Noise from electric vehicles

Measurements

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NOISE FROM ELECTRIC VEHICLES – MEASUREMENTS

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2 SUMMARY

This report describes and concludes on noise measurements of electrical passenger cars and similar combustion passenger cars. As part of the Electromobility+ project COMPETT the noise reducing potential of electrification of urban traffic was investigated.

Two kinds of noise measurements were carried out and described. Controlled Pass-By (SPB) measurements were done with two electrical and two combustion passenger cars during steady driving, acceleration and decelerating by engine brake. These measurements are used in the discussion of the potential of sound reduction in urban areas as an effect of replacing part of or all passenger cars with electrical vehicles. Part of the discussion takes offset in the noise mapping of traffic noise.

Results from noise measurements of Close-ProXimity (CPX) of Energy Saver tyre types and the Standard Reference Test Tyres from a variety of surfaces are analysed. The Energy Saver Tyre types are recommended for electrical vehicles since they are having a lower rolling resistance, therefore use less energy to travel the same distance.

The conclusions indicated that the noise reduction potential of electrical vehicles are negligible, when the traffic mores with higher speeds than 30 km/h. At higher speeds the tyre type is dominating the noise emission. The energy saver tyre type emits less noise than the standard reference test tyre but the right choice of pavement is a more effective noise reduction measure.

3 PREFACE

This report is part of the COMPETT (Competitive Electric Town Transport) project, which is financed by national funds pooled together within ERA-NET-TRANSPORT.

In January 2011 ERA-NET-TRANSPORT initiated a range of projects about electric vehicles under the theme ELEKTROMOBILITY+ concerning topics from the development of battery and charging technology to sociological investigations of the use of electric vehicles.

Twenty European project consortia have been initiated including the COMPETT project. COMPETT is a co-operation between The Institute of Transport Economics in Norway, The Austrian Energy Agency, The University College Buskerud in Norway, Kongsberg Innovation in Norway and the Danish Road Directorate. The objective of COMPETT is to promote the use of electric vehicles, particularly with focus on private passenger cars. The main question to answer in the project is “How can e-vehicles come in to use to a greater degree?”

This report is a measurement study on noise emission from electric vehicles. It will present results and conclusions on measurement done on noise emitted by two set of battery electric vehicles (BEV) and similar internal combustion engine vehicles (ICE). The results of these measurements will also be used as a source of noise mapping, investigating what influence the introduction of electrical vehicles could have on the traffic noise in urban areas.

Read more about the project on www.compett.org

4 INTRODUCTION

There is no unique or easy solution to the noise problems caused by road transport in Europe. A solution will have to consist of a combination of many measures and one of these could be the introduction of electrified vehicles. Noise abatement strategies including different tools will have to be implemented over a longer period.

Electric power units in vehicles are often considered almost completely silent. If this is true electric vehicles could be used for noise abatement in urban areas. Since the largest source of noise in these areas is the road transport system. This can be seen in the noise mapping performed according to the EU noise directive. Therefore the noise consequences of introducing electric vehicles will be analysed in COMPETT in order to investigate whether electric vehicles can contribute to a better noise environment in the urban areas in Europe. The focus will be on passenger cars.

4.1 Background

A literature survey [1] on knowledge about noise from electrical vehicles was performed as the first task in work packet 3 on noise in the COMPETT project. The findings in this literature survey show that there is a potential for noise reduction by replacing Internal Combustion Engine ICE vehicles with Battery driven Electric Vehicles (BEV), but the findings also show that there is a great deal of uncertainty about how large this potential is. The reduction in noise found in the references differs greatly and seems to depend very much on how the comparison between the noise from ICE vehicles and BEVs is carried out. Most references do, however, confirm the assumption that it is only at low speeds that noise reduction can be expected. However, up to which speed and what the result in noise levels in the cities would be is not clear from the findings.

If the noise reduction in a city is to be predicted, then a thorough investigation is also needed of the driving patterns. One reference assumed that the driving pattern in a city corresponded to driving partly at 50 km/h and partly accelerating from 50 km/h. This would, for many cities, be an overestimation of the speed and the amount of acceleration. One reference found that the average speed in an urban area was 22 km/h, but no information was given about the amount of acceleration or the amount of time the car spent in hold at junctions e.g.

There is a tendency for BEVs to be smaller than most ICE cars and in some cases the comparisons were carried out with cars that were not of equal size, which could influence the results. When very similar cars are compared lower reductions are seen.

The findings about the frequency content of noise from BEVs generally show that there can be some peaks at middle or high frequencies, which have the potential to be heard as single tones and therefore could be perceived as annoying. This is also confirmed by some reported experiences from electric cars, but no thorough subjective investigation has been found which can validate this.

The literature survey also found that more knowledge is needed on the tyres used on BEVs. Many of the references found in this study were very unspecific about the vehicles used for measuring, including the type of tyres used on the vehicles. One reference was very specific about the fact that the exact same tyres were used on both the electric and the ICE car, but this reference found a difference in noise from the electric car and the ICE at high speeds, which is rather strange as the tyre/road noise should dominate the propulsion noise at these speeds. This indicates that further measurements and more knowledge are needed on tyre/road noise from BEVs. To fully explore the subject, it would also be relevant to examine what types of tyres are generally used on electric cars.

In most of the references there was no information about the road type which the measurements were carried out on and none of the references used different types of road surface for comparison. To be able to predict a reduction in the sound level in a city, knowledge of the different types of road surfaces in the city is needed. A high noise surface can mean that the tyre/road noise is more dominant at lower speeds than it would be on a low noise surface and there can therefore be a difference in how great a noise reduction can be obtained. The same is also true for the tyres on the vehicles. Therefore, an investigation of the influence of the road surface on the tyre/road noise is needed.
References predicting the potential noise reduction in cities were also found. These show that a reduction of anywhere between 0 dB and 6 dB can be obtained if silent tyres are also used. These results are based on measurements of the noise from a few vehicles and a chosen city, street or route in an urban area. The expected reduction therefore seems to depend very much on the chosen example and the vehicles used for estimating the noise reduction by a single vehicle.

4.2 Aim

The scoop of the measurements in this project is to analyse how electric powered vehicles could affect the noise environment in urban areas. By driving patterns with acceleration and deceleration it is unknown if the engine noise will be dominate at low speed. At higher speeds the tyre/road noise will dominate the noise emission from passenger cars which will probably be the same for EVs. An investigation on tyres typical to electric vehicles and their ability to emit noise compared to a standard reference test tyre (SRTT) should also be performed.
In order to investigate the differences in noise contribution from BEVs and ICE cars it is therefore relevant to perform detailed noise measurements on these different types of vehicles under different typical urban driving conditions and also on different typical road surfaces.

5 MEASUREMENTS

Traffic noise measurements can be carried out in various ways, depending on the issue of interest. The COMPETT project aim to investigate the different in noise emitted from electrical and internal combustion engine vehicles under urban driving conditions.
Traffic noise consists of two different sources: the engine noise and noise as an effect of the tyres rolling on the road surface, also called tyre/road noise. For ordinary ICEs the combustion noise is dominant at low speeds beneath about 30 km/h. This is the speed where the contributions from engine noise and tyre/road noise are almost equal depending on the tyre and the engine type. Tyre/road noise is dominant at high speeds above about 30 km/h for passenger cars.
Urban driving situations with uneven driving pattern are supposed to cause higher noise level emitted from the engine of the vehicle. COMPETT want to investigate the difference in noise level from BEVs and ICEs under uneven driving patterns. In order to estimate a potential noise reduction by replacing ICEs with BEVs in urban areas with a maximum speed limit at 50-60 km/h.
The two different measurements were carried out to investigate the difference in total noise under urban driving conditions and the tyre/road noise. The measurements of total noise is done by controlled pas-by (CPB) where the test site is a constant, but the vehicle and driving pattern are variables. The measurement of tyre/road noise was done by the close proximity (CPX) method.
The measurements were planned in order to give some answers to the questions about the differences in the noise from ICEs and BEVs. In the following the measurements are described in more details.

5.1 Controlled Pass-By (CPB)

Controlled pass-by (CPB) measurements were carried out in according to the ISO standard method described in [3]. With this method it is possible to measure noise emission from specific vehicles under given driving conditions.
Three driving patterns were chosen in order to simulate urban driving such as steady driving, going up to and away from junctions. These were measured to investigate the typical uneven driving pattern from urban driving situations. The maximum measured speed was about 60 km/h because most urban areas in Europe have lower speed limits. Steady driving was simulated with measurements at steady speed of 10, 20, 30, 40, 50 and 60 km/h, decelerating by engine braking was measured from 20, 30, 40, 50 and 60 km/h and acceleration of different degree from 10, 20, 30 and 40 km/h.

Figure 1 Photo for the CPB test site from the summer 2012, before it was repaved. The red dots symbolize the traffic cones confining the measuring zone. The black dot symbolizes the microphone, which is 7.5 m from the center of the test lane.

5.1.1 Test site

The noise emitted from ICE passenger cars driving at speeds under 30 km/h is dominated by the propulsion noise. It is the common opinion that BEVs are very silent at low speeds, since they have no propulsion. Thus the test site had to be silent without disturbing traffic or background noise. The surface should have no signs of wear and tear, which could be suspected to pollute the measurements.

A large carpark in an industrial area was chosen, see Figure 1. The lane connecting the different sections of the carpark have been repaved within the last 2 years and had no sign of wear, see Figure 3. It is assumed that the pavement is soft asphalt (dense graded asphalt concrete with soft binder).
The traffic at the carpark was limited. Only a few other cars entered the carpark throughout the whole measurement.

5.1.2 Measurement setup

The setup for the SPB measurements is shown in Figure 2 and Figure 4. The operative vehicle was parked in the opposite site of the test lane 37 meter before the microphone position. From the operative van the air temperature and the speed of the vehicles in the moment of passing the microphone is measured. The microphone position fulfilled the requirements of the ISO standard [2]. The microphone was placed 7.5 m from the centre of the driving lane and 1.2 m above terrain.

Traffic cones were placed before and after the measuring zone to guide the driver into right lane, see Figure 1. The cones were also used to control the driving pattern. In steady speed diving situations, the steady speed should be achieved at the traffic cones when entering the measuring zone and held steady until passing the traffic cones leaving the measuring zone.

In the measurement of noise emission from decelerating cars, the car should drive at steady speed when it reaches the traffic cones entering the measuring zone, where the driver should release the foot from the “gas” pedal. The car should then decelerate using engine beak throughout the measuring zone.

When measuring the noise emission from accelerating cars, the car should drive up to the first traffic cones with steady speed then accelerating through the measuring zone trying to reach a given speed when passing the last cones.

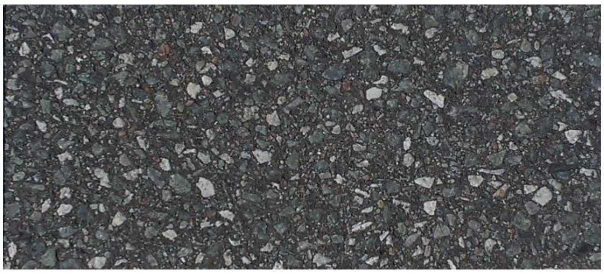

Figure 3: The new road surface on the test site is assumed to be a dense graded asphalt concrete with soft binder

Figure 2: Photo of the measurement operative vehicle. In the center speed is measured with a laser to the right the air temperature is measured. The mount furthest to the right was used to record some measurements on film.

5.1.3 The vehicles

The type of ICE vehicles for comparison was considered thoroughly. Should the comparison be made between new ICE vehicles and new electric vehicles, or ICE vehicles and electric vehicles of the same size? A comparison could also be made of the current vehicle fleet with electric vehicles. If it is assumed that the people who buy electric vehicles would have bought a new ICE vehicle had they not chosen to buy an electric vehicle then new vehicles should be compared. It was concluded that the comparison should be made between cars of comparable type, size and abilities.

Figure 4 Microphone setup with part of a traffic cones to the right and the Nissan Leaf passing the microphone.

Four cars where used in the measurements, chosen to be comparable in weight and form The cars were two Citroën Berlingos an ICE and an BEV, a Nissan Leaf and a VW Golf Variant ICE, see Figure 5. The Berlingos and the Nissan Leaf were kindly lent to the Danish Road Directorate to conduct the measurements from the car suppliers. The VW Golf Variant is one of the cars in the fleet of the Danish Road Directorate. The cars were chosen to be similar in pairs to justify the comparison of the noise emissions.

The cars were supplied with different tyre types, see Table 1. The Berlingo BEV were supplied with Michelin Agilis The other cars where supplied with Michelin Energy Saver of different dimensions. The tyres of the Golf and the Leaf have the same dimensions. In Table 1 the noise label of the tyres are listed. The Michelin Agilis tyres are labelled with a higher noise level than the Energy saver. BEVs are normally supplied with tyres with low rolling resistance, such as the Energy Saver, in order to drive longer on the charged battery.

Citroën Berlingo EV	Citroën Berlingo ICE	Nissan Leaf EV	VW Golf Variant ICE
Michelin Agilis 51	Michelin Energy Saver	Michelin Energy Saver	Michelin Energy Saver
195/70 R15C	195/60 R15 G1	205/55 R16	205/55 R16
71 dB	69 dB	70 dB	70 dB

Table 1 Tyre type, dimension and labelled noise level for the different vehicles.

Figure 5: The cars included in the measurements from the left to right: Citroën Berlingo EV, Citroën Berlingo ICE, Nissan Leaf and VW Golf Variant.

