A reduction in urban areas could still be expected as the engine noise is significantly lower. Since mid 2021, the "Acoustic Vehicle Alert System" (AVAS) is mandatory for new electric vehicles to improve safety for pedestrians and cyclists, creating artificial noises for speeds up to 20 km/h. Overall, the impact of AVAS on urban road noise remains unclear as the emission varies between different cars and can also be in magnitude of combustion engine noise emissions. As part of recent research, a noise simulation was carried out using detailed noise emissions for single cars (ROTRANOMO/TraNECaM). Rolling noise and propulsion noise (noise from the engine, the exhaust and the transmission) are calculated for various traffic situations in second by second steps, depending on the vehicle's acceleration and speed. The model allows the detailed simulation of AVAS as the emission is only active for low vehicle speeds. Simulations were carried out for different crossing situations with percentages of cars passing at higher speed and stopping. Results will be presented as well for the average noise level as for an assessment of the changing noise level and single noise events.
Keywords: vehicle noise, electric cars, AVAS

1 Introduction

Besides their environmental impact on e.g. air pollution, electric cars are often expected to bring a noticable reduction in noise emissions of road vehicles. A reduction in urban areas (at low vehicle speeds) could still be expected as the noise emission of an electric motor is significantly lower than the noise emission of an internal combustion engine. This advantage could be deteriorated by the "Acoustic Vehicle Alert System" (AVAS) which has become mandatory since mid 2021for new electric vehicles to improve safety for pedestrians and cyclists, creating artificial noises for speeds greater than 0 km/h up to and inclusive 20 km/h. The requirements and limitations of the AVAS are specified in UN-ECE Regulation 138 [1]. Revision 1 of this Regulation permits the activation of the AVAS beyond 20 km/h (up to 32 km/h, which is equivalent to 20 mph, the upper speed limit of the US regulations).

From previous measurement reports and experience e.g. with TraNECaM [2] (see chapter 2.1) it is known that vehicle emissions from electric and combustion vehicles are almost identical at speeds of 50 km/h and above, as these are dominated by rolling noise and propulsion noise is low in modern passenger cars. In contrast, at speeds around 30 km/h and below, the propulsion noise may dominate for internal combustion engine vehicles. Electric vehicles could therefore be fundamentally quieter in this range than internal combustion engine vehicles - due to the lower propulsion noise. However, the use of AVAS at speeds below 20 km/h adds an additional emission, the effect of which we want to demonstrate in this presentation.

From the emission modelling in TraNECaM/ROTRANOMO, the emissions of rolling noise and propulsion noise will be available on a second-by-second basis for individual vehicle types and vehicle speed traces representing individual traffic situations. The emissions are to be located along the route with second-by-second resolution. Thus, the influence area of an intersection with regard to noise emissions can be identified in noise propagation calculations. This allows the determination of the distance from the intersection to which the influence of an AVAS will have an effect in noise levels and how vehicle emissions will change from vehicles with internal combustion engines to vehicles with electric motors in an intersection location.

In addition, the difference in emissions is determined in comparison with the "free flow" traffic situation. For the area "approaching" the intersection (deceleration), lower emissions may be expected, for the area "leaving" the intersection (acceleration), higher emissions may be expected. By superimposing the traffic (proportion of accelerating and decelerating vehicles), the difference to the "free flow" situation can be assessed.

2 Emission model

For the intended analysis, an emission-sensitive noise calculation is required, in which a separation of rolling noise and propulsion noise is possible. Based on this, the differences in propulsion noise between vehicles with an internal combustion engine and an electric motor (lower engine and no exhaust noise for electric vehicles), but also additional noise emission by artificial sound from AVAS for electric vehicles can be taken into account. The relevant noise emission by AVAS will be determined, and as a result, noise emissions for vehicles with different variants of AVAS emissions will be generated and compared.

