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The effect of electric vehicles on urban noise maps

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A B S T R A C T

The electric vehicle is the best-positioned alternative to the ICE conventional vehicle become of, among other reasons, its environment friendly properties. One of its most significant properties is its quiet electric engine which can be a good tool for decreasing noise pollution in cities.

In this respect, the electric vehicle can be acoustically assessed from different points of view; on the one hand, as a moving point source, its detectability or annoyance for pedestrians can be studied, and, on the other hand, as part of the traffic flow in a road its effect on the whole noise map. In this paper the effect of introducing a flow of electric vehicles into real urban traffic has been studied and quantified. For this purpose, experimental procedures were used to add to the NMPB ROUTES noise prediction model of the electric vehicle as a potential noise source in the traffic flow. Several conditions have been analysed and was evaluated the change in the number of citizens exposed to diverse ranges of noise levels.

1. Introduction

Sales of electric (EV) and hybrid electric (HEV) vehicles have increased in recent years, and they have become more common in urban fleets. Electric technology, in addition to reducing the emission of polluting gases, also impacts on the noise maps of the cities. The absence of mechanical noise is expected to significantly reduce noise levels in urban areas, having a positive effect on noise maps. According to Directive 2002/49/CE [1], a noise map is a graphic designed for the global assessment of noise exposure in a specific area due to different noise sources or for overall predictions for such an area. EU Member States are required to produce strategic noise maps for their main cities (and other infrastructure and industrial sites). The main objective is to make a general diagnosis of noise pollution that can lead to action plans and noise management that can be implemented in terms of action plans and acoustical planning. There are several models for making noise maps. Some use empirical models, based on experimental approaches, but most of the models are based on the physics of propagation of sound outdoors implemented in a theoretical sound power generation model that changes with the characteristics and number of traffic sources. In none of those models, is the potential presence of electric vehicles considered.

This paper presents the assumptions and experimental tests developed to integrate the EV as a noise source in a traffic noise prediction model, as well as the expected effect of those vehicles on a noise map under different traffic conditions.

2. Methodology. New model and influence of warning sounds

To be able to develop computational noise maps, it is necessary to use a prediction model that simulates the real conditions of the area of study. With this purpose and taking in account the recommendations of the European Directive, the French official noise prediction model, NMPB ROUTES has been used to evaluate noise levels as a function of traffic flow conditions.

The French model needs different inputs to develop the simulation, the main ones are:

– Flow of light vehicles per hour (weight < 3.500 kg).
– Flow of heavy vehicles per hour (weight > 3.500 kg).
– Speed of both types of vehicle.
– Boundary conditions.

After introducing the parameters into the model, it provides the sound pressure level (dB(A)/hour) along the area of simulation, taking into account reflections and the effect of elements such as barriers, buildings or green areas.

In order to introduce electric vehicles into the noise prediction model, it is necessary to know the sound power level emitted by an electric vehicle and to develop an algorithm to model the sound level depending on the source's speed.

The modelling process was carried out based on an initial assumption "The acoustic behaviour of an electric vehicle could

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be assumed as a conventional internal combustion engine (ICE) vehicle without mechanical noise", supported by some experimental measures of several ICE and EVs under coast-by and pass-by conditions [2], see Figs. 1 and 2.

In order to implement this assumption in the French noise traffic prediction model, a careful study of the algorithms used in the model for obtaining the sound power level of different noise sources was made. According to the guidelines of the model, noise produced by a vehicle is divided into two main independent sources [3,4], see Eq. (1) and Fig. 2:

- The engine and other mechanical sources.
- Tyre/road source, rolling noise (aerodynamic sound is considered part of this source).

$$L_A(V,R,p,a) = L_{rolling}(V,R) + L_{engine}(V,p,a) \quad (1)$$

where
- L_A is Pass-by level of the vehicle (dB(A)) [3],
- R is the road platform surface category,
- p is the road gradient (%),
- V is the speed of the traffic flow (km/h),
- a is the traffic flow type (steady speed, acceleration, deceleration).