5.2 Close ProXimity (CPX)

Close proximity (CPX) measurements were carried out according to the ISO standard method described in [3]. With this method it is possible to measure tyre road noise emission from specific sets of tyres on given surfaces.

The measurements were carried out with the open CPX trailer of Danish Road Directorate which can be seen in Figure 6.

Tyre measurements were carried out in as a NordFou project called NordTyre [4]. More than 30 set of tyres were measured on 33 different test sections of 13 different types of typical European road surfaces mixtures. In the COMPETT project only the data from two sets of tyres will be investigated the Standard Reference Test Tyre (SRTT) which is used as a reference tyre, and the Energy Saver type which was mounted on the ICE Berlingo, the Nissan Leaf and the Golf Variant.

The Energy Saver tyre types supposed to have a slightly smaller rolling resistance, which make them more energy effective. A vehicle with Energy Saver tyres mounted should be able to drive further on the same amount of fuel than with an ordinary set of tyres, no matter whether it runs on petrol, diesel or electricity. It is commonly used on BEVs since BEVs have a shorter travel distance when fully charged, than most ICEs have on a full tank. A disadvantage of the Energy Saver type of tyre is that they are not as robust and easier goes flat. Fleets of BEVs are therefore seen with ordinary tyres mounted instead of the Energy Saver type.

Figure 6 The open CPX trailer of the Danish Road Directorate.

6 RESULTS OF MEASUREMENTS

6.1 Controlled Pass-By (CPB)

The driving pattern measurements as described above were carried out Saturday, the 22th of June, 2014 between 10:30 am and 12:45 pm and the temperature was 16.6 °C. The results are normalized to 20 ° C using a correction factor of -0.05 dB per °C.

6.1.1 Steady speed

The results of the steady speed measurements will be presented in this section. The results and the polynomial trend lines of the measurements for the Berlingos are shown in Figure 7. The Berlingos are driving through the measuring zone a various steady speeds from about 10 km/h to about 60 km/h.

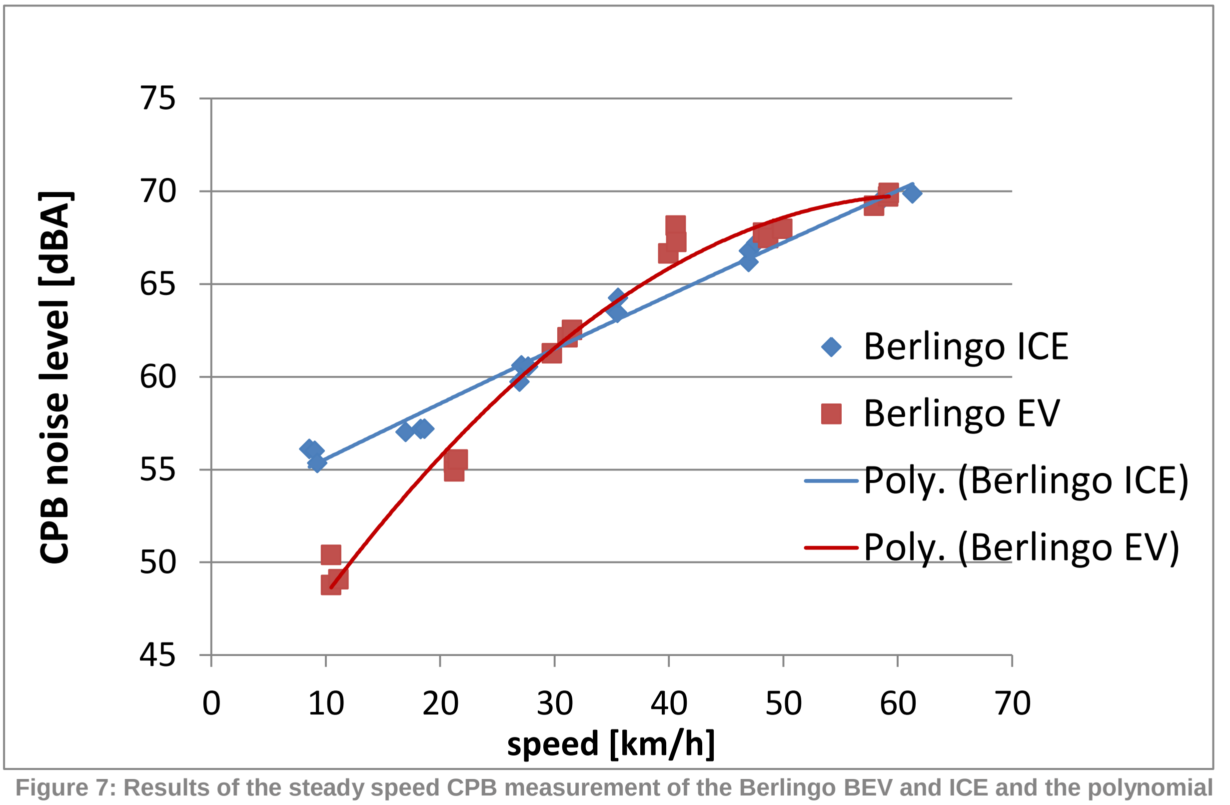

Figure 7: Results of the steady speed CPB measurement of the Berlingo BEV and ICE and the polynomial trend lines.

The BEV emits 5 dB less noise than the ICE at 10 km/h, at 30 km/h and 60 km/h they are equally noisy. Between 30 km/h and 60 km/h the ICE emits less noise than the BEV with a maximum difference of the trend lines of about 2 dB.

The steady speed results of the Nissan Leaf and the Golf variant and the polynomial trend lines are shown in Figure 8. For all the measurements speeds the Leaf emits less noise than the Golf. At about 10 km/h the Leaf emits about 4 dB less noise than the Golf but the difference is only 1.5 dB and seems steady from about 40 km/h and up to 60 km/h.

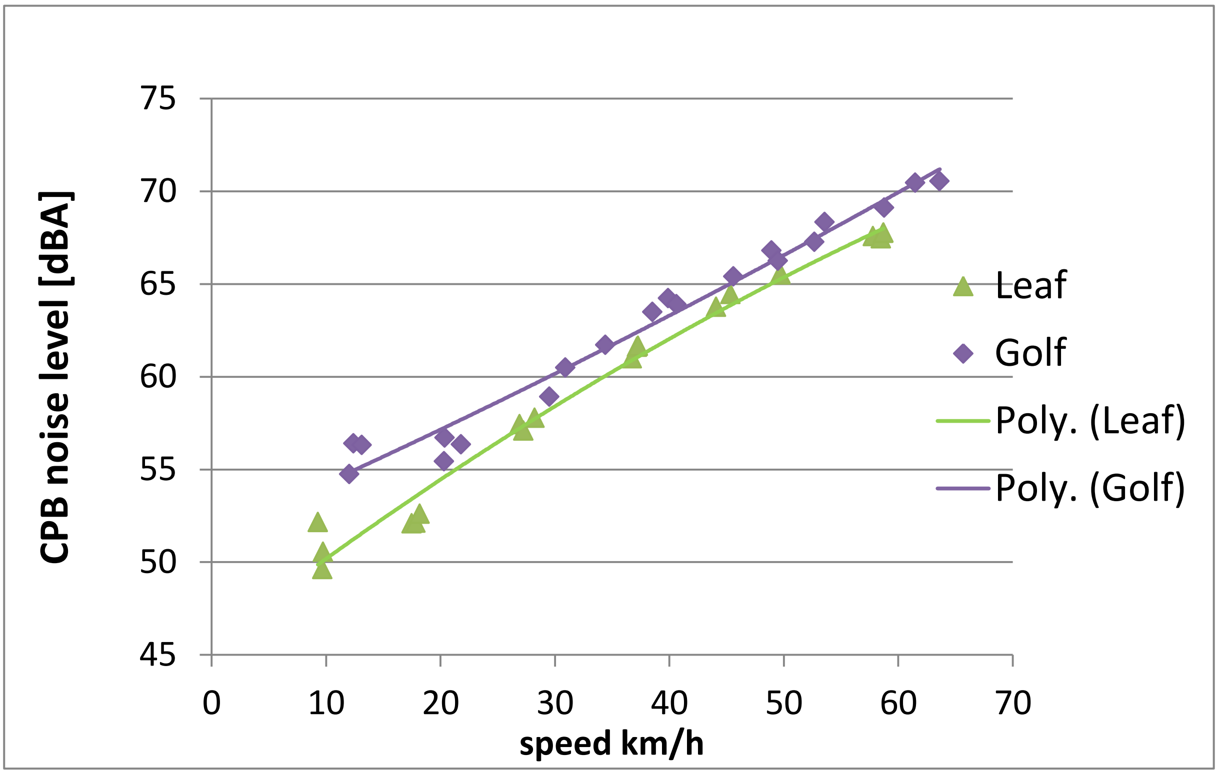

Figure 8: Results of the steady speed CPB measurement of the Nissan Leaf and the VW Golf Variant and the polynomial trend lines.

Figure 9 and 10 shows A-weighted 1/3 octave band spectra for noise levels measured at lowest and highest measured speed at steady driving for each car. The broken lines are low speed measurements. Both BEVs have a narrow peak in the spectra at low speed. The Berlingo has its peak at 1 kHz and the Leaf has its peak at 2 kHz.

The ICEs have peaks at lower frequencies both at their lowest and highest speed. The peak shifts to a slight higher frequency in the spectra for the higher speed compared to the spectra at low speed. These peaks has a lower noise level than the broad frequency band between 400 Hz and 3150 Hz except for the Golf at low speed, its peak at the lower frequencies has about the same noise level as the broad band.

At the higher speed the spectra of the BEVs are similar to the ICEs with a band of frequencies of almost equal noise levels between 500 Hz and 2500 Hz.

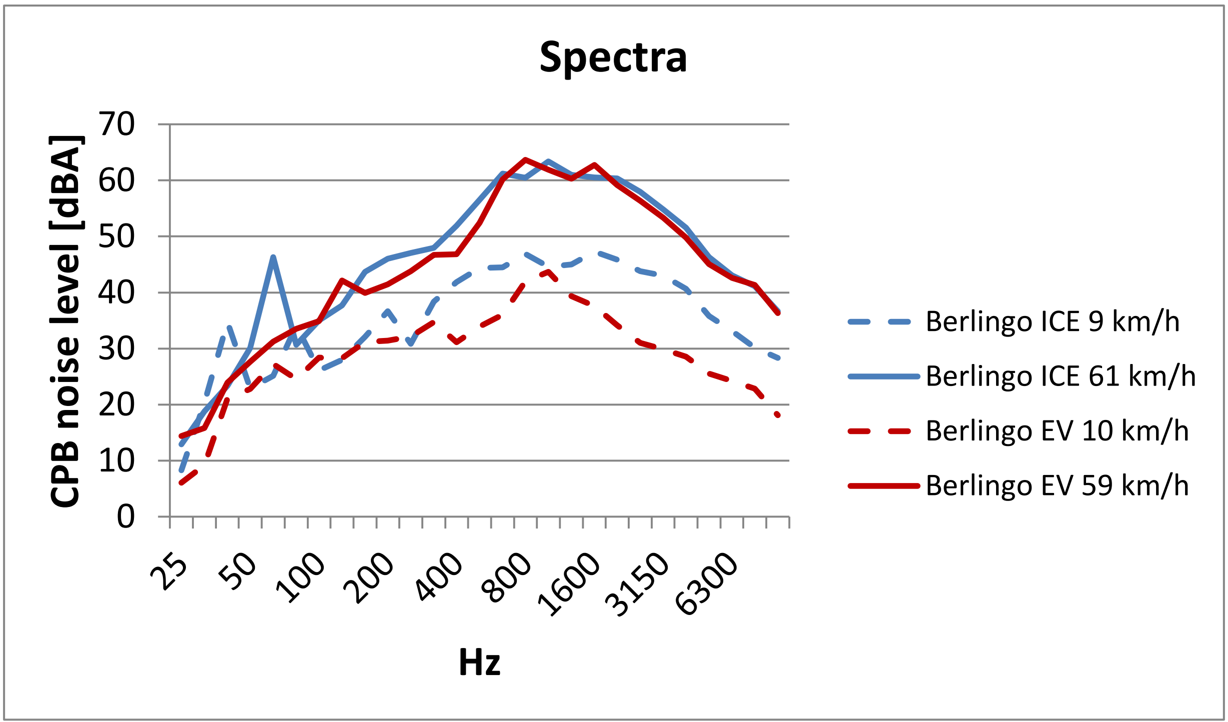

Figure 9: Spectra from CPB measurements of the Citroën Berlingos driving at steady speed.

