The noise reduction potential of “silent tyres” on common road surfaces

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Summary

Tyre/road noise dominates at velocities above 15 km/h for modern cars. In this light, acoustic optimisation of both road surface and tyre may constitute an effective means to reduce road traffic noise. With its tyre label, the European Commission attempts to encourage the purchase of low-noise tyres by benchmarking their noise emissions along with measures on fuel consumption and wet grip. Several studies suggest, however, that the noise reduction stated on the label cannot be directly transferred to real world environments mainly because label values refer to the noise levels obtained on a special standard surface which is usually not found on roads. As a basis for decision-makers, this study, evaluates the noise reduction potential of “silent tyres” on the most common road surfaces in Switzerland and elsewhere in Europe. Noise emissions were measured for 14 carefully selected tyres with different dimension, profile and noise label on a set of 12 different road surfaces of varying type. The measurements were conducted with a modified CPX (close-proximity) trailer allowing for adjustments of the tyre load in order to respect the UN/ECE 117 standard’s requirements regarding carrying capacity. The study revealed that the narrowest tyre of the sample (common tyre for e.g. electric BMW i3) is about 5 dB quieter than the widest assessed tyre (common tyre for e.g. Audi RS5). Within the same dimension class the noise reduction potential was found to be up to 4 dB. The obtained noise reductions are similarly high for all assessed road surfaces. Since other studies indicate that a tyre’s noise reduction potential does not significantly diminished with tyre age, it is recommended for policy makers to devote more resources to the proliferation of “silent tyres” (e.g. by improving label relevance and understanding) as this may contribute towards lower traffic noise levels on a large scale.

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1. Introduction

Rolling noise from a modern vehicle fleet for passenger cars (construction year 2005 and newer) dominates the overall vehicle noise emission even at speeds of 15 km/h [1]–[3]. Therefore, a great potential to reduce traffic noise exists at the source i.e.: low noise road surfaces and silent tyres. In the European Union a regulation on the labelling of tyres was introduced in 2012 (and two years later in Switzerland). This regulation specifies a labelling system of the parameters rolling resistance, wet grip and rolling noise. The rolling noise is measured on an ISO 10844 [4] road surface with mounted tyres on a vehicle. The coast-by levels (pass-by with a switched-off engine in a neutral gear) are registered by two microphones at a speed between 60 to 90 km/h. These measured rolling noise emissions of different tyres result in today’s labelling system of noise levels between 67 and about 74 dB. Earlier studies suggested that the rolling noise level of the tyre labels are often not directly applicable to those obtained in real world conditions [5], [6], with the explanation that the standardized road surface [7] does not represent the surface characteristics of common roads. The standardized road surface usually features a rather smooth surface (similar to asphalt concrete, AC 8) which is rarely built on roads in Switzerland and elsewhere in Europe. Therefore, the noise reduction potential of silent tyres on common roads is not known.

The goal of this study is to determine the noise reduction potential of tyres on the most common road surfaces in Switzerland. To evaluate as many combinations of tyres and road surfaces as possible, a measurement concept was arrived at which allows the assembly of tyres on the close proximity (CPX) trailer. A special construction allows the load of the measurement trailer to be set according to the specific load index of the tyres and thereby to perform the rolling noise emission measurements efficiently. Additionally, the noise reduction potential in combination with low noise road surfaces is determined. The most important parameters influencing the silent tyre's noise reduction potential are identified and quantified to draw plausible prognoses about the future trends.

2. Measurement Campaign

To investigate the noise reduction potential of tyres on most common used road surfaces, test tyres that are usual in the market were chosen of different dimensions and applied on a test track, which was chosen to represent several different types of road surfaces. The UN ECE Reg. 117 [8] requires a specific load according to the load index of each of the four tyres mounted on a car to perform valuable coast-by measurements.

Figure 1: Modified CPX trailer to apply the required weight according to the tyre's load index.

As for each road surface type a closed road track must have been found to perform coast-by measurements, a more efficient measurement method was used in this study whereas only two tyres were mounted on a modified CPX trailer (see Figure 1). To investigate the difference between the two methods of a coast-by measurement after UN ECE Reg. 117 [8] and with a modified one using the CPX trailer was done at a test track of the Dynamic Test Centre in Switzerland. Thereby, the measurement uncertainties were estimated by performing a direct comparison between the coast-by method using three different cars and mounting the rear wheel at the modified CPX trailer and applying the required weight according to the load index, respectively (see Figure 2). The results of the estimation of the measurement uncertainties of the two methods are discussed in section 3.1.

