Research Article

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CNOSSOS-EU road surface types: Evaluation of the influence of different national values on noise emissions

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Abstract: Europe is acting to fight noise pollution. The Environmental Noise Directive (2002/49/EC) requires EU Member States to determine the exposure to environmental noise through strategic noise mapping, and elaborate action plans to reduce noise pollution. Road traffic noise is a common environmental noise source; henceforth, EU countries are obliged to produce strategic noise maps for all major roads, railways, airports, and agglomerations, on a 5-year basis. These noise maps are used by national competent authorities to identify priorities for action planning and by the European Commission to globally assess noise exposure across the EU. A thorough investigation is conducted in this article to assess how different road surface types affect road traffic noise levels in selected EU member states which are incorporating CNOSSOS-EU into their national law. It has been done by comparing the nationally published noise data to those published by CNOSSOS-EU in 2021 for various vehicle categories by obtaining the rolling and propulsion noise for each road surface type while ignoring other factors. The aim of this study is to address the deficiency in the assessment and show a comparison between the noise generated from different surface types which can potentially enhance the effectiveness of strategic noise mapping.

Keywords: environmental noise, road traffic noise, CNOSSOS-EU, noise modelling, noise mapping, road surface types

1 Introduction

In today's world, noise can pose a serious problem in many fields for society. One major source of environmental noise in urban areas in Europe is road traffic noise [1], which is not only considered loud but is also a persistent nuisance problem affecting a wide range of aspects of life [2]. Road traffic noise is considered the second most disturbing environmental noise source [1,3,4] affecting the daily life activities and mental health of individuals residing in noisy urban environments and negatively influences their well-being [5–7]. After the pollution of fine particles, road traffic noise is considered the most common environmental risk factor to our health in Europe [8]. Its adverse health effects include various detrimental consequences on both a mental and a physical level, which are usually caused by the nuisance of loud engine sounds, tire-road interaction which increases with the vehicle's speed, and vehicle horns, leading to a weary body and mind, evoking sometimes unpleasant emotions [9]. Furthermore, this can be allied with long-term risks of cardiovascular illnesses [10–12], such as heart attacks or hypertension [13,14]. To a further extent, work and educational environments are affected too, and overall cognition, communication, and attention can all be weakened due to excessive prolonged noise [15–17]. On the other hand, the overall burden of road traffic noise in the European Union, including direct expenses and impacts like medical treatments and lost productivity, is estimated to be 40 billion euros each year [18]. Thus, some real active measures countering these adverse effects are desirable to reduce road traffic noise pollution.

To address the problem and its scale thoroughly, the Environmental Noise Directive 2002/49/E (END) was implemented in 2002 by the European Union as a common measure of environmental noise assessment [19]. Each member state is obligated to carry out a systematic evaluation in the form of dose–effect relations [20] of sound power levels in heavily inhabited locations, near transit centers, and alongside key through fares in order to harmonize the parameters

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of noise evaluation by creating strategic noise maps from traffic noise data collection [19,21]. Important insights can be obtained that aid the authorities in ranking locations of intervention and assessing the extent of the problem. The EU aims to produce calmer and more comfortable living conditions for member states' residents utilizing the END. In 2019, The European Commission introduced "The European Green Deal" with the aim of protecting the well-being and health of citizens from environmental risks [22]. At the core of that, a Zero Pollution Action Plan was launched in 2021 with the ambition to reduce environmental pollution by 2030. One of its key targets is to reduce the number of people chronically affected by transport noise, including road traffic noise, by 30% compared to 2017, while striving to achieve zero pollution by 2050 [23,24]. The Commission's aim is to tackle noise at its source, by ensuring effective on-site execution of roads and enhancing the EU noise-related regulatory framework for tyres and road vehicles, where appropriate [23]. Therefore, members are encouraged to coordinate strategies for mitigating noise pollution while ensuring public health and safety by endorsing quieter means of transport, such as electric vehicles (EVs), reducing road speed limits, promoting the use of quiet tyres, applying low-noise pavements on road surfaces [25], constructing durable noise barriers [26], and preparing strategic noise maps every round as main tools [19].

The END's execution plan incorporates strategic noise mapping at its heart by utilizing complex methodologies and tools to visualize and calculate sound pressure levels, are they are considered well-known measures of sound quality or annoyance [27]. EU member states have been obliged to prepare strategic noise maps every 5 years since 2007 for agglomerations with over 250,000 inhabitants, and for agglomerations with over 100,000 inhabitants since 2012, in addition to roads with over 3 million vehicles passing per year outside agglomerations [19,28]. These maps are presented in a day–evening–night noise equivalent level L_{den}, and night noise equivalent level L_{night} as harmonized noise indicators [19,29]. This can be done by finding and categorizing noise hotspots and patterns to create a geographical map of these patterns, which in turn helps the official representative of the member states in adapting new policies or regulations regarding noise mitigation [19]. Additionally, noise mapping can simplify tracking advancement or deterioration over time, aiding a member state in evaluating its noise policies and risk communication with the public by transferring these noise maps into risk maps [30]. One vital initiative that has been developed within the END directive is the Common NOise aSSessment methOdS (CNOSSOS-EU) [8,19].