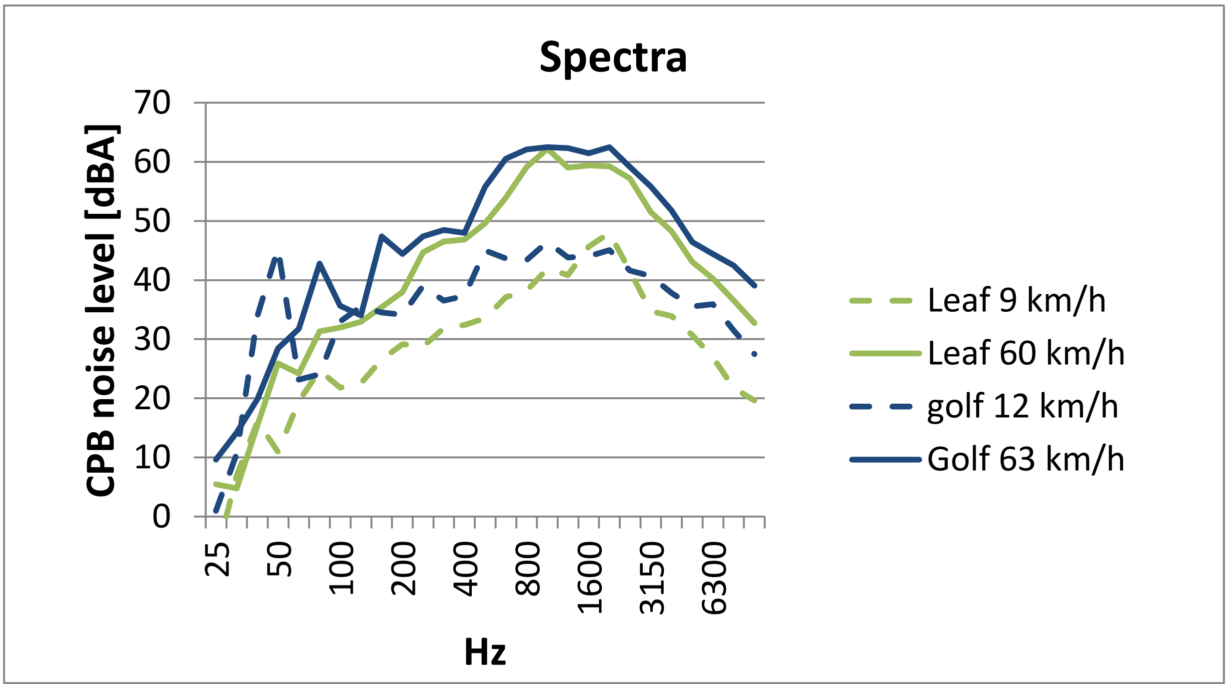

Figure 10: Spectra from CPB measurements of the Nissan Leaf and VW Golf Variant driving at steady speed.

6.1.2 Decelerating by engine braking

In this section the results of the deceleration measurements by engine braking is presented. The results and the polynomial trend lines for the Berlingos are shown in Figure 11. For the Golf and Nissan the results and trend lines are shown in Figure 12.

The Berlingo BEV is emitting about 4 dB less noise than the ICE at about 15 km/h. But at 30 km/h and higher speeds the noise levels of the two Berlingos are similar.

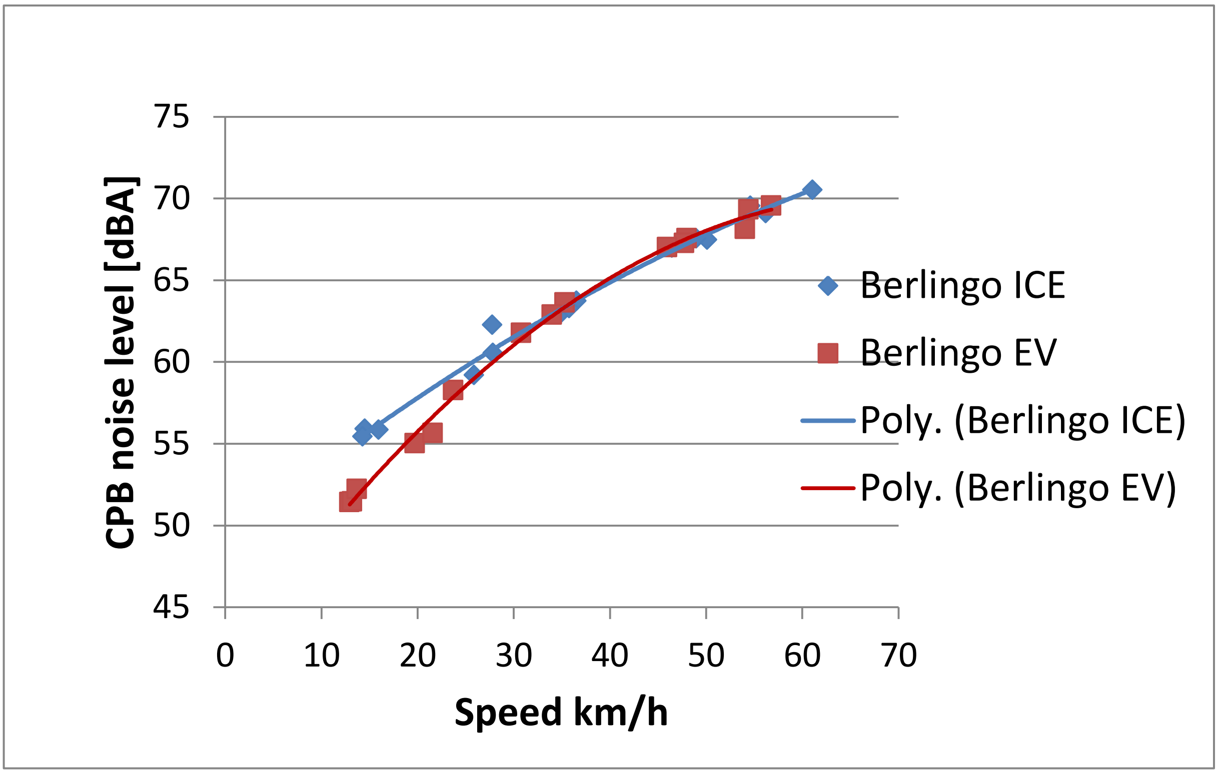

Figure 11: Results of the deceleration CPB measurement by engine braking of the Berlingos.

The Leaf is less noisy than the Golf for all the measured speeds but the difference between the Leaf and the Golf decreases when the speed increases. At about 20 km/h the difference is 2 dB and at about 60 km/h it is 1 dB less.

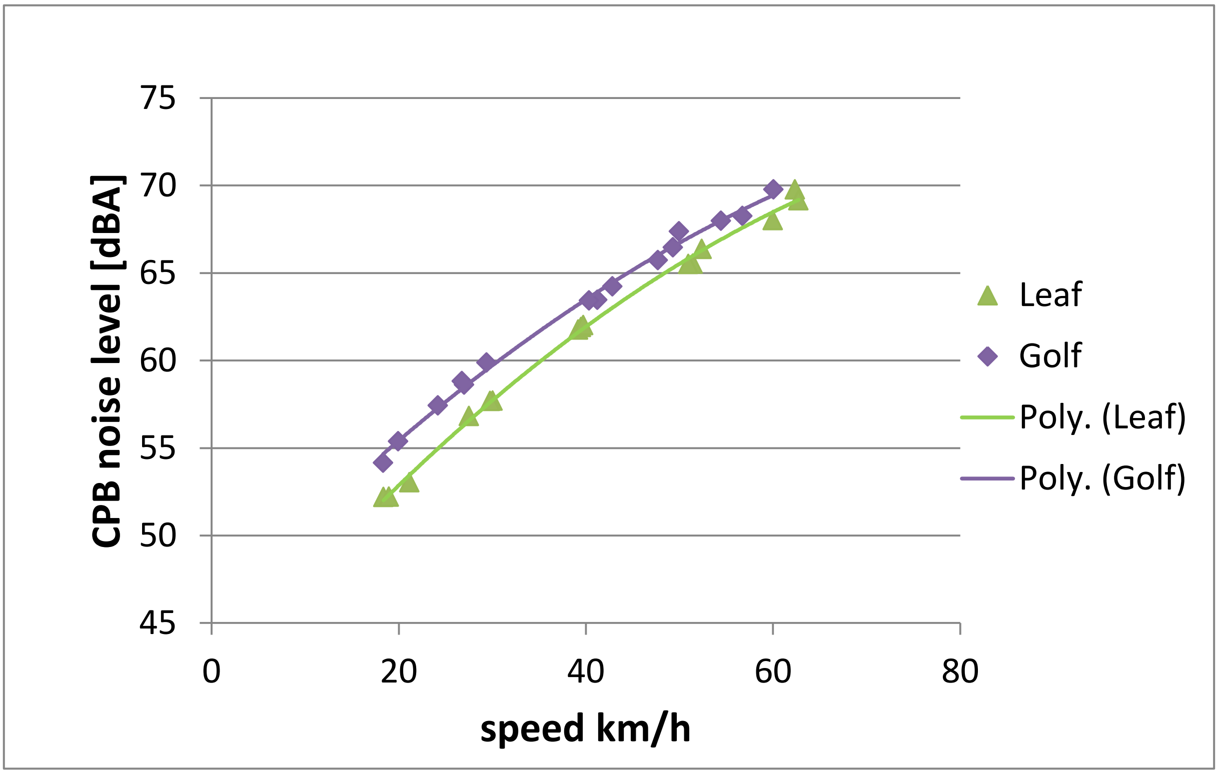

Figure 12: Results of the deceleration CPB measurements of the Nissan Leaf and the VW Golf Variant.

Figure 13 and 14 shows A-weighted 1/3 octave band spectra for noise levels measured during deceleration by engine brake at low and high speed for each car.

The Berlingo BEV has a narrow peak in the spectra, at 1 kHz, at low speed, and a less narrow peak, at 800 Hz, at high speed. The Berlingo ICE has a slight peak, at 1 kHz, at high speed and no peak at low speed. The spectra are almost similar for the Berlingos at high speed. But at low speed there is a distinctive difference where the ICE has a broad frequency band of frequencies of equal noise level between 400 Hz and 3150 Hz.

The spectra in figure 14 for both the Golf and the Leaf show a slight peak for both, at 1 kHz, at 18 km/h and no significant peak at high speed.

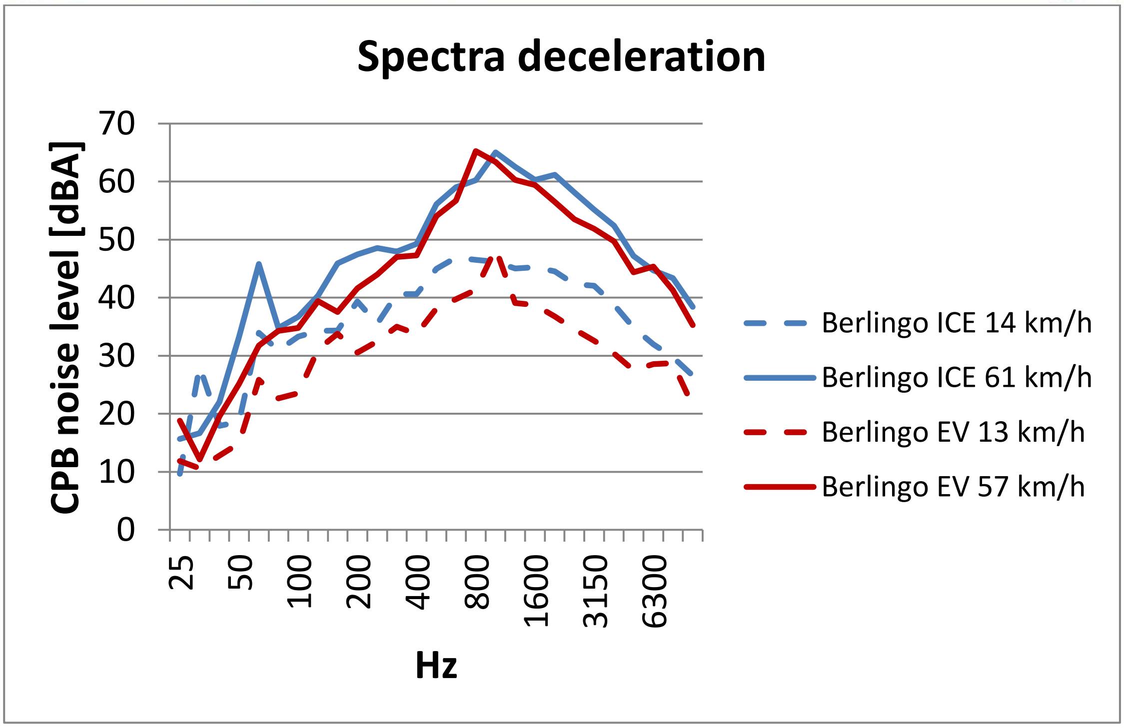

Figure 13: Spectra from CPB measurements of the decelerating Berlingos.