2.1 TraNECaM/ RoTraNoMo

For the analysis, the noise model TraNECaM (Traffic Noise Emission Calculation Modell) [2] was used. This model was developed within a research project for the German Federal Environment Agency (UBA) in 1998 to 2000. It allows a more detailed emission calculation than the conventional calculation models and also takes into account the technical progress of motor vehicles. The data basis of the model is considerably broader in terms of road and vehicle categories than that of the conventional models and was originally developed on behalf of the Federal Environment Agency.

It was expanded and updated with financial support from the EU Commission and the Norwegian Pollution Control Authority. In Norway, TraNECaM has been used to quantify nationwide the effects of abatement measures that could be used to achieve policy abatement targets. Up to 2021 the traffic situations stored in TraNECaM were based on the traffic situations from HBEFA 3.1 [3], which is a comparable model for emission factors of air pollutants. Since the traffic situations and the underlying driving cycles were significantly updated in the time period 2018 to 2020, leading to the publication of HBEFA 4.1, in 2021 a complete recalculation of the TraNECaM model was performed using the driving cycles from HBEFA 4.1. This recalculation required an upstream model of TraNECaM, the RoTraNoMo model in analogy to the HBEFA model which requires the PHEM model as upstream model.

The RoTraNoMo model was developed within the project ”Development of a Microscopic Road Traffic Noise Model for the Assessment of Noise Reduction Measures” funded by the European Community under the ‘Competitive and Sustainable Growth’ Programme. The model calculates an instantaneous pass by level for different vehicle subcategories and emission stages on the basis of second by second vehicle speed traces separately for tyre/road and propulsion sound levels. The model was developed in 2003 to 2005 but was updated in later projects in order to cover also the 3 emission stages defined in 2009/661/EU and 540/2014/EU, phase 1 to phase 3.

Based on the experience of previous research projects, the vehicle related noise sources (engine, powertrain, exhaust, intake) are summarised as propulsion noise and modelled as function of engine speed and engine load. A further split into different sources is possible in principle but at present there is no data available for the development of such an amendment. The tyre/road, or rolling, noise component L_{roll} is modelled as a function of the tyre, the road surface and the vehicle speed.

2.2 AVAS

When modelling the noise emissions of an electric vehicle approaching, crossing and leaving an intersection by RoTraNoMo, we found that the influence of AVAS in the intersection area depends very much on the chosen approaches for the emissions of the AVAS.

Regarding the "minimum requirements", we can apply the emissions according to UNECE Regulation 138 "Uniform provisions concerning the approval of Quiet Road Transport Vehicles with regard to their reduced audibility (QRTV)" [1]. However, it is to be expected that in reality vehicles do not comply exactly with these minimum standards (tolerances, liability issues, etc.).

A requirement for the maximum emission level for the AVAS can also be found in Annex VIII of EU Regulation 540/2014 [7] in No. 3.c): "The sound level generated by the AVAS shall not exceed the approximate sound level of a vehicle of the M1 category equipped with an internal combustion engine and operating under the same conditions." This emission is normally lower than the maximum allowed AVAS sound emission according to UNECE Regulation 138 (75 dB(A) at 2 m distance).

Overall, the range (at 10 km/h: 50-75 dB(A) at 2 m) is very high, the result (especially for a detailed consideration in the intersection area) is virtually solely determined by the modelling approach. For a better assessment of real emission levels, a limited literature survey was conducted, supplemented by contacts to car manufacturers.

A study from 2019 [4] conducted measurements on a number of cars and showed that emissions with AVAS differed greatly between manufacturers. The minimum required value is exceeded by 4-13 dB (lowest value: Smart, highest value: Renault Zoe). The AVAS was virtually undetectable in an eGolf. In some cases, significant deviations between the left and right side of up to 7 dB (Renault Zoe) were determined. This is increasingly the case when only one loudspeaker is used to generate sound: To ensure minimum emission in each direction, the emission in one direction may be significantly higher than required. Another earlier publication [5] concluded that in those cases analysed, an all-electric operation without AVAS showed the lowest noise levels. The combustion engine is slightly louder than the electric vehicle without AVAS at lower speeds. However, at low speeds the combustion engines noise level is on average lower than the noise level of a vehicle with AVAS system. In a further study [6], AVAS was not detectable at 20 km/h (Nissan eNV200). The rolling noise had been dominant.

