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# CEDR Transnational Road Research Programme Call 2012: Noise

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## FOREVER

# Final Technical Summary Report

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# CEDR Call2012: Noise FOREVER Future Operational impacts of Electric Vehicles on European Roads

## Final Technical Summary Report

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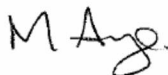
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## 1 Introduction and background

The Environmental Noise Directive (END), 2002/49/EC [1], aims to prevent/ reduce environmental noise from sources such as road traffic where necessary and preserve noise quality where it is good. For addressing road traffic noise, ways in which this might be achieved include the use of

- quieter vehicles, which emit lower levels of powertrain and/or tyre noise
- low-noise road surfaces,
- noise barriers
- Innovative 'smart' mitigation measures, which can either adapt to local conditions to control noise either directly or as a secondary function.

One option for quieter vehicles is the use of vehicles powered by electric motors, i.e. fully electric vehicles (EVs) or hybrid-electric vehicles (HEVs). Based on current national government strategies and public attitudes towards energy efficient and sustainable transport, the use of electric vehicles across Europe is increasing and is expected to continue to do so.

Much of the research to date has focused on the potential risks to vulnerable road users in low-speed environments, in relation to the perceived lack of noise from these vehicles, e.g. [2, 3, 4, 5, 6]. However, relatively little research has addressed the potential noise impacts on roads under the jurisdiction of National Road Authorities (NRAs), where speed limits are likely to be higher. As the percentage of national vehicle fleets comprised of electric/hybrid vehicles increases, National Road Authorities (NRAs) are keen to understand the potential impacts on their road networks.

## 2 Overview of the FOREVER project

The FOREVER (Future Operational impacts of Electric Vehicles on national European Roads) project was commissioned, as part of the CEDR Transnational Road Research Programme Call 2012 on Noise, to provide information to NRAs with respect to this issue.

The project was developed with three key objectives:

**To identify the noise emission levels from electric and hybrid vehicles.** This has been achieved through practical measurements of noise from electric and hybrid cars, vans and trucks. The information has been used to develop correction factors to allow such vehicles to be included within state-of-the-art noise prediction models and to investigate subjective responses to these vehicles when part of traffic on NRA roads.

**To identify the noise emission of tyres used on electric and hybrid vehicles.** This has been achieved through practical measurements of noise for different types of tyres, with the aim of identifying whether specific tyres are/can be used for electric vehicles.

**To assess the potential future noise impacts of electric and hybrid vehicles.** A state-of-the-art noise prediction model has been used, with data from the practical trials, to assess the noise impacts close to the road for a range of different road type/traffic speed/traffic composition scenarios.

## 2.1 The FOREVER project consortium

The FOREVER project has been carried out by a consortium with longstanding and wide ranging expertise in road traffic noise, vehicle noise measurement and prediction, and subjective assessment. The consortium members were:



## 3 Noise emission levels from electric and hybrid vehicles

This work was undertaken within Work Package 2 of the project and is reported in full in [7]. It was entirely focused on external noise and intended on one hand to assess the noise emission from electric and hybrid vehicles from a physics perspective, considering in particular propulsion noise, and on the other hand to study the noise impacts of electric vehicles from the perspective of human listeners through a series of subjective participant trials. In the first approach, light<sup>1</sup> and medium heavy<sup>2</sup> vehicles were investigated.

The work sought to:

- determine the noise levels emitted by electric and hybrid vehicles under a range of operating conditions,
- develop correction factors to allow electric and hybrid vehicles to be taken into account with state-of-the-art noise prediction models, and
- investigate the subjective response to electric and hybrid vehicles when operating within traffic on NRA roads

### 3.1 Results on the noise emission levels from electric and hybrid electric vehicles

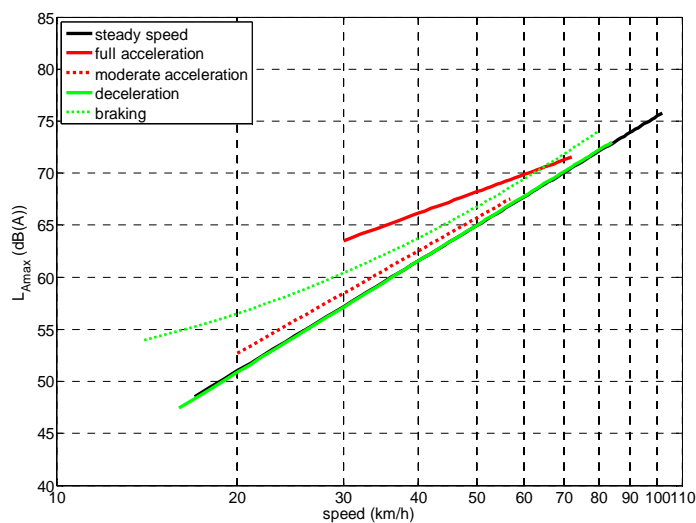
Experimental tests were undertaken by IFSTTAR, with the measurement of the noise emission of a small electric car, a larger hybrid car and an electric truck at pass-by, involving microphones at the standard position (distance 7.5 m) and a microphone array. The results showed that:

<sup>1</sup> Vehicles with a gross vehicle weight  $\leq 3.5$  t.

<sup>2</sup> Vehicles with two axles and a gross vehicle weight larger than 3.5 t.