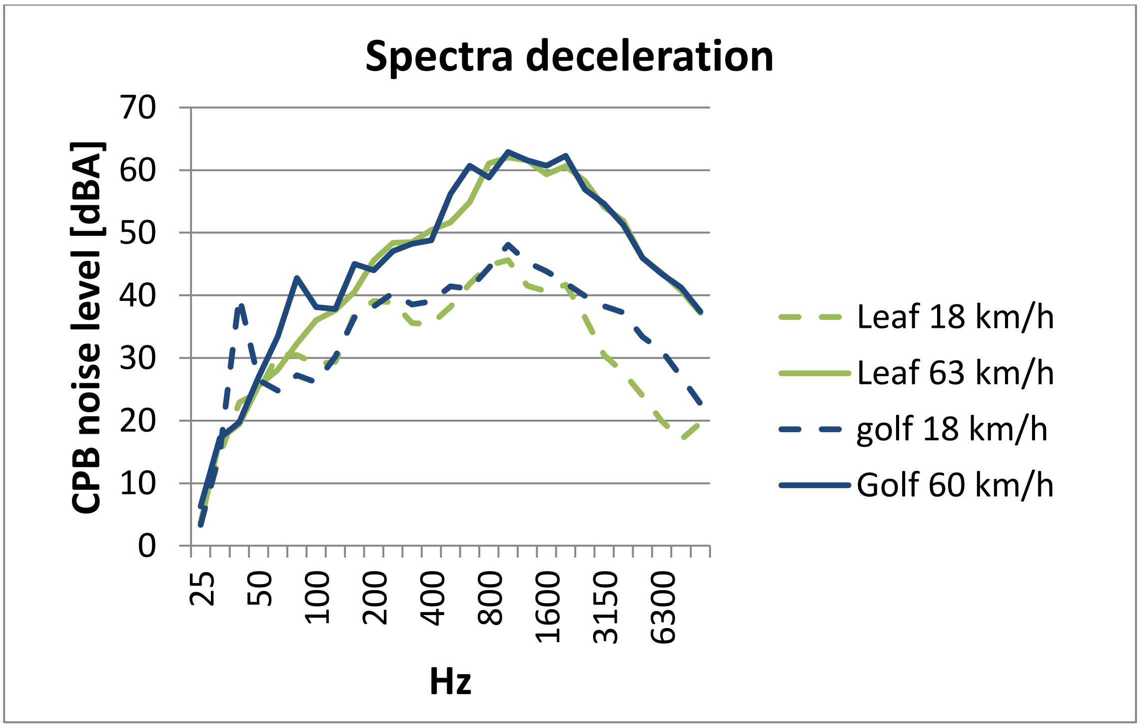

Figure 14: Spectra from CPB measurements of the decelerating Leaf and Golf.

6.1.3 Accelerating

This section will present the results of the noise measured at different degree of acceleration form different speeds. In figure 15 the noise level versus the acceleration is shown for the Berlingos. Figure 16 is the equivalent figure for the Leaf and Golf.

For the ICE Berlingo the small degree of acceleration is not obtained, see figure 15. The noise levels at accelerations between 2 and 3 m/s^2 do not differ much between the BEV and the ICE Berlingo. The ICE Berlingo has some noise levels which stand out at about 2 and 3 m/s^2, the drivers choice of transmission level could have influence on the noise level.

For the Leaf and the Golf, in figure 16, the golf seems to be emitting more noise by all degrees of accelerations, and even have two different tendencies of noise emission level. The golf and the leaf have a bigger variety of degree of acceleration than the two Berlingos.

In figure 17-20 the noise levels measured during acceleration is shown relative to the actual speed, and the acceleration is labelled for each measurement. The measurements of noise emitted by the Berlingo ICE with different degrees of acceleration and speeds are seen in figure 17. There is a difference of about 2-5 dB of noise level from low to high speed, depending on the degree of acceleration. At the same speed with different degree of acceleration the noise level raises with the degree of acceleration for all speeds but at 30 km/h.

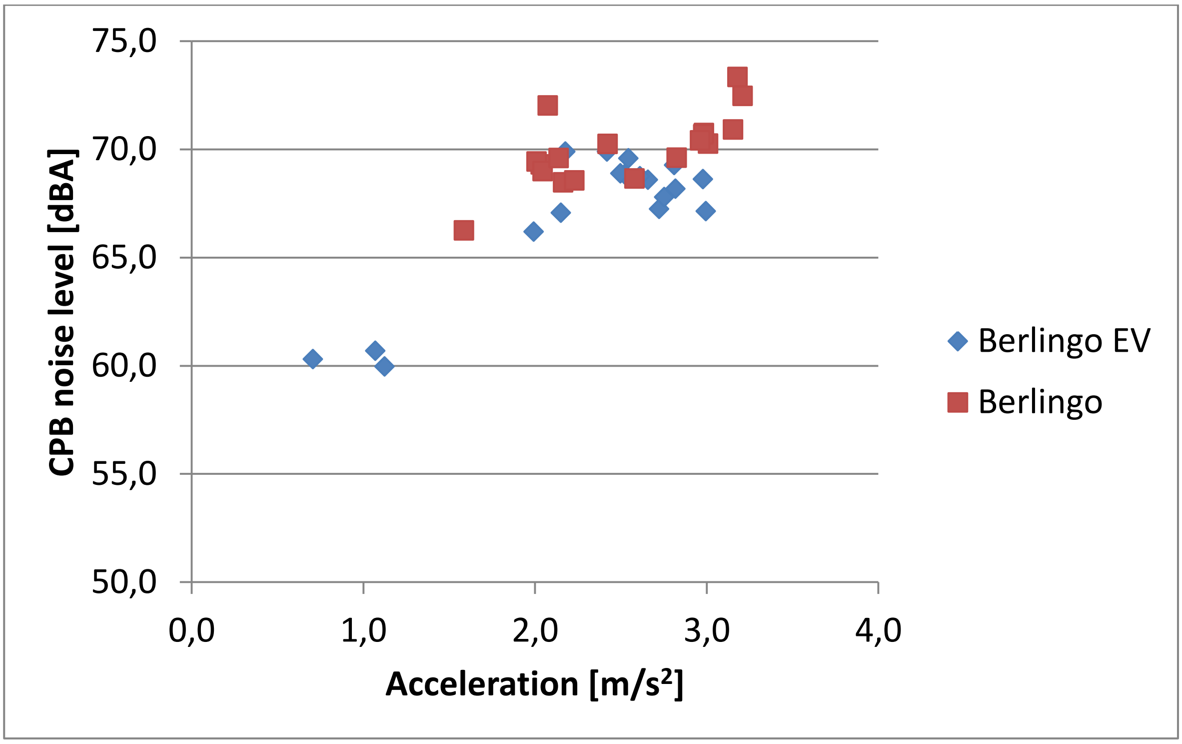

Figure 15: Results of the acceleration CPB measurement of the Berlingos

The results of the measurements of the accelerating Berlingo BEV are shown in figure 18. At low degree of acceleration and speed the emission of noise is also low. The low degree of acceleration (0,7-1,1 m/s^2) for speeds between 20 and 30 km/h are not measured at other level of speed. The emission of noise at the same speeds with different degree of acceleration is increasing with the acceleration. Only at 37 km/h this is not the case. At this speed the acceleration of 2,5 m/s^2 emits about 1,5 dB higher noise level than when accelerating wig 2,8 m/s^2.

The measurements of the VW Golf variant are shown in figure 19. As in figure 16 four measurements are placed higher in noise level than the rest of the measurements. These measurements increase in noise level as the speed and acceleration increases. The rest of the measurements vary 4 dB in noise level. As the acceleration decreases the noise level gets smaller. Measurements with the same degree of acceleration and different speeds emit almost the same noise level.

Figure 20 shows the results of the measurements of the accelerating Nissan Leaf. At low speeds between 20 and 35 km/h the difference of emission is increasing with about 10 dB. At these speeds the degree of acceleration also increases for 1,5 m/s^2 of 4,4 m/s^2. For speeds between 40 and 60 km/h the difference in acceleration is 0,9 m/s^2. The level of emitted noise is also almost steady in this interval of speed.

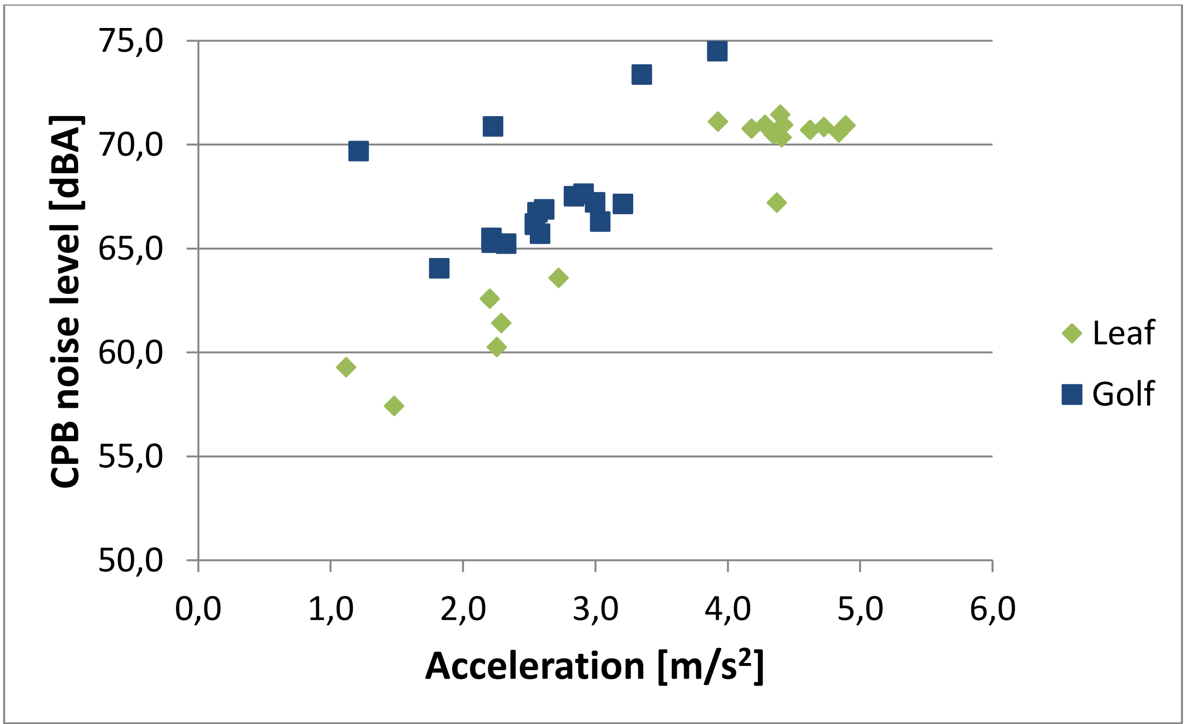

Figure 16: Results of the acceleration CPB measurement of the Leaf and Golf.

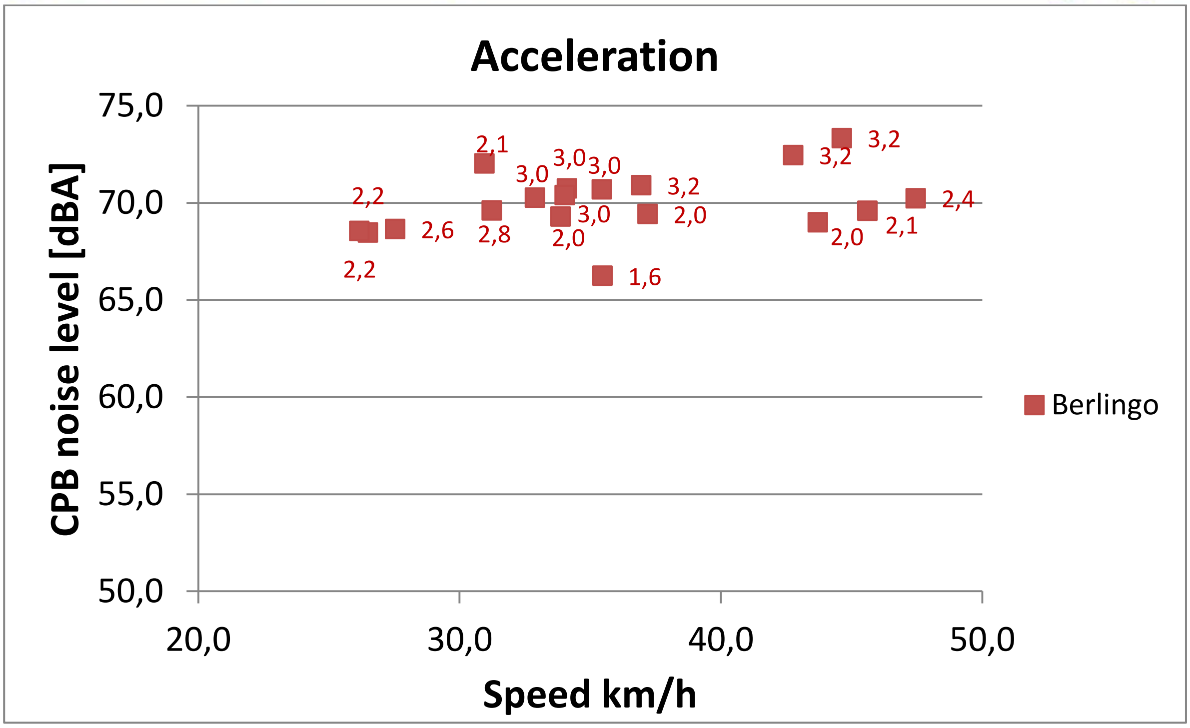

Figure 17: Results of the CPB measurements of the ICE Berlingo while accelerating.