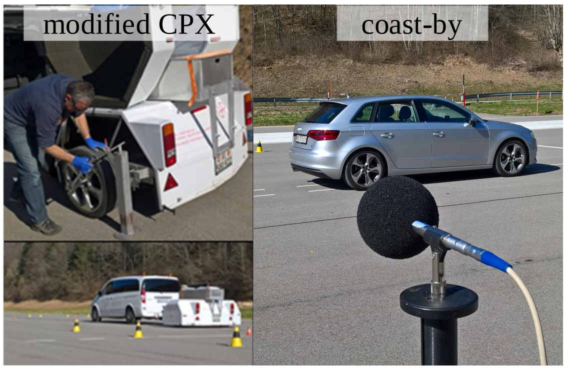

Figure 2: Measuring two Continental ContiSportContact tyre mounted on the modified CPX trailer applying the required weight according to the load index (left) and mounted at the rear of an Audi A3 performing coast-by measurements (right).

2.1. Test Tyres [9]

The test tyres were selected to address the following questions: I.) comparison of rather silent and loud tyres according to their noise labelling of the same dimension (it has to be stated that it was not focus of this study to evaluate the reliability of tyre labels), II.) investigation of the influence of acoustic properties of the tyre width according to the same tyre model at three different tyre widths and III.) noise implication according to a large difference in tyre width investigating a tyre featuring an extremely small and an extremely large tyre width.
These questions revealed in a selection of 14 different tyre models listed in Table I. Four tyre models are selected featuring a tyre width of 185, 205 and 225 mm, respectively. Within each tyre width class a rather silent, middle and loud tyre were selected, respectively (I), according to the noise emission label and the regular measurements of Touring Club Switzerland (TCS; www.tcs.ch). The Dunlop Sport BluResponse tyre was selected to be in all three tyre width classes (II) to determine influencing values on the acoustic properties as well as to examine the difference in acoustics solely regarding tyre width without changing the model. To investigate the influence of tyre width on the noise emissions, a rather small and large width of 155 mm (usually mounted on e.g. the electric car BMW i3) and 295 mm (usually mounted on e.g. Porsche Panamera, Jaguar F-Type, etc.), respectively, were selected (III). Additionally, the two reference tyres for CPX

Table I. Specifications of the investigated tyres within this project.

ID	*brand*	*model*	*width*	*aspect ratio*	*radial*	*load index*	*speed index*	*rolling resistance*	*wet grip*	*noise emission*
1	Infinity	Ecosis	185	65	15	88	H	E	C	70
2	Hankook	Kinergy Eco K425	185	65	15	88	H	E	A	69
3	Semperit	Comfort-Life 2	185	65	15	88	H	E	C	70
4	Dunlop	Sport BluResponse	185	65	15	88	H	B	A	67
5	Hankook	Kinergy Eco K425	205	55	16	91	V	B	B	70
6	Nokian	Line	205	55	16	91	V	C	A	71
7	Dunlop	Sport BluResponse	205	55	16	91	V	B	A	68
8	Pirelli	Cinturato P7 Blue	205	55	16	91	V	B	A	72
9	GT Radial	Champiro HPY	225	45	17	94	Y	E	B	70
10	Hankook	Ventus S1 evo2 K117	225	45	17	94	Y	E	A	71
11	Yokohama	Advan Sport V105	225	45	17	94	Y	F	A	72
12	Dunlop	Sport BluResponse	225	45	17	94	Y	B	A	69
13	Bridgeston	Ecopia EP500	155	70	19	84	Q	C	B	69
14	Michelin	Pilot Super Sport	295	25	21	96	Y	E	A	73
15	Uniroyal	Tigerpaw SRTT	225	60	16	97	S			
16	Avon	AV 4	195	-	14	106	N	F	C	74

* Reference tyres applied for CPX measurements after ISO/TS 11819-3 2017 [9]

measurements were used to perform reference measurements at the beginning and at the end of the campaign to exclude any possible alterations of the CPX trailer occurred during the campaign.

