Health & Safety

LIFE-Soundless Project: Noise Reducing Asphalt Mixes with Recycled Materials

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Abstract

LIFE-Soundless is a demonstrative project (ending in August 2019), co-funded by European Union within LIFE Program and which main objective has been the noise pollution mitigation at source in urban areas through the implementation of asphalt mixes with high noise-reducing acoustic performance and durability. In this Project several asphalt mixes (SMA) with addition of recycled plastics and/or products from recycling of end-life tyres (rubber powder or nylon fibres) has been designed and tested in two noisy points on the Andalusian road network. The acoustic and surface characteristics of the new pavements have been monitored every six months during two years after the construction of the pilot section and compared with the initial situation and with a reference asphalt concrete also laid in one of the pilot sections. The paper presents and analyses the results of all monitoring campaigns developed until the end of the project and the conclusions about the effect in the noise mitigation and durability of this kind of asphalt mixtures. Furthermore, environmental and social costs considerations of these solutions are exposed

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1 INTRODUCTION

Noise pollution involves an environmental problem especially in urban areas, where the number of people affected is higher. Nowadays, no one questions the relationship between environmental noise and specific health effects such as cardiovascular problems, sleep disorders and cognitive impairments [1]. It is worth noting the results published in the EBoDE Project [2], which points to traffic noise as the second factor causing environmental stress, with the aggravating factor that the trend in Europe is that noise exposure has increased in comparision with other stressors that are decreasing (exposure to smoke, dioxins, or benzene). Due to its relevance, in 2002, within the framework of the Environmental Noise Directive, the European Commission developed an action plan focused on controlling this problem. Nevertheless, noise pollution continues to be a worrying problem in Europe.

Within this priority area, the EU-funded LIFE SOUNDLESS project "New generation of eco-friendly asphalts with recycled materials and high durability and acoustic performance", is framed. This project has been coordinated by the Directorate-General for Infrastructures of the Junta de Andalucía with Cidaut Foundation (specialist in environmental acoustics) and Eiffage Infraestructuras (experts in design, production and laying of asphalt mixtures for road construction), taking part as partners.

LIFE-SOUNDLESS has been focused on the evaluation of effectiveness and durability of noise-reducing SMA mixes in Mediterranean climates (southern Europe), where weather conditions are very different from those in the northern countries. The traditional noise-reducing asphalt mixes (porous asphalts) have not yielded the expected results in dry and warm climates due to voids filling or problems of ravelling in urban areas with severe tangential stresses.

To stress the environmental nature of LIFE SOUNDLESS mixtures, they incorporated different waste from other industries (rubber and fibres from end-life tyres, plastic waste), whose effect in noise reduction was intended to be studied in the project. In all cases, the addition of these components was by dry process, that is, direct incorporation of wastes in the mixer of asphalt plant together with the other constituents (aggregates, filler and bitumen).

2 NOISE-REDUCING ASPHALT MIX DESIGN

As noted in the previous section, the choice of a SMA (stone mastic asphalt) structure for our LIFE SOUNDLESS mixes rather than a PA (porous asphalt) mix has been motivated by the concern of proposing a type of asphalt mixes that do not lose their acoustic properties in Mediterranean climates of low rainfall. It is well known that one of the problems of porous mixtures in this type of climate is the filling of the voids with the dust and dirt of the pavement, which causes them to lose their phono absorbent characteristic in a relatively short time. In addition, it is also common the failure of this type of mixes in urban areas subject to tangential efforts (roundabout turns, accelerations and braking in traffic light areas, etc.). These drawbacks have been intended to be saved with the design of SMA mixtures, which, although they do not get at first the noise reduction that is achieved with porous mixtures, it is expected that the noise-reducing effect will be maintained for longer, as they are mixes with great cohesion at the same time as having good surface characteristics thanks to its negative macrotexture.

Moreover, environmental sustainability in the frame of circular economy was another objective of this project. Therefore, residual materials have been used as raw materials in the process: plastic waste and rubber and nylon fibres from end-life tyres.

The different waste used as additives of SMA mixes are shown in **Figure 1**.