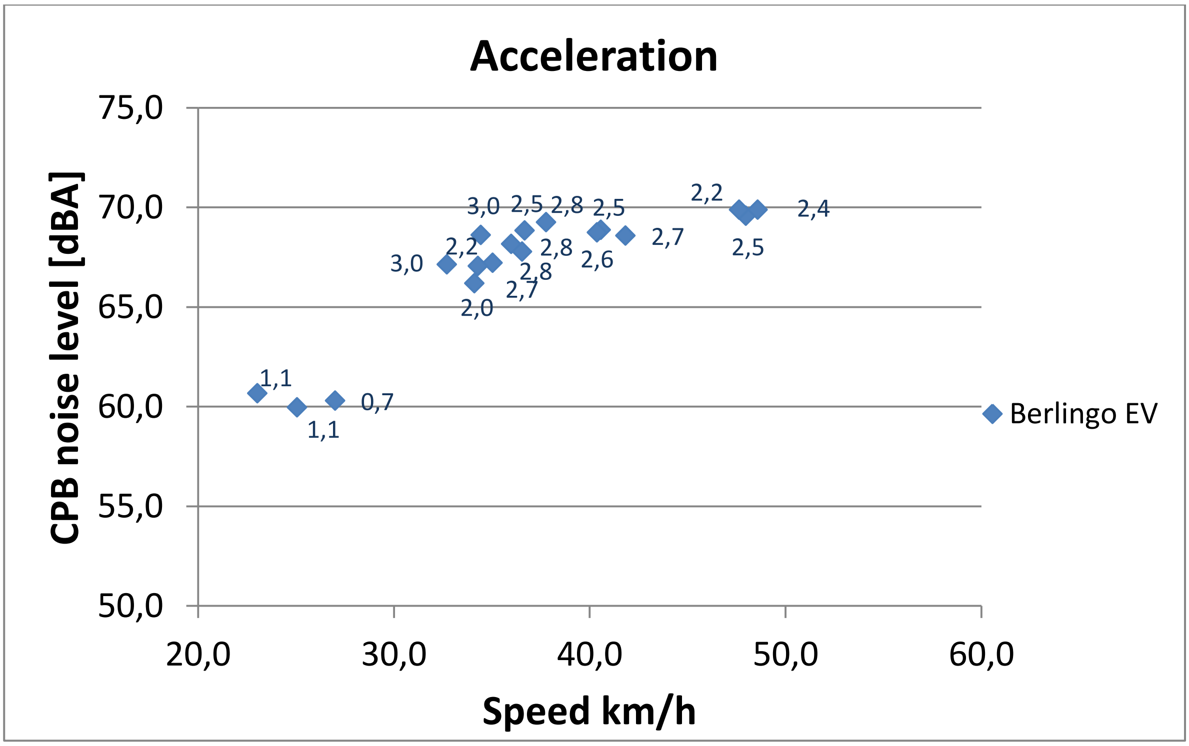

Figure 18: Results of the CPB measurements of the BEV Berlingo while accelerating.

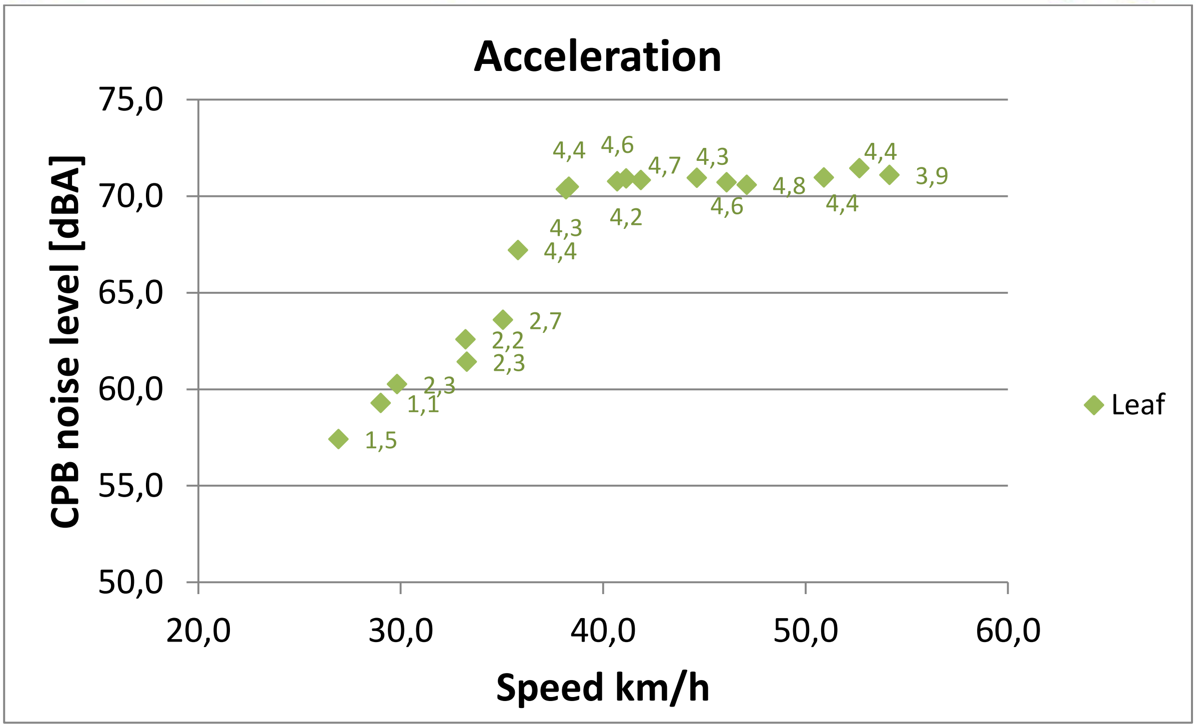

Figure 19: Results of the CPB measurements of the BEV Nissan Leaf while accelerating.

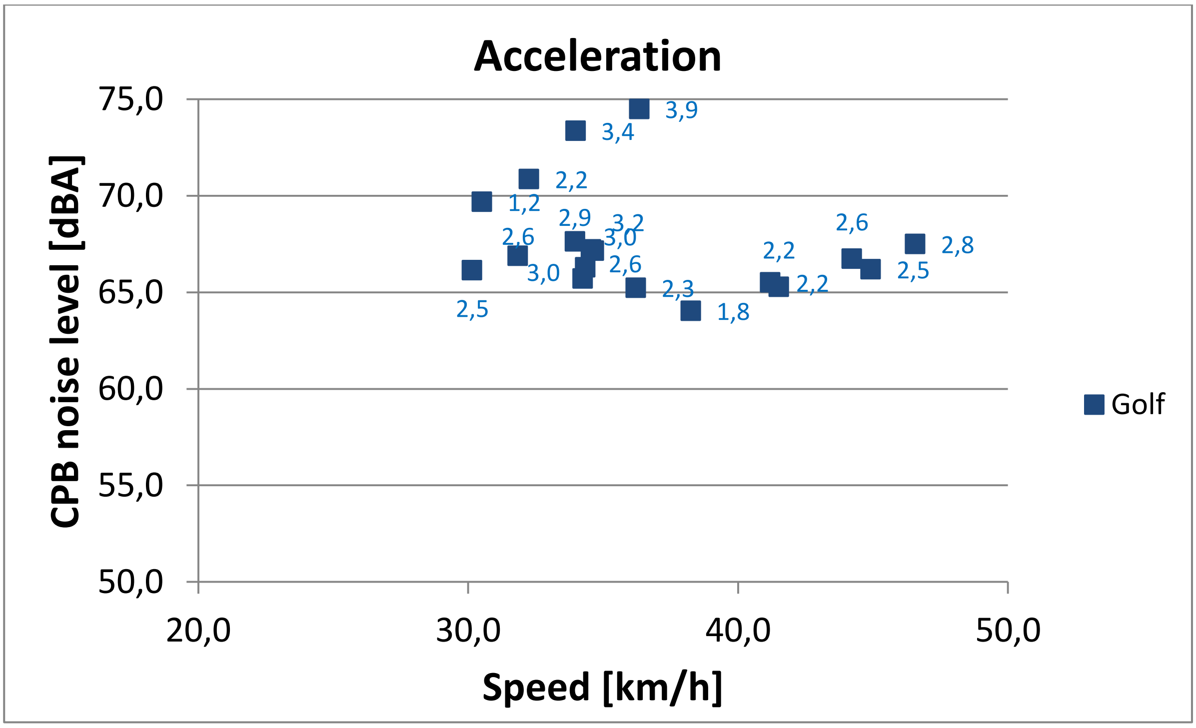

Figure 20: Results of the CPB measurements of the ICE VW Golf Variant while accelerating.

In figure 21-24 spectra of some of the measurements done during acceleration of the vehicles are shown. For each vehicle the measurements for which the spectra are shown are chosen in the following manner:

- The lowest emission and speed
- A set of measurement where the vehicle passes the microphone with the same speed but different acceleration.
- The highest speed

The spectra for the ICE Berlingo, in figure 21, have no significant difference between them. At low frequencies (50-63 Hz) the spectre peak is higher for at lager degree of acceleration of the same speed. The spectres of the BEV Berlingo in figure 22 also have no significant differences between them, when the difference due to the speed has been taking into account. For the set of measurements at almost equal speed there is a difference of 5 dB at the 400 Hz peak.

The spectre of the measurements carried out for the accelerating Golf is found I figure 23. The measurement of the Golf at34 km/h with an acceleration of 3,4 m/s^2 is one of the measurements which has a high level of noise emission compared to other measurements at the same speed, see figure 20. It has one dominating peak at 160 Hz. The other measurements have smaller peaks at 1 kHz and lower frequencies. Overall they have more fluctuating spectres. The Measurement at 46,6 km/h and with 2,8 m/s^2 acceleration has two peaks at 63 Hz and 125 Hz. The peak of the three remaining measurement are placed at 80 Hz.

The spectres of the Nissan Leaf measured during acceleration are shown in figure 24. The spectres have no significant peaks. The set of measurement at similar speeds and different acceleration have of 2-5 dB in noise level from 315 Hz to 2,5 kHz, the highest acceleration give the highest level of noise. Above 2,5 kHz the difference gets bigger. From 80 Hz to 400 Hz the two measurements have more or less the same level. At lower frequencies the measurement of higher acceleration has higher noise levels.

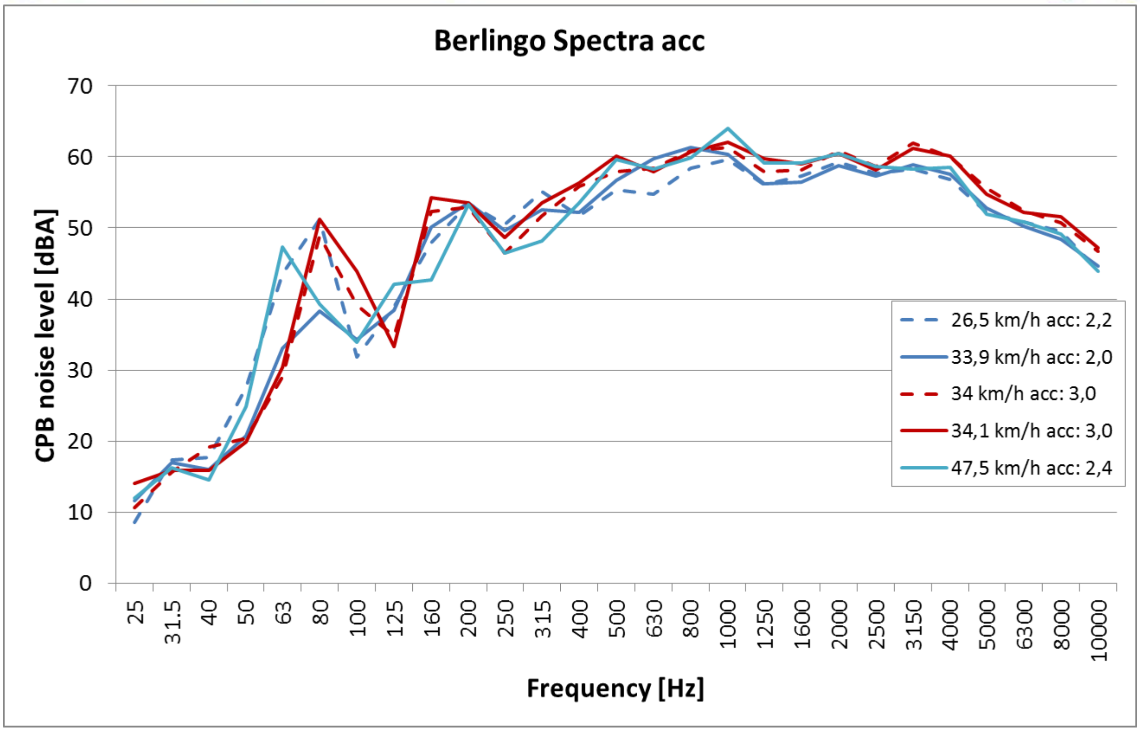

Figure 21: Spectre of the chosen results of the CPB measurements of the ICE Berlingo while accelerating.