Therefore, to be able to model the sound level emitted by the EVs, only the tyre/road noise source (rolling noise) has been considered, removing all mechanical noise sources from the algorithm that calculates the power level of an EV. As is done with other types of vehicle, the power level of an EV was evaluated as a function of traffic speed and added to the general algorithm of the French model, see Eq. (2).

$$L_Awi = 10 * \log 10((Evl + 10 * \log 10Q\,vl) + (Evh + 10 * \log 10Q\,vp) + (Eve + 10 * \log 10Q\,ve)) \quad (2)$$

where
- Ev(i) sound power emitted for each category of vehicle ((dB(A)/veh)) (l - light vehicle, h - heavy vehicle, e - electric vehicle),
- Qv(i) average flow rate for each category (veh/h).

Fig. 1. Pass-by test of an electric vehicle.

Before developing the general study about the effect of electric vehicles on real noise maps, it must be commented that special attention has been paid to urban speed, <50 km/h, as above that speed the contribution of rolling noise is similar to the total noise of ICE vehicle, see Fig. 3.

a. Free field traffic lane with electric vehicles

The first step of this work was to analyse the noise emitted by a free field traffic lane of vehicles and assess the variations in the emitted sound pressure levels by changing the proportion of electric vehicles in the traffic flow.

With this objective, a road with a constant traffic flow of conventional ICE vehicles was implemented, simulated and validated with real traffic noise measurements, Fig. 4.

To evaluate the effect of electric vehicles on these conditions, the proportion of electric vehicles in the total number of light vehicles was varied, Eq. (3), and the sound level emitted by the traffic lane was calculated.

$$QTotal - lightV = (1 - N\%) * Qlight - ICEV + Qlight - EV \quad (3)$$

where
- N% percentage of electric vehicles,
- QTotal − lightV, total traffic flow of light vehicles (veh/h),
- Qlight − ICEV(i), average flow of ICE vehicles (veh/h),
- Qlight − EV(i), average flow of electric vehicles (veh/h) according to:

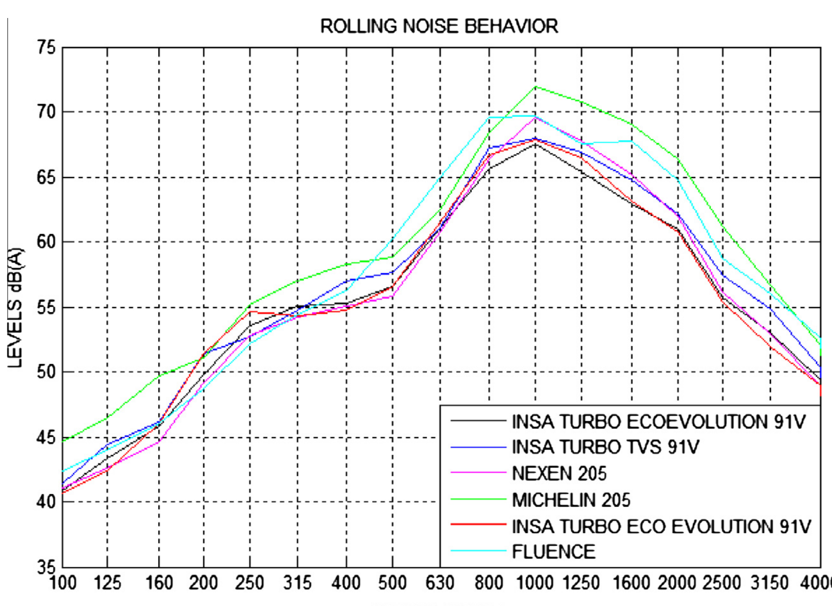

Fig. 2. Comparison of sound emitted by an electric vehicle vs ICE vehicles tyre/road noise.