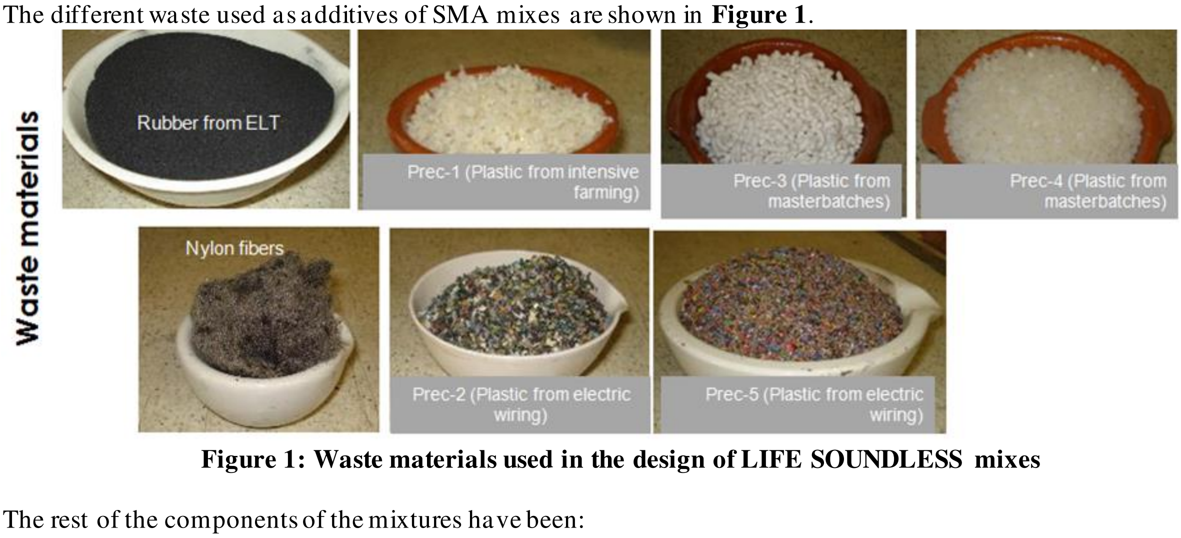


Figure 1: Waste materials used in the design of LIFE SOUNDLESS mixes

The rest of the components of the mixtures have been:

- Ophitic coarse aggregate
- Limestone fine aggregate
- Calcium carbonate as filler
- Bitumen: 50/70

The variables in the optimal design of SOUNDLESS mixtures were the percentage of recycled waste used and the grading curve, looking for voids content in the mix around 12%. As a result, 23 mixes compositions (Table 1) were studied.

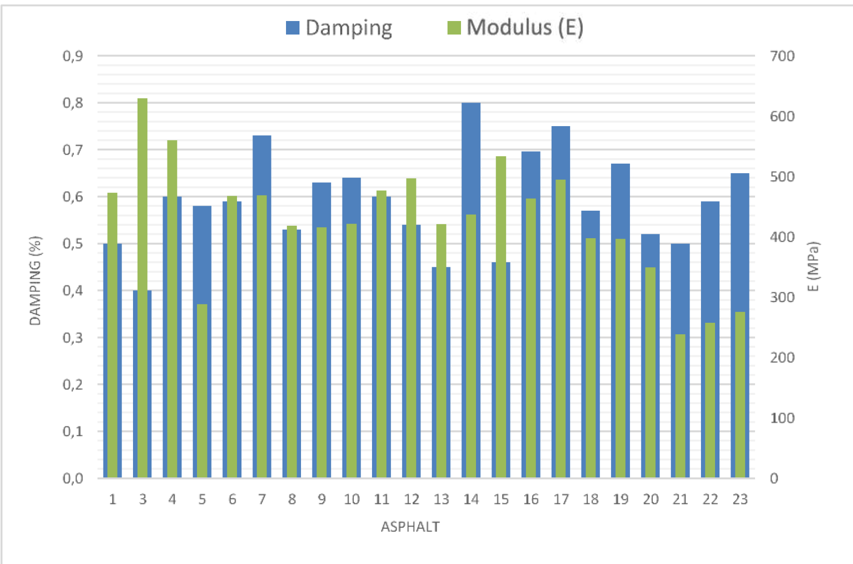
Table 1: Asphalt mixes studied in LIFE SOUNDLESS PROJECT

