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Materials Science and Technology

Comparison of CNOSSOS-EU (Road) & sonROAD18

Imprint

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Contents

Abstract

The European CNOSSOS-EU model describes, among others, a road traffic noise emission calculation method and proposes default internal parameters. The current Swiss road traffic noise engineering model sonROAD18 also consists of a calculation method and a corresponding source database derived from measurement campaigns in Switzerland. This report compares the two models formally and by emission calculation results. The model structures and algorithm of CNOSSOS-EU and sonROAD18 are very similar. For the two relevant noise sources, i.e. propulsion noise and rolling noise, the calculations are nearly identical.

Differences between the models are identified in their detailed descriptions. Apart from that, sonROAD18 calculates spectra in 3rd octave bands, whereas CNOSSOS-EU in full octave bands. It is demonstrated that the existing differences only minimally affect the overall A-weighted emission levels in the standard geometry. Using their default internal parameter sets, considerable differences of up to 3.8 dB(A) between the models' results were found. However, using Swiss input data, average differences between calculated emission levels with the CNOSSOS-EU model and the sonROAD18 model are **below 0.5 dB(A)**. This leads to the conclusion that sonROAD18 has a high level of conformity with CNOSSOS-EU.

1. Mandate

By contract from 25 May 2021 the Laboratory for Acoustics/Noise Control at Empa, the Swiss Federal Laboratories for Materials Science and Technology, was mandated by the Swiss Federal Office for the Environment (FOEN) to conduct a study on road and aircraft noise emission modeling (Empa project number 5214.027361). This involved comparisons of the following emission models regarding model structure and calculation results of relevant exposure cases. The results are documented in separate reports, namely, the comparison of (i) the Swiss sonROAD18 and CNOSSOS-EU road traffic noise emission models in Empa report No. 5214.027361-1, (ii) the Swiss FLULA2 and CNOSSOS-EU aircraft noise engineering models in Empa report No. 5214.027361-2, and (iii) the Swiss sonAIR and CNOSSOS-EU aircraft noise engineering models in Empa report No. 5214.027361-3.

These comparisons were made with the goal to assess the conformity of sonROAD18, FLULA2 and sonAIR with CNOSSOS-EU. They are a follow-up of the comparison of railway noise models [1].

The **present report No. 5214.027361-1** documents the comparison of the road traffic noise models **sonROAD18 and CNOSSOS-EU**.

2. Introduction

In 2002 the Environmental Noise Directive (END) [2] on the assessment and management of environmental noise was adopted in the European Union (EU). Its original annex II about the assessment methods describes the adaptation of national computation methods. In 2015 the EU published the CNOSSOS-EU model [3], henceforth referred to as CNOSSOS, as a replacement of annex II of the END which among other noise sources describes a road traffic noise emission model. CNOSSOS describes a calculation method of road traffic noise emission and proposes default values for the model's internal parameters [3]–[5]. However, [2 (2.1.2)] states that *in the application of the method, the input data shall reflect the actual usage* and that *in general there shall be no reliance on default input values*.

CNOSSOS was twice corrected in 2018 [4] and 2020 [5]. These corrigenda affect the frequency range of road vehicles' sound power levels, the rolling noise and propulsion noise coefficients A and B and the road surface coefficients α and β.

The sonROAD18 road traffic noise emission model, developed by Empa and funded by FOEN, was published in 2018 [6]. It involved in-situ measurements on Swiss roads capturing regular traffic. The resulting data was used to develop the Swiss road traffic emission model consisting of a calculation algorithm and a corresponding internal parameter set.

In 2018 – 2021, sonROAD18 was upgraded with new vehicle categories (hybrid & electric vehicles, dedicated bus and tram models, agricultural vehicles) and an interface for the convenient use of CPX measurement results to derive road surface parameters.

3. Model comparison

The European 'CNOSSOS' model describes a calculation method for noise emission from road traffic and proposes default internal parameters. Similarly, the Swiss road traffic noise emission model sonROAD18 incorporates a calculation method and a corresponding internal parameter set, however derived from measurement campaigns in Switzerland. This report compares the two models formulaic and by their calculation results.

3.1. Commonalities

For the major part, the calculation approach in CNOSSOS and sonROAD18 is equivalent.

3.1.1. Vehicle categories

Both models include the following vehicle categories, which make up the largest share of the traffic volume:

- Light Motor Vehicles such as passenger cars and vans ≤3.5 t of permissible total weight
- Medium Heavy Vehicles with two axles such as vans, buses, or motorhomes >3.5 t
- Heavy Vehicles with three or more axles, with or without trailers
- Motorbikes with up to four wheels

3.1.2. Speed-dependent propulsion & rolling noise

Both models use the two parameters A, the level spectrum at reference speed $v_{\text{ref}} = 70\ \text{km/h}$, and B, the speed-dependent addend. As shown in formulae 1–4, A and B are used to calculate the propulsion noise $L_{W,P}$ originating from the drive train and the rolling noise $L_{W,R}$ resulting from the interaction of the vehicle's tyres with the road surface.

Going uphill or downhill has an influence on the engine load, which is considered based on the road's incline per $\Delta L_{W,P,\text{grad}}$. The type of road surface and temperature affect the noise emission from the tyres and thus the rolling noise which both models take into account per $\Delta L_{W,P,\text{road}}$ and $\Delta L_{W,R,\text{temp}}$. Terms written in green are exclusive to the respective model and are discussed separately in sections 3.2.7, 3.2.8, and 3.2.10.

sonROAD18	Formula 1	$L_{W,P} = A_P + B_P \cdot \frac{v - v_{\text{ref}}}{v_{ref}} + \Delta L_{W,P,\text{grad}}$
	Formula 2	$L_{W,R} = A_R + B_R \cdot \lg\left(\frac{v}{v_{\text{ref}}}\right) + \Delta L_{W,R,\text{road}} + \Delta L_{W,R,\text{temp}} + \Delta L_{W,R,\text{tyre}}$
CNOSSOS	Formula 3	$L_{W,P} = A_P + B_P \cdot \frac{v - v_{\text{ref}}}{v_{ref}} + \Delta L_{W,P,\text{grad}} + \Delta L_{W,P,\text{road}} + \Delta L_{W,P,\text{acc}}$
	Formula 4	$L_{W,R} = A_R + B_R \cdot \lg\left(\frac{v}{v_{\text{ref}}}\right) + \Delta L_{W,R,\text{road}} + \Delta L_{W,R,\text{temp}} + \Delta L_{W,R,\text{tyre}} + \Delta L_{W,R,\text{acc}}$

3.1.3. Total sound power level

The energetic sum of both propulsion and rolling noise gives the total sound power level.

sonROAD18	Formula 5	$L_W = 10 \cdot \lg\left(10^{\frac{L_{W,P}}{10}} + 10^{\frac{L_{W,R}}{10}}\right) + \Delta L_{W,\theta}$
CNOSSOS	Formula 6	$L_W = 10 \cdot \lg\left(10^{\frac{L_{W,P}}{10}} + 10^{\frac{L_{W,R}}{10}}\right)$

3.2. Differences in sonROAD18

The models differ in the following details.

3.2.1. 3rd octave bands

All spectral internal parameters in sonROAD18 are given in 3rd octave bands for a greater ease of using propagation models also formulated in 3rd octave bands. To adapt the calculated emission data to other propagation models with lower frequency resolution, the 3rd octave band levels within a full octave frequency band can simply be summed up energetically.

3.2.2. Valid speed range

Valid Speeds range from 20 km/h to 130 km/h for sonROAD18, whereas CNOSSOS widens that range by stipulating the sound power for vehicles going slower than 20 km/h to be the same as for 20 km/h. No upper speed limit is mentioned for CNOSSOS, but given the valid speed ranges in [2 (Table F-4)], 130 km/h can be assumed as the highest valid speed modelled.

3.2.3. Vehicle categories

The four shared vehicle categories mentioned above are enumerated differently. Furthermore, sonROAD18 features a more detailed separation of sub-categories, dedicated bus models, and adds electrified vehicles, agricultural machinery, and trams. However, the distinction between mopeds and motorcycles is neglected. Therefore, this comparison only regards the aforementioned (see section 3.1.1) four vehicle categories.

Table 1: SWISS10 vehicle categories used in sonROAD18 and their corresponding CNOSSOS vehicle categories
Adapted from [7 (Table 3.1)]

SWISS10 cat.	Description	CNOSSOS cor. cat.	Description
1	bus	3	heavy vehicle
1b	electrified/hybrid bus	-	
2	motorbike	4b	motorbike
3	passenger car	1	light motor vehicle
3b	hybrid passenger car	-	
3c	electrified passenger car	-	
4	passenger car with trailer	1	
5	van <3.5 t	1	light motor vehicle
6	van <3.5 t with trailer	1	light motor vehicle
7	van <3.5 t with semi-trailer	1	light motor vehicle
8	truck	2*	medium heavy vehicle
9	truck with trailer	3	heavy vehicle
10	truck with semi-trailer	3	heavy vehicle
11	electrified truck	-	

***** In [7 (Table 3.1)], the SWISS10 category 8 and the CNOSSOS category 3 are designated as corresponding. However, the broad overlap of the SWISS10 category 8 with the CNOSSOS category 2 also renders their comparison sensible. For the lack of a common descriptor and to avoid confusion with the heavy vehicle categories >7.5 t, this category will henceforth be pragmatically referred to as "vans >3.5 t" as in [4 (Table 2.2.a)]. The comparing plots (figures 7–9, 21–23) are headlined "Vans >3.5 t" as well.

3.2.4. Reference temperature

The reference temperature in sonROAD18 is 10°C opposed to 20°C in CNOSSOS.

3.2.5. Tyres

sonROAD18 is prepared for rolling noise calculations for varying types of tyres, although data representative for the Swiss vehicle fleet is still to be obtained. CNOSSOS offers a correction for studded tyres.

3.2.6. Surfaces

The reference road surfaces in the two models differ: ACMR8 is the representative surface in Switzerland and therefore the reference ($\Delta L_{W,R,\mathrm{road}} = 0$) in sonROAD18.

In CNOSSOS, the average of ACMR 11 and SMA 11 is taken as the virtual reference surface [2 (2.2.2)].

3.2.7. Surface-dependent engine & rolling noise

In contrast to CNOSSOS, sonROAD18 applies the surface-dependent level correction only to the rolling noise and ,moreover, does not consider the vehicle's speed. Therefore, the corresponding correction term directly represents a pavement property. This simplification has no relevant effect on the calculations' quality [7].

3.2.8. Acceleration-dependent engine & rolling noise

Unlike CNOSSOS, sonROAD18 neglects the vehicle's current distance to or from a junction where vehicles brake towards and accelerate from. The effect on the engine load can, however, be assessed via equivalent inclines (see $\Delta L_{W,P,\mathrm{grad}}$ in formula 1) as shown in [7]. An effect on the rolling noise is not considered by sonROAD18.

3.2.9. Incline correction terms

At inclines, the propulsion noise generated by all vehicle categories >3.5 t are uniformly corrected in sonROAD18, whereas CNOSSOS specifies a separate incline correction arithmetic for vans >3.5 t:

sonROAD18	Formula 7	$$\Delta L_{W,P,\mathrm{grad}}\ (> 3.5\ \mathrm{t}) = \begin{cases} \frac{\min(-s, 12\%) - 4\%}{0.5\%} \cdot \frac{v-10}{100} & : \quad s < -4\% \\ 0 & : \quad -4\% \le s \le 0\% \\ \frac{\min(s, 12\%)}{0.8\%} \cdot \frac{v}{100} & : \quad s > 0\% \end{cases}$$
CNOSSOS	Formula 8	$$\Delta L_{W,P,\mathrm{grad}}\ (\mathrm{vans} > 3.5\ \mathrm{t}) = \begin{cases} \frac{\min(-s, 12\%) - 4\%}{0.7\%} \cdot \frac{v-20}{100} & : \quad s < -4\% \\ 0 & : \quad -4\% \le s \le 0\% \\ \frac{\min(s, 12\%)}{1\%} \cdot \frac{v}{100} & : \quad s > 0\% \end{cases}$$

3.2.10. Radiation directivity

In favour of a realistic inclusion of noise protection structures and exposure calculation for elevated receivers, sonROAD18 considers the radiation directivity to be non-omni-directional. To model this feature, the term $\Delta L_{W,\theta} = D_1(c) \cdot \sin(\theta)^3 \cdot \left(\lg(f) + D_2(c)\right)^3$ depending on vehicle category c and frequency f was introduced to the calculation of the total sound power (formula 5). Motorbikes are considered omni-directional.

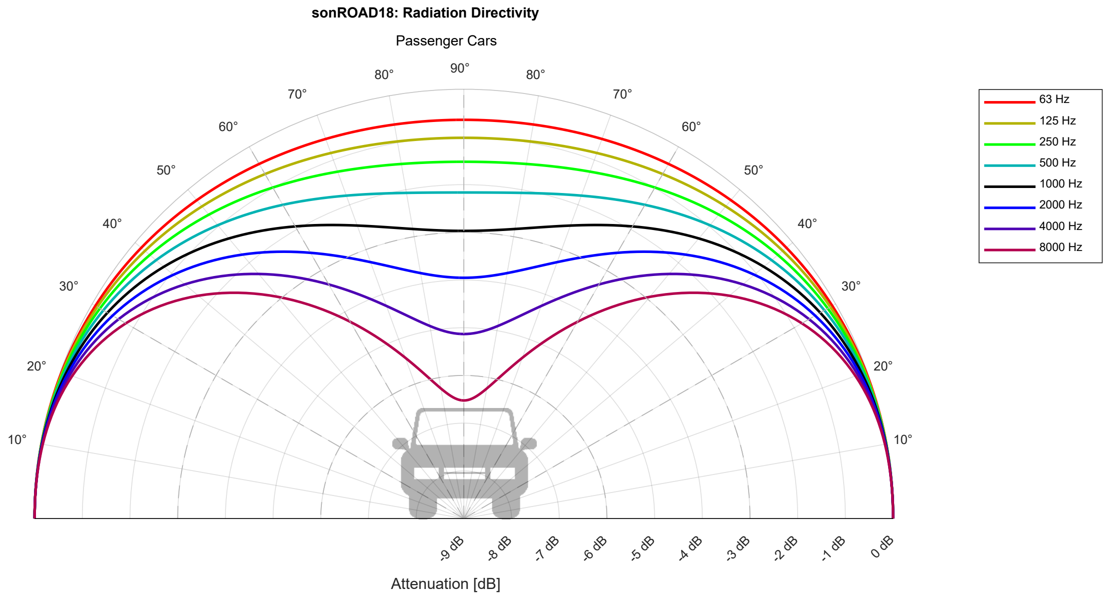

Figure 1: Radiation directivity of cars in sonROAD18

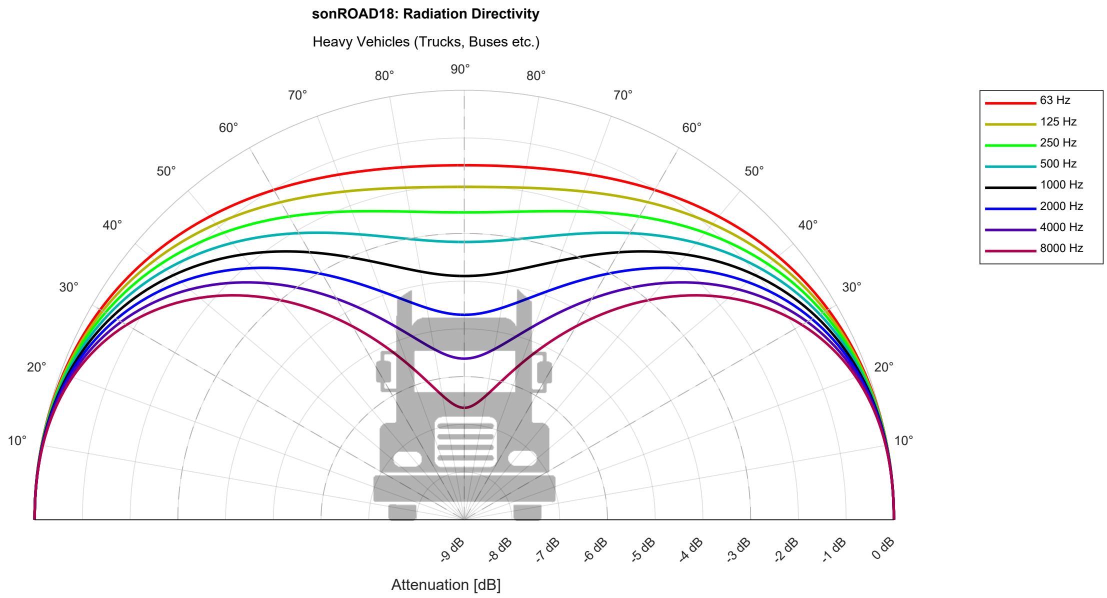

Figure 2: Radiation directivity of heavy vehicles in sonROAD18

4. Comparison of calculation results

The two models' results are compared in three steps:

1. Comparing individual calculation results with each model's default internal parameters and identical inputs, i.e. reference road surfaces, equivalent vehicle categories, normal tyres, an air temperature of 15°C (the average of both reference temperatures), no inclination, acceleration or deceleration.
   With this comparison, the disparity of the obtained internal parameters of the models becomes obvious which is due to different vehicle fleets and road surfaces. For passenger cars going 20 km/h, CNOSSOS calculates a total level 3.8 dB(A) higher than sonROAD18, which is the maximum difference occurring between the two models (see p. 10, 4.1.1).
   Spectra calculated by sonROAD18 are converted from 3rd to the lower full-octave resolution.