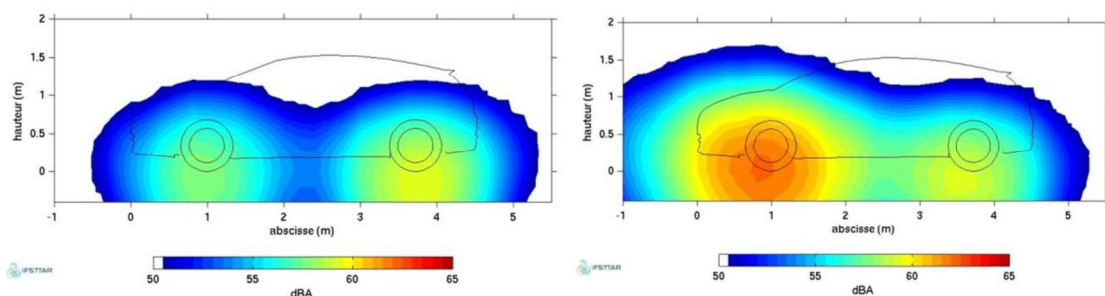


- The electric and hybrid electric vehicles generally use either a direct transmission or an automated gearbox and the transmission cannot be disengaged. The propulsion noise component and the rolling noise component cannot be separated from common pass-by noise measurement without complementary information. The use of indoor test condition and/or simultaneous on-board instrumentation might help to focus on the propulsion noise component.
- At steady speed the global A-weighted noise pressure level at vehicle pass-by increased linearly with  $\log(\text{speed})$ , for all vehicles tested in all-electric mode. The middle frequency bands were dominating over most of the speed range. Deceleration (without braking) did not change much the emitted noise if the deceleration rate was moderate, but the noise was observed to increase significantly if the energy recovery was strong, with or without braking ([Figure 3.1](#)).



**Figure 3.1: Comparison of the global A-weighted maximum sound pressure level emitted by a small electric passenger car in all operating conditions, at 7.5 m from the track centre, on a dense asphalt concrete 0/10 road surface**

- At steady speed with the hybrid passenger car, global noise emission differences between the electric and the hybrid mode occurred up to 40 km/h ([Figure 3.2](#)). There was no difference over 40 km/h. The noise level in braking situation was similar to moderate acceleration.



**Figure 3.2: Noise maps of the hybrid car at steady speed 23 km/h in electric mode (*left*) and in hybrid mode (*right*) – Global sound pressure levels in dB(A) at the reference distance 2.7 m from the vehicle side**

In order to set out an appraisal on the noise emission of electric and hybrid electric vehicles, appropriate data available by the project partners were collected. Only measures at steady speed providing noise levels at 7.5 m from the track centre were considered. They were compared with the sound emission model provided in CNOSSOS-EU. The results are indicative, due to the limited number of vehicles available in the data collection. They showed that:

- Concerning light vehicles in electric mode: the global noise emitted by all vehicles followed a linear trend with  $\log(\text{speed})$ . The difference between the quietest and the noisiest vehicle was 4.5 dB(A) at any speed of the range 20-50 km/h. The noise increase was not linear in some frequency bands. In its present form, CNOSSOS-EU overestimates propulsion noise emission from light electric vehicles in all octave bands and, consequently, in global levels. A corrected version for EVs is required if a prediction of the noise impact from a traffic flow including EVs is needed.
- Concerning light vehicles in hybrid mode, the noise emitted by the few hybrid vehicles in the data collection exhibits a quite similar behaviour.
- Concerning the medium heavy vehicles, the analysis concerned few vehicles, evaluated on one test site. For the vehicles in all-electric mode, large noise level differences were noticed between vehicles of dissimilar gross vehicle weight and tyre size. For the vehicles in hybrid mode, the type of hybridization might be a key parameter for the powertrain noise contribution.

An adaptation of CNOSSOS-EU has been proposed for light EVs and HEVs. *Since the number of vehicles available in the analysis was limited, the results given in the report should be taken as indicative but values provided represent a first step towards the specification of electric vehicles in CNOSSOS-EU. Confirmation by complementary studies is necessary.*

The specifications for a corrected version of CNOSSOS-EU for light electric vehicles are:

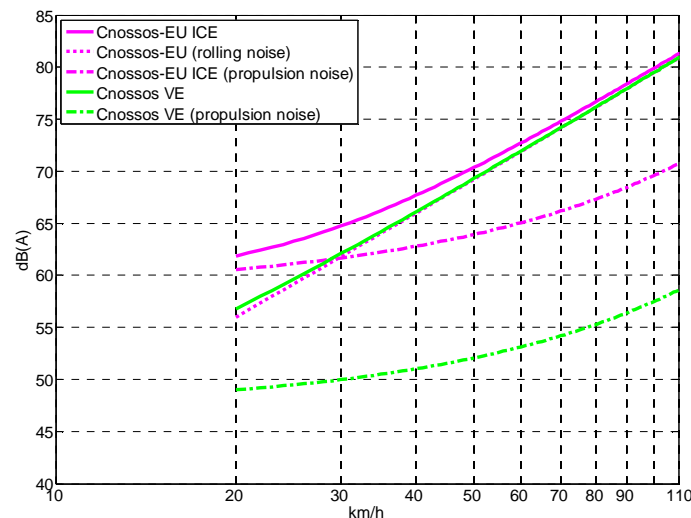
- The approach is based on constant correction terms to be applied on the propulsion noise component given in CNOSSOS-EU for ICE cars, as long as another equation, physically consistent with the actual propulsion noise from electric vehicles, has not been determined.
- The values of these correction terms were determined and are given in each octave band from 125 Hz to 4000 Hz ([Table 3.1](#)).
- Conclusions on rolling noise were drawn and are reported in WP3 of FOREVER [8].
- In global levels ([Figure 3.3](#)), the weight of the propulsion noise component in the total noise from EVs remains small (if not negligible) in the total noise, which is not systematically true in some octave bands.