Asphalt mixes	Test conducted
4 reference mixes (1 AC16 and 3 SMA8)	Maximum density
2 with greenhouse plastic waste (0,5%-1%)	Bulk density, % voids
4 with wiring plastic waste (0,5% -1%)	Water sensitivity
2 with masterbatches plastic waste (1%)	Wheel tracking
2 with nylon fibers from ELT (0,2%-0,5%)	Loss of particles
6 with rubber powder from ELT (0,5%-1%-1,5%-2%)	Marshall stability
1 with rubber powder from ELT and wiring plastic waste (0,5%+0,5%)	Stiffness and fatigue
2 with rubber powder from ELT and greenhouse plastic waste (0,5%+0,5% - 1%+0,5%)	

As result of this laboratory study, we concluded that all mixtures studied apart from those incorporating wiring plastic waste met the Spanish specifications for BBTM B surface layer, except for the specification of voids content (>12%), remaining around 10% (mainly due to the higher mastic content of SMA mixes). Asphalt with wiring plastic waste showed rutting higher than allowed. The final criterion for the selection of asphalt mixes would be that of acoustic behaviour, once their compliance from a mechanical and structural point of view has been ensured.

For this type of mixtures, in which the voids are not interconnected, what defines best their future acoustic behaviour is the mechanical impedance [3], in the sense that it indicates the excitation produced by the radiation of the tyre hitting the pavement during rolling. Two parameters are extracted from the mechanical impedance test. On the one hand, dynamic stiffness (Young modulus equivalent): the lower this value, the lower the wheel excitation and, therefore, less propensity to noise generation. The other parameter is the damping factor, i.e. the gap between the tyre response and the force that excites it: the higher this damping the delay will be greater, generating a lower level of noise.

The results obtained in the mechanical impedance test are presented in Figure 2. From these results it is concluded that the best asphalt mixes in terms of acoustic attenuation are those who show low dynamic Young's modulus and, at the same time, high damping factor. Accordingly, from an acoustic point of view, the last mixes (16 to 23) are the most appropriate to be implemented as noise reducing asphalt.



1	SMA 08 45/80-65
3	AC16 35/50 S
4	SMA8 P REC-1 (0,5%)
5	SMA8 P REC-1 (1,0%)
6	SMA8 P REC-2 (0,5%)
7	SMA8 P REC-2 (1,0%).
8	SMA8 NYLON (0,2%).
9	SMA8 NYLON (0,5%).
10	SMA8 ELT (0,5%).
11	SMA8 ELT (1,0%).
12	SMA8 ELT (1,5%).
13	SMA8 ELT (2,0%)
14	SMA8 ELT (0,5%) P REC-2(0,5%).
15	SMA8 45/80-65
16	SMA8 ELT (1,5%) 6.5% Bitumen
17	SMA8 ELT (1%) 6.0% Bitumen
18	SMA8 ELT (0.5%) + P REC-1 (0,5%)
19	SMA8 ELT (1%) + P REC-1 (0,5%)
20	SMA8 P REC-3 1%
21	SMA8 P REC-4 1%
22	SMA8 P REC-5 0,5%
23	SMA8 P REC-5 1,0%

Figure 2: Results of Mechanical impedance tests

3 IMPLEMENTATION AND ACOUSTIC EVALUATION OF PILOT SECTIONS

3.1 Previous analysis of the study area

First, a previous study was made for the tracks where it was intended to implement the LIFE SOUNDLESS pavements. The purpose of this task was firstly to justify the suitability of the areas in order to evaluate the proposed solution and secondly, to carry out a current assessment of the existing solutions in order to be able to be compared later.

The sections selected were:

- Scenario 1: A-8058 (Sevilla-Coria). 600 m. 50 km/h. ADT (Average Daily Traffic) 30,000 vehicles
- Scenario 2: A-376 (Sevilla-Utrera). 800 m. 80 km/h. ADT 80,000 vehicles

Considering noise maps elaborated by the Directorate-General for Infrastructures of the Junta de Andalucía, noise pollution in both scenarios was important. But it had to be confirmed that the dominant noise source was due to road traffic. For that, microphones were placed at different points to register and calculate the sound pressure levels for 24 hours (Figure 3 and Table 2). In addition, a frequency analysis was performed to assess whether the rolling noise was dominant at the pilot sites or, conversely, there were other noise hotspots that could make the application of a noise-reducing pavement inefficient.