Own investigations with interviews of car manufacturers have shown that, in addition to the pure A-weighted sound level, especially the frequency response requirements at different speeds have a strong impact on the emissions. To ensure the required emissions, a high tolerance of the systems used must be foreseen, which according to oral testimony (at individual frequencies) can be up to 12 dB.

2.3 Emission cycle and noise emission contributions

From the set of road types implemented in the newest version of TraNECaM with the update to road types of HBEFA 4.1, one representative cycle was chosen for a typical intersection. The cycle chosen is used for "distributor roads" with a speed limit of 50 km/h, "saturated" [1] level of service (quality of traffic flow) and 0 %

[1] Level 3 of 5, where 1 is free flow and 5 is high congestion

gradient. .The whole cycle covers about 500 s and a travelled distance of about 3.3 km. The vehicle speed over the time travelled is shown in Figure 1.

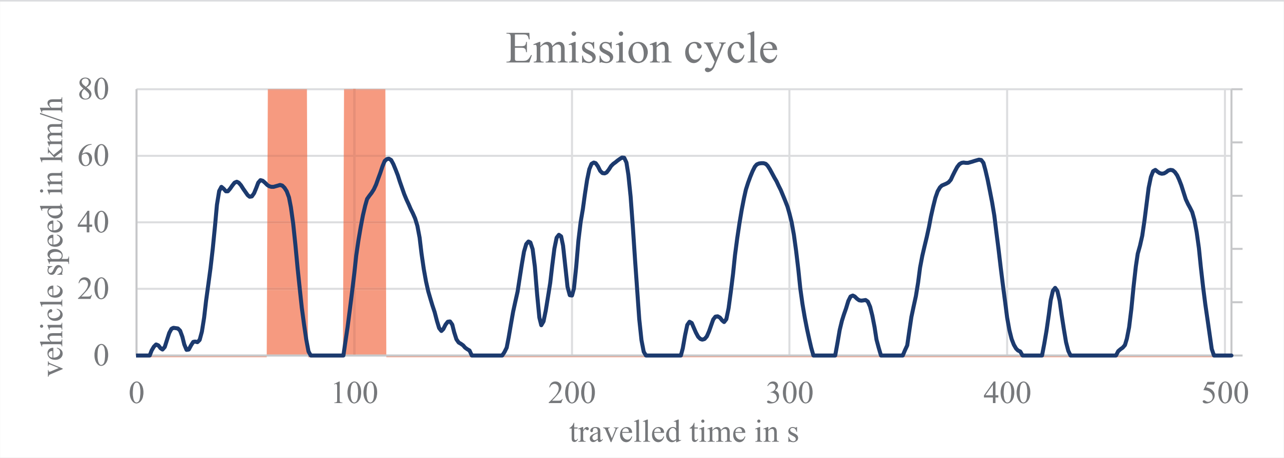

Figure 1: Vehicle speed in the emission cycle, selected section highlighted in red

For a typical intersection on a distributor road the segment as marked red in Figure 1 was chosen. The vehicles approach at a speed of ~50 km/h, come to a full stop and accelerate again to about ~60 km/h.. As just a small section of the cycle was used, the level of service has low influence on the resulting noise emissions.

For more congested traffic, the average speed will be lower, especially if it takes a car more than one cycle to cross the intersection (see Figure 1, second 270-370) . The results of such traffic situations was not simulated, but considered in the conclusions.