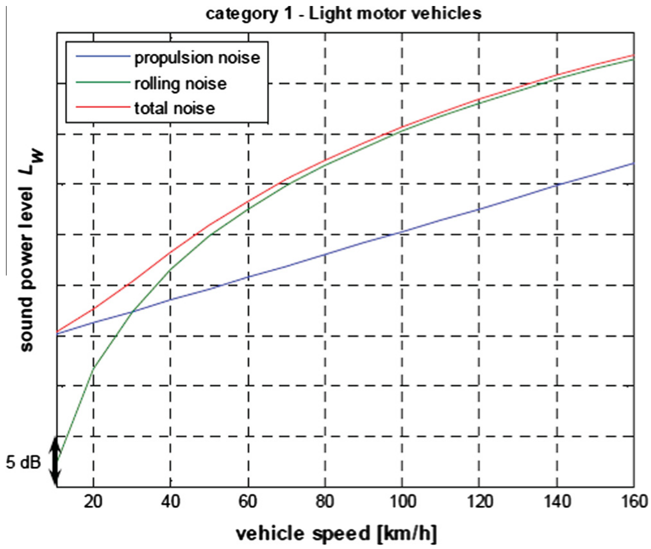

Fig. 3. Contribution of different sub-sources to the total sound emitted by a vehicle [5].

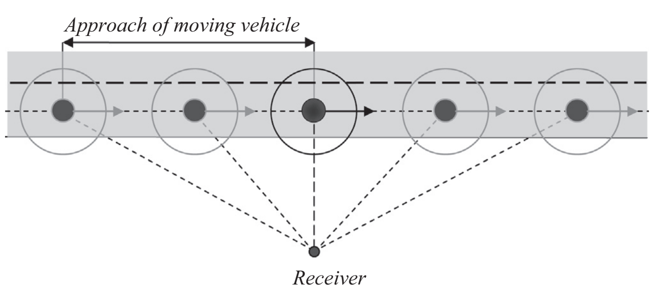

Fig. 4. Free field traffic lane.

Qlight − EV = N% · Qlight-ICEV;

Furthermore, considering that EV'sare expected to be provided with Acoustic Vehicle Alerting Systems (AVAS), the optimal sound power level of the warning sound was integrated into the model, following previous studies developed at INSA-Lyon [6].

These AVAS are deemed necessary due to the lack of mechanical sounds of electric vehicles, and it is estimated that increasing the total sound pressure level of an EV by 2 dB at 20 km/h, their detectability will be near to that of an ICE vehicle [6]. For that simulation, the model was adapted to include the emission of the warning sound by all the electric vehicles, and the environmental effect of EV's with AVAS against ICE vehicles was compared.

Before presenting the results, it is necessary to define the conditions of the simulations: all of the results shown in this paper are the A-weighted sound pressure levels emitted by a traffic flow under different traffic conditions, taking into account that all calculations were developed according to the conditions assumed by the French Noise Prediction Model NMPB ROUTES:

- Constant speed,
- Constant traffic flow,
- Favourable environmental conditions (no rain, no wind),
- Only traffic noise as source.

The results of the simulation of a free field lane traffic flow have been studied in two different cases: all vehicles being ICE light vehicles and all vehicles being EVs; in both cases, the total flow of vehicles is 1350 units and they are running under the same conditions. See Fig. 5.

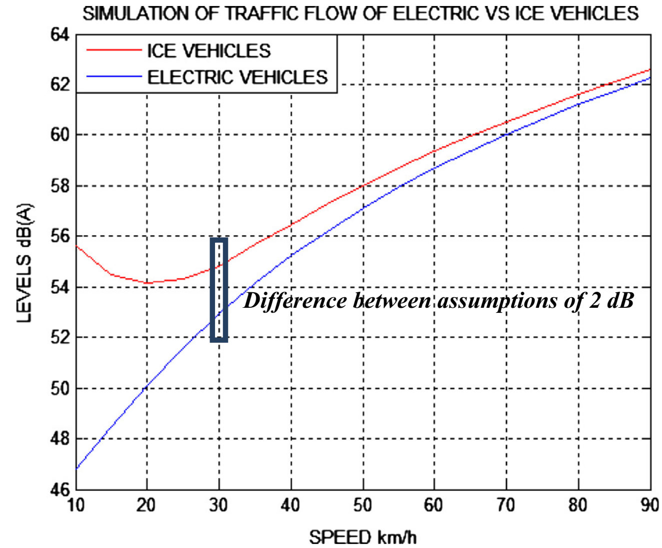

Fig. 5. Simulation of traffic flow of electric vs ICE vehicles.