2. Comparing CNOSSOS calculations using the CNOSSOS algorithm, but sonROAD18's internal parameters vs. sonROAD18 calculations
   With this comparison, the formulaic conformance of both algorithms becomes obvious. The differences in total levels of up to only 0.3 dB(A) are due to rounding errors occurring at the conversion of the correction terms $\Delta L_{W,\ldots}$ from 3rd octaves to full octaves (max. 2.3 dB @ 63 Hz, see Figure 16, Motorbikes going 130 km/h).
   Spectra calculated by sonROAD18 are converted from 3rd to the lower full-octave resolution.

3. Exemplary calculations demonstrating features exclusive to sonROAD18

In the following figures, data points acquired with the CNOSSOS algorithm are plotted in blue, those from sonROAD18 in red. Since sonROAD18's frequency resolution is in 3rd octaves and added up to octave bands, the primal result in 3rd octaves is plotted as well in faint red.

To clearly distinguish CNOSSOS data obtained with the original internal parameters from those generated with converted sonROAD18 values, 'CNOSSOS (default)' and 'CNOSSOS (CH)' are used in the legends.

All results are calculated at the reference speed (70 km/h), the lowest valid speed (20 km/h), and the common inner-city speed limit (50 km/h). On highways, cars and motorbikes can reach higher speeds and are therefore additionally compared at 130 km/h, i.e., the highest valid speed.

4.1. CNOSSOS with default internal parameters vs sonROAD18

4.1.1. Passenger cars (CNOSSOS category 1, sonROAD18 category 3)

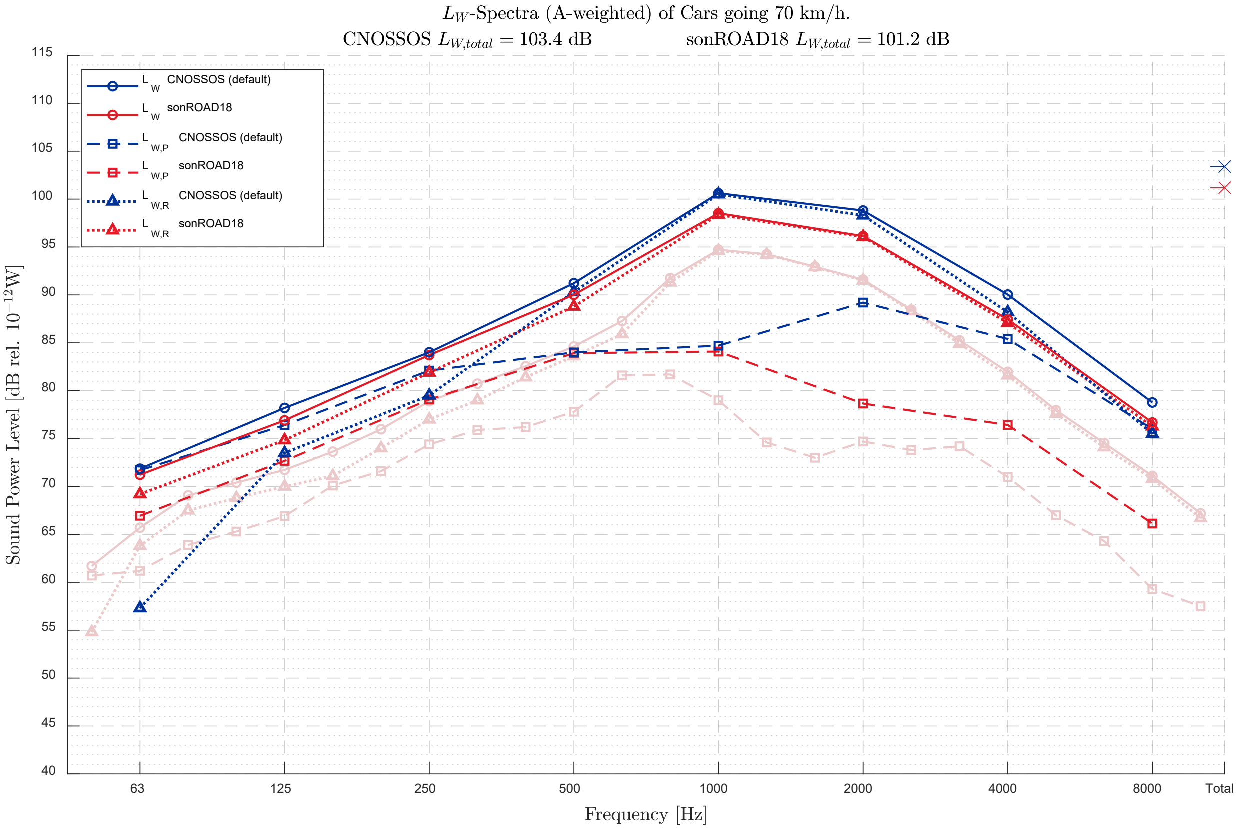

Figure 3: Comparison of sound power spectra (passenger cars, default internal parameters, 70 km/h)

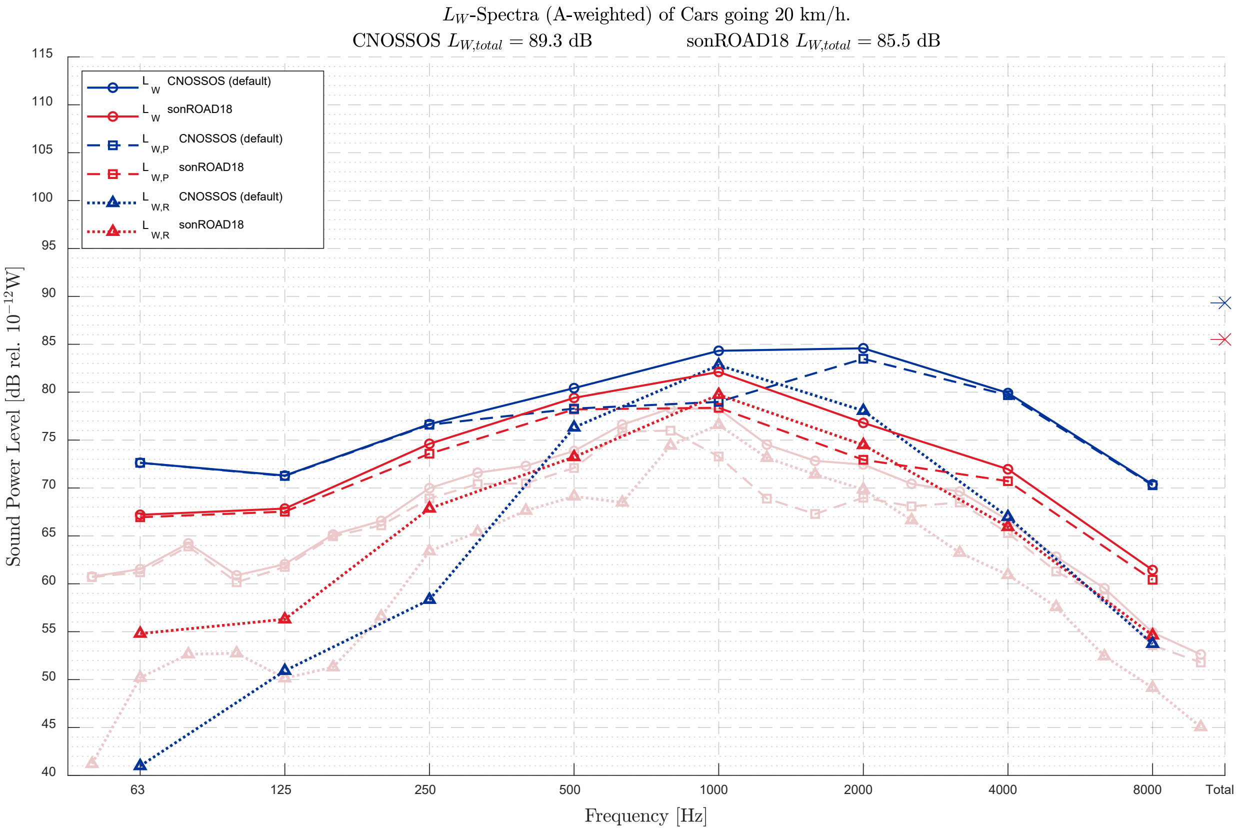

Figure 4: Comparison of sound power spectra (passenger cars, default internal parameters, 20 km/h)

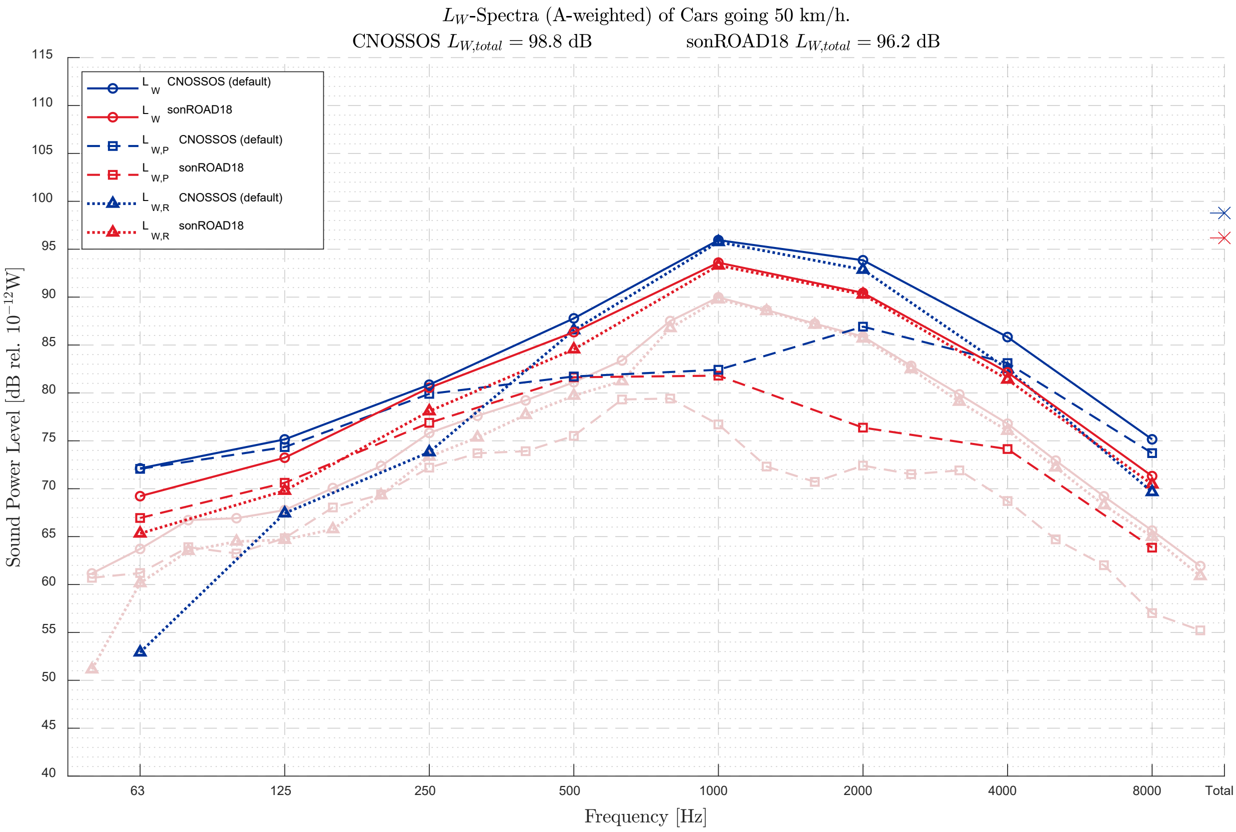

Figure 5: Comparison of sound power spectra (passenger cars, default internal parameters, 50 km/h)

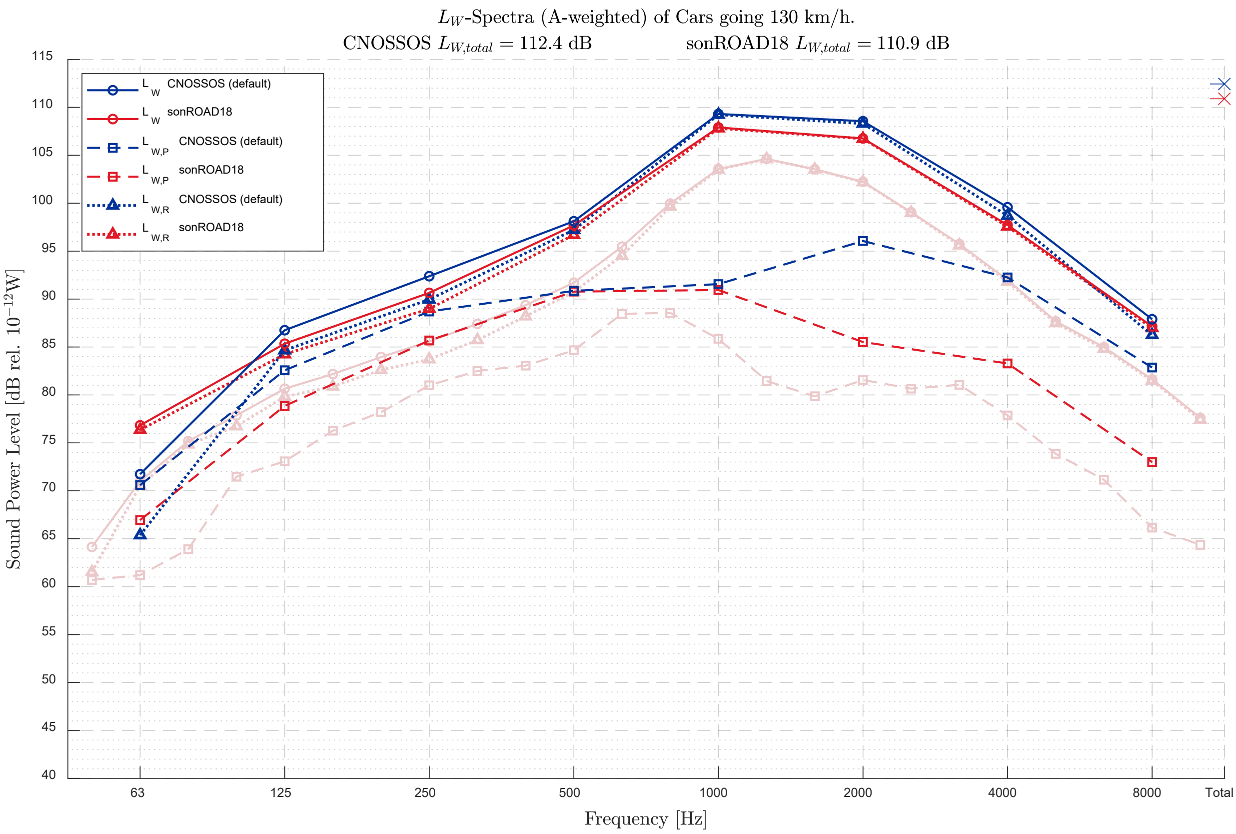

Figure 6: Comparison of sound power spectra (passenger cars, default internal parameters, 130 km/h)