For light hybrid vehicles operating in hybrid mode, no correction is necessary and CNOSSOS-EU specifications are recommended. When operated in electric mode, hybrid vehicles behave like full-electric vehicles.

**Table 3.1: Correction coefficients  $\Delta L_{WP, EV, i}$  for the propulsion noise component, to be applied to CNOSSOS-EU propulsion noise component for the light vehicles in all-electric mode**

octave	125Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Correction coefficient	-1.7 dB(A)	-4.2 dB(A)	-15 dB(A)	-15 dB(A)	-15 dB(A)	-13.8 dB(A)

Remark: the correction coefficients have been arbitrarily limited to -15 dB(A).



**Figure 3.3: Comparison of CNOSSOS-EU (for light ICE vehicles) and CNOSSOS-EV (for light electric vehicles) in global levels**

Concerning CNOSSOS-EU for medium heavy ICE vehicles, the characteristics of the prediction model raises questions, about the balance granted to propulsion noise over the whole speed range relatively to rolling noise. In addition, test results available by partners with ICE vehicles are not consistent with this prediction, as well as other results published in the literature. Further investigation is needed on ICE prior to considering the relevance of a correction to CNOSSOS-EU for electric and hybrid vehicles in this category.

### 3.2 Results from perception studies

The work conducted by Trinity College Dublin has demonstrated the potential for industry standard pass-by data to generate realistic auralizations of road traffic environments with various vehicle mixes. This is useful tool for many stakeholders wishing to judge community responses to a change in the road traffic make up. Auralizations are inherently easier to understand and communicate than dB levels as the audience can experience for themselves the acoustic environment beside a national route way. The University of Bath have demonstrated that these auralizations can be used effectively to measure a change in the perception of human listeners to the noise.

The results of the participant study showed that traffic noise was rated more favourably when there were 100% EVs rather than the current situation of 100% conventional vehicles. This is

an interesting finding, as it suggests that a move to a higher proportion of EVs on national roads is likely to improve, rather than impair, the experience of people living and working nearby. The participant study also showed that the preference for 100% EV mixes seems to be caused by information in the 500-2000 Hz frequency band. This suggests that it is the change in tonal content, rather than overall level, which is driving the improved subjective response to the noise. This is significant since the frequency content, in particular engine tones, is not currently considered in vehicle noise assessment.

## 4 Noise emission from tyres on electric and hybrid vehicles

This work was undertaken within Work Package 3 of the project and is reported in full in [8].

The FOREVER project studies the effect of electric and hybrid vehicles on the noise produced on national roads. While the previous work package focuses on the overall noise produced by the electric and hybrid vehicles, including powertrain noise, Work Package 3 focused on the rolling noise, which is the noise produced by the interaction of the tyres on the road-surface. Tyres for electric and hybrid vehicles have been taken into consideration, with a particular focus on low-noise tyres. Following a market study, a set of tyres has been selected and then used to perform controlled pass-by measurements (CPB) with a selected vehicle. The measurements results have been analysed in detail and their relation with the CNOSSOS-EU model has been established.

As a first step, the tyres present in the market have been analysed (Task 3.1). At the point of the study, very few tyres specifically produced for electrical vehicles were available on the market. This is due mainly to the fact that tyres are often produced for electric and hybrid vehicles, as purely electric vehicles are rarer than hybrid.

Additionally, as energetic and safety considerations are the main goals not only for electric vehicle tyres, but also for tyres in general, a real distinction rarely makes sense. What can be normally found is a tyre that is explicitly developed for one particular electric vehicle. In the case where the electric vehicle is a small, one mainly meant for urban routes, the tyre can dare to use unconventional dimensions, such as narrower width and larger diameter. But for medium and larger sized vehicles considerations on the FOREVER deals specifically with non-urban roads and as such takes in consideration vehicles that are more apt for long distances and higher speeds.

A tyre selection has been performed in order to represent the current market of tyres for electric and hybrid vehicles. As shown by the literature study carried out within task 3.1, the selection of tyres for electric vehicles by car and tyre manufacturers is currently driven by fuel efficiency requirements, relying on the rolling resistance performance of the tyre. No relation is currently present between rolling resistance and rolling noise. There is currently no evidence of a trend between the rolling resistance performance and the EU rolling noise labels. The study has chosen a set of tyres as a good candidate for the future market of electric and hybrid vehicles. This set has been chosen based on a low energy (low resistance) and a good safety, low-noise behaviour, according to the label values.

Based on the market analyses eight of these tyres have been selected and used, together with a chosen vehicle (Renault Fluence ZE) and a chosen track, to perform the controlled pass-by measurements (Task 3.2). Additionally to the eight tyres selected after the market analysis, one more dedicated tyre has been added afterward, the Michelin Energy E-V. This tyre is particularly interesting because it has been exclusively produced for electric vehicles, specifically for the Renault ZOE, which was the vehicle used during the additional

measurement campaign. [Table 4.1](#) shows the set of tyres chosen for the measurements, where the EU label is in the format Rolling Resistance / Wet Grip / Noise Emission.