Focusing the attention on a representative low speed, for example, 30 km/h [7], the difference between a traffic lane of ICE vehicles and the same one running only EVs is 2. This difference grows quickly if it is evaluated at a lower traffic speed (it is not common to simulate a traffic street on a noise map with a velocity lower than 30 km/h) and the difference is approaching zero with speeds higher than 50 km/h, see Fig. 6.

Fig. 6 shows the difference between a flow of EVs and ICEVs without heavy vehicles running. That sequence changes when heavy vehicles are considered in the traffic flow. In this case, the heavy traffic was taken into account as 5% of the total traffic, because the French Model recommends a maximum of 5% of heavy vehicles in urban areas, see Fig. 7. Once the heavy vehicles were introduced into the traffic flow, the decrease generated for electric vehicles is lower than 2 dB in any case, and at 30 km/h it is of 1.2 dB.

In the same way, the expected effect of introducing warning sounds on electric vehicles was evaluated. The warning sound signals developed at INSA-Lyon [6] were taken into consideration, obtaining as a result that the noise emitted by an EV with AVAS is, in any case, lower than that emitted by an ICEV under same conditions, as shown in Fig. 8.

The Impact of electric vehicles using warning sounds is lower than that of electric vehicles without them but they do not exceed the levels of combustion vehicles. In this case, the decrease is 1 dB approximately if there are no heavy vehicles and, when they are considered in the traffic flow, the decrease is lower than 0.6 dB.

b. Simulation of electric vehicles running in a real urban area

From another perspective of the study, the variation of sound pressure level in a real noise map after taking into account electric vehicles running through the streets was assessed. In that regard, European Directive 2002/49/CE [1] requires that municipalities prepare noise maps whose results reflect the number of inhabitants affected by noise on different ranges of annoyance.

That information must be extracted from noise maps, using the maximum façade noise level assigned to all the inhabitants of the building. There are several methods for calculating the number of people exposed to noise in urban areas and, after analysing the different methods studied by Arana et al. [8], Lee et al. [9] or Licitra [10,11], the study has been developed using the German National Method VBEB [12].

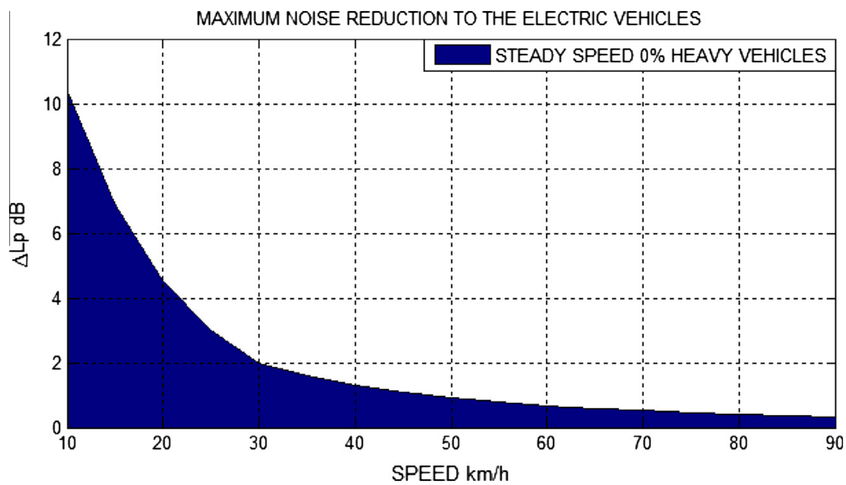

Fig. 6. Variation of noise levels between 100% EV vs 100% ICEV traffic flows, no heavy vehicles.