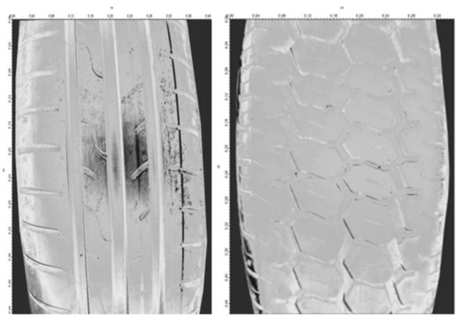

Figure 3: Tread pattern of tyre ID 2 (symmetrical profile) and 15 (block profile).

Several studies reveal a significant influence of the tyre's profile on the noise emission resulting from the interaction between the tyre and the road surface [10]–[13]. These are mainly two noise generation mechanism: 1) excitation of the tyre due to the interaction between the profile blocks and the road surface texture, and 2) due to the compression/expansion of air in the tread grooves resulting from the roll over the road surface [14]. With regard to this issue, tyres featuring a symmetrical profile instead of a block profile are recently more often produced. Therefore, all test tyres used in this study, feature a symmetrical profile except for the CPX reference tyre Avon AV4 (see Figure 3).

Table II. Information of the road surface type, year of installation and its length.

road surface type	*year of installation*	*length*
DAC 16	1995	440
DAC 32	unknown	280
SD 11	1997	200
SD 3/6	unknown	120
SD 6	unknown	280
SD 6 (damaged)	unknown	200
SD 6/8	unknown	560
SDA 4-12	2015	380
SMA 11	2011	340
SMA 11	unknown	180
SMA 8	unknown	100

DAC = dense asphalt concrete; SD = surface dressing;
SDA = semi-dense asphalt (void 12.5 %);
SMA = split mastic asphalt

2.2. Test Track

The test track was selected to include as many possible road surface types represented in Switzerland. A road section in the Region Aargau fulfils these demands consisting of 11 different road surfaces including a low noise road surface of the type of semi dense asphalt. Table II lists all road surfaces on the test track with information about the road surface type, year of installation and length.

2.3. Measurement Methods

All measurements were conducted by mounting two tyres on a CPX trailer. The CPX trailer was modified to apply the required weight on the tyres according to the load index according to UN/ECE Reg. 117 [8]. Therefore, close proximity measurements were performed instead of free-field measurement. To prevent any distortions of the noise emissions due to rigid rubber of the tyres [15], the measurements were performed at the tyre's operation temperature. This has been done by warming up the tyres at the test track in a bidirectional manner resulting in a length of 6 km with speed of 50 km/h for warm-up before performing the measurements on the same track. A valid measurement was defined by capturing the road surfaces on the test track twice in both directions per tyre model.
After each change of tyre, the load of the trailer was adapted according to the requirements of the load index of the tyre. UN/ECE Reg. 117 prescribes using a load of 75±5% of the load index of the respective tyre. This resulted in an additional load on the trailer from 20 kg (for the Bridgestone Ecopia EP500) to 320 kg (for the Michelin Pilot Super Sport). The load could be adjusted in 20 kg steps by loading and unloading cement bags evenly distributed in an aluminium case lengthwise mounted at the top of the trailer (see Figure 1).
The tyre pressure is defined according to the exact load at the trailer and thus was 1.8 bar for all the test tyres.

3. Results and Discussions

3.1. Efficiency in Tyre Testing

In this project the acoustic properties of tyres were measured with two tyres mounted on a modified CPX trailer and loaded after UN/ECE Reg. 117 [8] according to the tyre's load index. The use of two tyres mounted on a modified CPX trailer instead of coast-by measurements using four tyres mounted at a car results in a much more efficient process. To estimate the measurement uncertainties of the difference between close proximity and measurements at 7.5 m distance was investigated by performing coast-by measurements of three different cars as well as by mounting the same rear wheels at the modified CPX trailer. These measurements were conducted on a test track for measuring noise emitted by road vehicles and their tyres after ISO 10844:2014 [7]. The cars were selected to address a wide range of vehicle classes: compact car (Mercedes-Benz A180), middle class car (Audi A3 SB) and a van (Mercedes-Benz Vito).