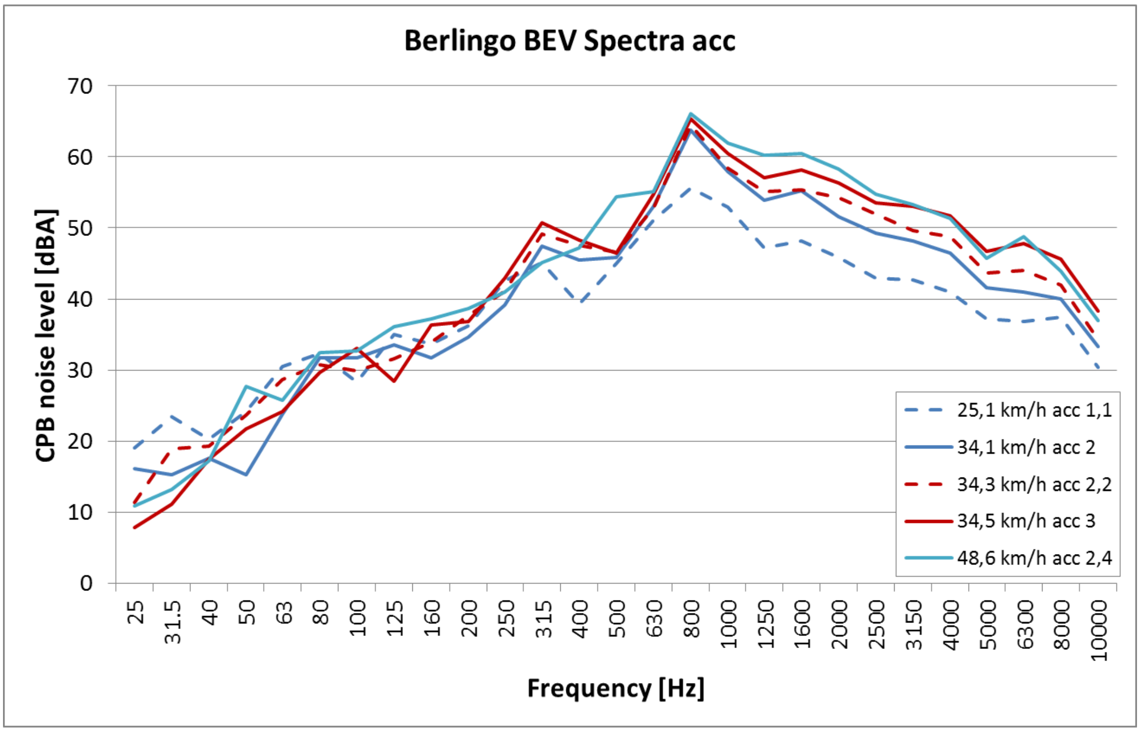

Figure 22: Spectre of the chosen results of the CPB measurements of the BEV Berlingo while accelerating.

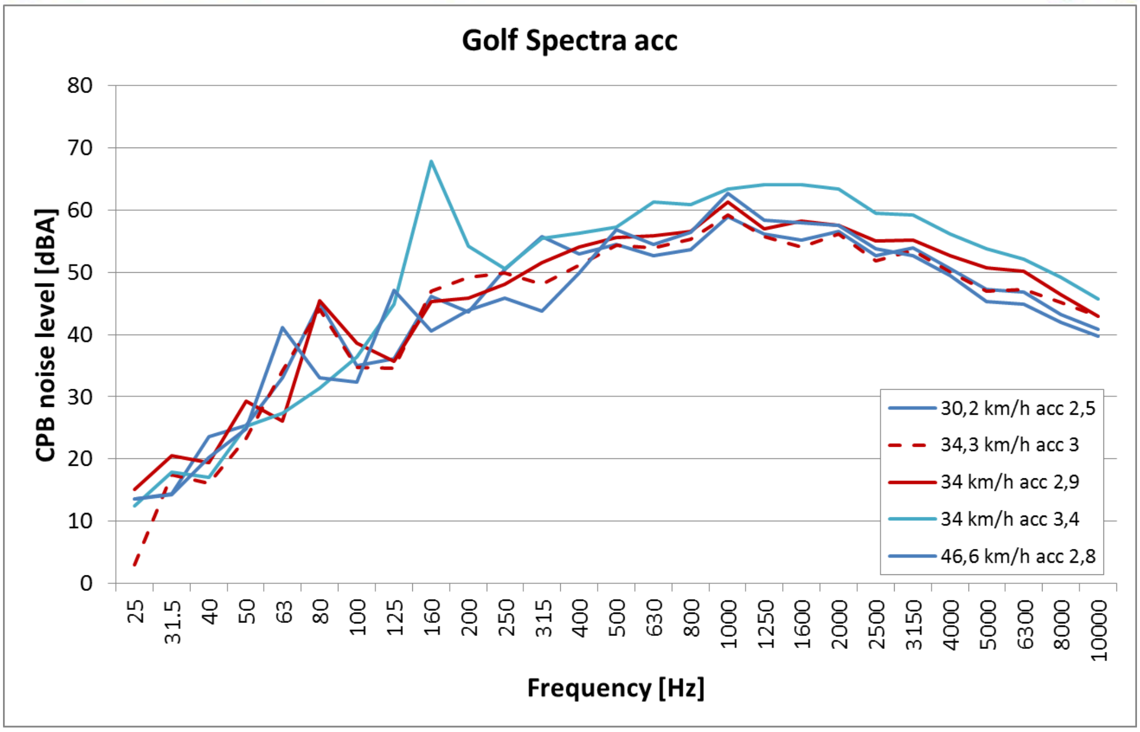

Figure 23: Spectre of the chosen results of the CPB measurements of the ICE VW Golf Variant while accelerating.

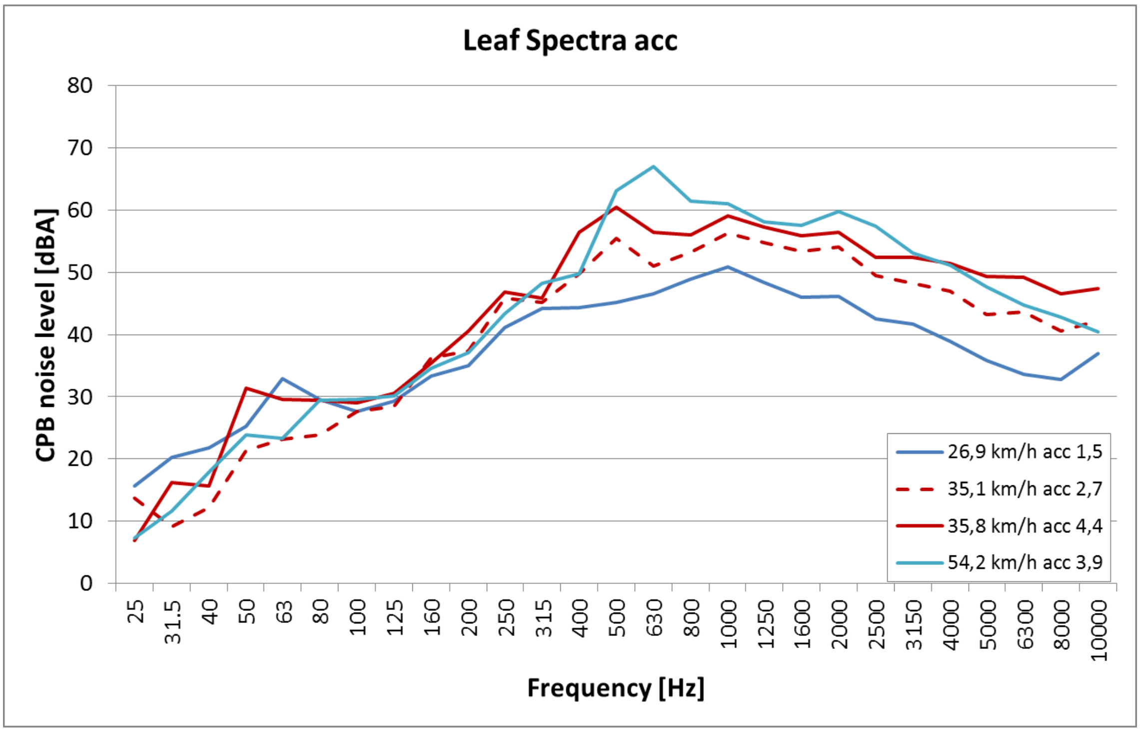

Figure 24: Spectre of the chosen results of the CPB measurements of the BEV Nissan Leaf while accelerating.

6.2 Close ProXimity (CPX)

The measurements of different tyres where carried out in the NordTyre project. The tyres where driven on 34 different surfaces of 14 different types. In figure 25 the average noise levels of the emission from the SRTT and the Energy-saver tyre for 12 different types of pavement used in urban areas in Europe.

The SMA 6, SMA 6+8, SMA 6+11, AC 6o and AC 6d are pavements with a small aggregate size of 6 mm (for the +8 and +11 there are added some bigger aggregates). They are used in areas where a low traffic noise emission is wanted. This could be near dwellings and recreational areas. The pavements with the bigger stone aggregates such as SMA 11, AC 11d, AC 12d and SMA 16 are used where the level of noise emission has lower priority and the durability of surface are of higher priority. This could be in areas with much traffic and a large amount of heavy vehicles. The surfaces with the maximum aggregates of 11, SMA 11 and AC 11d, are often used as reference in comparison to noise reducing pavements. Since these are most commonly used pavements on highways.

From figure 25 it is seen that the biggest difference in emission between the references SRTT and the Energy Saver is found for the dens asphalt concrete types: AC 6d (2,4 dB), AC 8d (1,2 dB) and AC 11d (0,9 dB). But for all the other types of pavements the Energy Saver are also emitting less noise. If it is assumed that all Urban roads was paved with AC 6d then there would be a potential noise reduction in choosing a BEVs with Energy Saver tyre types instead of an ICEs with standard tyres. But for the highest noise reduction the better choice would be to pave urban areas with AC 6o, SMA 6+11 or SMA 6+8. For the SMA6+11 and AC 6o the noise emission is less both for the SRTT and the Energy Saver than the emission on the AC 6d. While the emission from the Energy Saver is almost the same for the SMA 6+8, but the emission from the SRTT is less, which will result in an overall noise reduction compared to the AC 6d.

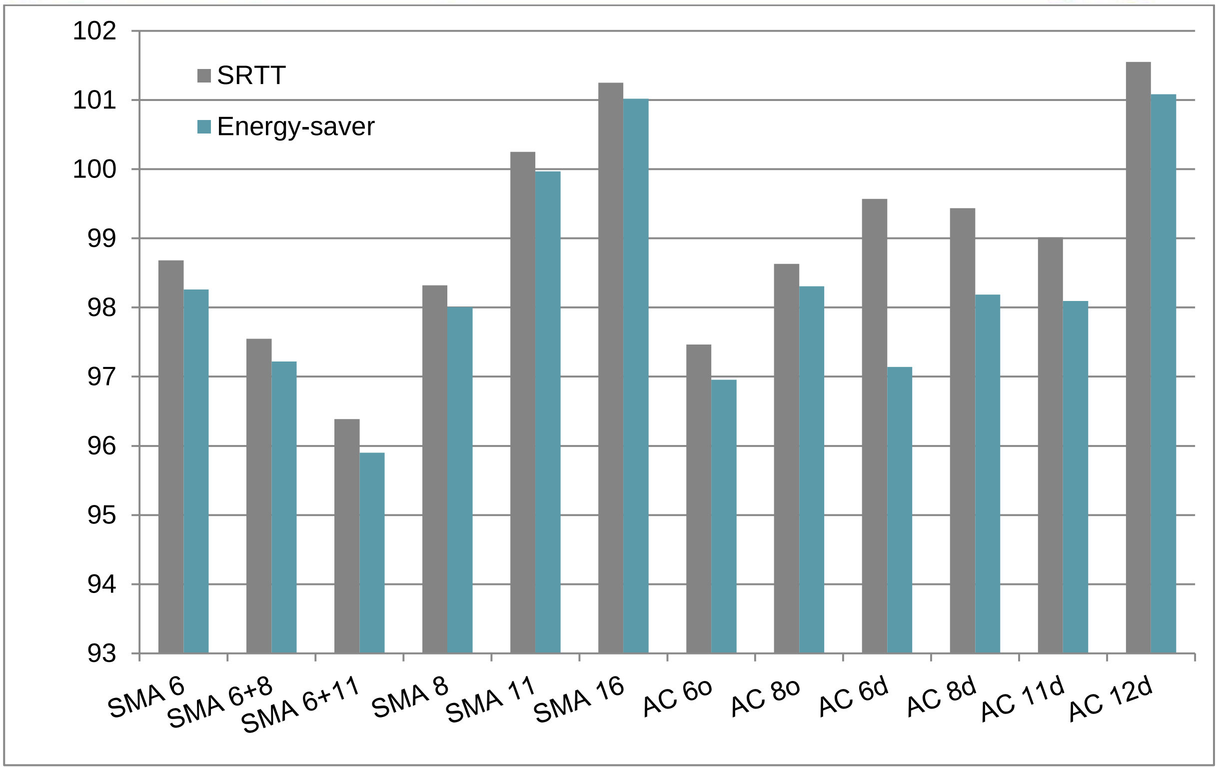

Figure 25: Noise emission from SRTT and Energy-Saver tyres on different surface types at 80 km/h. Data is measured as part of the NordFoU project NordTyre

7 DISCUSSION ON RESULTS

In the preceding sections the results of CPB measurements made to investigate the differences in noise emission from BEVs and ICEs of similar vehicles in different driving conditions which would occur in urban areas.

7.1 The two Berlingos

Noise levels from two Berlingos, the BEV and the ICE, were measured in different driving conditions. The BEV was mounted with tires labelled noisier than the tires mounted on the ICE. This is probably why the BEV is emitting more noise than the ICE in steady speed at speeds between 30 and 60 km/h. When decelerating at various speeds the two Berlingos emits similar noise levels at speeds above 30 km/h.

When comparing the trend lines of the Berlingos in the two driving situations the ICE has the same level at 10 km/h for both situations, while the BEV has a slightly (about 1 dB) higher level when decelerating. Between 30 and 60 km/h the BEV emits the same levels for both driving situations, while the ICE emits about 1.5 dB higher noise level. This might be explained by the suspicion of noisier tires on the BEV. The tire road noise will be dominant at a lower speed level when the tires are noisier and the engine is less noisy. The electric engine will be emitting more noise when decelerating than in steady speed driving situations. This will explain the slightly higher noise level at low speeds in the deceleration measurements. The less noisy tires on the ICE will mean that the tire/road noise will become dominant at a higher speed than if noisy tires were mounted on the car.