(a) (b)

Figure 3: Microphones placed in the pilot sections. (a) A-8058 (in red) (b) A-376 (in green)

Table 2: Equivalent sound pressure level values

Equivalent Noise Levels A-	A-8058	A-376-1	A-376-2
L night (dBA)	63	70	73
L day (dBA)	70	76	79
L evening (dBA)	69	76	78
L den (dBA)	72	79	81

As an example, the frequency analysis for Scenario 2 is presented in Figure 4 on a 3D chart, where the X axis illustrates time, the Y axis is the frequency axis, and the noise level in dB refers to colors. It is perfectly appreciated that the 1000Hz frequency band is dominant for high noise levels. This phenomenon is typical in the identification of rolling noise [4] and confirmed that it made sense, as a measure for decreasing of environmental noise, to replace the existing pavement by a noise-reducing asphalt.

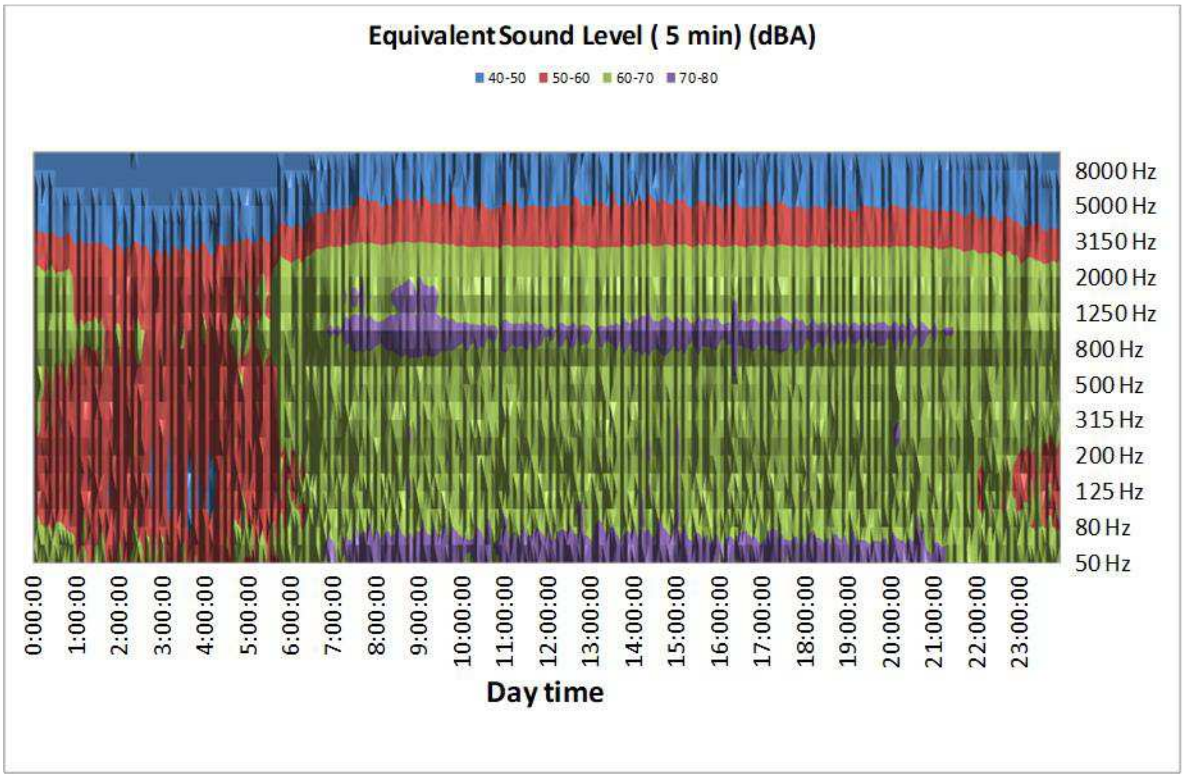


Figure 4: Sound pressure spectrum collected by the fixed station of Scenario 2

The last evaluation tests performed in the pilot tracks before the implementation of the noise reducing asphalts were the monitoring using the CPX (Close ProXimity) method [5] and the SPB (Statistical Pass By noise) method [6]. The equipment used for these measurements was showed in Figure 5. The CPX method allows to know in detail the level of rolling noise generated by the pavement and, therefore, makes it possible to compare different pavements, whereas the SPB method responds more faithfully to the actual noise levels to which citizens are subjected by traffic.