**Table 4.1: Set of tyres chosen for the measurements. The EU label is in the format Rolling Resistance / Wet Grip / Noise Emission.**

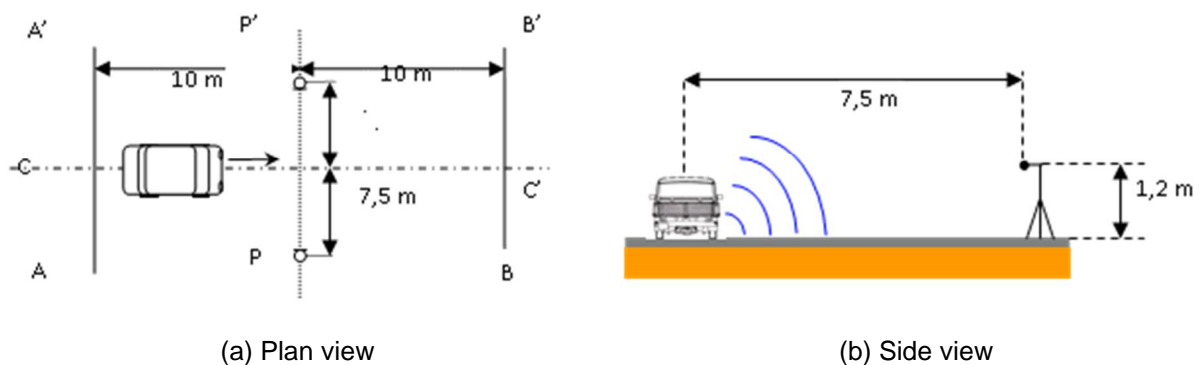
Short form	Brand	Model	Dimensions		EU Label
A	Dunlop	Sport BluResponse	205/55	R16 91H	B/A/68
B	Goodyear	Efficient Grip	205/55	R16 91H	C/C/68
C	Kumho	Ecowing ES 01 KH27	205/55	R16 91V	B/B/67
D	Pirelli	Cinturato P1 Verde	205/55	R16 91H	B/B/70
E	Toyo	NANOENERGY 2	205/55	R16 91V	A/C/70
F	Bridgestone	Ecopia EP150	205/55	R16 91H	B/B/69
G	Michelin	ENERGY SAVER	205/55	R16 91W	B/A/70
H	Hankook	Kinergy Eco K425	205/55	R16 91H	B/B/70
I	Michelin	ENERGY E-V	195/55	R16 91Q	A/A/70

Tyre-road noise produced by an electric vehicle has been analysed by controlled pass-by measurements (CPB). The measurement set-up is as close as possible to common standards on vehicle noise (ISO 11819-1, 2002), (UN Reg. 117, 2014).

Measurements were taken between summer and fall 2013. The method used was based on the determination of the maximum A-weighted sound pressure level ( $L_{AFmax}$ ) during the run of a test vehicle at steady speed on asphalt pavement, where

$$L_{AFmax} = 10 \log_{10} \left( \frac{p_{AFmax}^2}{p_0^2} \right) \text{ in dB(A)} \quad (1)$$

[Figure 4.1](#) shows the measurement set-up. Four test tyres have to be mounted on the vehicle that rides from C to C' on the test pavement. The microphone is at point P and is positioned 7.5 m far away from the line C-C', its height is 1.2 m from the ground. The measurements have been analysed with a 3 dB signal-to-noise ratio criterion.



**Figure 4.1: WP3 measurement set-up**

Figure 4.2 on the following page shows the maximum pass-by levels ( $L_{AFmax}$ ) for all examined tyres after performing a logarithmic regression.

Figure 4.3 shows the EU noise labels of the 8 tyres fitted to the Fluence and the specific tyre fitted to the ZOE, listed in Table 4.1, compared with the noise levels measured on the AC11 road surface, calculated from the regression equations at the reference speed 80 km/h.

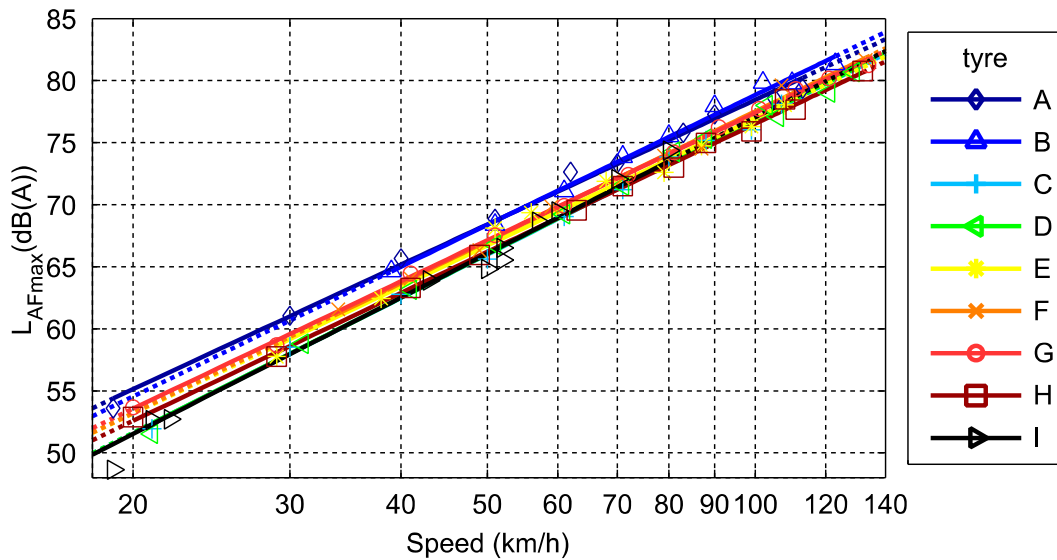


Figure 4.2: Maximum pass-by level for different tyres, the symbols mark the individual measurements used for the regression, dotted lines are extrapolated.