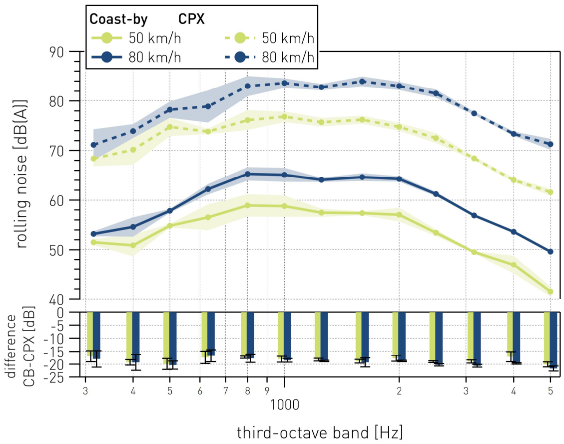

Figure 4: Mean coast-by (solid line) and CPX (dashed line) measurements at a speed of 50 km/h (green) and 80 km/h (blue) of the three cars (compact and middle class car, and van). The standard deviation is indicated with the colour band, respectively. Spectral difference of the coast-by (CB) minus the modified close proximity (CPX) measurements at speed of 50 km/h (green) and 80 km/h (blue) are indicated in bars.

Figure 4 shows the mean coast-by and mean CPX measurements at speed of 50 and 80 km/h of the three different tyre models mounted at three different cars (upper panel).
The direct comparison of the results of these two measurements leads to a transfer filter between close proximity and measurements of maximum noise level measurements. The mean transfer filter of all the three cars at speed of 50 and 80 km/h, respectively, gives an estimate of the measurement uncertainty using only two tyres mounted on the CPX trailer instead of four tyres mounted on a car (see Figure 4, bottom panel). The transfer filter (difference of the coast-by minus the CPX measurements) lies between 16.8 and 21.5 dB. There is only a small difference of about 0.5 dB measured at both speeds of 50 and 80 km/h in the middle frequencies between different tyres and cars. Larger differences were found for the lower and higher frequencies with differences between 1 and 2.5 dB. Nevertheless, the differences between

the coast-by and CPX measurements are rather low with an estimation of a mean measurement uncertainty of about 1.3 dB and of only 0.5 dB for the decisive middle frequencies. Thus, it can reasonably be concluded that the modified CPX trailer is a valid adaptation of the UN/ECE Reg. 117 by using two tyres mounted on a CPX trailer instead of four tyres mounted on a car.

3.2. Noise Reduction Potential

The goal of the study is to establish the noise reduction potential of silent tyres on common road surfaces. To address a variety of commonly used tyre dimensions, three different tyre width classes were investigated in the campaign.
Figure 6 indicates the rolling noise emission measured at the whole test track as a function of the tyre width of each measured tyre. Generally, within the tyre width class the EU label for rolling noise increases with the measured rolling noise emission, with the exception of tyre ID 1, which exhibits a rather low rolling noise emission. There is a clear trend with an increase in rolling noise emission with tyre width. For the selected tyres, the values increase by 0.1 dB per 5 mm tyre width. Within the investigated tyre width classes a variation of 1 to 4 dB was found. This means that using an appropriate tyre which is optimized regarding the acoustic properties leads to a noise reduction potential of up to 4 dB.

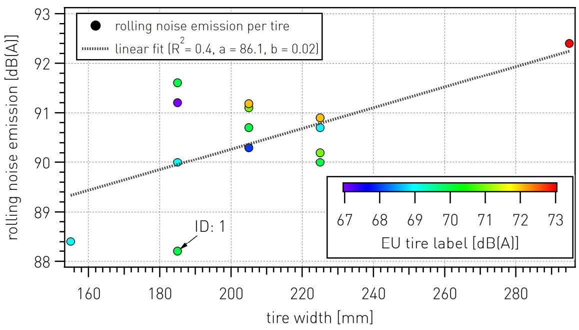

Figure 6: Rolling noise emission of each tyre as a function of tyre width. Colour code indicates the EU tyre label.