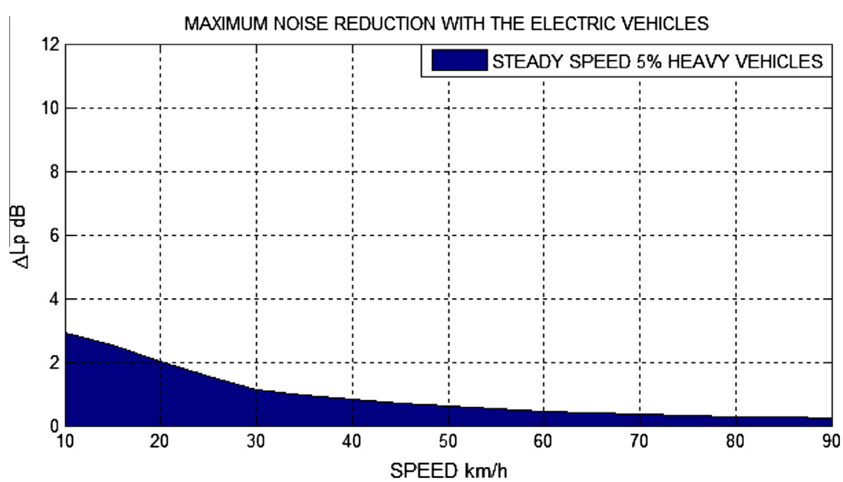

Fig. 7. Variation of noise levels between 95% Light EV vs 95% Light ICEV, plus 5% ICE heavy vehicles of the total.

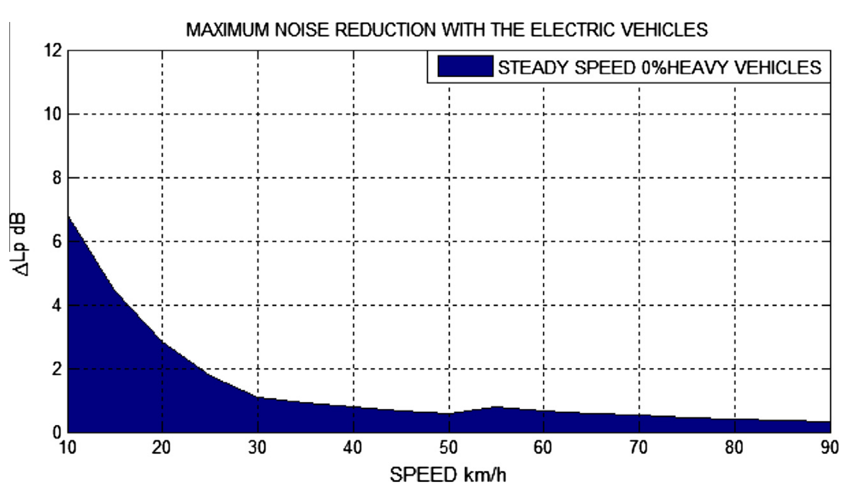

Fig. 8. Variation of noise levels between 100% AVAS-EV vs 100% ICEV traffic flows, with no heavy vehicles.

The method VBEB evaluates the noise levels received on the façade of a building by means of a grid of receivers located at different heights on the façade, see Fig. 9. Once the levels in the facade have been obtained, the next step is to establish how many inhabitants are in each building, according to their characteristics. For this purpose, Eq. (4) was used.

$$EZ_{building} = \frac{G_{building} \cdot GZ_{building} \cdot 0.8}{WE} \tag{4}$$