In Figure 2, the contribution of rolling noise (green) and propulsion noise (blue) of a typical combustion car is depicted for the selected segment. The corresponding speed (orange) influences both noise emissions. However, the propulsion noise is also dependent on the necessary engine power and the resulting engine speed, giving a lower emission on decelerating (seconds 70-80) than on accelerating (seconds 95-100). The idling of the engine has not (yet) taken into account an automatic start-stop system.

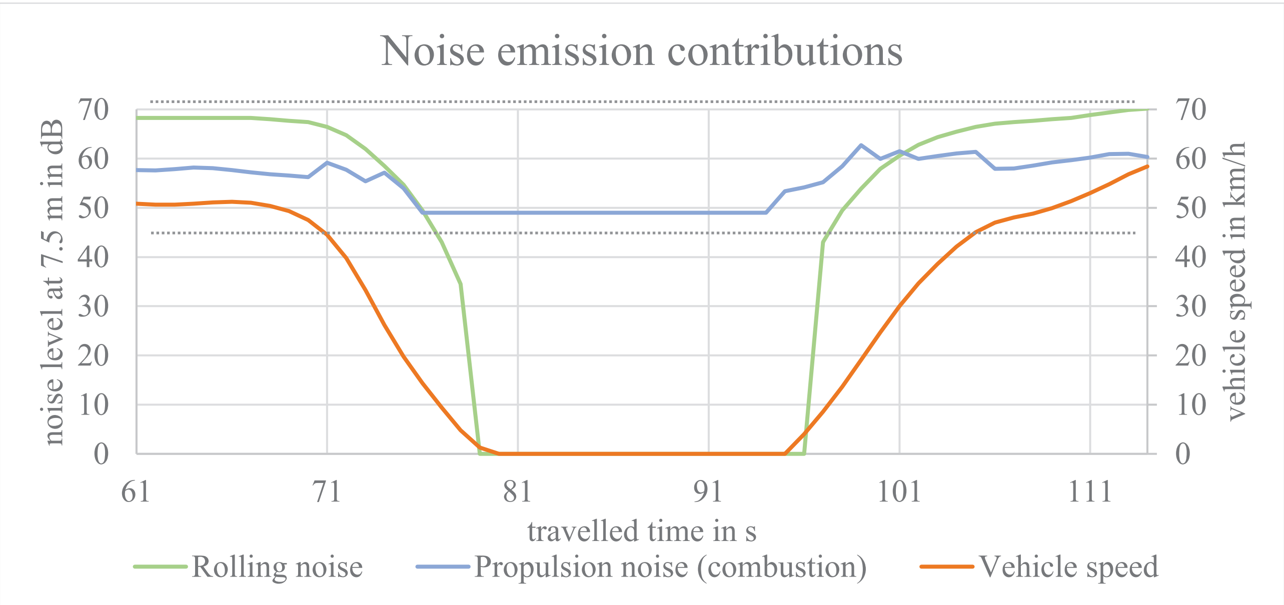

Figure 2: Contribution to the noise emission – rolling noise and propulsion noise

In addition to the emissions of a combustion engine, the limits for AVAS noise emissions are also shown (dotted lines parallel to the x-axis). The values mentioned before were converted to a distance of 7.5 m instead of 2 m, giving a maximum of 66 dB and a minimum of 41 dB. It is clearly visible that typical combustion engine noise is significantly lower than the maximum allowed for AVAS. The minimum noise level allowed for AVAS is in most cases more than 10 dB lower than the combustion engine noise. For low speeds and close to idling, the difference is lower, closer to 8 dB.

2.4 Modelling of AVAS noise emission

Based on the variance of possible noise emissions of vehicles equipped with AVAS (as shown in paragraph 2.2), two variants were modelled besides a vehicle with combustion engine and an electric vehicle without AVAS. The two variants will be referred to as AVAS (60) and AVAS (50) in regard to their AVAS noise level at 7.5 m (60 dB and 50 dB). The electric car without AVAS is modelled with a propulsion noise level of 40 dB at all speeds. For speeds > 20 km/h, this is also used for the vehicles with AVAS. The variant without AVAS was added in order to show the maximum noise reduction potential an electric vehicle fleet would have.