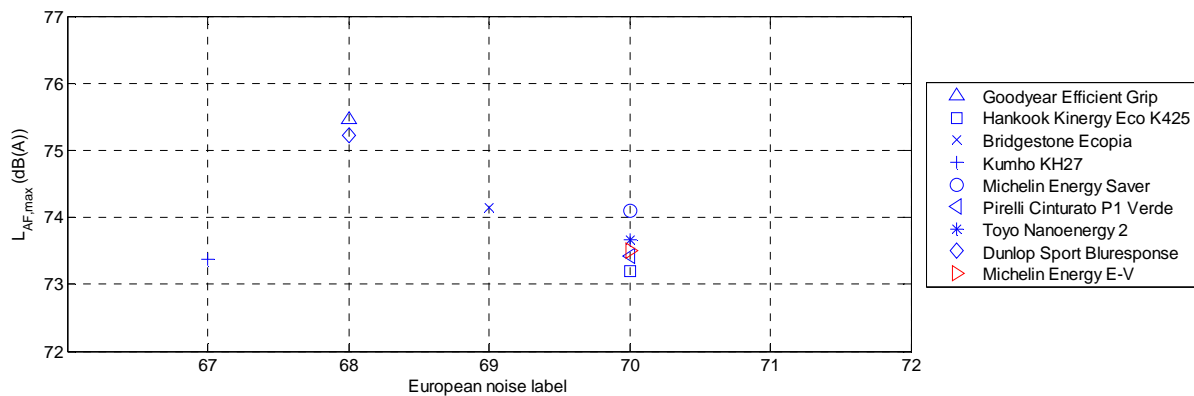


Figure 4.3: Noise levels measured at 80 km/h on AC11 compared with the EU noise labels, for the 8 tyre types fitted to the Fluence (blue) and 1 tyre fitted to the ZOE (red)

The noise measurements at 80 km/h are spread on a reduced noise scale in relation to the EU labels: the tyre labels range over 4 label values from 67 to 70 dB(A)) while the measured noise levels are contained within an interval width of approx. 2 dB(A). Furthermore, it turns out that the EU labels do not properly render the tyre ranking given by the noise measurement on the AC11 surface: the tyre with the lowest label and those with the highest

labels yield similar noise levels, whereas the largest noise levels are due to tyres with an intermediate label.

The lack of a common trend can be noticed between noise labels and the actual noise levels. A possible cause is that the ISO surface used for the EU noise label is a smooth surface, which doesn't excite many vibrations on a tyre.

Investigations carried out on the basis of the noise measurements with the nine tyres selected in Task 3.2, including one tyre (tyre I) exclusively designed by the car manufacturers for their EVs, with regard to the corresponding EU-labels showed that:

- There is no relationship between a tyre ranking relying on the exterior noise EU-label and the noise actually measured on the test road surface, which is representative of commonly used surfaces.
- There is no evidence of a trend between the rolling resistance performance and the rolling noise measured on actual road surfaces.
- Any tyre selection relying on a low-noise requirement based on EU noise labels would most likely have no clear effect on the rolling noise measured on actual road surfaces.
- The few tyres selected by car manufacturers to be fitted on their electric vehicles did not acoustically behave differently from conventional tyres.

Considering these findings together with the measurements from WP2 with several cars and those available from WP3 with various tyres, it is inferred that, from the present perspective, no correction for EVs is required for the rolling noise component given in CNOSSOS-EU.

To sum up, it is recommended for the model CNOSSOS-EV (standing for an EV extension of standard CNOSSOS-EU)

- to exclude the octaves 63 and 8000 Hz from the model specifications due to the lack of reliable information (in accordance with the CNOSSOS-EU validity domain for the other vehicles),
- to apply the correction terms of the propulsion noise already proposed in WP2, and
- to use 'as is' the rolling noise component given by CNOSSOS-EU for conventional vehicles.

Due to the still limited amount of data available for assessing the proposed model, further investigation is required and any laboratory or organisation having appropriate data is welcome to compare its own measures with this CNOSSOS-EV model in order to further the model validation.

Based on these conclusions from the WP3 investigations, then the following are considered to be the key outcomes:

1. Tyres designed or selected by manufacturers for EVs have no effect on global rolling noise compared to conventional tyres. A wider set of EV specific tyres is required to conclude on frequency differences possibly impacting the roadside traffic noise.

2. On the basis of current knowledge, it turns out that rolling noise from light electric vehicles does not differ from conventional vehicles. Thus, for predictions of traffic noise according to the European assessment method, the use of the rolling noise component given in CNOSSOS-EU remains available without amendment for light electric vehicles. Only the propulsion noise component requires correction terms, as proposed in the final report of Work Package 2 of the FOREVER project.