4.1.2. Vans >3.5 t (CNOSSOS category 2, sonROAD18 category 8)

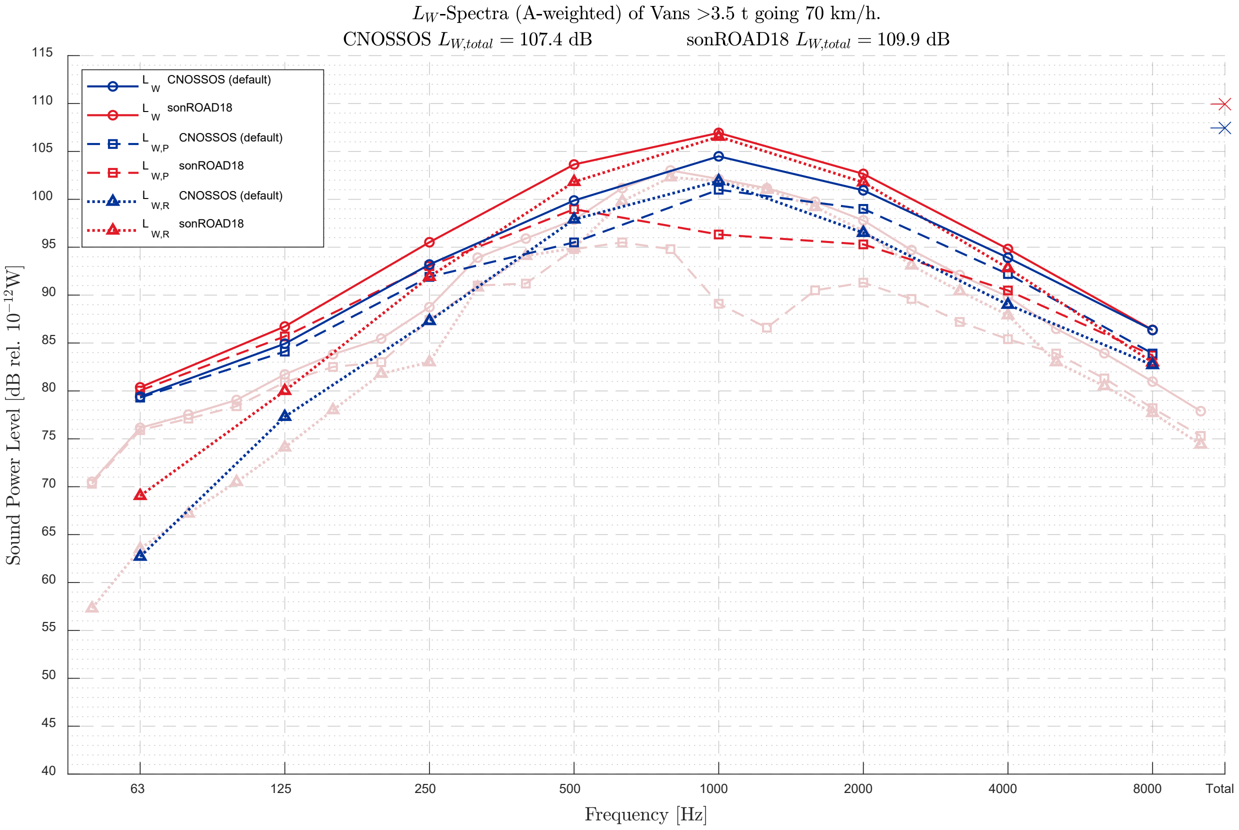

Figure 7: Comparison of sound power spectra (vans >3.5 t, default internal parameters, 70 km/h)

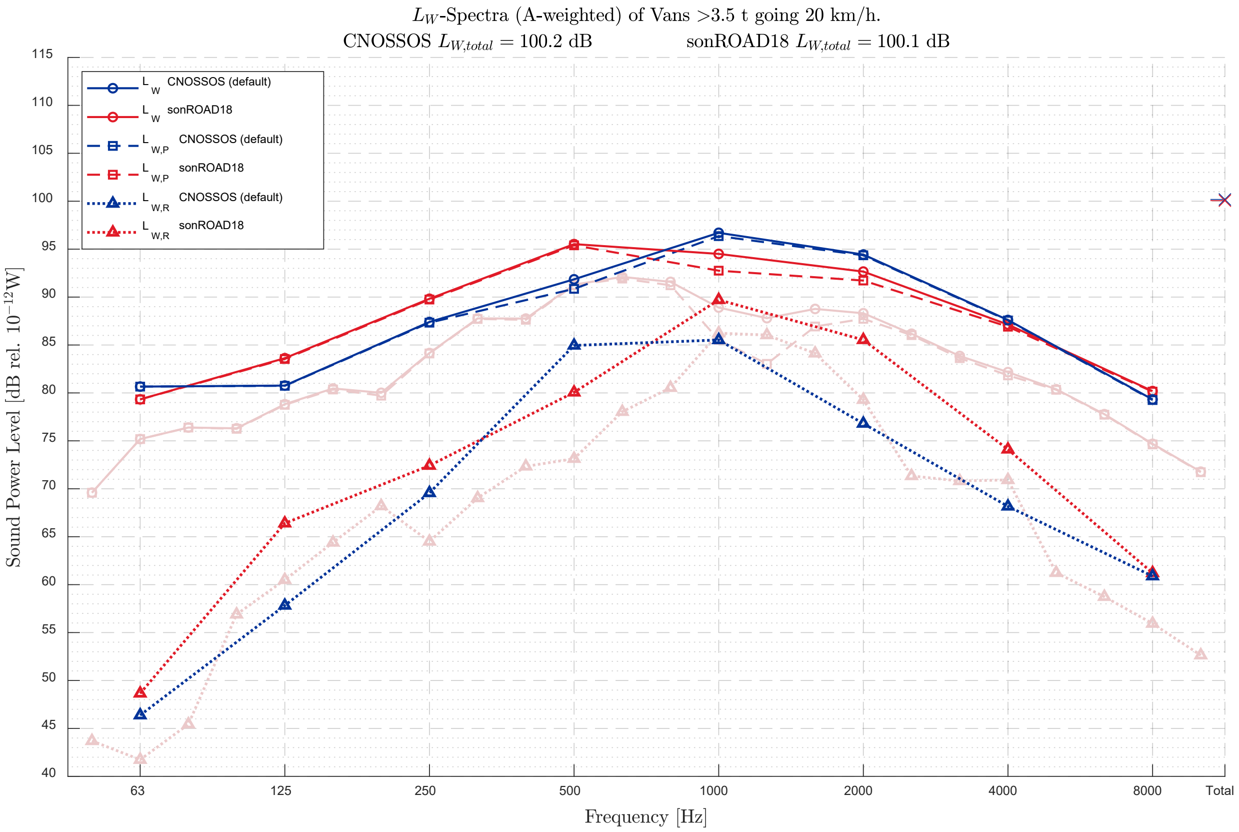

Figure 8: Comparison of sound power spectra (vans >3.5 t, default internal parameters, 20 km/h)

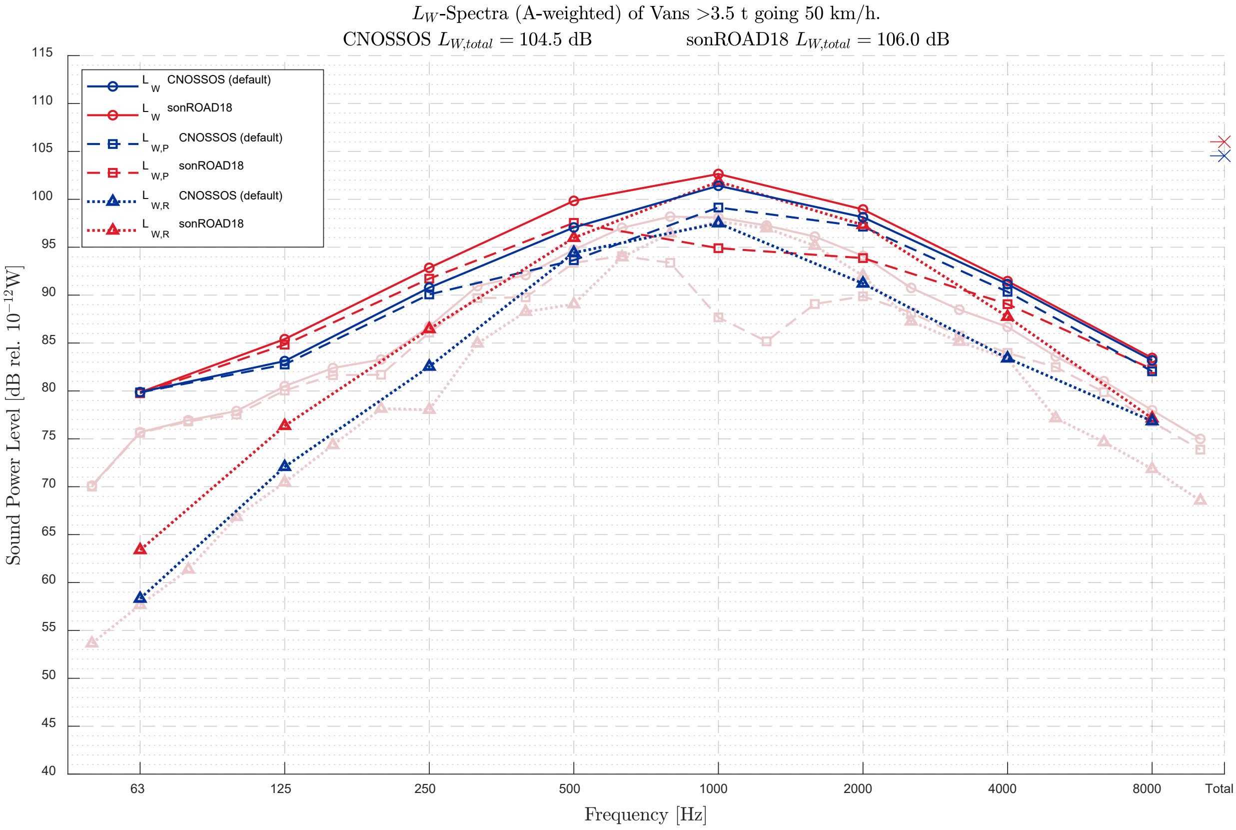

Figure 9: Comparison of sound power spectra (vans >3.5 t, default internal parameters, 50 km/h)

4.1.3. Trucks with trailers (CNOSSOS category 3, sonROAD18 category 9)

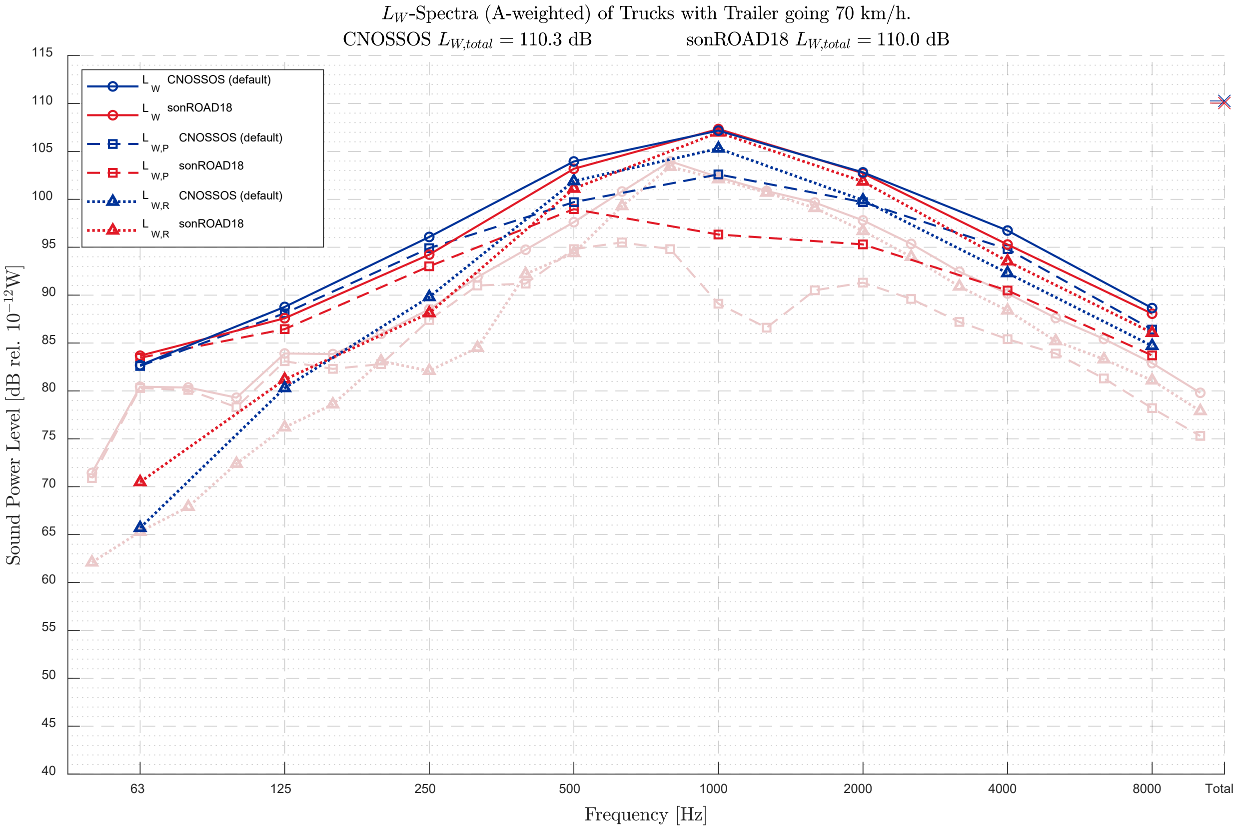

Figure 10: Comparison of sound power spectra (trucks with trailer, default internal parameters, 70 km/h)

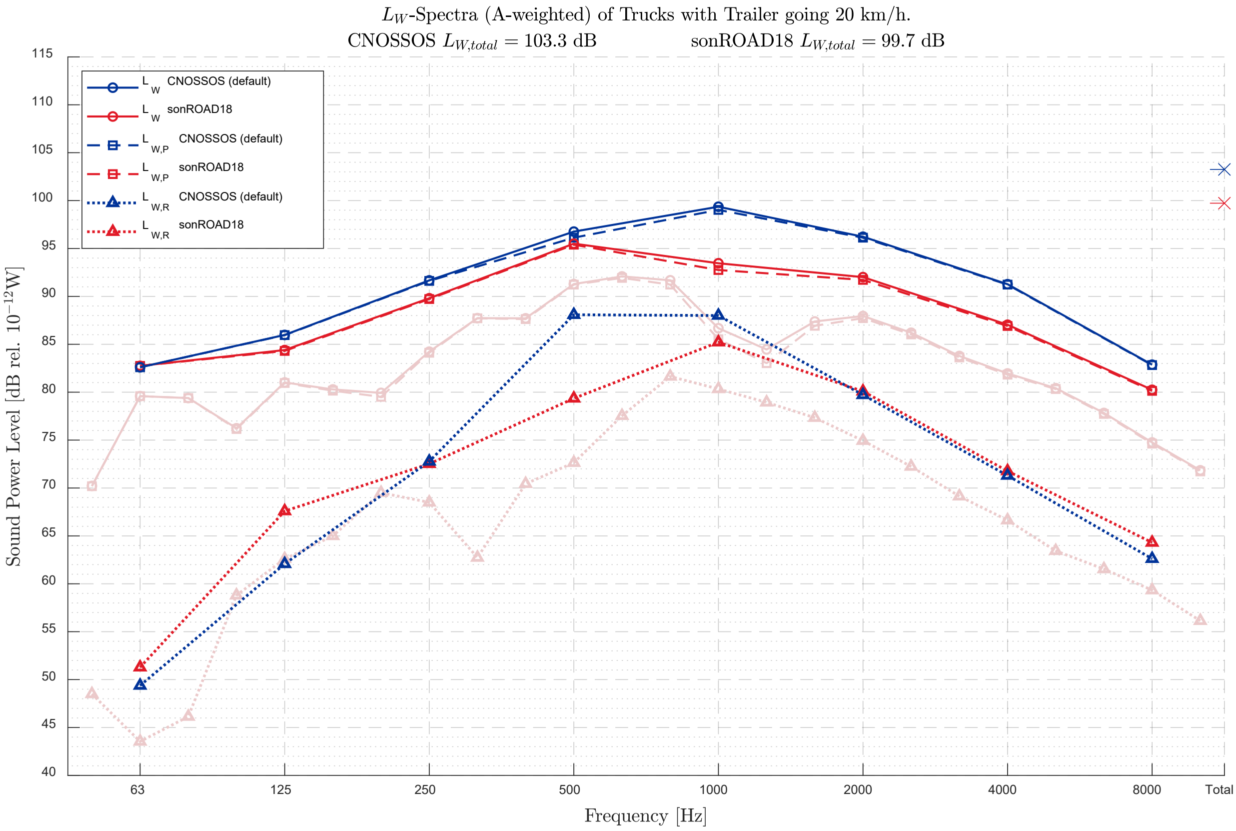

Figure 11: Comparison of sound power spectra (trucks with trailer, default internal parameters, 20 km/h)