The variant with “maximum AVAS emissions” (66 dB) will not be pursued further, as it can be assumed that this value will only be fully exploited in individual cases. However, individual vehicles that use the AVAS as a "sound design" to stand out from the mass of vehicles will not dominate acoustically on long term average noise levels.

In summary, the modelling takes into account the following scenarios:

- Combustion engine vehicle
- Electric vehicle without AVAS
- Electric vehicle with low AVAS emissions, still about 9 dB above minimum requirements
- Electric vehicle with high AVAS emissions, about 15 dB above minimum, but still 6 dB below maximum

The maximum pass-by levels of TraNECaM were converted to emission (L_{eq}) in accordance to the documentation of TraNECaM [2]. In addition, for the upcoming modelling, the emission was spread on the corresponding segments of a road (1 m) that a noise source is active during a time step. The exposure time for each segment is taken into account. Thereby, at low speeds, the same pass-by level results in higher emission levels due to higher exposure at each segment.

The resulting noise emission levels are depicted in Figure 3. The steps visible are caused by the 1 Hz time resolution of the emissions. The combustion vehicle is shown in blue. The electric vehicles show a slightly lower noise emission at speeds of ~50 km/h due to the slightly lower propulsion noise. Closer to the intersection at decreasing speeds (~ - 40 m), the electric vehicles show a higher decrease in noise emissions.

At a distance of about 10 m to the intersection, the speed is below 20 km/h and the noise emission of AVAS sets in. For the AVAS (50) vehicle, the noise levels of the decelerating car are close to the combustion engine car, whereas the AVAS (60) vehicle shows higher noise emissions.

For accelerating vehicles, the emission of the AVAS (50) vehicle are close to the combustion engine vehicle in the first seconds but quickly decrease. The AVAS (60) vehicle shows a significantly higher noise emission for the first ~10 m and a level comparable to the combustion engine vehicle up to ~25 m from the intersection.