The spectra in figure 9 and 13 shows that both in steady speed and deceleration driving situations the EV has a narrow peak at 1 kHz these peaks are heard when the car is passing by, and can be described as annoying especially in the case of deceleration by engine brake. The two Berlingos are having similar levels of noise emission for speeds above 30 km/h when accelerating. At low speeds the measurements of the Berlingos are not comparable as they do not have the same degree of acceleration. When comparing the noise emission of different degree, the noise emission is almost similar. Thus the acceleration does not seem to give rise to differences in noise emission level between the two cars. But when comparing to the noise levels for steady driving, figure 11, the noise level is seen to be much higher at low speeds when accelerating.

7.2 The Leaf and Golf

The noise levels form a Nissan Leaf and a VW Golf Variant with similar tires were measured in different driving conditions. The Leaf was emitting less noise for all speeds between 10 and 60 km/h under both driving condition, but the difference were getting smaller as the velocity went up. This could be explained by the fact that the tire/road noise is becoming more dominant the higher the speed. This can also be seen in the spectra, where there is a big difference between the Leaf and The Golf at low speed, while at higher speeds the spectra is getting more similar because of the dominance of the tire/road noise.

The measurements from acceleration of the Nissan Leaf and the Golf are not comparable at speeds below 30 m/s^2. Since the Golf was not passing the microphone at such speeds while accelerating. The measurements of the Golf going from 20 km/h towards 30km/h, 40 km/h, 50 km/h and 60 km/h are the ones lying higher than the rest between 30 km/h and 35 km/h. This is properly because of wrong choice of gearing. This might explain the peak in the spectra, for the set of measurements at almost the same speed but different degree of acceleration. The leaf has an almost 5 dB higher level of noise emission during acceleration than the Golf for speeds above 40 km/h. But the Leaf has much higher degree of acceleration than the Golf. When the degree of acceleration is compared the Golf is emitting about 2 dB more noise than the Leaf at the same degree of acceleration when the Golf is driven in the right gearing.

7.3 Energy Saver tyres versus standard tyres

The noise emissions of different tyres on different surfaces have been measured with the CPX method. The results of the Energy Saver tyres and the standard SRT Tyres have been shown in section 6.2. The results show that the emission difference is small for most of the noise reducing pavements but for the dense asphalt concrete AC 6d there is a huge difference.

As long as there is no demand on the use of Energy Saver tyre types, it would be a better noise reduction strategy to choose a SMA 6+11 which emits less than the AC 6d for both sets of tyres.

8 DISCUSSION ON NOISE MAPPING

The measurements of the EVs and the ICEs illustrates that there is a difference in noise levels at low speeds. The dominating noise is at high speeds, where the measurements show no benefit of EVs- An illustration of the effect of noise reduction at different constant speeds, by replacing part of the vehicle fleet to EVs, is illustrated in Figure 26. The reduction is calculated from energy averaged noise levels at different percentage EV's and ICEs, by means of the regression expressions in figure 4 and 5. The figure illustrates that there is a big potential reduction at 10 and 20 km/h, whereas the reduction at 30 km/h is very moderate. By changing 100 % of the fleet from ICEs to EVs is the reduction only at 0.6 dB at 30 km/h.

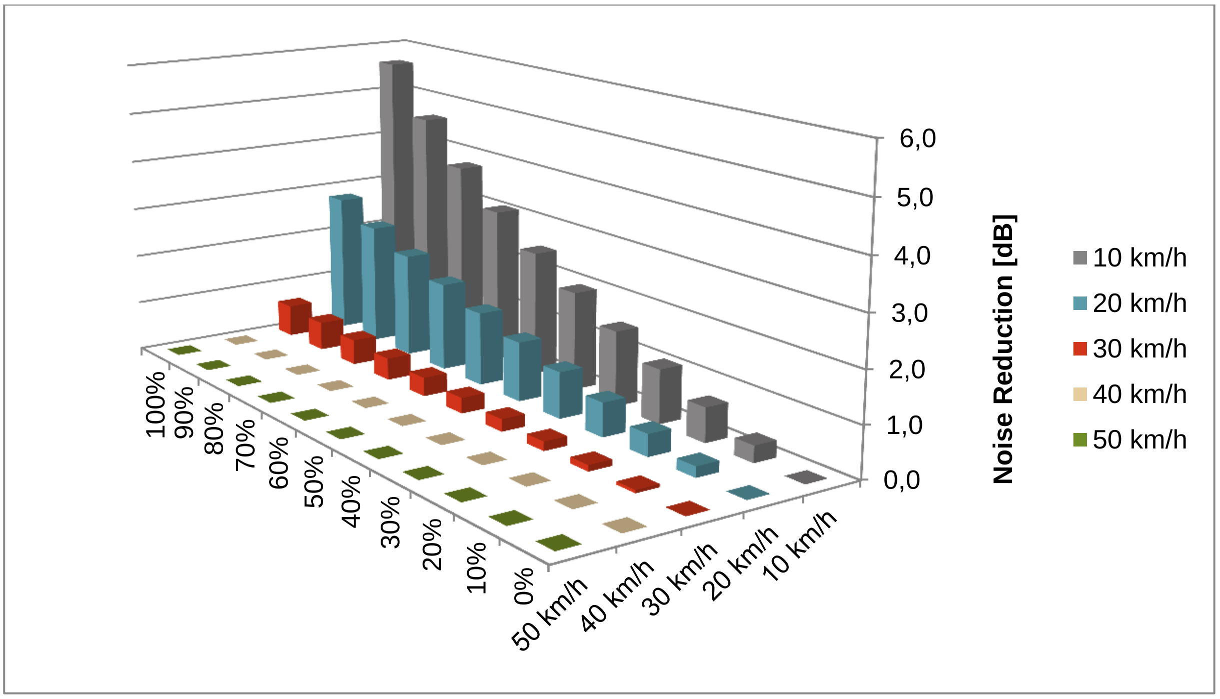

Figure 26: Noise reduction at different speeds by replacing percentages of the vehicle fleet.

The noise action plans made by authorities and municipalities are based on noise mapping. The noise mapping takes the traffic amount and the speed of traffic into account, whereby the major roads are the most dominating at the maps. Figure illustrates the road noise map of Copenhagen, where the motorways and access expressways are the most dominating. The focus of this project is traffic in the cities, are roads with speed limits higher than 60 km/h not taking into account. Figure 28 illustrates a closer up view of the south east part of the city. A motorway is present in the south part of the map, but several other roads are dominating due to speed limits at 60 km/h and a high amount of traffic. Figure illustrates an even closer up view, where residential roads are placed between collector roads. The figure illustrates that the noise at the residential roads, where the speed limit is 50 km/h, is within the lowest mapped interval 55-60 dB. Even though the noise mapping would be performed at speeds down to 30 km/h, would the reduction of 0.6 dB at 30 km/h not be visual at the noise maps.

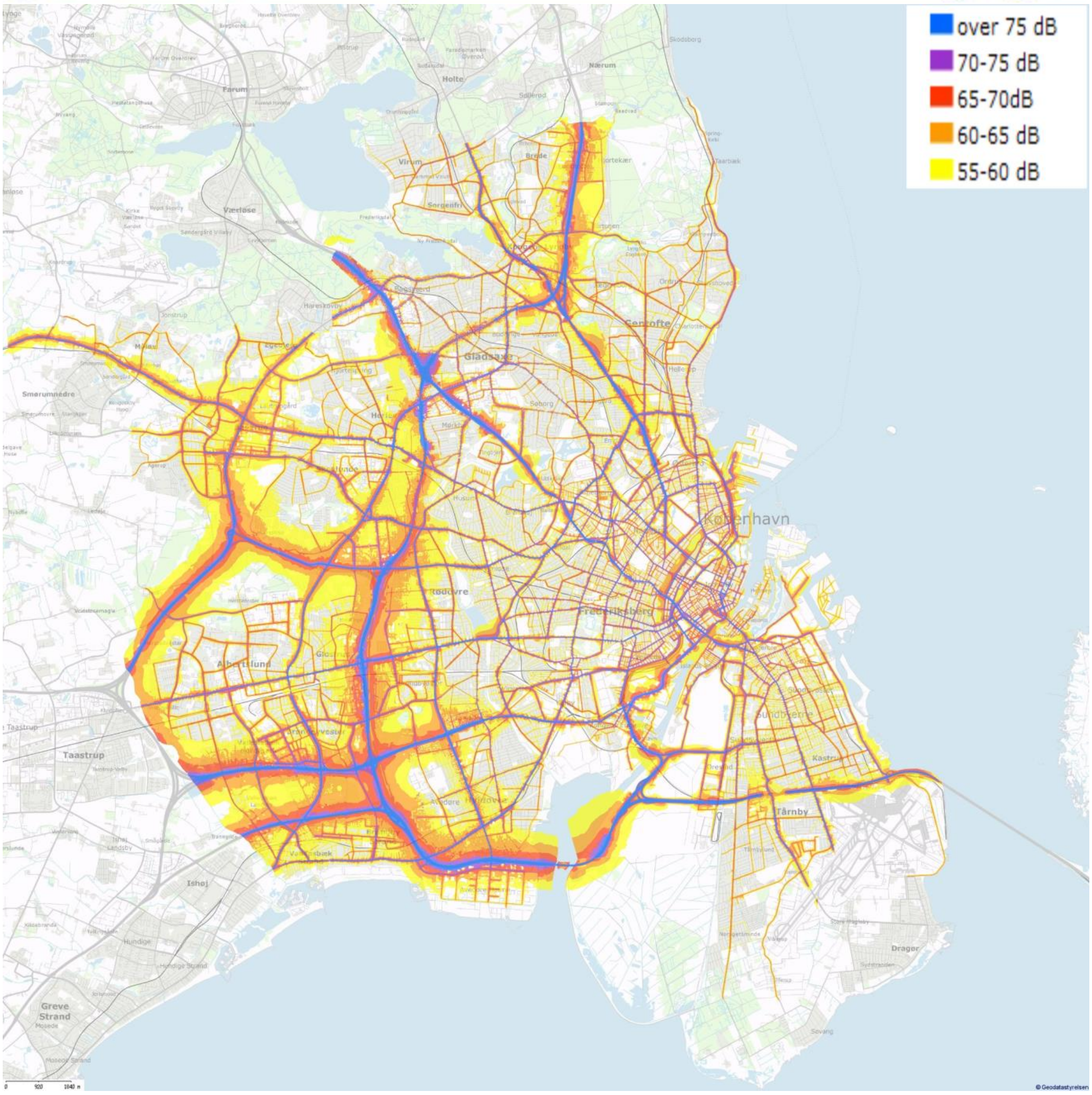

Figure 27: Noise map of entire Copenhagen. Source: Geodatastyrelsen

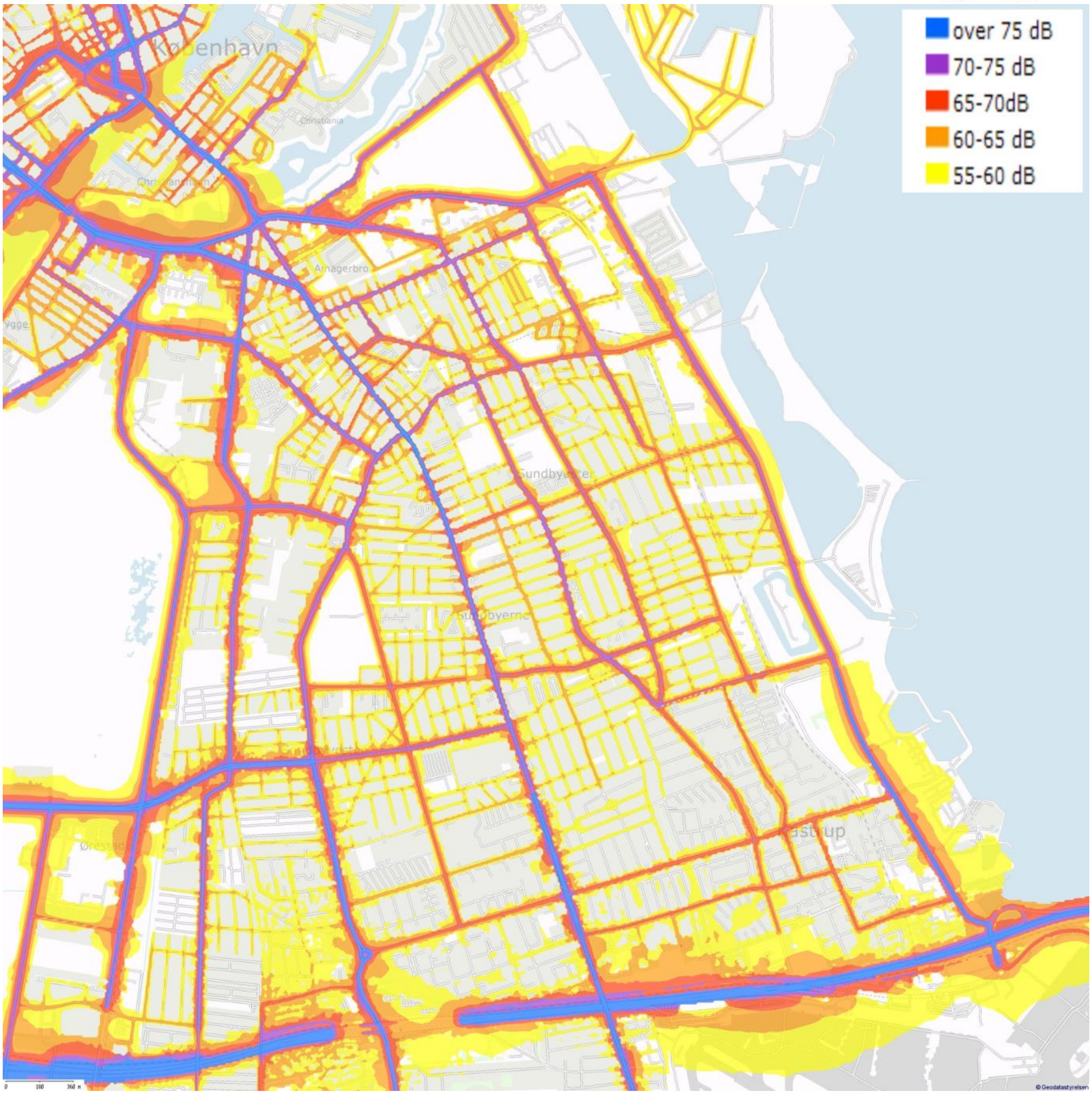

Figure 28: Noise map of part of Copenhagen with Motorway, residential areas and collector roads Source: Geodatastyrelsen