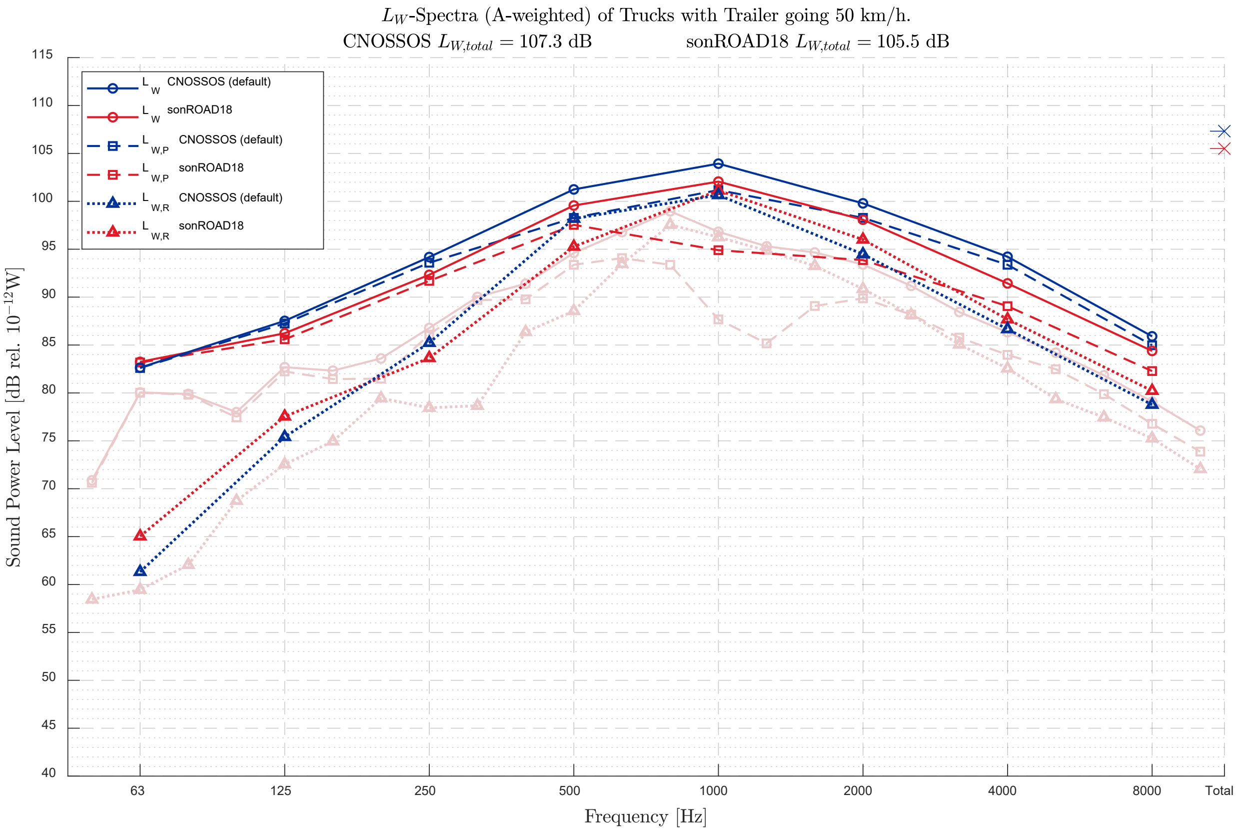

Figure 12: Comparison of sound power spectra (trucks with trailer, default internal parameters, 50 km/h)

4.1.4. Motorbikes (CNOSSOS category 4b, sonROAD18 category 2)

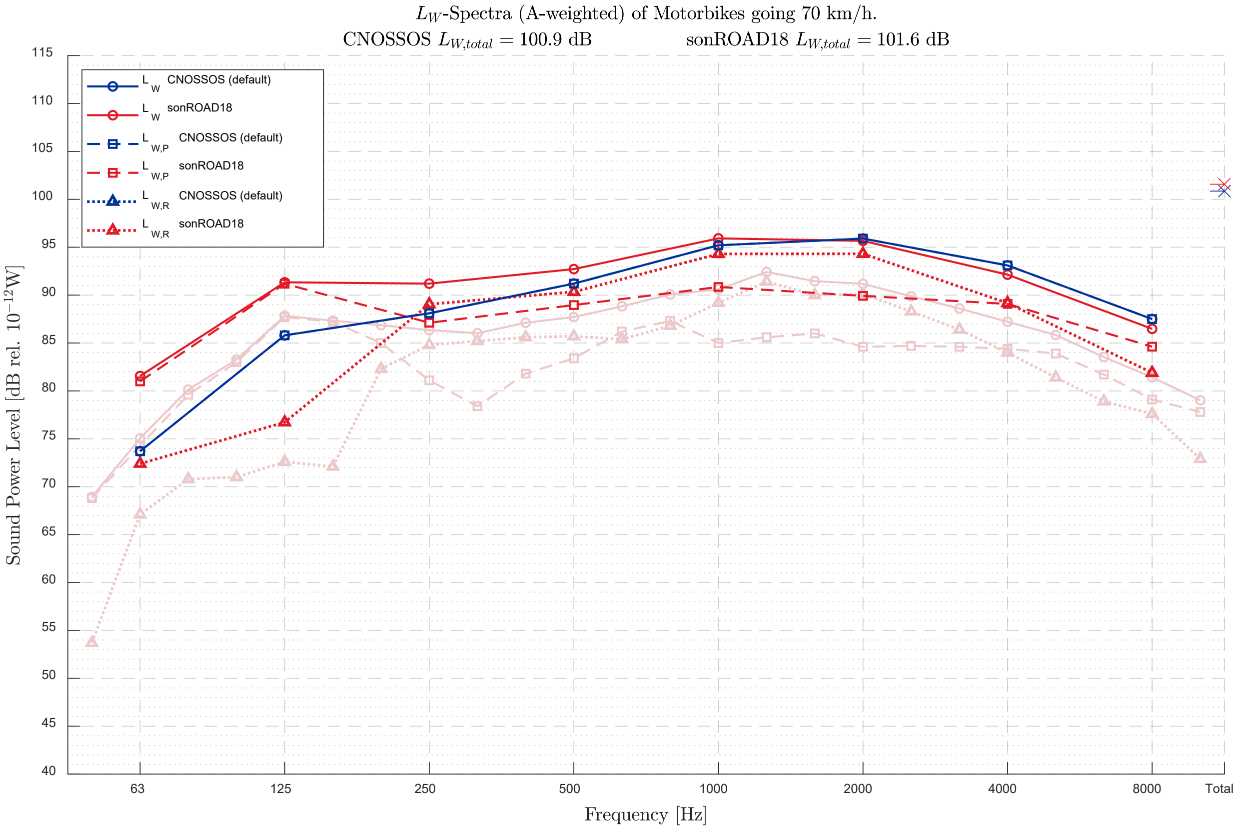

Figure 13: Comparison of sound power spectra (motorbikes, default internal parameters, 70 km/h)

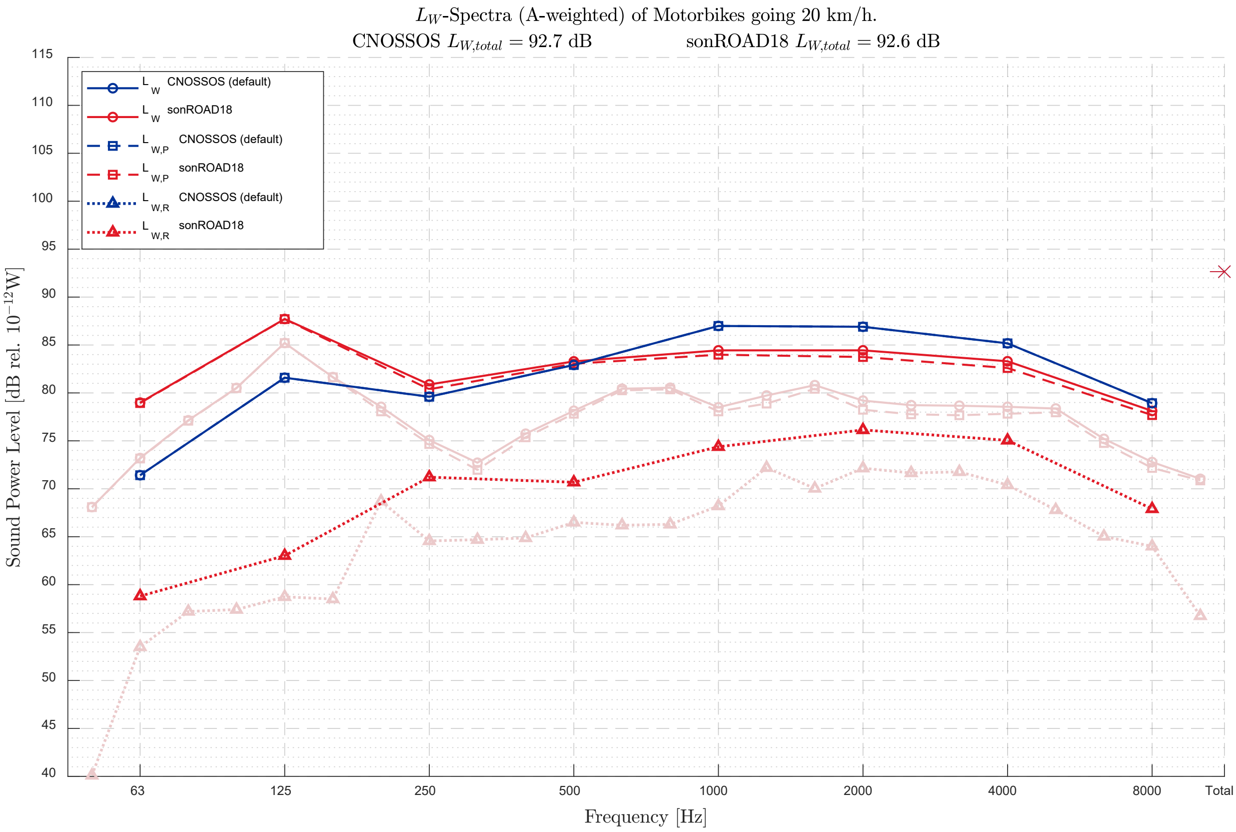

Figure 14: Comparison of sound power spectra (motorbikes, default internal parameters, 20 km/h)

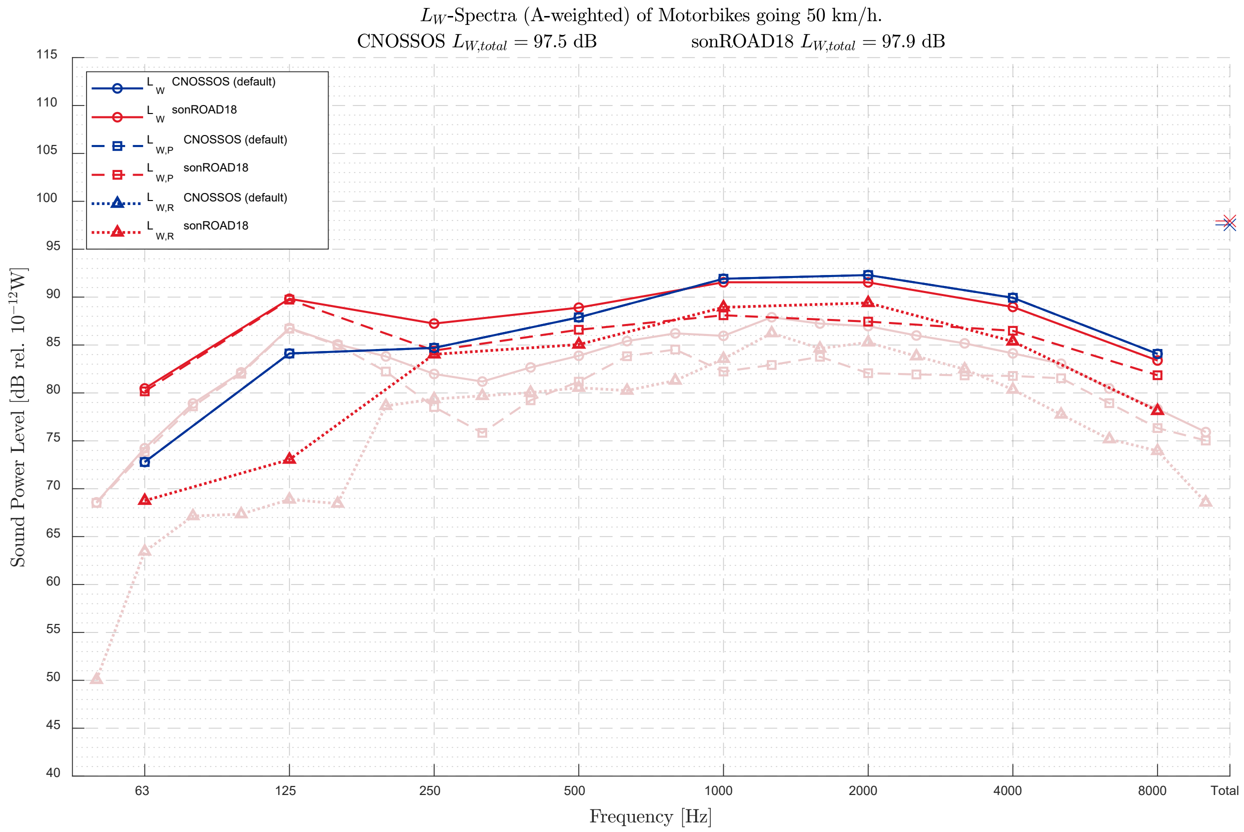

Figure 15: Comparison of sound power spectra (motorbikes, default internal parameters, 50 km/h)

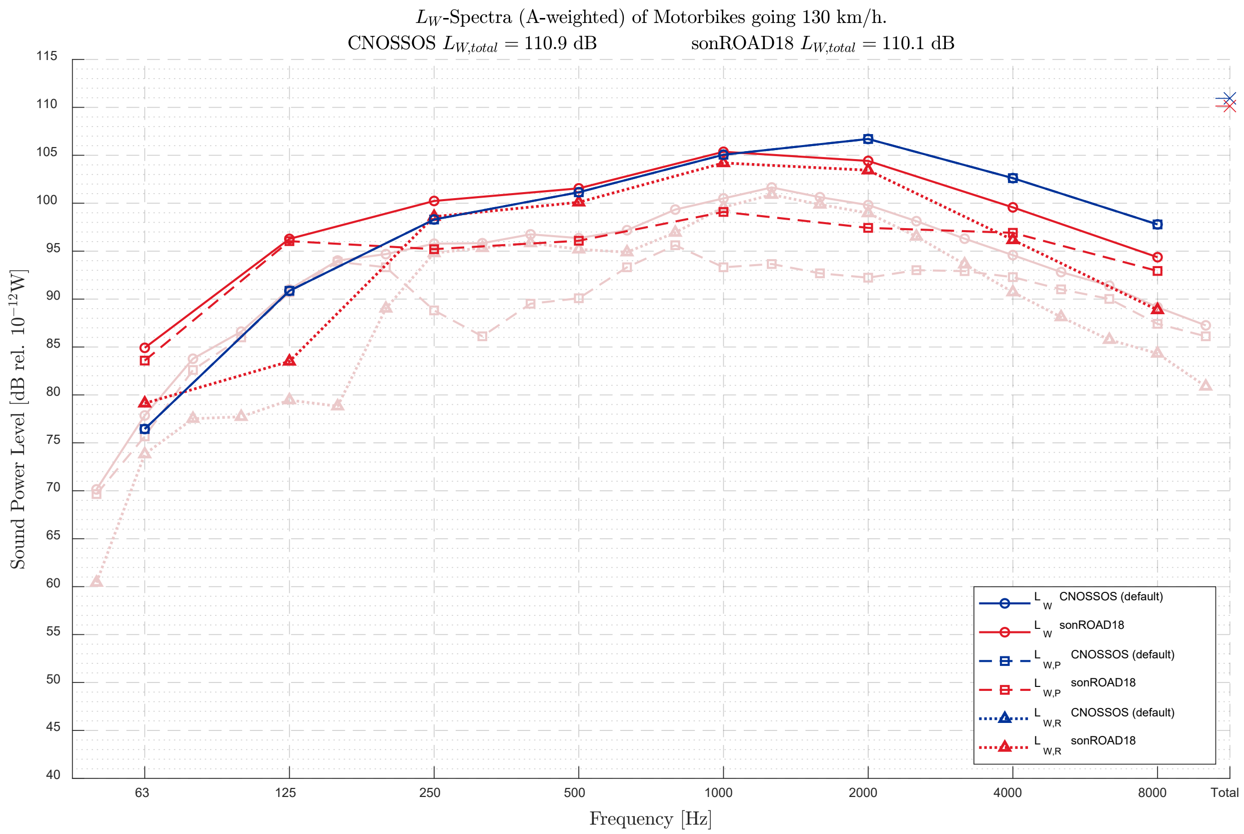

Figure 16: Comparison of sound power spectra (motorbikes, default internal parameters, 130 km/h)