Figure 5: Devices used by Fundacion CIDAUT for acoustic monitoring. Left: CPX. Right: SPB

Results obtained in the initial acoustic characterization with CPX and SPB method are summarized in Table 3.

Table 3: Preliminary acoustic characterization of the pilot sections

Scenario	Test speed	SPB (dBA)	CPX (dBA)
1. A-8058 C[1]	50 km/h	74	92
1. A-8058 S[2]	50 km/h	-	93
2. A-376 U[3]	50 km/h	-	96
2. A-376 S	50 km/h	77	95
2. A-376 U	80 km/h	-	104
2. A-376 S	80 km/h	83	104

[1] C: direction Coria; [2] S: direction Sevilla; [3] U: direction Utrera; -: without data

3.2 Acoustic evaluation of noise-reducing asphalts in pilot sections

According the results of the mechanical impedance test shown in Figure 2, the following mixtures were selected for the real-scale demonstrators executed in April 2017 (Figure 6):

Scenario 1: A-8058
- SMA8 with 1% crumb rubber from ELT and 6% bitumen
- SMA8 with 1.5% crumb rubber from ELT and 6.5% bitumen

Scenario 2: A-376
- SMA8 with 0.5% nylon fibres from ELT
- SMA8 with 1% recycled plastic waste (Prec-4)
- SMA8 with 0.5% crumb rubber from ELT + 0.5% recycled plastic waste (Prec-4)
- Reference asphalt mix: AC16 SURF

Figure 6: Noise-reducing asphalts implemented in pilot sections. Left: A-8058. Right: A-376

Within the LIFE SOUNDLESS project, five acoustic monitoring campaigns (every six months) have been carried out. Measurements at 80 km/h were made only in Scenario 2 (A-376), as the nominal speed in the Scenario 1 (A-8058) is 50 km/h. Results of CPX are summarized in Table 4 and Figure 7 and Figure 8. From these data it can be concluded that, although in the last campaign (after 2 years of laying the new asphalt) the noise level has increased in all the pavements, this acoustic worsening is greater in the case of the conventional asphalt taken as reference (AC16). The better behaviour in terms of acoustic performance of LIFE SOUNDLESS pavements is more significant at higher speeds (80 km/h). As for the most noiseless asphalt, the results obtained give the first place to the SMA8 with 1,5% of crumb rubber from ELT.

Table 4: CPX monitoring results (Values rounded to the nearest integer)

		OLD pavement		LIFE SOUNDLESS pavement									
		Feb-16		May-17		Oct-17		May-18		Oct-18		Abr-19	
Road	**Asphalt mixture**	**$CPXI_{50}$ (dBA)**	**$CPXI_{80}$ (dBA)**	**$CPXI_{50}$ (dBA)**	**$CPXI_{80}$ (dBA)**	**$CPXI_{50}$ (dBA)**	**$CPXI_{80}$ (dBA)**	**$CPXI_{50}$ (dBA)**	**$CPXI_{80}$ (dBA)**	**$CPXI_{50}$ (dBA)**	**$CPXI_{80}$ (dBA)**	**$CPXI_{50}$ (dBA)**	**$CPXI_{80}$ (dBA)**
A-8058C	1% ELT	92	-	90	-	90	-	90	-	91	-	91	-
A-8058S	1,5% ELT	93	-	89	-	90	-	89	-	90	-	91	-
A-376U[1]	0,5% Nylon	95	-	91	-	91	-	91	-	92	-	91	-
A-376U	1% Prec-4	96	104	91	97	91	96	91	97	92	98	92	98
A-376S	0,5 ELT + 0,5 Prec-4	95	104	91	97	90	96	91	97	92	98	92	98
A-376S	AC16	95	104	93	101	93	101	95	102	95	103	96	103