## 5 Potential future noise impacts of electric and hybrid vehicles

This work was undertaken within Work Package 4 of the project and is reported in full in [9].

Relatively little research has, to date, addressed the potential noise impacts on roads under the jurisdiction of National Road Authorities (NRAs), where speed limits are most likely to be of the order of 80 km/h or greater. On these roads, rolling noise will be the dominant noise source from road traffic when traffic is free-flowing. However, in congested, slow-moving traffic, the differences in propulsion noise for electric and hybrid vehicles will be more significant.

The FOREVER investigations sought to

- provide information on current and predicted future numbers of electric and hybrid vehicles within national vehicle fleets; and
- to assess, using a state of the art noise model CNOSSOS-EU and the correction factors developed elsewhere in the project, the likely noise impacts close to the road for a range of different road type/traffic speed/traffic composition scenarios that would be relevant to NRAs.

The main part of the work package makes use of the information gathered in the rest of the project to model roadside traffic noise levels for a number of different scenarios designed to highlight the noise impact of an uptake of electric vehicles. The model uses the CNOSSOS-EU source noise algorithm and makes use of the corrections to the propulsion noise component for EVs derived in WP2 and the recommendations with respect to the rolling noise component made in WP3.

An original aim for the modelling was to use the fleet compositions from the literature review but subsequently this has been deemed unnecessary since it is not representative of actual traffic. This is because the composition of the fleet does not reflect either vehicle kilometres travelled for each vehicle type or individual roads which, for example, may have a high percentage of EVs in urban areas and a low percentage of EVs in rural areas.

The final part of WP4 investigated the frequency content of ICEs and EVs in the context of the CNOSSOS-EU model and the results of the participant study undertaken in WP2 to see if existing noise annoyance metrics, developed for similar noise problems, can be used to develop a beneficial level correction factor which could be applied when modelling EV traffic mixes.



## 5.1 Fleet Review

Despite new passenger car registrations falling from 2007 to 2012 light-duty vehicle stock is still expected to rise by over 30% by 2030. The recent decline in new vehicle registrations mirrors somewhat the economic conditions of countries in Europe, as such southern Europe has seen more of a pronounced decline in sales, a decline of 60% in Spain and 45% in Italy since 2007. It remains the case that three quarters of all new registrations come from the top five countries – Germany, France, United Kingdom, Italy and Spain.

The vast majority of new cars remain powered by petrol or diesel engines with hybrid and electric cars accounting for around 1% of new registrations, lagging behind both the US and Japan. This area of the market is however both expanding and diversifying; in 2001 only two hybrid models were available in Europe selling around 2,000 cars whereas by 2012 this had risen to over 30 models accounting for around 130,000 sales.

Overall EV uptake is expected to increase slowly but steadily over the next few years and not see significant market penetration until around 2030. Overall figures for Europe are commensurate with the expected worldwide market share of 5 to 10% in 2030.

## 5.2 Modelling Impacts

In order to provide an overview of the potential impact of electric vehicles on the traffic noise environment it is important to have a clear understanding of the key parameters determining traffic noise and how these interact, how they will change in the future and which can be clearly accounted for given available data and modelling restrictions.

The approach adopted in this work package focuses on determining appropriate parameters for the calculation of roadside noise levels and the isolation of the impact of electric cars from other road infrastructure changes. Given the wide variation in traffic noise environment between different road types in different member states absolute noise levels pertaining to specific locations are not the focus of the calculations. The emphasis is instead on providing an understanding of the extent to which traffic noise would be altered if a significant proportion of cars were to be electric vehicles and how this relates to potential changes to traffic noise from other alterations to the associated environment and infrastructure.

Modelling is carried out using CNOSSOS-EU, including the correction factors derived in WP2<sup>3</sup>, to provide octave levels for the rolling and propulsion noise components of all vehicles in the traffic stream. These levels are then combined to provide indicative changes to  $L_{Aeq,1h}$  roadside noise levels.

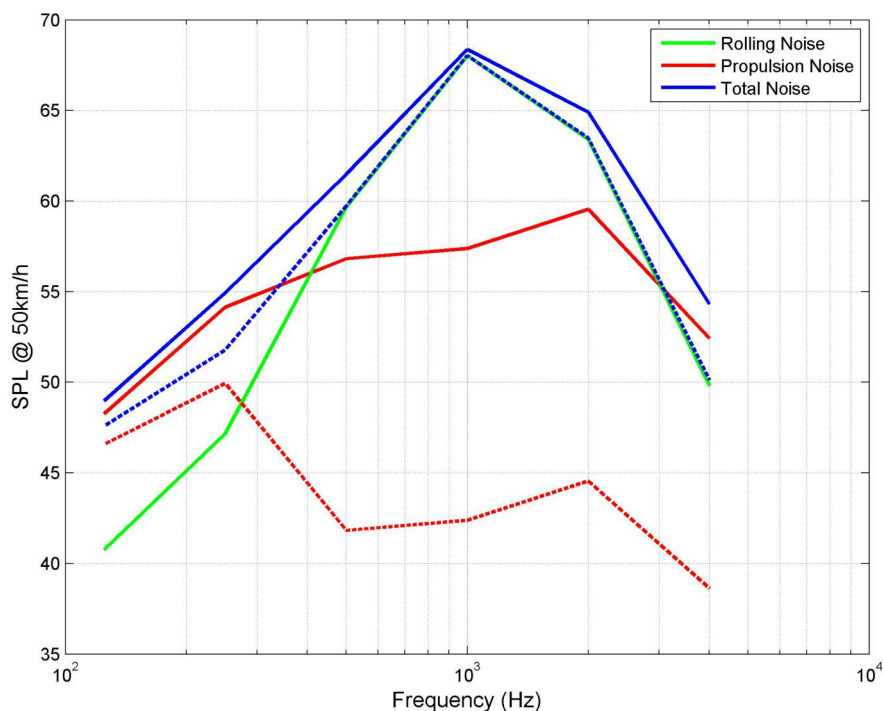
Baseline scenarios are each compared to alternative scenarios under which varying proportions of the cars on the road are fully electric (or hybrid cars in fully electric mode). Given the aim of providing top level boundaries to changes in traffic noise rather than focussing on the very minimal changes which may arise from small variations in the fleet, traffic streams with 10, 50 and 100% of cars running in electric mode are considered.