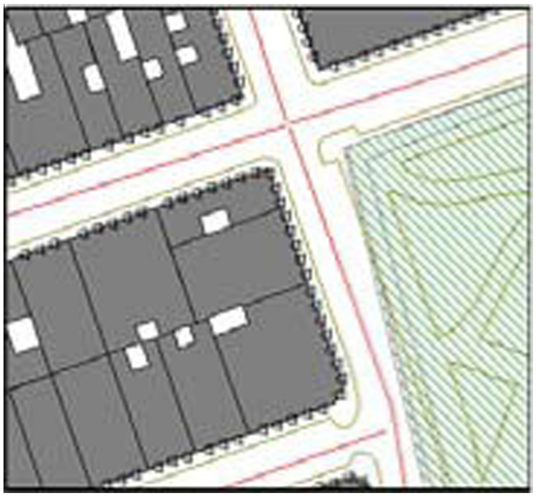

Fig. 9. Distribution of receivers on the façade of buildings.

where

- $EZ_{building}$ is the number of inhabitants.
- $G_{building}$ is the surface of building (m^2).
- $GZ_{building}$ is the total height (m).
- WE Square metres allocated per inhabitant in the area (m^2).

In the assessment process, two different cases were studied. The first analysed the current state of traffic flow (no electric vehicles), and the second took the assumption that all light vehicles were electric vehicles. Both cases have been applied in an urban area of Elche (Spain) whose surface is approximately 450,000 m^2 and has 875 buildings of different heights, see Fig. 6.

The urban noise map was simulated using the commercial software Predictor, adding the sound power levels emitted by the flow of electric vehicles by means of a modification implemented to the French Model by Matlab. Finally, taking into consideration the real traffic in the area studied, the acoustical situation of 12,232 inhabitants was evaluated, by means of 5600 receivers located on the buildings' facades with the receivers located in a grid of 5 m × 5 m, see Fig. 10 and Table 1.

At this point, the results of a noise map with and without EVs on the traffic flow were compared. For this purpose, the map was calculated in accordance with Spanish legislation [13], that limits to 65 dB(A) the maximum sound level permitted to be registered on the façade of a building or receiver.

The traffic flow of the noise maps was extracted from a real traffic count carried out in the area, where the traffic was composed of light vehicles and heavy vehicles indistinctly and the speed limitation in the area under study was 30 km/h.

The comparison of the results of these two maps, see Fig. 11, shows the number of citizens who improve their acoustical conditions. The impact of using 100% EVs as light vehicles would generate an improvement for 10% of the citizens who would be under the limits fixed by legislation.

Table 1
Example of traffic flow veh/h of Fig. 10.

Street	Qlight	Qheavy
1H	163	14
2H	98	0
3H	124	3
4H	84	5
5H	159	10
1V	244	10
2V	67	4
3V	88	10
4V	57	0
5V	165	10

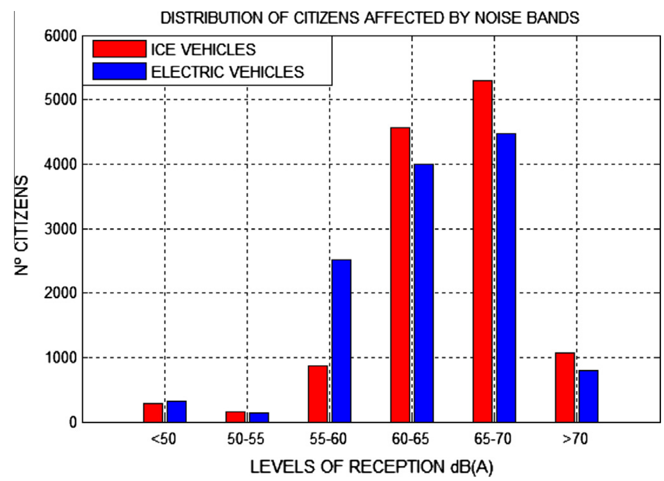

Fig. 11. Number of citizens exposed to different reception noise levels, considering a traffic flow of electric vs ICE vehicles.

3. Noise maps with electric vehicles provided with AVAS

Finally, the same noise map was fully simulated with EVs, but adding the sound increment in the emission of on-board AVAS (AVAS + EV's). The exposition of the result will be developed in 2 different stages, in the first there will be comparison of ICEs versus AVAS + EV's, and secondly, EVs versus AVAS + EV's.