Figure 5 shows the noise reduction potential per tyre width and the development of the rolling noise emission of each tyre at each road surface type. The noise reduction potential is calculated by the difference of the maximum and minimum of the rolling noise emission of each tyre width class. The road surface types are sorted in increasing order according to their acoustic performance measured with a CPX trailer. In contrast to the study [16], it shows that in general all tyre models feature the same rank at each road surface type except for the low noise road surface and the SMA 11 (+1.9). For the SMA 11 surface type a few tyre models show a shift of order. Interestingly, the combination of tyres with a low noise road surface (SDA4-12) seems to increase the noise reduction potential of the tyres by 1 or

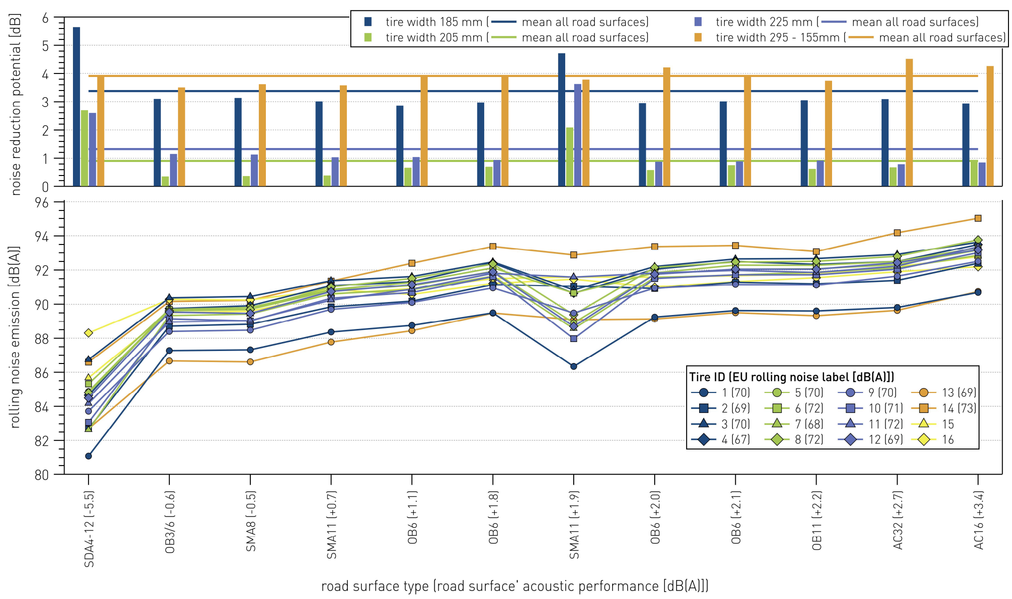

Figure 5: Noise reduction potential of (top) and development of each tyre model's rolling noise emissions (bottom) on each road surface type at the test track. The road surface types are sorted in increasing order according to their acoustic performance (measured with a CPX trailer after ISO 11819-2:2016 [19] in relation to a common road surface).

2 dB. However, this result relies on one tyre model per tyre width class that show an exceptional noise reducing combination of the tyres with low noise road surfaces. Therefore, the additional noise reduction potential of tyres in combination with low noise road surfaces should be considered with caution. Additionally, the study [17] reveals that the tyres after 15000 km in use still feature the same order in rolling noise emission as in the beginning. This means that the tyre models initially shown as silent tyres are still the most silent after 15000 km use compared to the other tyres.

A mean noise reduction potential of about 3 dB was found for the tyre width class 185 mm and about 1 to 1.5 dB for the tyre width classes 205 and 225 mm, respectively. Determining the noise reduction potential by incorporating the variation of tyre width and extrema from 155 to 295 mm, reveal, a noise reduction potential of about 4 dB on all road surfaces. The study [18] performed modified CPX and coast-by measurements of 31 different tyre models on common Nordic road surfaces. They found a theoretical noise reduction potential of 3 dB on dense asphalts and is in the same range as our findings in this study for common road surfaces in Switzerland.

The bottom panel of Figure 5 shows the development of each single tyre on the different road surfaces. The tyre with ID 1 featuring a tyre width of 185 mm results in the quietest of all analysed tyres. Within the tyre width class of 185 mm it reveals a 4 dB smaller rolling noise compared to the loudest tyre. In the tyre width class 205 mm the tyre with ID 7 results in a 1 dB lower rolling noise emission compared to the maximum in the same tyre width class. Additionally, the rolling noise of tyre ID 7 is also smaller compared to ID 3 and 4 of the tyre width class 185 mm. In the tyre width class of 225 mm the tyre ID 9 resulted in 1 to 2 dB lower rolling noise emission (depending on road surface type) compared to the loudest tyre model within its tyre width class.