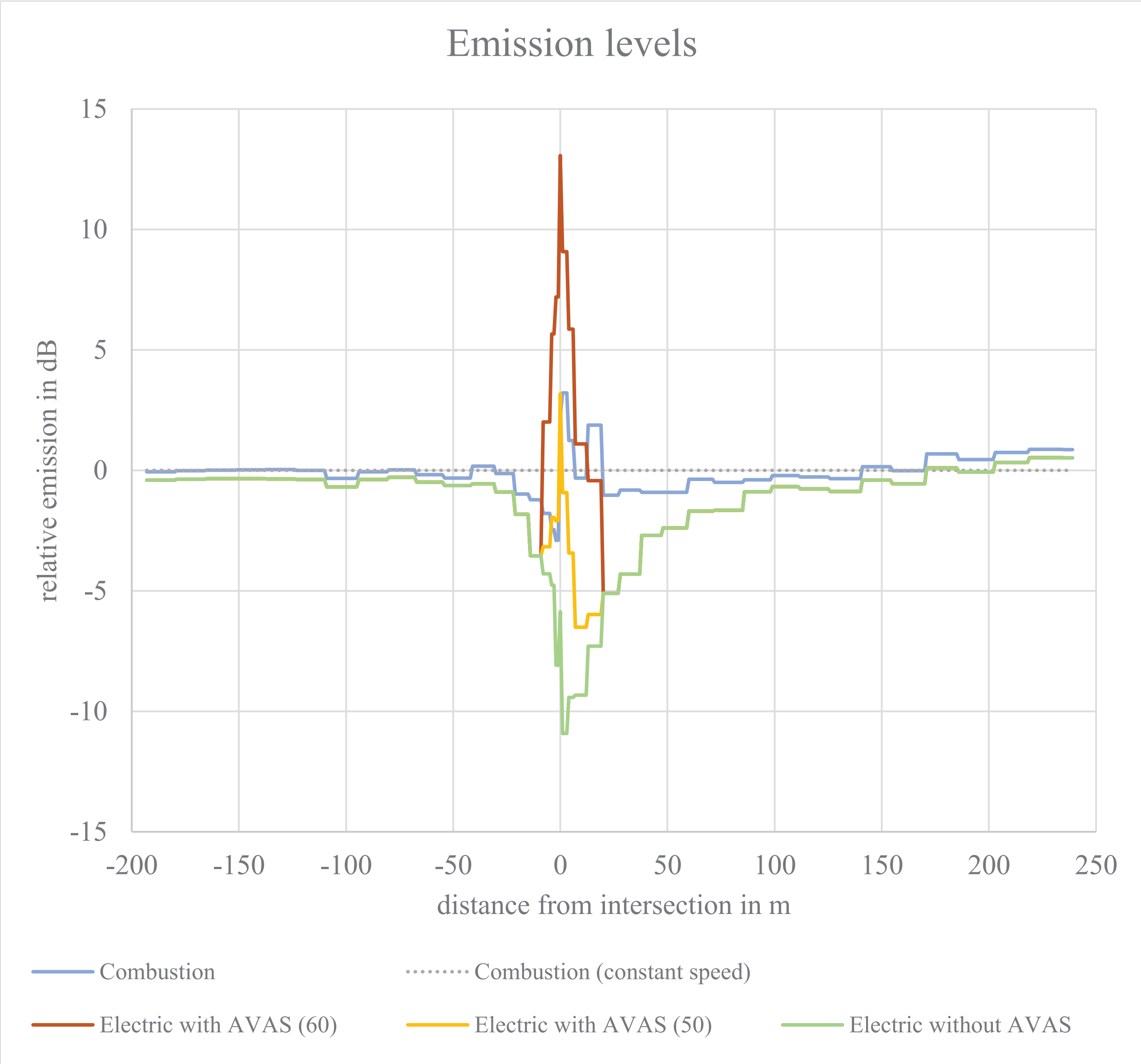

Figure 3: Emission levels (relative to constant speed of combustion engine) for the different vehicle types

In comparison to the combustion vehicle with a stop at an intersection, a combustion vehicle with constant speed is taken into account. The speed equals the speed of the cars before the intersection. At a distance of about 150 m after the intersection, the speed of the other cars exceeds this constant speed and thus the noise emission is slightly higher.

Not taken into account are several other factors that could affect the noise emission close to the intersection:

Start-stop systems for combustion engines compared to AVAS emissions for vehicles at standstill: Most modern cars are equipped with start-stop systems, switching off the engine at standstill and thus reducing the noise emission. For AVAS systems, the behaviour for stopped vehicles is not modelled. Several observations show a possible continuing noise emission even seconds after full halt (e.g. in [8] still active, another example in [9] shows the emission stops when the transmission is in "park mode"). It is presumed in the following calculations that both systems are equal during the standstill phase and have no relevant emissions.

The noise level of AVAS might change with the vehicle's speed. Mandatory is a change in frequency, but an additional change in noise levels could be implemented. A higher emission could either be implemented on higher engine power (e.g. at initial acceleration) but also at increasing speeds. It is presumed that the noise level of both variants is around the given values of 50 dB and 60 dB, but constant.

Regarding AVAS emission above 20 km/h, a sudden "cut-off" is considered in the emissions. Dependent on the implementation, AVAS emissions might still be audible above 20 km/h, but the contribution to the overall noise level will be almost insignificant due to the increasing rolling noise.

Depending on the sound of the AVAS, a tonal component might influence the perception and annoyance reaction.