Fig. 12 shows the number of citizens exposed to different reception noise levels. In this case it is also observed that the number of inhabitants exposed to noise levels lower than 65 dB(A) also increases, even when the traffic flow is replaced by a fleet of EVs equipped with AVAS. Here, the effect of using EVs with AVAS

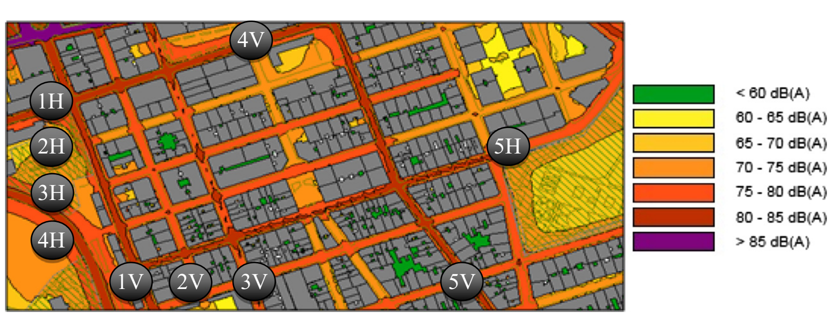

Fig. 10. Results of the noise mapping simulation.

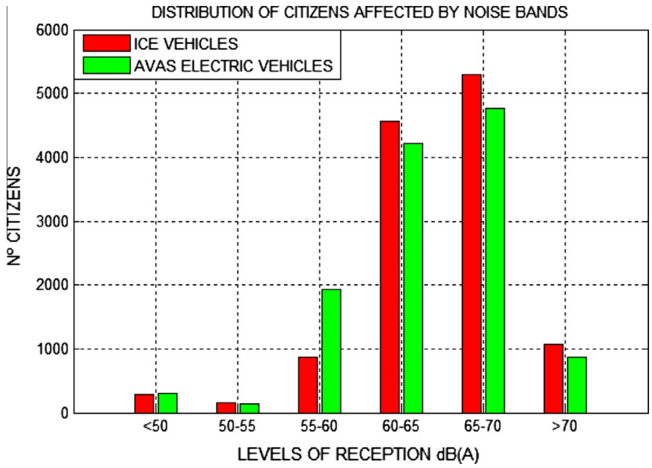

Fig. 12. Difference of simulation of traffic flow of AVAS vs ICE vehicles.

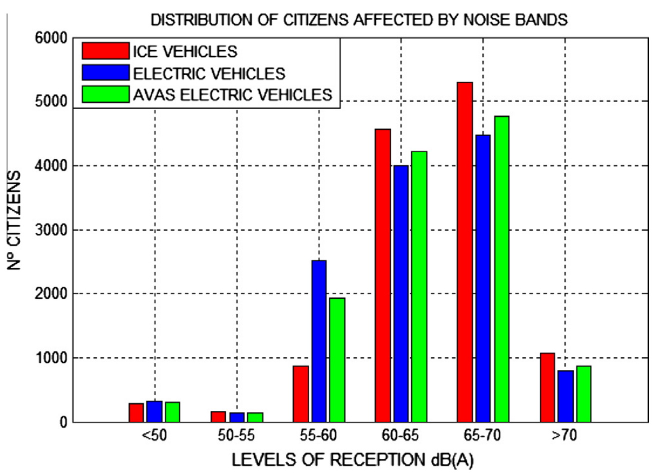

Fig. 13. Difference of simulation of traffic flow of 3 types of vehicle.

implies a reduction of 6% of citizens receiving levels above than the limit.

As might be expected, the results for the case of EVs equipped with AVAS are worse than those not emitting a warning sound. Nevertheless, the levels would never arrive to equate to current situation with ICE vehicles. For that reason the aim of these systems to improve the perception of vehicles can be achieved without aggravating the current environmental acoustical situation on noise maps. Fig. 13 summarizes the results obtained for the three cases under study.