3.3. Factors Determining the Noise Reduction Potential

The most important influencing factors on the noise reduction potential of tyres are investigated in detail. This was done by the comparison of the tyre model Dunlop Sport BluResponse at three different tyre dimensions. Figure 5 showed the development of these three tyres with ID 4, 7 and 12 on each road surface. With the exception of SMA 11 (+1.9) and the low noise road surface SDA4-12, the variance lies within 0.4 to 1 dB, whereas the tyre ID 4 with a width of 205 mm is at minimum and the ID 7 with a width of 185 mm was at maximum value. This rather small variance suggests that both the tyre's structure and composition probably have a larger influence than expected, or that the rolling noise emission of the larger tyre width is compensated by another parameter of the tyre (e.g. due to a different construction of the body ply given by the varied speed index of the three tyres).

Table III. Main influencing parameters and their significance level to the mean rolling noise emission for all the tyres analysed within this study on common road surfaces. The asterisk indicates the significance of a parameter at α=0.05.

main influence parameters	level of significance (α=0.05)
tyre's width	0.03*
tyre's radius	0.12
rubber hardness (side wall)	0.12
EU label for rolling resistance	0.15
rubber hardness (profile)	0.17

Since little information of either the tyre's structure or composition is known, a multivariate regression analysis (stepwise forward selection) was performed with all the available parameters as independent variables - both the tyre's radius and width, aspect ratio, speed index, rolling resistance, rubber hardness (ShoreA) at the profile and sidewall as well as the load index of all the analysed tyres within this study. The analysis resulted in a coefficient of determination (R^2) of 0.76 describing the mean rolling noise emission at all common road surfaces (exclusively the low noise road surface) with the parameters of both the tyre's width and radius, rubber hardness and the EU label for rolling resistance (see Table III). It was found that the tyre's width resulted in a significant increase (significance level, α=0.05) in rolling noise emission. The other parameters describe the rolling noise emission at significance between 0.12 and 0.17.

To investigate the effect of silent tyres in combination with low noise road surfaces, a separate multivariate regression analysis for the SDA4-12 low noise road surface type was performed. It resulted in a R^2 of 0.47 whereas the parameters EU label for rolling resistance, tyre's width and rubber hardness describe the rolling noise emission of the tyres on a low noise road surface. The influence of the tyre's radius on the rolling noise emission on a low-noise road surface seems to be negligible. Furthermore, it was found that the tyre's width on a low noise road surface only has a small contribution of 0.06 (compared to 0.21 on common road surfaces) to the R^2 of 0.47. Thus, the tyre's width seems to have a significantly smaller effect on the rolling noise emission in combination with low noise road surfaces compared to common road surfaces. This is in contrast to common road surfaces, where the tyre's width shows a significant influence on the rolling noise emission (see Sect. 3.2). This can be explained by the decreasing importance of the horn-effect on absorbing road surfaces (while the horn-effect itself is influenced by tyre width).

3.4. Future Trends and Scenarios

The study showed that the parameters of tyre's radius and width, rolling resistance label and rubber hardness describe the rolling noise emission. The development of these parameters in terms of future market trends lead to other possible scenarios regarding tyre/road noise emissions. Moreover, the noise reduction potential originating from silent tyres can be estimated using different assumptions regarding the adoption rate of the market.

It was shown that ageing rates of the rolling noise emission of several tyre models do not significantly vary (see Sect. 3.2). Since the tyre rubber hardness of a statistical vehicle fleet is assumed to remain constant over time, this parameter can be neglected in the development of trend scenarios. Thus, important parameters to evaluate future trends of noise reduction potential of silent tyres are both the tyre's width and radius and the tyre's structure. The study [17] showed the development of tyre's radius (rim size) and tyre's width from 2005 and 2015 in Switzerland. An increase in mean tyre radius (rim size) of 0.7 inch and an increase in the mean tyre width of 9 mm in this period were claimed (see Figure 7). According to these developments within this period, combined with the findings of this study, the future trend scenarios of the noise reduction potential of silent tyres were estimated and indexed by today's potential.