4.2. CNOSSOS with sonROAD18's internal parameters vs sonROAD18

4.2.1. Passenger cars (CNOSSOS category 1, sonROAD18 category 3)

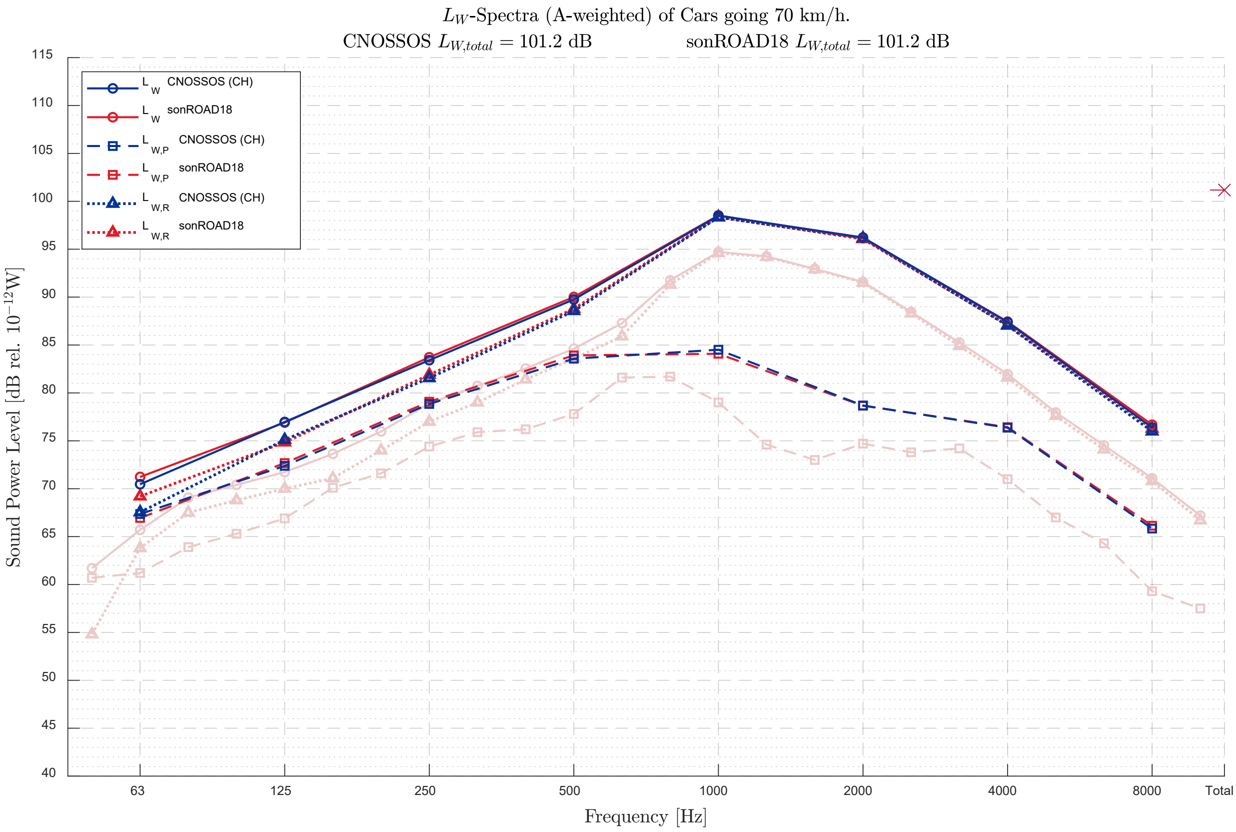

Figure 17: Comparison of sound power spectra (passenger cars, adapted internal parameters, 70 km/h)

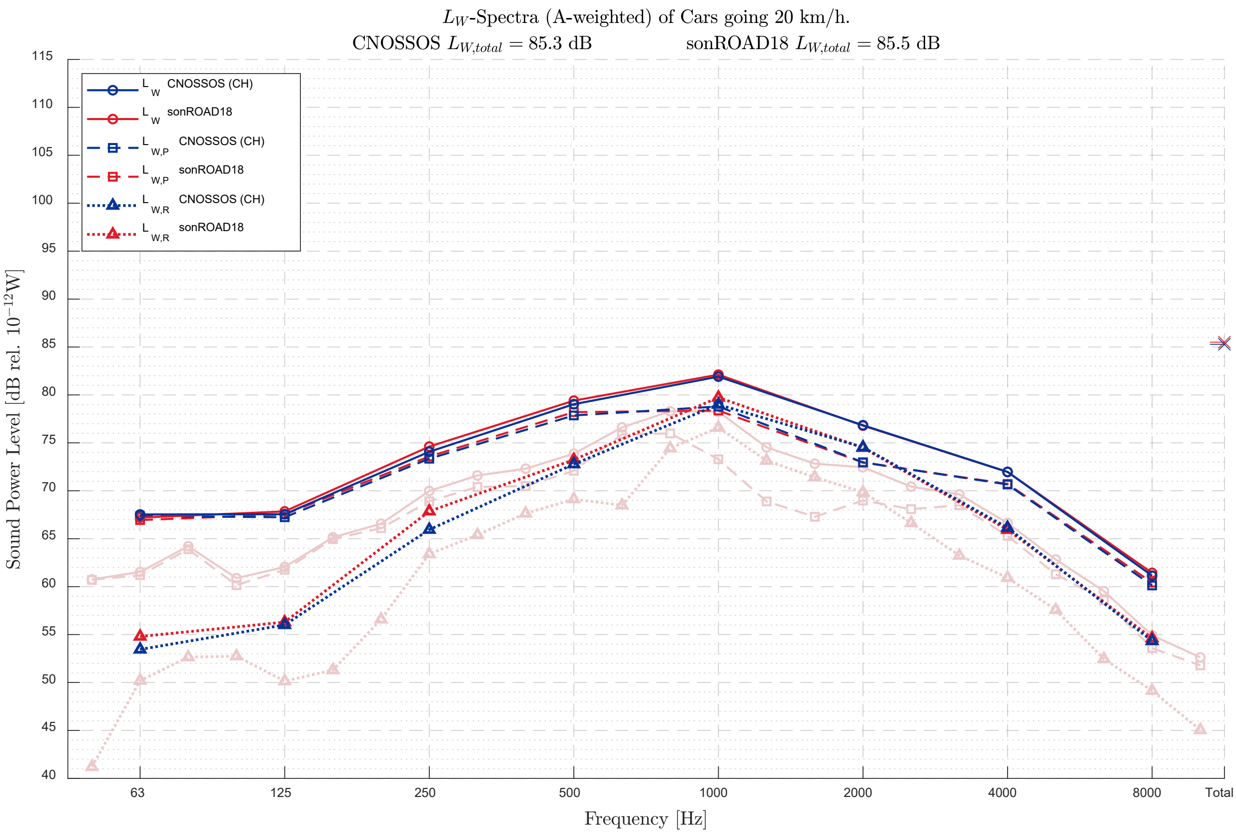

Figure 18: Comparison of sound power spectra (passenger cars, adapted internal parameters, 20 km/h)

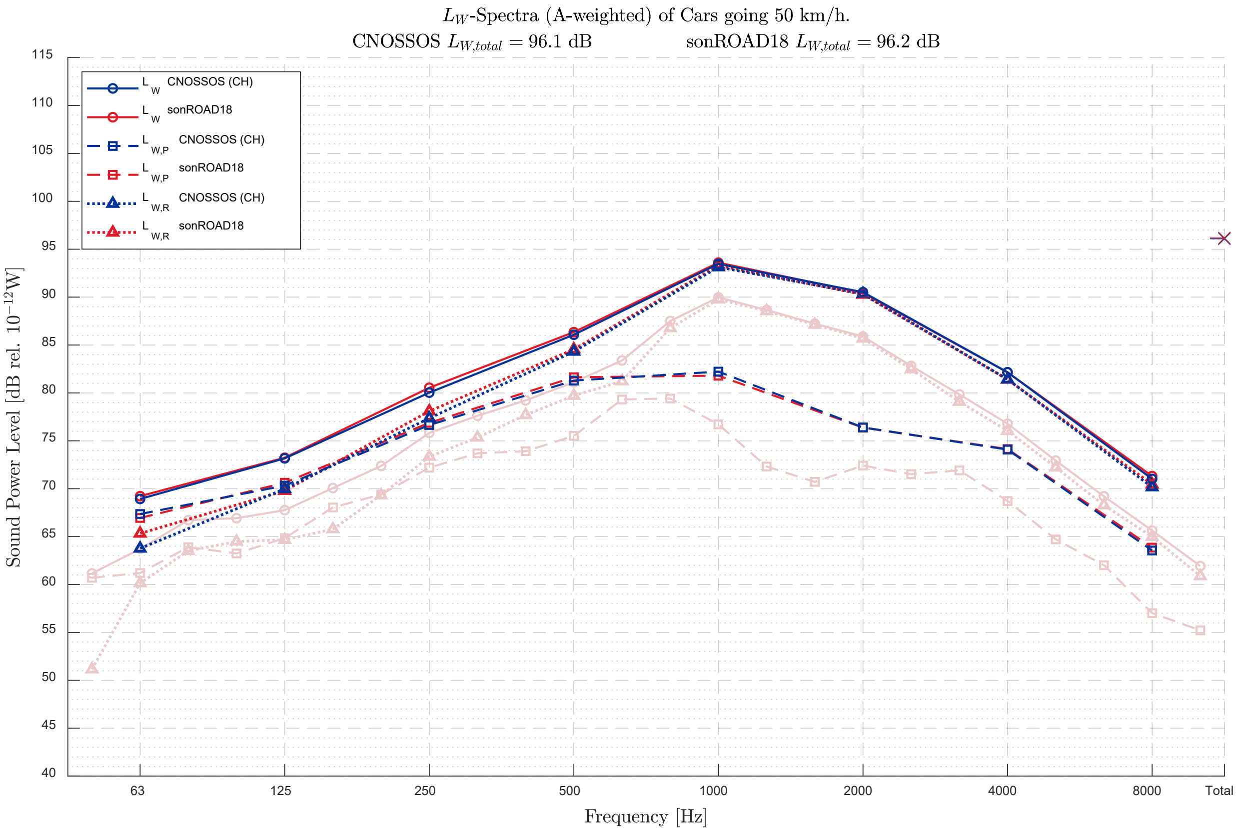

Figure 19: Comparison of sound power spectra (passenger cars, adapted internal parameters, 50 km/h)

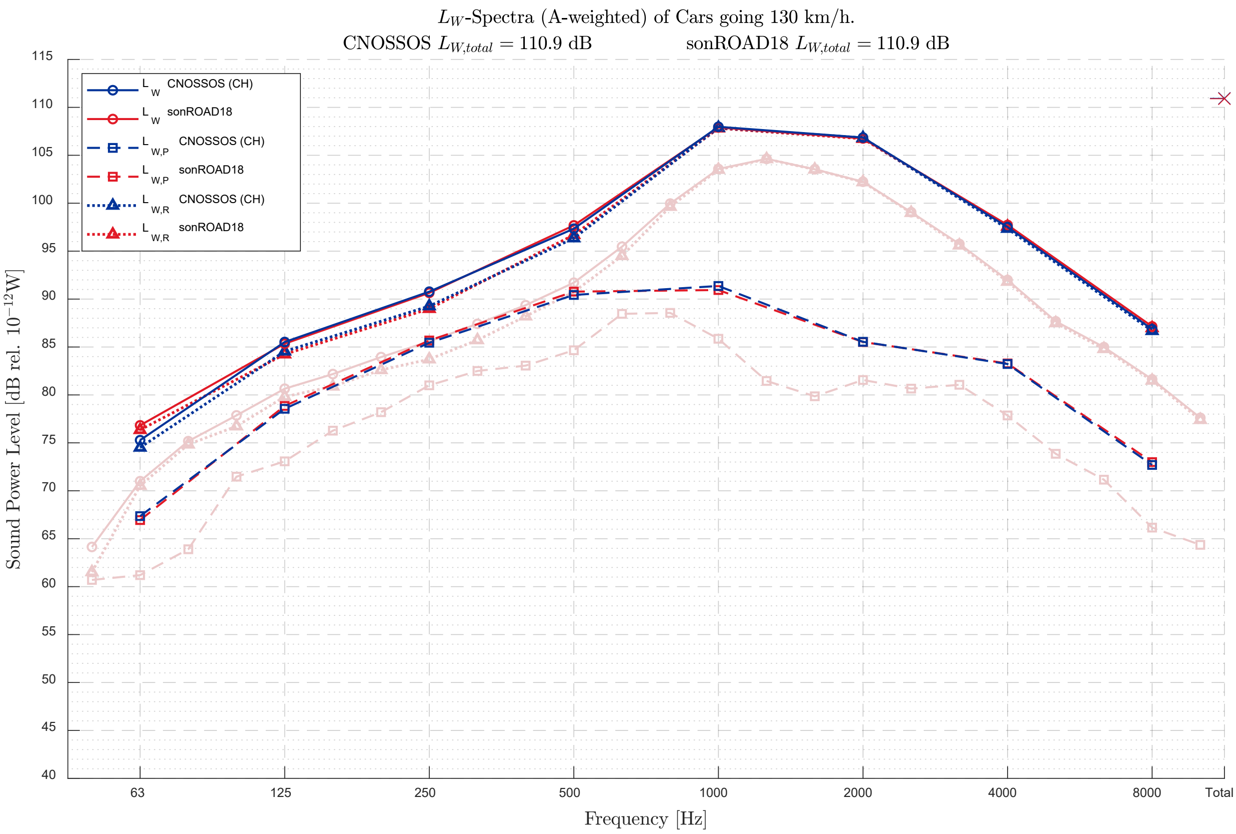

Figure 20: Comparison of sound power spectra (passenger cars, adapted internal parameters, 130 km/h)

4.2.2. Vans >3.5 t (CNOSSOS category 2, sonROAD18 category 8)

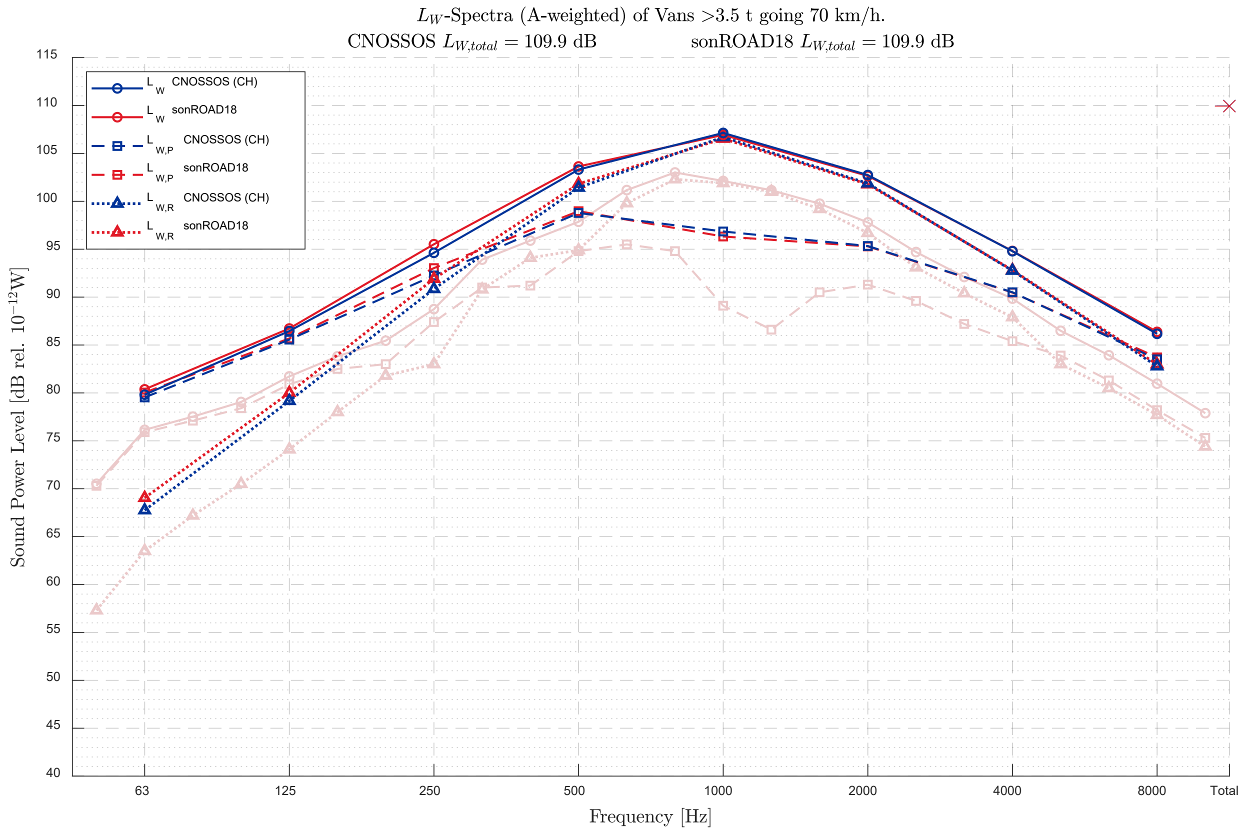

Figure 21: Comparison of sound power spectra (vans >3.5 t, adapted internal parameters, 70 km/h)