4. Conclusions

The work presented in this paper describes the expected noise effects of EVs on noise maps, and it has been developed by means of measurements and simulation of the noise emitted by an EV. The simulations have been based on a modification of the French Noise Prediction Model NMPB ROUTES and results have been shown for four different cases:

- Electric vehicle running in free field traffic lane.
- Electric vehicle equipped with AVAS running in free field traffic lane.
- Electric vehicle running in a real urban area.
- Electric vehicle equipped with AVAS running in a real urban area.

It could be expected that the emergence of traffic flow without engine noise would improve the environmental acoustic conditions, but the results of the present study indicate that considering extra-urban speeds, i.e. above 50 km/h, the benefits are poor or negligible due to the dominant contribution of rolling noise. When a whole flow of EVs running at 30 km/h is studied in a free field lane, the estimated reduction of the sound pressure level is 2 dB, if all light vehicles are electrics and heavy vehicles do not appear in the simulation.

On the other hand, if electric vehicles use warning sounds to improve the security of pedestrians, the result changes and in this case de reduction is 1 dB without heavy vehicles in the traffic flow.

Finally, a real noise map was simulated to show that the substitution of ICE vehicles by EVs would generate an improvement of 10% of citizens (or 6% in the case of the supposed EV's being equipped with AVAS systems) who would improve their acoustic environment, reducing it to under the limit of the Spanish legislation.

References

[1] Directive 2002/49/CE of the European Parliament and Council of 25 June 2002 relating to the assessment and management of environmental noise.
[2] Campello H, Campillo N, Peral R, Velasco E. Caracterización sonora experimental de un vehículo eléctrico. Malaga: XX Congreso Nacional De Ingeniería Mecánica; 2014.
[3] Road Noise Prediction 1 – Calculating sound emissions from road traffic Sétra. Service d'études sur les transports, les routes et leurs aménagements; June 2009.
[4] Road Noise Prediction 2 – Noise propagation computation method including meteorological effects (NMPB 2008). Service d'études sur les transports, les routes et leurs aménagements; June 2009.
[5] Blokland G, Peeters B. Modeling the noise emission of road vehicles and results of recent experiments. In: Internoise, Ottawa (Canada); 2009.
[6] Parizet E, Ellermeier W, Robart R. Auditory warnings for electric vehicles: detectability in normal-vision and visually-impaired listeners. Appl Acoust 2014;86:50–8.
[7] Calvo JA, San Román JL, Álvarez C, Quesada A. Influencia de los Parámetros de Conducción en el Ruido Emitido por un Automóvil en el Tráfico Urbano. In: XIX Congreso Nacional De Ingeniería Mecánica Castellón; 2012.
[8] Arana M, Perez D, Nagore I. Using noise mapping to evaluate the percentage of people affected by noise. Acta Acustica United Acustica 2009;95:550–4.
[9] Lee Jaewon, Gu Jinhoi, Park Hyunggyu, Yun Heekyung, Kim Samsoo, Lee Wooseok, et al. Estimation of populations exposed to road traffic noise in districts of Seoul metropolitan area of Korea. Int J Environ Res Public Health 2014;11:2729–40.
[10] Licitra G. Noise mapping in the EU: models and procedures. CRC Press; 2012.
[11] Licitra G, Ascari E. Gden: an indicator for European noise maps comparison and to support action plans. Sci Total Environ 2014;482–483:411–9.
[12] Vorlaufige Berechnungsmethode zur Ermittlung der Belastetenzahlen durch gebungslarm (VBEB): Preliminary calculation method for determining the exposure figures caused by environmental noise. Federal German Gazette of 20th April; 2007. p. 4.
[13] Real Decreto 1367/2007, de 19 de octubre, por el que se desarrolla la Ley 37/2003, de 17 de noviembre, del Ruido, en lo referente a zonificación acústica, objetivos de calidad y emisiones acústicas.