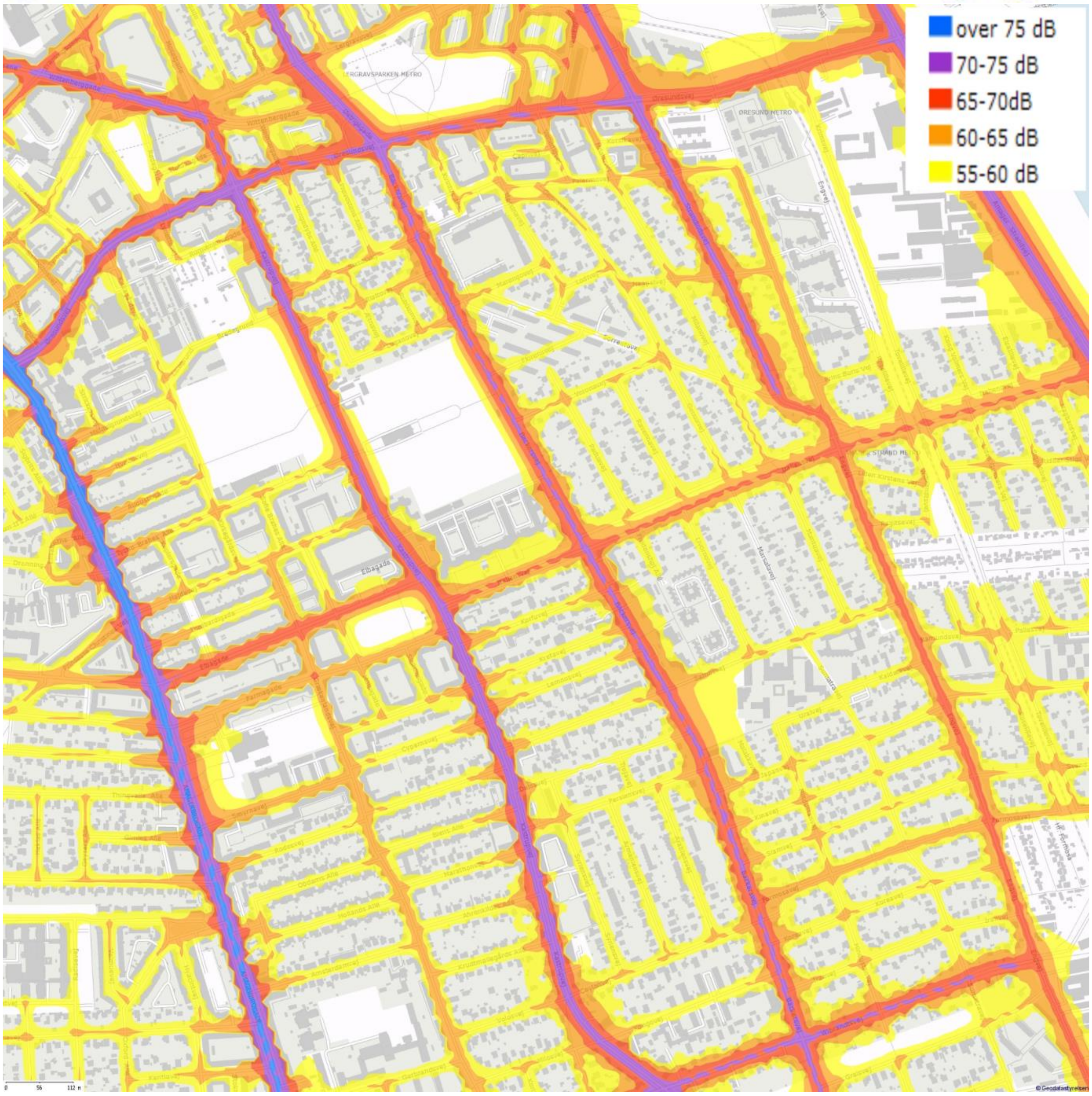

Figure 29: Noise map of part of Copenhagen with residential areas and collector roads. Source: Geodatastyrelsen

When the noise maps are performed is the sound level at different dwellings mapped, in order to see how many citizens are exposed to which levels. To make the noise action plans are the relation between transport noise and annoyance. For this relation are the Number of Highly Annoyed persons calculated, by means of the expression for percentage of highly annoyed (%HA) [5]. The expression is illustrated in Figure 30, and is illustrating the weighting of different noise levels as a function of the noise levels L_{den} where the citizens live. In the figure is the distribution of the annoyed dwellings in Copenhagen. The figure illustrates how the annoyance is weighted more the higher the exposure level is, whereas the distribution of exposure levels are opposite with the majority of exposed dwellings has lower levels.

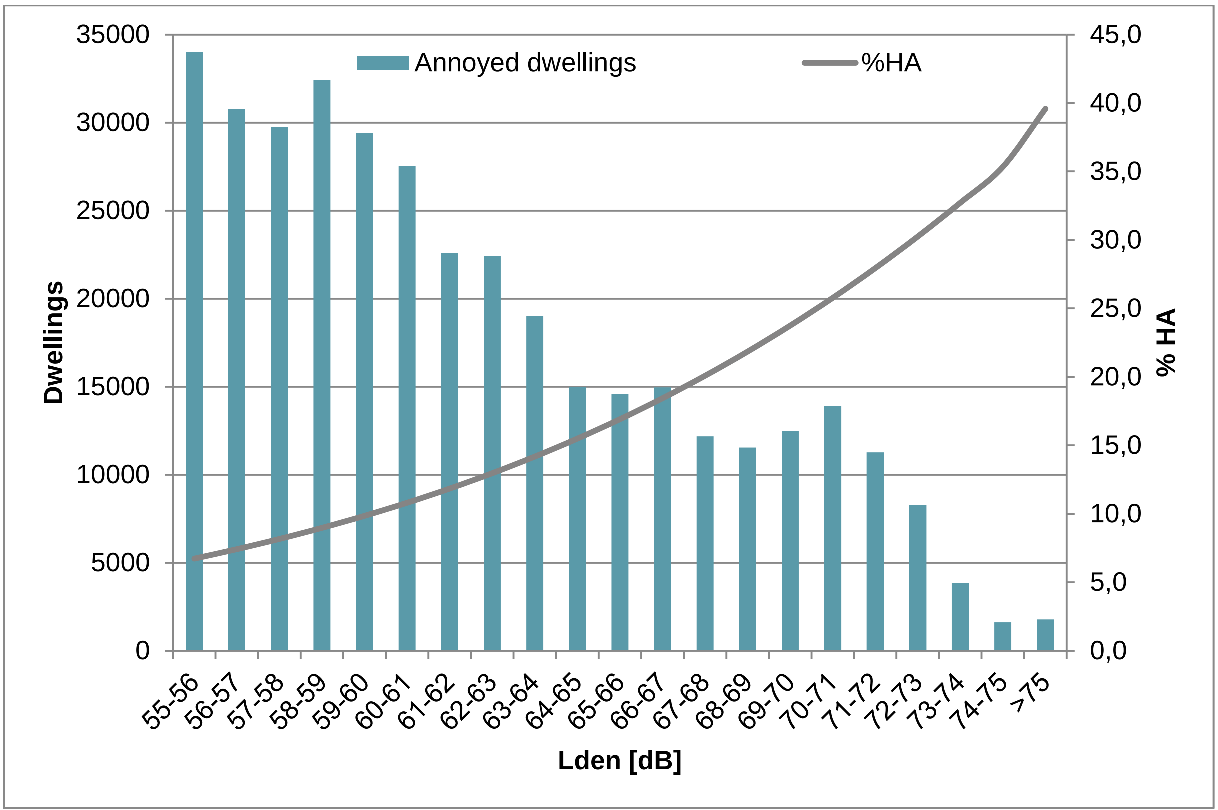

Figure 30: Illustration of the distribution of dwellings in Copenhagen at different noise levels, and the weighting curve of percentage of highly annoyed persons (%HA).

Figure 31 illustrates the number of highly annoyed persons as a function of the noise levels, which is a combination of the exposure of dwellings and the weighting by the percentage of highly annoyed persons. The figure clearly illustrates that the weighting of the higher noise levels dominates the number of highly annoyed persons in the city. As the benefit of the EVs are most significant at 10-20 km/h, will these not be visible at the noise mapping, and if the noise maps were performed down to such low levels, would they be weighted so little that they would not be a part of the noise action plans.

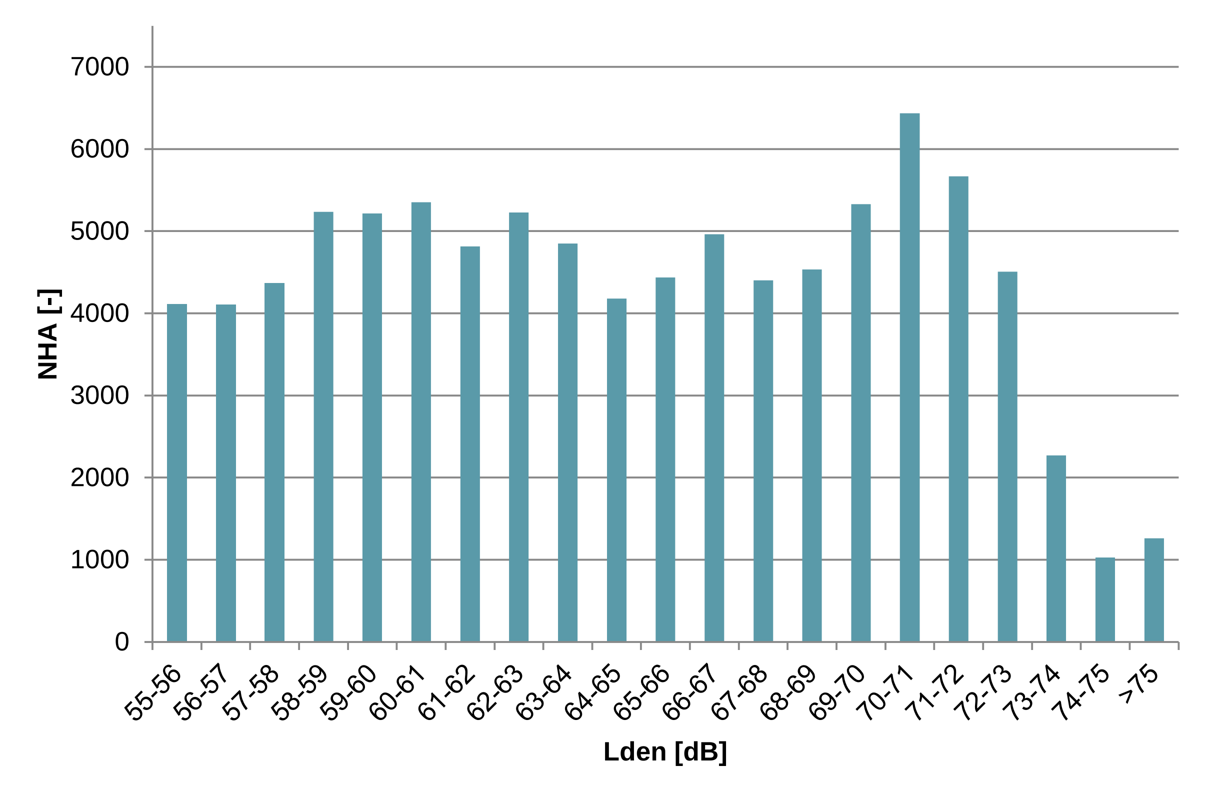

Figure 31: Distribution of number of highly annoyed persons in Copenhagen, at different exposure levels.

9 CONCLUSION

EV's are 4-5 dB less noisy than similar ICE at low speed when driving at steady speed. But at about 30 km/h the difference in emitted noise is not significant. For speeds higher than 30 km/h the tire/road noise gets dominant and from there on the choice of tire is more essential to noise reduction.

When decelerating by engine breaking the EV's are 2-4 dB less noisy than ICE's at low speed. At higher speed the difference decrease as the tire/road noise is getting dominant.

It can be concluded that EV's will reduce the traffic noise in carparks and on streets with low speed restriction where the velocity of the vehicle will be under 30 km/h. In urban areas where the speed it often above 30 km/h the introduction of EV's will not have a great influence on the traffic noise.

If speed restrictions under 30 km/h are introduced to lower the noise in recreational areas, then the introduction of EV's would make these areas even less noisy. But for some EV types there are narrow peaks in the spectra at low speed which are possible to hear, and could be described as annoying.

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