<sup>3</sup> Only electric cars are considered in the modelling. Electric trucks are not considered since (a) further measurement programmes are required before robust correction factors can be determined (b) they constitute such small fraction of the fleet as to have negligible impact at present and (c) data on the future uptake of electric power within the HGV fleet are very difficult to come by.

The use of studded tyres is not modelled but their inclusion would increase the rolling noise component slightly thereby reducing the beneficial impact of the introduction of electric vehicles. Therefore when interpreting the results the changes in traffic noise may be considered as slight over-estimates in the case where studded tyres are being used.

Whilst there are a number of complex and interdependent parameters which fit into the calculations of traffic noise in the various scenarios the difference in traffic noise introduced through the use of electric vehicles is reflected purely through the difference in noise level of an ICE and electric car. This difference is shown across the octave bands of CNOSSOS-EU, for rolling, propulsion and total noise components on a minor road under current conditions, in [Figure 5.1](#). In the figure the solid lines represent the noise components of the ICE car and the dashed lines the corresponding noise components of the electric car. A dashed green line is not visible since the rolling noise component remains unchanged.

It is clear that the large differences in propulsion noise between the two vehicles translate to relatively small differences in total noise given the domination of the rolling noise component which remains unchanged. The overall difference in noise level in this case is 0.9 dB(A) which is, as expected, close to the 1 dB(A) difference listed in Table 10 of the WP2 report.



**Figure 5.1: Octave band noise from ICE and electric car – current**

Once the reductions in noise level, shown in [Figure 5.1](#), are diluted through the other modelling parameters such as the presence of HGVs in the traffic stream, higher traffic speeds and fractions of the cars being fully electric overall reductions in  $L_{Aeq,1h}$  for traffic noise are relatively small. The immediate noise benefits of switching to electric cars are around 0.1-0.5 dB and even the associated future benefits, in absolute terms, are not expected to be more than 0.5-1 dB.

Overall the traffic noise in a typical agglomeration in a few years' time with around 10% of cars being battery powered is expected to be around 0.1 dB quieter than it would be if there were no electric cars on the road. However the perception of the traffic noise may nevertheless have altered and this is discussed below.

### **5.3 Modelling changes in perception**

As technology and our understanding of the human response to noise have advanced new annoyance metrics designed to predict the human response to noise have been developed. Some noise problems have required the application of more advanced noise metrics which take into account the various features of the noise source; for example the problem of aircraft noise has seen the adoption of measures such as EPNL (Effective Perceived Noise Level) to take account of the distinctive nature of the noise event. Measures such as this are necessary due to the fact that the human response to noise exposure is more complex than can be predicted by level alone.

The suitability of these existing annoyance metrics to detect the difference in noisiness and annoyance associated with the ICE and EV pass-by tests has been examined. The improved subjective response of the human participants to increased EV traffic mixes is likely due to a combination of reduced level and reduced tonal content. The results of the WP2 participant study demonstrated the importance of frequencies between 500-2000Hz in improving the subjective response.

The methods used are easily applied to time histories of vehicle pass-by tests. It is possible that level correction factors, which take account of noise annoyance, could be developed to reflect the likely improved experience of electric vehicle noise exposure.

### **5.4 Work package conclusions**

This work package has looked at the potential impact on actual and perceived environmental noise from the increased use of electric cars. The work has been restricted to a direct comparison with ICE vehicles, as opposed to considering the knock-on impacts of electric car ownership on traffic noise. Such indirect impacts could include the potential for a change in driving habits (such as a reduction in vehicle mileage) or a potential redistribution of the fleet composition (such as a move towards smaller cars) arising from the increased uptake of EVs.

From this direct comparison electric cars are no more than 1-1.5 dB quieter, at speeds over 40 km/h, than their ICE counterparts and the resultant change in traffic noise is expected to be lower still since not all vehicles will be electrically powered. Future changes in traffic noise are more likely to arise from advances in traffic management and engine, tyre and pavement technology and some of these factors are considered in the CEDR funded project DISTANCE.

Despite this minor change in overall level it has been illustrated that the elimination of certain tones through the use of electric vehicles could improve the subjective response to transport noise. This has been demonstrated in the participant study of WP2 and has been classified here in terms of existing annoyance metrics. It is suggested that beneficial level correction factors could potentially be applied to EVs in CNOSSOS in order to reflect the elimination of engine tones.