[1] Service road, -: no measured

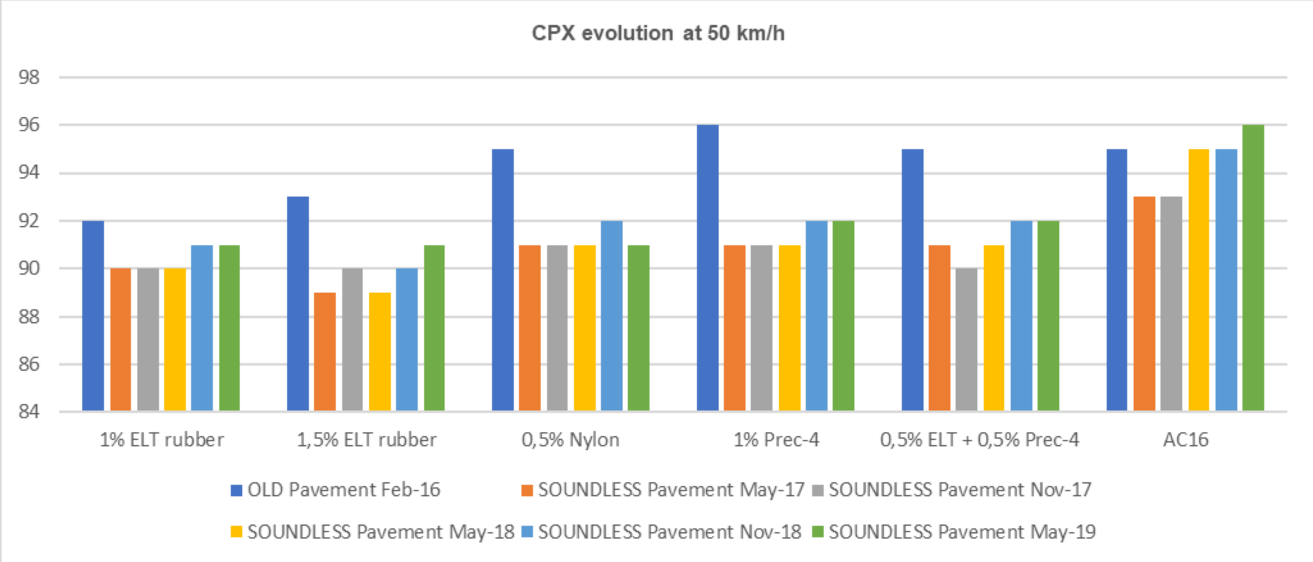


Figure 7: CPX evolution at 50 km/h

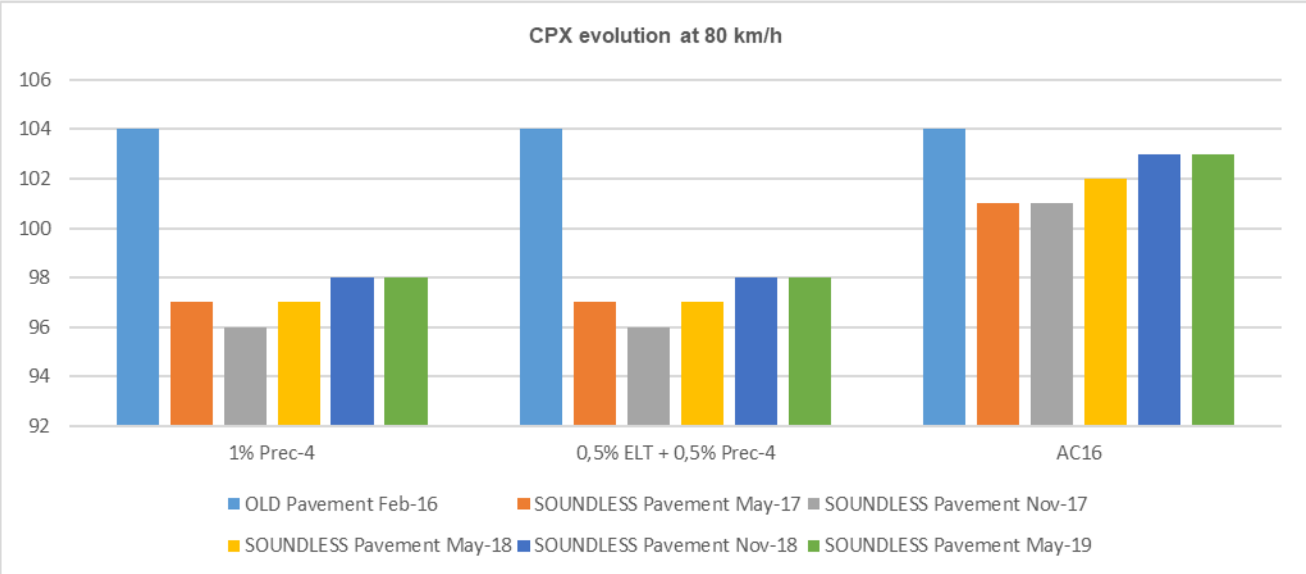


Figure 8: CPX evolution at 80 km/h

Now, we focus on the analysis of SPB results at 50 km/h. As it can be seen in

Table 5, acoustic performance after two years of SOUNDLESS pavement laid, is considered quite good, remaining 3 dB below in the Scenario 1 (A-8058) and 8 dB in Scenario 2 (A-376). The surprisingly low value obtained from the A-376 direction Utrera has its explanation in that due to the high traffic density the SPB measure had to be made at night, when the background noise of the area is less, and therefore so is the result obtained.

Table 5: Sound pressure level registered by SPB method.

			Lveh (dBA)					
Road	**Asphalt mixture**	**Type of vehicle**	**Feb-16**	**May-17**	**Oct-17**	**May-18**	**Oct-18**	**Abr-19**
A-8058 C	1% ELT rubber	Light	73	68	68	68	69	70
		Heavy	78	76	78	78	78	79
A-376 S	0,5% ELT rubber+0,5% Prec-4	Light	77	68	68	68	69	69
		Heavy	81	73	75	78	78	78
A-376 U	1% Prec-4	Light	n.m.[1]	64	67	64	64	62
		Heavy	n.m.	79	77	n.m.	n.m.	n.m.

[1]n.m.: No measured

Finally, a sound measurement of noise global was done. Results of noise attenuation, calculated as the difference between before and after (18 months) of laying SOUNDLESS pavements, are presented in the table below (Table 6).

Table 6: Noise attenuation level

	A-376-1	A-376-2	A-376 AC16	A-8058 CS-1
L_{night} (dBA)	4	6	1	4
L_{day} (dBA)	6	7	1	3
$L_{evening}$ (dBA)	6	6	1	3

The points where the measurements have been taken are shown in the following photographs (Figure 9)

Figure 9: Locations of global noise measurements (Left: A-376; Right: A-8058)

As it has been reported using CPX and SPB, the major attenuation regarding the initial situation has been achieved in Scenario 2. In Scenario 1 the attenuation has been lower due to, in this site, the existing pavement was a double-porous asphalt (a noise reducing mixture), so the initial values were already low. Moreover, the road noise is