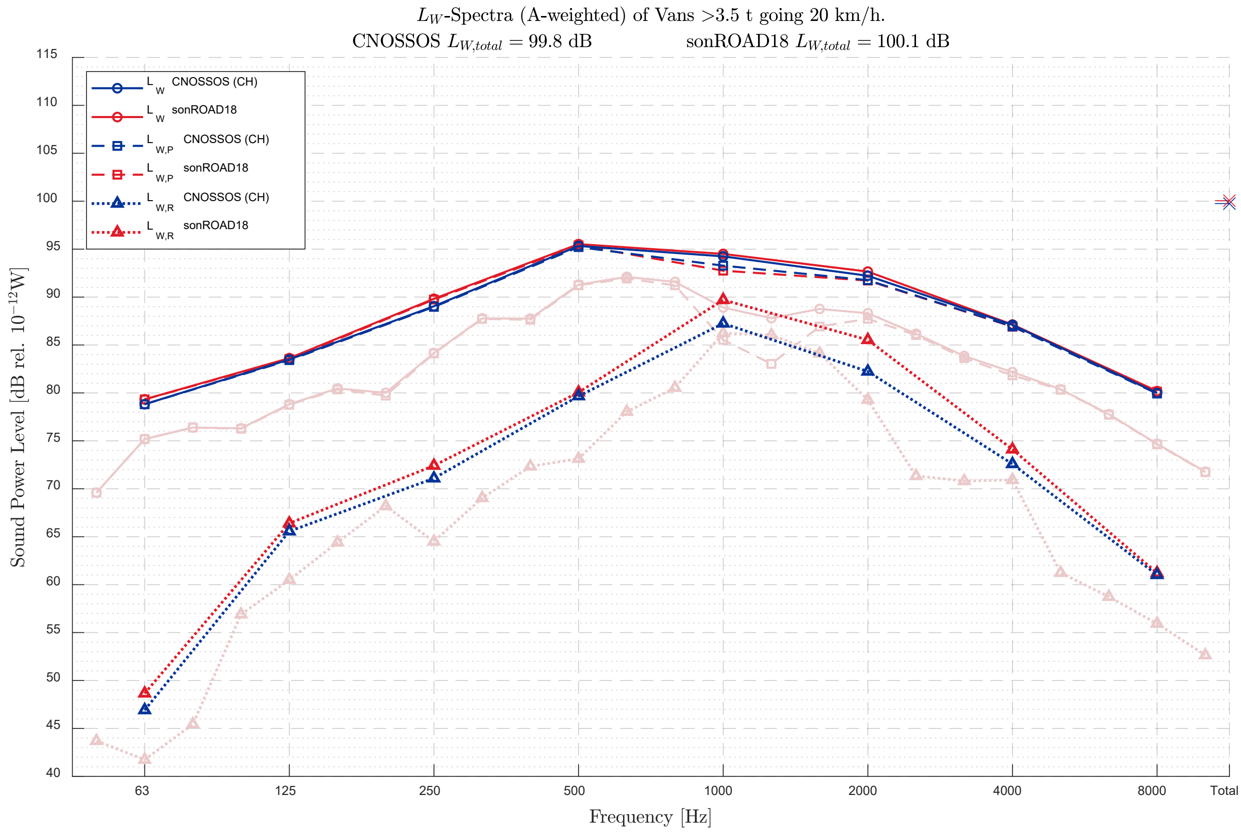

Figure 22: Comparison of sound power spectra (vans >3.5 t, adapted internal parameters, 20 km/h)

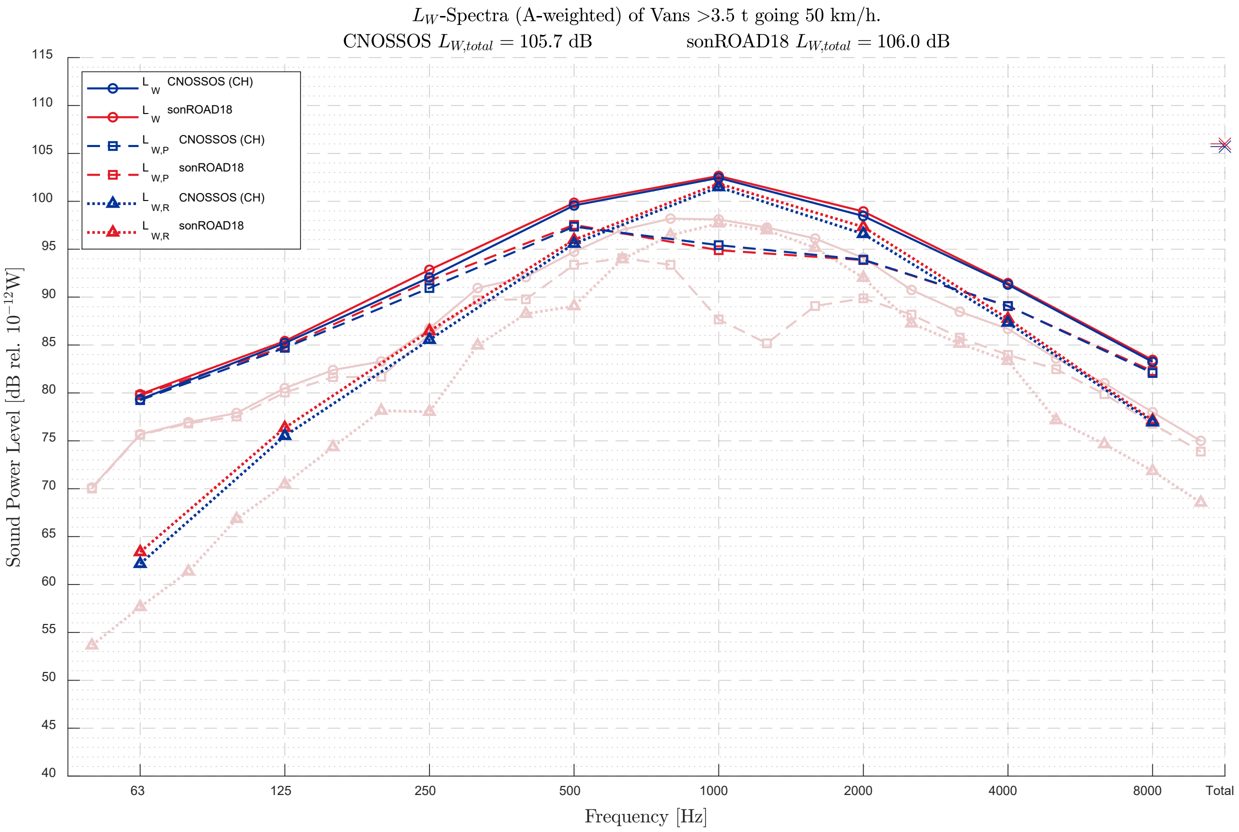

Figure 23: Comparison of sound power spectra (vans >3.5 t, adapted internal parameters, 50 km/h)

4.2.3. Trucks with trailers (CNOSSOS category 3, sonROAD18 category 9)

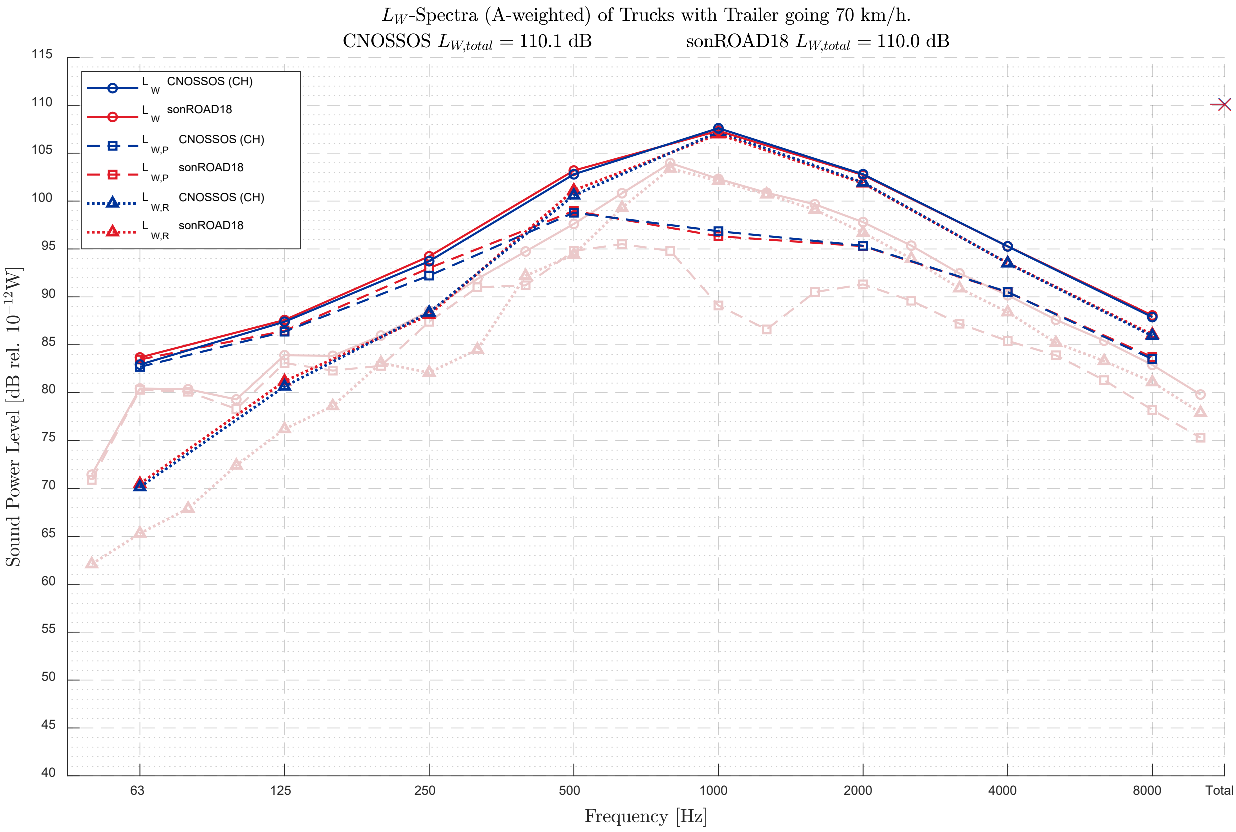

Figure 24: Comparison of sound power spectra (trucks with trailer, adapted internal parameters, 70 km/h)

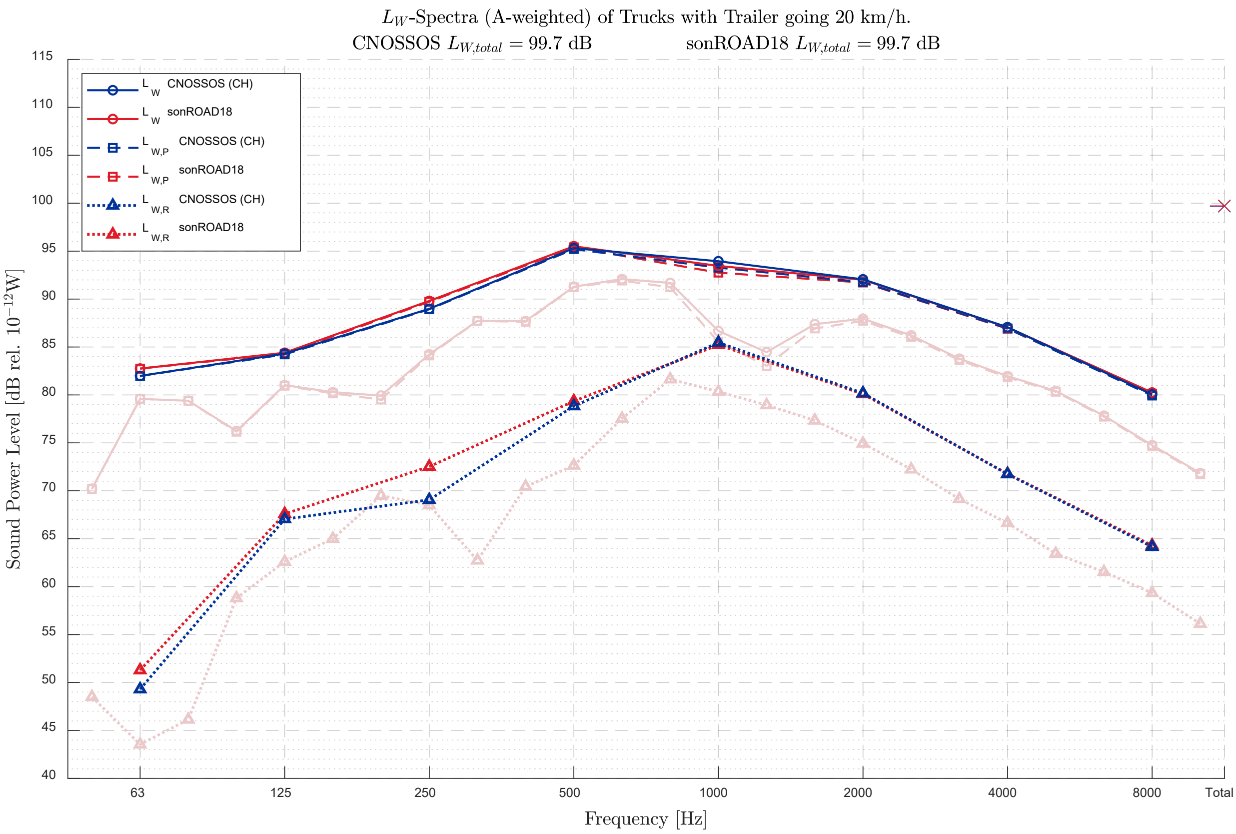

Figure 25: Comparison of sound power spectra (trucks with trailer, adapted internal parameters, 20 km/h)

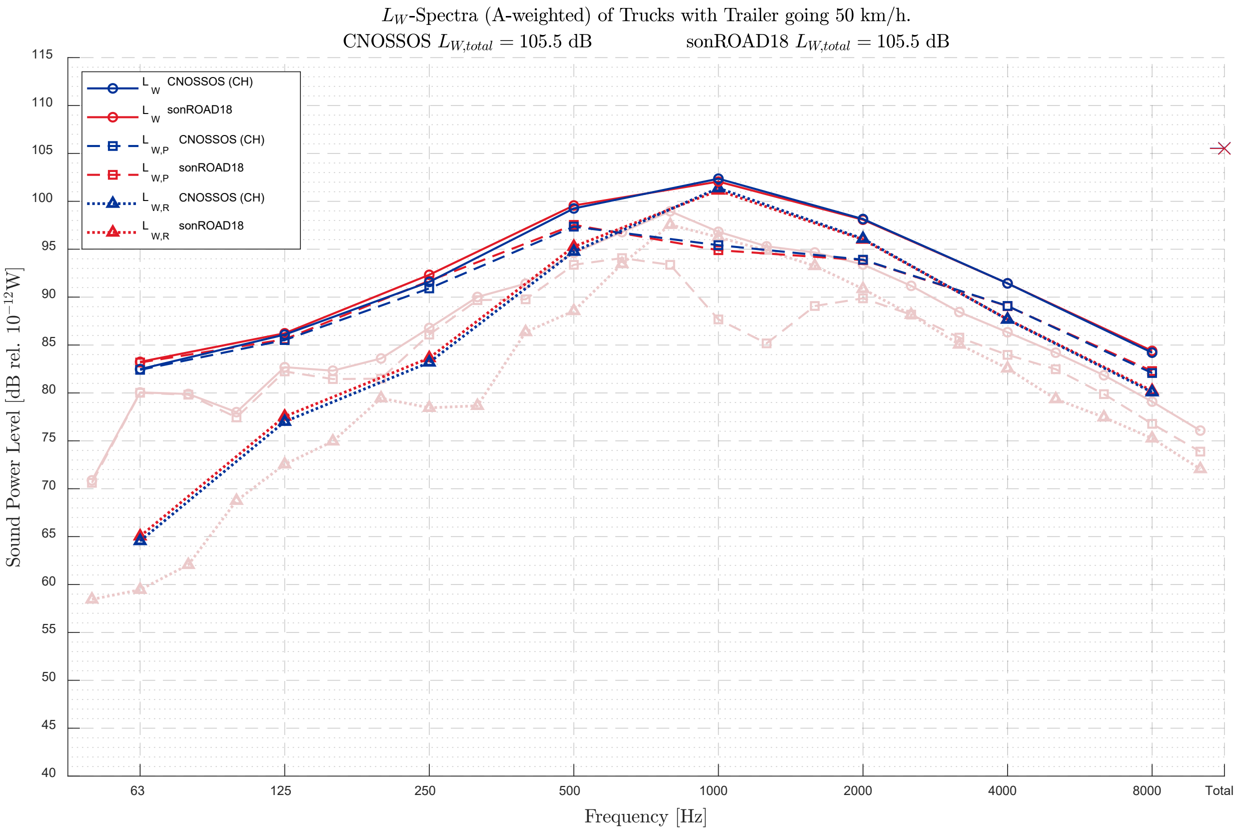

Figure 26: Comparison of sound power spectra (trucks with trailer, adapted internal parameters, 50 km/h)