## 6 Conclusions and recommendations

This work undertaken within the FOREVER project has provided a robust insight into how electric and hybrid vehicles are likely to affect noise levels and public perception on NRA roads. The following are the key conclusions from the project:

- Based on a limited sample set of electric vehicles, practical measurements have shown that for light vehicles operating in electric mode, the global noise emitted by all vehicles followed a linear trend with  $\log(\text{speed})$ . The harmonized EU road traffic noise model CNOSSOS-EU was found to overestimate the propulsion noise for such vehicles, so that a correction was required to allow electric vehicles to be included within a traffic flow. Indicative correction terms have therefore been developed for this purpose. No such correction terms were developed for medium heavy vehicles as there were concerns as to the accuracy of the CNOSSOS model when modelled levels and measured levels were compared.
- Further practical investigations have been undertaken to examine the impact of tyre-noise on electric vehicles. Measurements using a selection of test tyres, including tyres designed for or selected by manufacturers for use on electric vehicles have identified that such tyres have no effect on global rolling noise compared to conventional tyres. However, tests on a wider set of EV specific tyres are required to draw conclusions on differences in spectral levels that might affect roadside levels. Based on these results CNOSSOS-EU can use existing rolling noise terms for the modelling of electric vehicles.
- Work undertaken to use auralizations of road traffic noise to investigate subjective responses to traffic containing different percentages of electric vehicles found that traffic noise was rated more favourably when there were 100% electric vehicles rather than 100% conventional vehicles. The participant study also showed that the preference for 100% EV mixes seems to be caused by information in the 500-2000 Hz frequency band. This suggests that it is the change in tonal content, rather than overall level, which is driving the improved subjective response to the noise.
- Modelling work looking at the potential impact on actual noise levels at the roadside as a result of the increase use of electric cars found electric cars (and hybrid cars operating in electric mode) to be no more than 1-1.5 dB quieter, at speeds over 40 km/h, than their ICE counterparts and that the resultant change in traffic noise on public roads was found to be lower still since not all of the vehicles in the traffic stream will be electrically powered. Future changes in traffic noise are more likely to arise from advances in traffic management and engine, tyre and pavement technology and some of these factors are considered in the CEDR funded project DISTANCE.
- Despite this minor change in overall level it has been illustrated that the elimination of certain tones through the use of electric vehicles could improve the subjective response to transport noise. This has been demonstrated in the participant study of WP2 and has been classified here in terms of existing annoyance metrics.

The key recommendations from the project can be summarised as follows:

- Existing noise annoyance metrics, such as EPNL (Effective Perceived Noise Level), could be utilised to quantify differences in electric and non-electric vehicle noise which are not reflected in the overall noise level
- Since the number of vehicles available in the development of the CNOSSOS-EU corrections for electric vehicles was limited, the results given in the report should be taken as indicative, providing only a first step towards the specification of electric vehicles in CNOSSOS-EU. Confirmation of the correction terms by complementary studies on a wider range of vehicles are strongly recommended if there is a strong desire by NRAs and traffic noise modellers to be able to robustly model vehicle fleets on public roads.

## 7 References

- [1] European Commission (2002). Directive 2002/49/EC of the European Parliament and of the Council relating to the assessment and management of environmental noise. *Official Journal of the European Commission*, L189/12. Brussels, Belgium: European Commission.
- [2] Morgan, P.A., Morris, L., Muirhead, M., Walter, L.K. and Martin, J. (2011). *Assessing the perceived safety risk from quiet electric and hybrid vehicles to vision-impaired pedestrians* (PPR525). Crowthorne: Transport Research Laboratory
- [3] Conter, M., Czuka, M. and Wehr, R. (2014). Austrian study on the acoustic perception of electric cars. *Proceedings of FORUM ACUSTICUM 2014*, Krakow, Poland.
- [4] Czuka, M., Conter, M. and Wehr, R. (2014). Drivekustik- Acoustic detectability of Electric Vehicle. *Proceedings of the 6th Congress of the Alps Adria Acoustics Association*, Graz, Austria.
- [5] NHTSA (2010). *Quieter cars and the safety of blind pedestrians: Phase 1* (DOT HS 811 304). Washington DC: National Highway Traffic Safety Administration
- [6] Glaeser, K-P., Marx, T. and Schmidt, E. (2014). Testing the sound detection of electric vehicles by blind or visually impaired persons. *Proceedings of Forum Acusticum 2014*, Krakow, Poland.
- [7] Pallas, M.-A., Kennedy, J., Walker, I., Chatagnon, R., Bérengier, M. and Lelong, J. (2014). *Noise emission of electric and hybrid electric vehicles* [online] (FOREVER-WP2-R1\_v1). Lyon, France: IFSTTAR. Available from World Wide Web: <http://forever.fehrl.org>
- [8] Gasparoni, S., Czuka, M., Wehr, R., Conter, M., Pallas, M-A and Bérengier, M. (2014). *Impact of low-noise tyres on electric vehicle noise emission* [online] (FOREVER-WP3-D3\_1\_v5). Vienna, Austria: Austrian Institute of Technology. Available from World Wide Web: <http://forever.fehrl.org>
- [9] Muirhead, M. and Kennedy, J. (2014). *Environmental noise impacts of electric vehicles* [online] (FOREVER\_WP4\_D4-1\_v1). Crowthorne, United Kingdom: Transport Research Laboratory. Available from World Wide Web: <http://forever.fehrl.org>