lower for low speed (50 km/h), and, therefore, reaching high values of noise attenuation is more difficult. Regardless, the noise attenuation achieved is good according our point of view. Results obtained in the track with the reference mixture AC16 confirms what has already been known: that these kind of semi-dense asphalt mixes are not noise reducing at all.

4 ENVIRONMENTAL AND SOCIAL COSTS

The environmental impact of the solutions implemented in the pilot sections was analyzed and compared to the reference with the commercial GaBi 4 tool [7] and its Professional database along with data generated ex process in LIFE SOUNDLESS project. In the life cycle study of the asphalt production and laying, the equivalent of a paved area of 10.00 m^2 has been taken as a functional unit.

Eco-indicator 99 (endpoint indicator) is probably still one of the most widely used impact assessment methods in LCA. The aim of this method is the comparison of products or components, so that the value itself is not most relevant but rather a comparison of values. To obtain the global value of Ecoindicator 99, several contributions have been considered: Electricity Grid Mix, Bitumen, Aggregates, Diesel Mix (transport), Heavy and Light Fuels. The values of global Eco-indicator 99 obtained for each asphalt mix are shown in Table 7. Durability of asphalt mixtures has not been considered in this assessment.

Table 7: Values of Eco indicator 99 for the asphalts mixes of LIFE SOUNDLESS Project

	A-8058 1% rubber ELT	**A-8058 1,5% rubber ELT**	**A-376 1% Plastic**	**A-376 0,5% Nylon ELT**	**A-376 0,5% Plastic 0,5% rubber ELT**	**AC-16 Reference**
Ecoindicator'99 (mPt)	135,5	139,1	134,7	135,3	135,1	157,1

As it can be seen from the results, asphalt developed within the LIFE SOUNDLESS project present a lower environmental impact regarding the reference bituminous mixture (AC16). Environmental impact of the LIFE SOUNDLESS mixtures is quite similar. However, slight differences can be seen due to the different bitumen content and loads of recycled materials.