4.2.4. Motorbikes (CNOSSOS category 4b, sonROAD18 category 2)

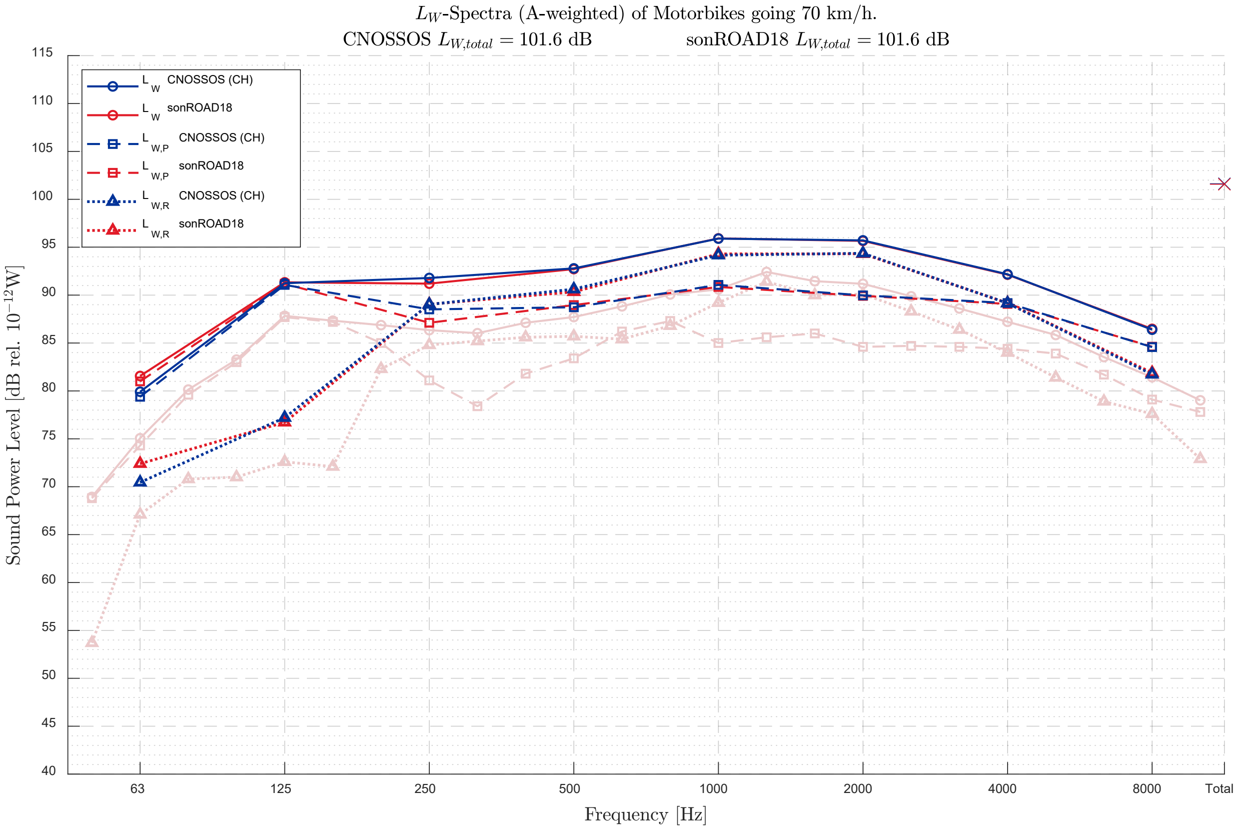

Figure 27: Comparison of sound power spectra (motorbikes, adapted internal parameters, 70 km/h)

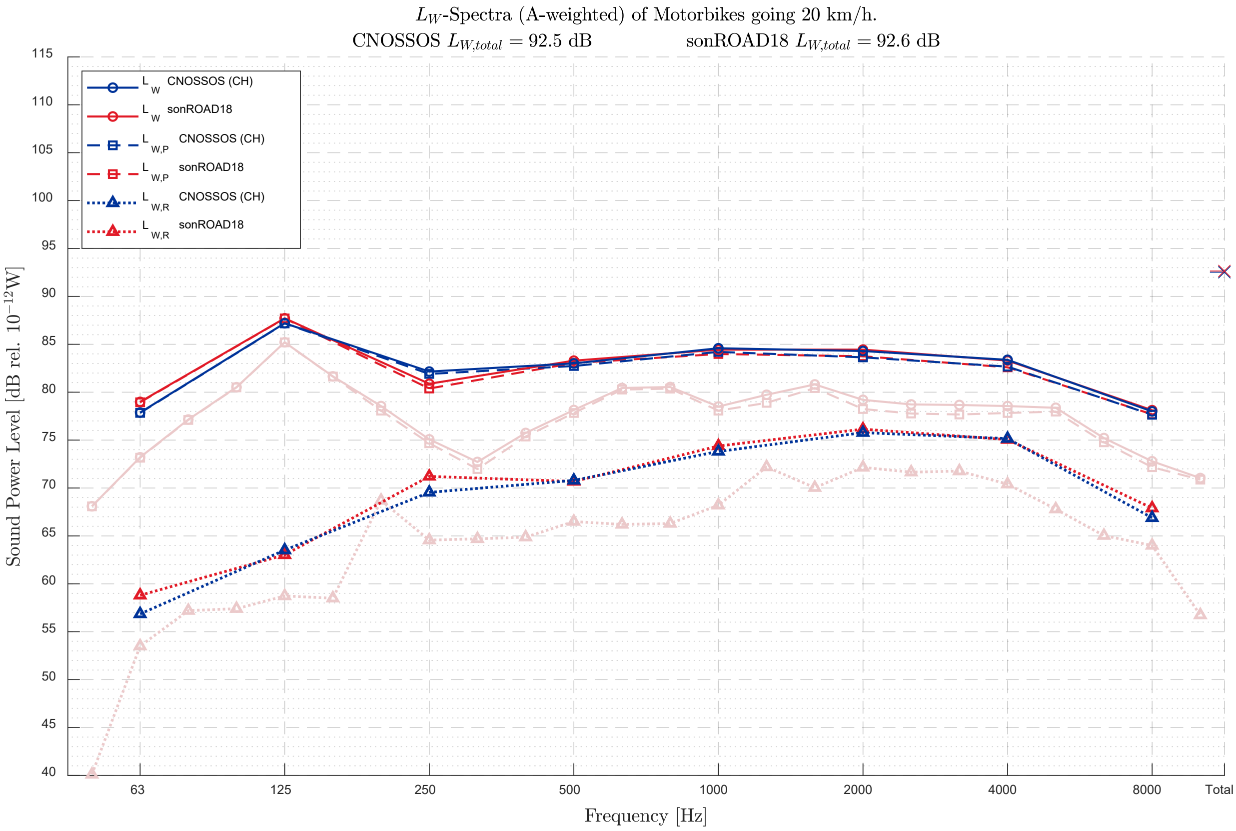

Figure 28: Comparison of sound power spectra (motorbikes, adapted internal parameters, 20 km/h)

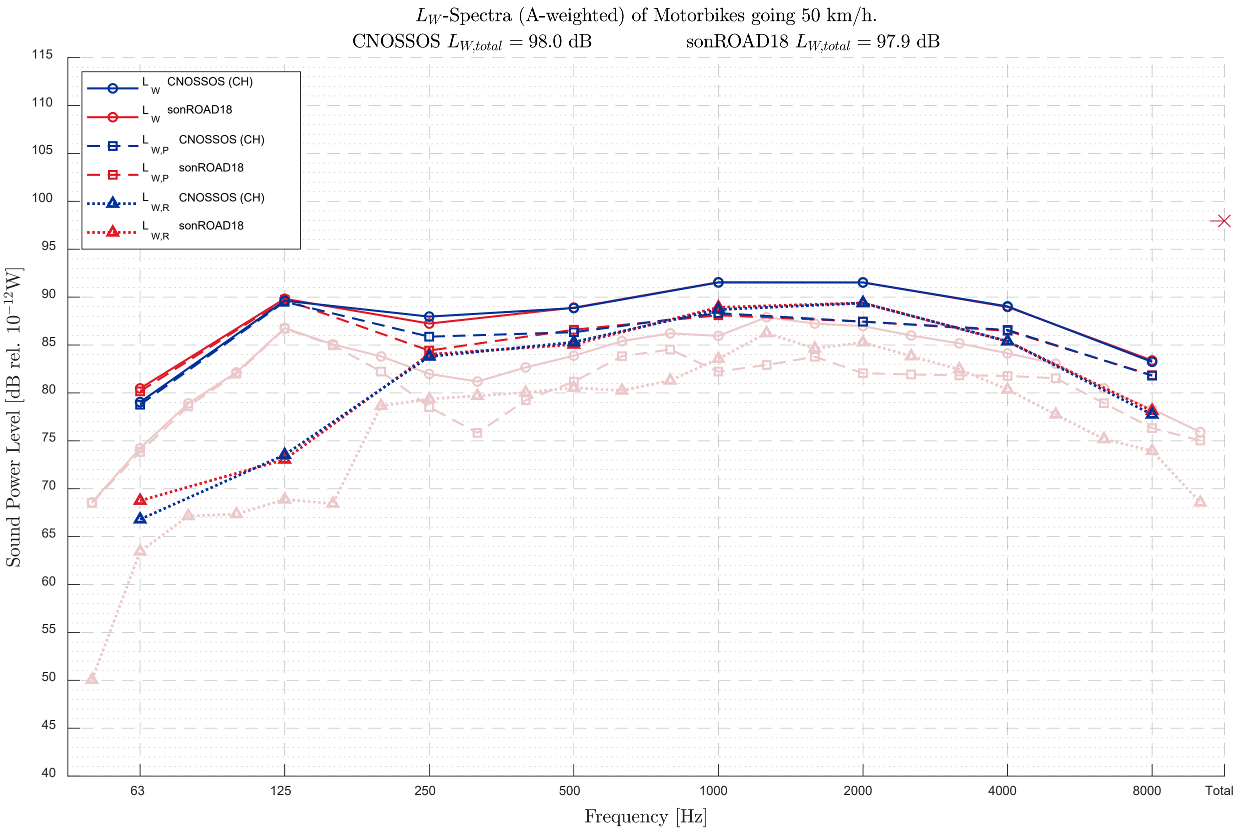

Figure 29: Comparison of sound power spectra (motorbikes, adapted internal parameters, 50 km/h)

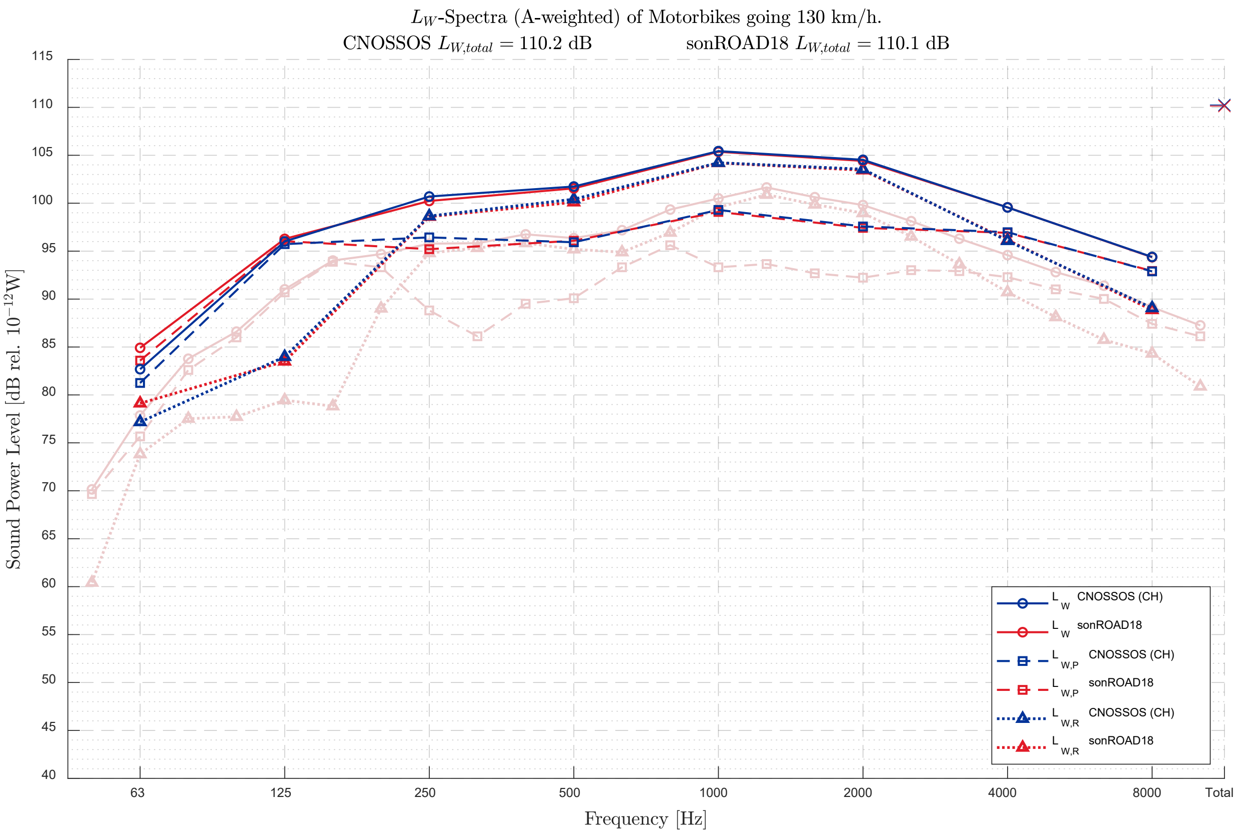

Figure 30: Comparison of sound power spectra (motorbikes, adapted internal parameters, 130 km/h)

4.2.5. Differences in total levels

The following plots show the differences in total levels L_W for all four vehicle categories depending on speed, incline and temperature. Again, all the graphs are practically identical except for the incline correction term of vans >3.5 t (see p. 7, section 3.2.9).

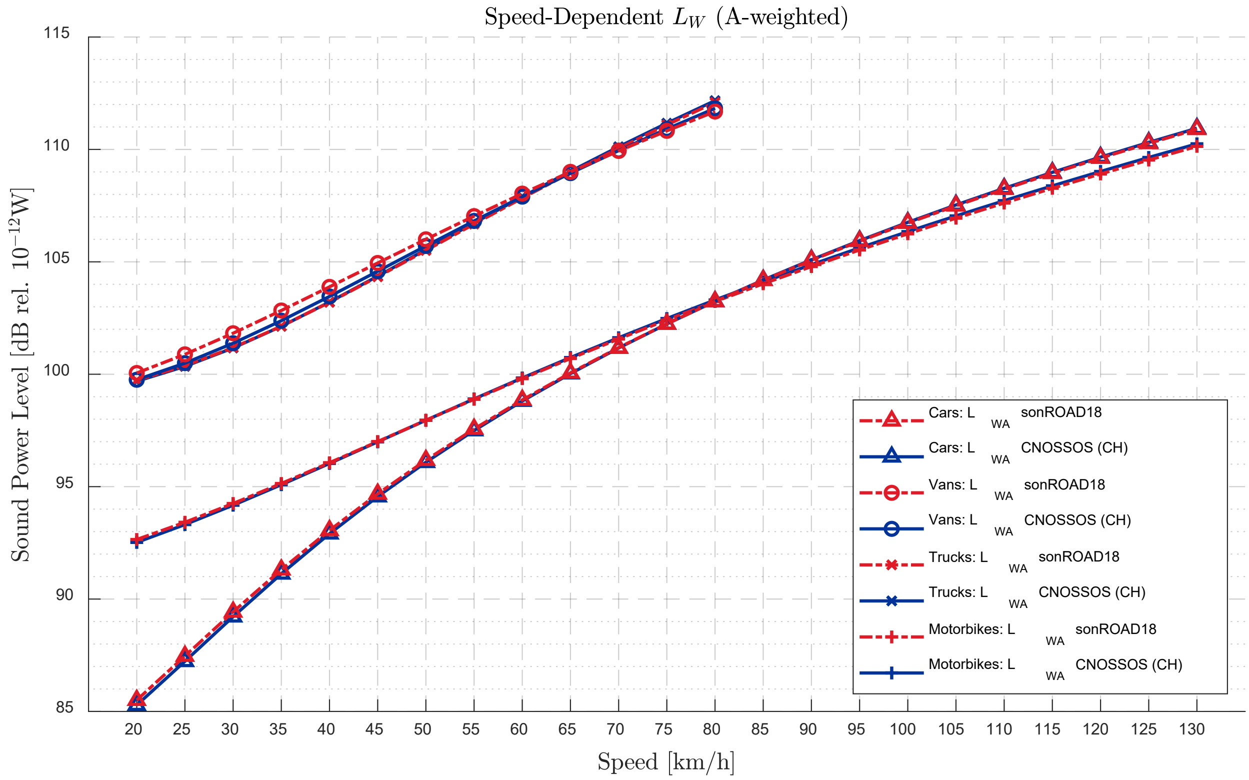

Figure 31: Total A-weighted sound power level of all four vehicle categories depending on speed