3 Noise propagation calculation

To assess the influence of the emission changes identified so far, a noise propagation calculation was carried out. The model is a simplified road stretch with segments of 1 m as a noise source. In the figures, the road source is a horizontal line (magenta). A second, vertical line (magenta) indicates the position of the intersection.

3.1 Model and scenarios

Calculations were carried out using SoundPLAN 8.2, with a DIN ISO 9613-2 line source. The height of the noise source was set to 0.5 m, the calculations were carried out for a grid of 1 m in a height of 2 m. The calculation is just approximating the noise levels as different noise calculation models used for road traffic (as the German national RLS-19 and BUB or the European CNOSSOS for environmental noise) may differ in certain specifics. Nevertheless, the results give a good indication on the possible deviations between the considered noise sources, using the difference in noise levels. Noise level changes below 1 dB will be considered almost irrelevant. Absolute noise levels will not be depicted.

The scenarios for the propagation calculations are identical with the variants on noise emissions:

- Combustion vehicle with stop
- Combustion vehicle with constant speed
- Electric vehicle without AVAS
- Electric vehicle with low AVAS emissions (AVAS 50)
- Electric vehicle with high AVAS emissions (AVAS 60)

The differences shown in the following Figure 4 are calculated for three variants of electric cars in comparison to the combustion engine with stop and in one variant for the combustion engine with stop in comparison to combustion engine with constant speed.

3.2 Results

The results are shown in Figure 4 for the different variants.

In the upper left, a clear influence of high AVAS emissions (AVAS 60) is visible. For an area of about 25 m behind the intersection, a noise level increase of more than 1 dB can be seen. In close proximity to the intersection at about 10 m, the increase ranges up to more than 3 dB. In the upper right, the results for lower AVAS emissions (AVAS 50) show a quite different picture. For the same area about 25 m behind the intersection, a decrease in noise levels of 1-3 dB can be seen.

In the lower left, the results for electric vehicles without AVAS show an even higher decrease in noise levels for a larger area.

In comparison of a stopping combustion car to a car with constant speed, shown in the lower right, shows almost no differences in noise levels. This can be derived from the emission characteristics shown in Figure 3: starting about 20 m before the intersection, the noise emission of the stopping car is slightly lower (up to 3 dB), for a stretch of about 20 m behind the intersection the noise emission of the then accelerating car is slightly higher (up to 3 dB).