Assuming that the increase in tyre's width linearly increases, a tyre width of 212 mm in 2030 is predicted. Thereby, a mean noise reduction potential for all tyre's width is estimated at about 1.5 dB according to Sect. 3.2. If the future development in tyre structure and rubber composition would also result in a noise reduction potential of 3.5 dB (as found for the tyre width of 185 mm) a significantly larger noise reduction potential in 2030 would be achieved. The light green area in Figure 7 shows this trend as the best case of the noise reduction potential originating from silent tyres until 2030.

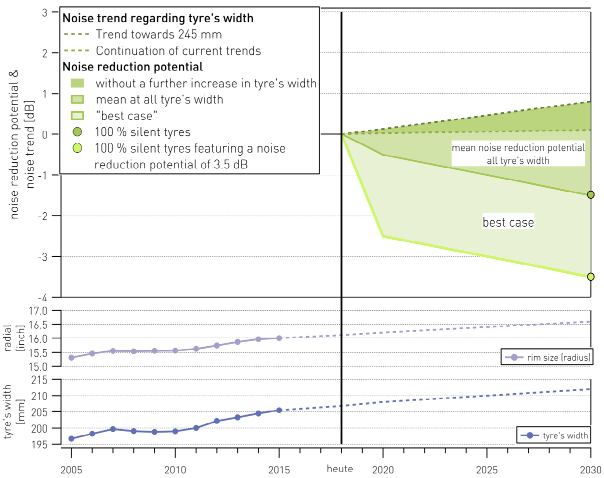

Figure 7: Trend scenarios of the noise reduction potential due to the increase in use of silent tyres and noise trend according to the increase in tyre width (top). Possible trends of rim size (tyre's radial) and tyre's width (bottom).

4. Conclusions

The study evaluated the noise reduction potential of common market tyres on the most frequently used road surfaces in Switzerland and elsewhere in Europe. It revealed that the simplified measurement procedure with a modified CPX trailer is suitable for predicting coast-by rolling noise emissions according to UN/ECE Reg. 117 with relatively high accuracy: uncertainties are estimated at 0.5 dB for the critical mid-frequency range. The advantage of the simplified measurement procedure with the modified CPX trailer is that only two instead of four tyres are needed to measure the specific rolling noise emission of the tyres and that the measurements on different road surfaces can be performed in a much more efficient way.

A noise reduction potential of 1 to 3.5 dB within the analysed tyre's widths was found. In contrast to findings of previous studies, the noise reduction potential was found to be similarly high on all 10 assessed common road surfaces. Thus, a high adoption rate of silent tyres would potentially lead to a noise reduction that corresponds to a halving of the number of vehicles. While the study was performed with new (but run-in) tyres, the results seem also be valid for an aged set of tyres as it may be present in a statistical vehicle mix, as a complementary study suggests.

Furthermore, the study revealed that the main influencing parameters defining the rolling noise emission on the tyre side are: tyre width and tyre radius, rubber hardness and the EU label for rolling resistance yielding in a high coefficient of determination.

Future trend scenarios were estimated according to recent tyre trends (increase in tyre's width and tyre's radius). Based on these trends a slight to moderate increase in noise emission originating from tyres is expected. If the adoption of silent tyres increased in the future, the noise emission could be reduced by a few decibels. Assuming that the noise reduction potential of 185 mm tyres can be achieved for all tyre widths, a noise reduction potential of 3.5 dB may be possible in the case of full adoption of silent tyres.

According to these results it is recommended for policy makers to increase efforts regarding the proliferation and distribution of silent tyres as rolling noise emission may be decreased considerably. This could either be done by increasing the attractiveness and meaningfulness of the tyre label for the consumer or by designing other mechanisms that boost the proliferations of silent tyres. The promising combination of silent tyres with low noise road surfaces provides an opportunity for a targeted optimization of the interaction with the aim of increasing the joint noise reduction potential. Furthermore, we recommend investigating the noise reduction potential in future developments in tyre equipment of electric vehicles as well as autonomous driving (power transmission versus downsizing of tyres). Future projects are planned to tackle these issues.

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