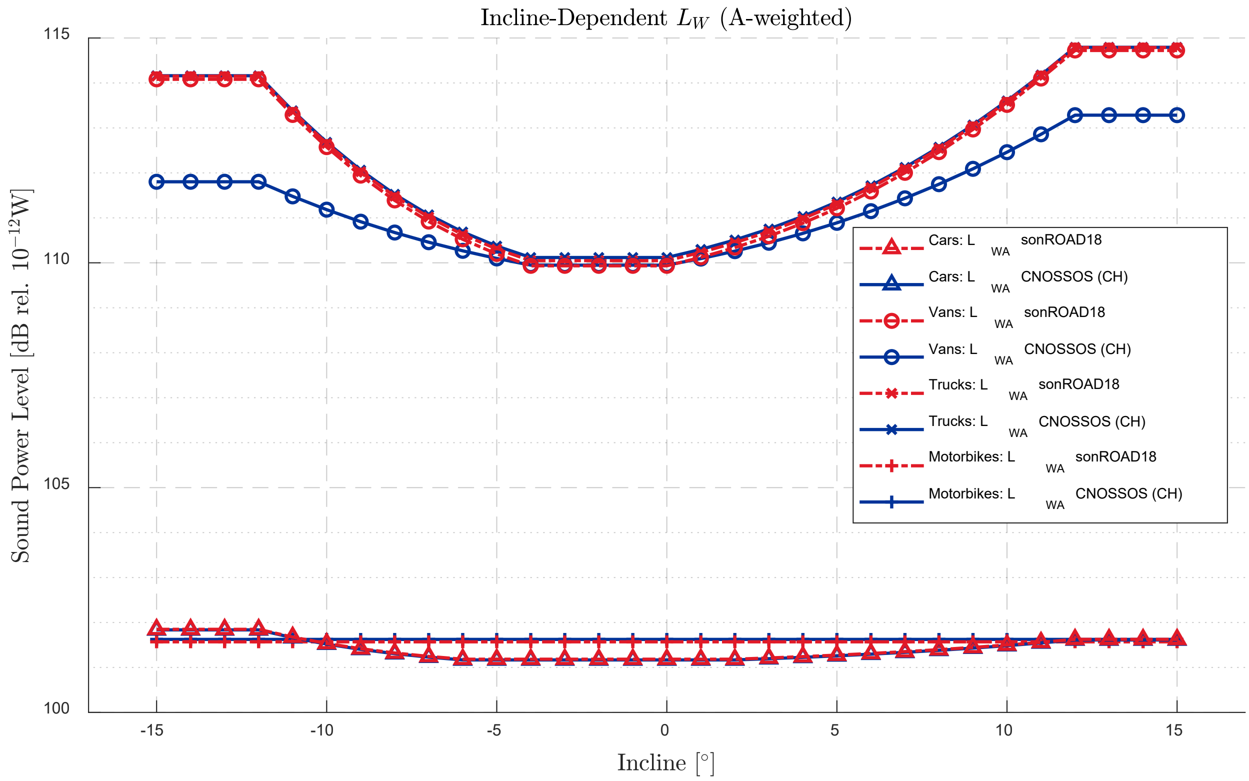

Figure 32: Total A-weighted sound power level of all four vehicle categories depending on the road's incline

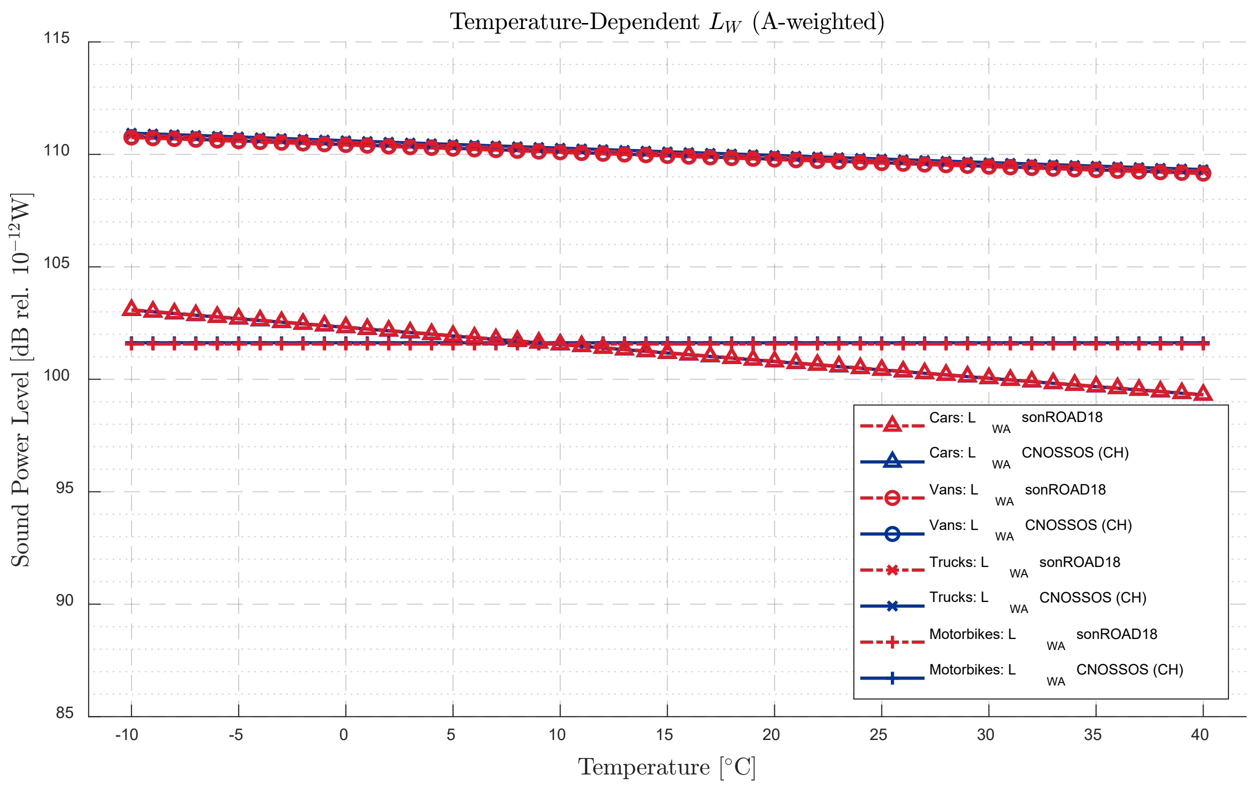

Figure 33: Total A-weighted sound power level of all four vehicle categories depending on ambient temperature

4.3. Exclusive sonROAD18 features

4.3.1. Additional vehicle categories

Besides cars, trucks, and motorbikes, sonROAD18 offers a range of 33 vehicle categories including electrified cars, buses and trucks, dedicated bus models and trams. The following three spectra give examples of calculation results with a tram in the city of Basel, an electric hybrid bus in the city of Zurich, and a forage harvester.

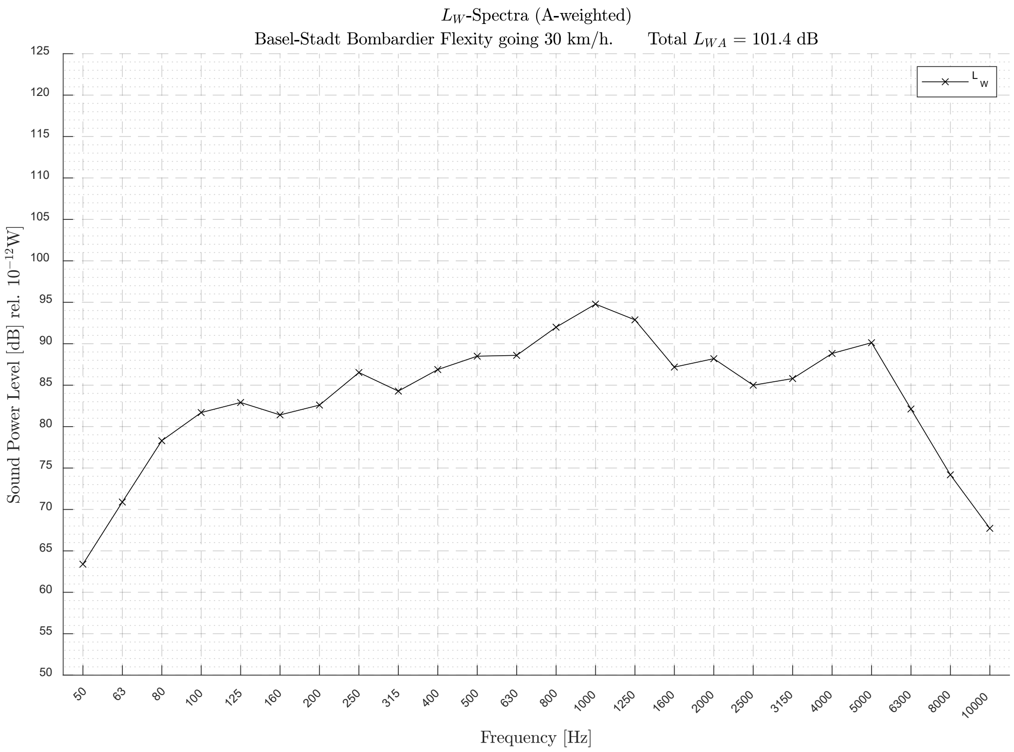

Figure 34: Sound power level spectrum of a Bombardier Flexity (Basel) tram going 30 km/h

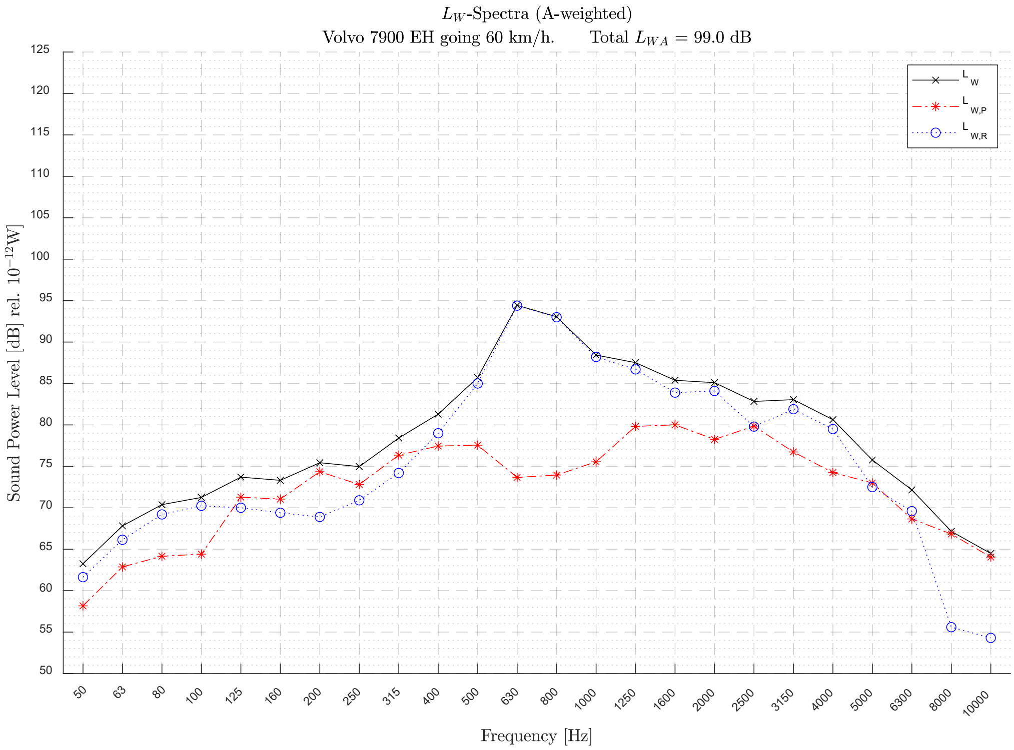

Figure 35: Sound power level spectrum of a Volvo 7900 EH electric hybrid bus going 60 km/h

Figure 36: Sound power level spectrum of a forage harvester going 20 km/h

4.3.2. Directivity

sonROAD18 considers a source directivity depending on the vehicle category as discussed and shown in 3.2.10. The following plots demonstrate the radiation angle's effect on the emission spectrum. 0° is to be understood as the standard microphone position in 7.5 m lateral distance to the lane center line and 1.2 m above the road surface. A 90° position is assumed above the lane center line (zero lateral distance).

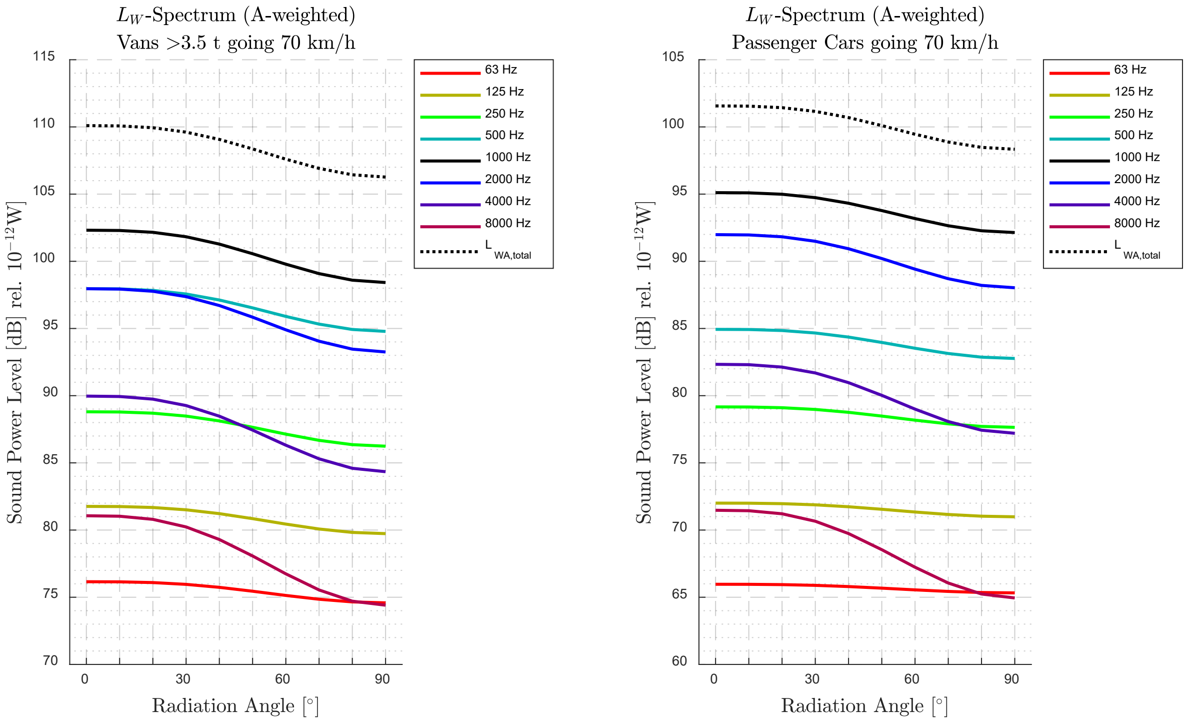

Figure 37: Dependency of the sound power level spectra of vans >3.5 t and passenger cars going 70 km/h on the radiation angle

5. Discussion and conclusions

The sonROAD18 road traffic noise emission model is very similar to the CNOSSOS-EU model. Several differences between the models were identified in the detailed model descriptions which however only minimally affect the overall A-weighted emission levels. Apart from that, sonROAD18 offers more specific vehicle categories and a higher frequency resolution, while simplifying parts of the algorithm without degrading the calculation results.

With the models' **unaltered default internal parameters**, differences of up to 3.8 dB(A) were found for identical case inputs varying the driven speed. To put that maximum difference of 3.8 dB(A) in context, note that it is the result of comparing passenger cars going only the lowest modelled speed of 20 km/h. At higher speeds the differences become smaller (see Figure 3–Figure 6).

As seen in section 4.1.1, the CNOSSOS propulsion spectra $L_{W,P}$ are considerably higher than sonROAD18's. This leads to the conjecture that the average passenger car in Switzerland emits less engine noise than one from the EU. For the four compared vehicle categories, the average and absolute maximum differences in total levels $L_{WA,\text{total,CNOSSOS}} - L_{WA,\text{total,sonROAD18}}$ across the valid speeds are:

Table 2: Mean and maximum total A-weighted sound power level differences of all four vehicle categories at speeds 20 – 130 km/h

	mean	maximum (absolute)
Passenger Cars	2.3 dB(A)	3.8 dB(A)
Vans >3.5 t	-1.4 dB(A)	2.9 dB(A)
Trucks	1.7 dB(A)	3.5 dB(A)
Motorbikes	-0.2 dB(A)	0.8 dB(A)

That attests the differences between the vehicle fleets, but does not allow any indication of the conformity of the two models.

However, using **converted Swiss input data**, average differences between emission calculations with the sonROAD18 model and the CNOSSOS-EU model are negligible (**below half a decibel**) which leads to the conclusion that sonROAD18 has a high level of conformity with CNOSSOS-EU.

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