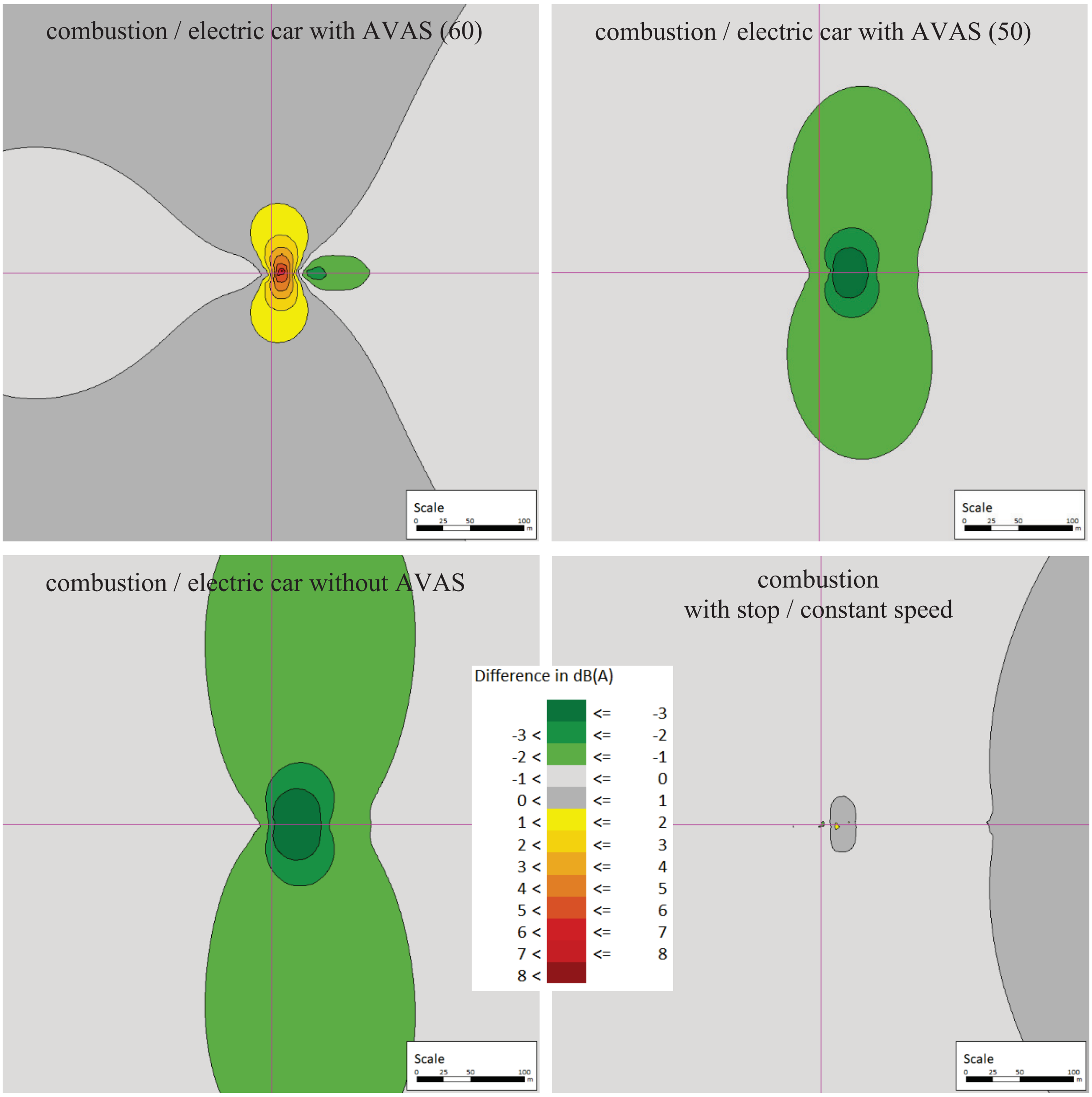

Figure 4: Differences in average noise levels around an intersection – noise source moving from left to right along the horizontal line, intersection at the vertical line. Results for combustion / electric car with AVAS (60) (upper left), combustion / electric car with AVAS (50) (upper right), combustion / electric car without AVAS (lower left), combustion with stop / combustion with constant speed (lower right).

4 Conclusions

A literature review shows that AVAS emissions can have a broad range, caused by the permitted range of about 25 dB given in the regulations. On the basis of the present regulations, it cannot be ensured that the noise emission of an electric vehicle with the use of AVAS is really quieter than a comparable passenger car with an internal combustion engine.

However, the noise emission alone does not give an indication on the noise exposure close to intersections. To assess the resulting effects, noise levels were calculated for different variants of cars. Calculations showed that the influence of a stopping combustion vehicle compared to a vehicle with constant speed is neglectable regarding the average noise levels (annoyance is not taken into account). For electric vehicles, a negative influence can be seen for vehicles with comparable high AVAS noise emissions. With comparable low noise emissions, which still exceed the minimum requirements by almost 10 dB, a slight noise reduction can be achieved.

As final conclusion, an "acoustic gain" cannot be reliably achieved by electric vehicles with the use of AVAS. Rather, the maximum emission level permitted by the AVAS might lead to much higher noise levels in proximity to intersections compared to combustion engine powered passenger car. From a technical point of view, the effect of the AVAS on the emission behaviour of electric vehicles must therefore be assessed as possibly negative in terms of noise. The extent to which noise emissions exceed those of combustion cars in the overall fleet still needs to be examined in further work.

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