Regarding social costs, we have focused on health improvement by noise reduction. Following the guide of DEFRA Publication (no. 14228) [8], a Transport Noise Marginal Values Model was used in order to calculate Health Social Cost. These costs are associated to the following health and well-being outcomes: Hypertension, through increased risk of stroke and dementia, sleep disturbance and annoyance and acute myocardial infraction (AMI). This tool doesn't consider all the effects that noise causes on people, but at least it guarantees the determination of minimum costs. According to a recent publication of European commission, "What are the health costs of environmental pollution?" [9], the methodology selected in SOUNDLESS project follows the dose-response or concentrationresponse relationship defined by the publication and obtained from WHO (World Health Organization) studies. In the same way, monetization approaches are based on QALY (quality-adjusted life year) and DALY (disability-adjusted life year) criteria, which are used in the study as well.

The model has been adapted as far as possible to the conditions of the area of study (Seville): cost of living and exposed population. To estimate the exposed people after the implementation of SOUNDLESS asphalt mixes, sound pressure in the area has been recalculated with the model used in the elaboration of noise maps, assuming 6dB of reduction in the source of the noise, corresponding to an average speed of 80 km/h for the A- 376 and a reduction of 2dB for the A-8058, corresponding to an average speed of 50 km/h. It is concluded that the decrease in the affected population is significant, reducing exposed people in half in Scenario 1 (A-8058) and by 22% in Scenario 2 (A-376) (see Table 8).

Table 8: Exposed population distribution

	Exposed People			
	Before SOUNDLESS		After SOUNDLESS (18 months)	
Level (dBA)	A-8058	A-376	A-8058	A-376
50-54	401	4372	376	4257
55-59	500	3311	175	2494
60-64	196	1381	120	1086
65-69	232	1154	204	342
70-74	151	354	2	119
>75	0	0	0	0
Total	1,480	10,572	877	8,298

Once the distribution of exposed people in terms of sound pressure is known, it is possible to calculate the total health cost of these people, both in the initial state and after noise reducing asphalt mixes:

- Scenario 1: A-8058
  - Health cost per year in the initial situation: € 1,017 million
  - Health cost per year in the current situation: € 0,498 million

- Scenario 2: A-376
  - Health cost per year in the initial situation: € 5,108 million
  - Health cost per year in the current situation: € 2,971 million

Thus, the health costs per year in these acoustically problematic areas are reduced in both cases by approximately half after laying the noise reducing asphalt. These health savings imply that the total cost of the functional unit (10 m^2 of pavement) in a period of five years is reduced by 42% in A-376 road (from 14,056 €/functional unit to 8,202 €/functional unit) and by 50% in A-8058 road (from 5,392 €/functional unit to 2,674 €/functional unit), comparing SOUNDLESS mixes with respect to AC16 reference mix.

5 CONCLUSIONS

The results obtained after the first two years of laying the LIFE SOUNDLESS pavements allows to draw the following conclusions regarding noise reduction:

- The noise level L_{day} near the roads has been reduced by 6 dB in the A-376 road (interurban road with average speed of 70 km/h) and by 3 dB in the A-8058 road (urban road with average speed of 50 km/h)
- SOUNDLESS mixes allow a reduction in road noise by 3 dB with respect to the new dense asphalt (AC 16 surf) at low speeds (50 km/h) and 4 dB at medium speeds (80 km/h).
- As for the quietest asphalt of all tested, the results obtained give the first place to the SMA8 with 1,5% of crumb rubber from End-Life Tyres.
- Waste materials, such as crumb rubber from end-of-life tyres and plastics, could be used as new additives in asphalt mixes as SMA.

Also, environmental and social costs have been analysed, and from this study the following conclusions can be drawn:

- The Noise Action Plan carried out in the demonstrative areas has allowed to reduce the affected population by noise by 50% in A-8058 road and by more than 20% in A-376 road
- Asphalt mixes developed within the LIFE SOUNDLESS project present a lower environmental impact (Eco-indicator 99), with respect to the reference bituminous mixture (AC16).
- Estimation of health costs reduction due to the better acoustic performance of SOUNDLESS mixes has been very significant and ensures the viability of these asphalt mixes over time.

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