Published in 2015 under the Commission Directive (EU) 2015/996, CNOSSOS-EU utilizes a multidisciplinary strategy or a harmonized method to develop solutions to road traffic noise by taking into consideration the economic, societal, and environmental aspects. In this way, it achieves equilibrium between conservation and growth, which in turn promotes the preservation of natural habitats and cultural settlements from the adverse effects of road traffic noise pollution [31]. For instance, CNOSSOS-EU integrates nature-based solutions within urban planning, such as acoustic landscapes, and green barriers. It also summarizes the noise emissions models of internal combustion vehicles into four main categories, in addition to a fifth "open category" reserved for future needs, such as EVs [32–34]. The cooperation between environmentalists, law-makers, and local EU societies is often required to ensure the success of such solutions.

CNOSSOS-EU, in its entirety, studies the road traffic noise generated from two sources, namely: rolling noise, generated from the tire and road surface interaction, and propulsion noise produced by the driveline (engine, exhaust, *etc.*) of the vehicle [32,33], which is considered zero for EVs [34]. It also introduces the noise emission difference from non-standard road surface types compared to a Reference Road for all vehicle categories and expresses that as correction coefficients presented in Annex II of CNOSSOS-EU documentation [32,35].

Generally, the road surface type and its composition play an important role in defining noise emissions [36,37], and have been under consideration in recent studies of automotive/acoustic engineering [38]. However, it can be argued that the amount of road traffic noise emissions depends on road surfaces of different materials and their various acoustic properties, such as tire model, pavement aging, texture, and mixture [37,38]. Thus, policymakers promoting the use of low-noise pavements can contribute to creating more attractive urban environments to reduce the adverse effects of road traffic noise pollution.

In 2020, Annex II of CNOSSOS-EU documentation was amended and re-published in 2021 with updated correction coefficients for 14 different road surface types [39,40]. However, no specified method was officially published yet to obtain correction coefficients for new road surfaces [41]. Thus, the amendment paved the way for further research on this topic. For instance, the Nord2000 Road Model was utilized to predict the correction coefficients for Swedish roads [40]. In Italy, a study was performed to calculate the correction coefficients for a motorway consisting of 3 sections vary in their characteristics by applying the statistical pass-by (SPB) method according to ISO 11819-1:2001 followed by noise modelling [42]. In Ireland, noise measurements employing the close proximity method (CPX) in line with ISO 11819-2:2017 were conducted to obtain the correction coefficients for the 3 most common road surfaces on the Transport Infrastructure Ireland Network for strategic noise mapping purposes [41]. Moreover, another research was published recently which assesses the correction coefficients for low-noise pavements utilizing the Urban SPB methodology [43].

This article presents a holistic approach to study the influence of different road surface types in the EU member states, specifically focusing on those countries whose data is accessible through commonly used noise mapping software (SoundPLAN, IMMI, and CadnaA), namely Germany, Austria, and Finland. The published national values were compared to the CNOSSOS-EU published values in 2021 for light, medium-heavy, and heavy vehicles by obtaining the rolling and propulsion noise for each road surface type and ignoring all other factors, such as studded tires, temperature, *etc.* The outcome of the article is expected to fill a gap in the evaluation and comparison of different road surface types, and it could be beneficial in many aspects, such as strategic noise mapping.

2 Material and methods

2.1 Methodology

A Reference Road, which consists of an average of stone mastic asphalt 0/11 and dense asphalt concrete 0/11 between 2 and 7 years old and in representative maintenance condition, is considered the base for rolling noise coefficients (A_R, B_R) and propulsion noise coefficients (A_P, B_P) calculations in CNOSSOS-EU, where coefficients (A_R, A_P) represent the sound power levels at the reference speed (70 km/h) (processed from SEL to L_W) [32,44], and coefficients ($B_\mathrm{R,}$ B_P) represent the slope expressed as log(speed). Both parameters (vehicle's pass-by speed and sound event level in dB) are recorded from field measurements. Vehicles are grouped into five different categories in the CNOSSOS-EU documentation based on their noise emission characteristics, and the rolling and propulsion noise coefficients vary for each category. These categories are as follows: Category 1 includes light motor vehicles, such as passenger cars, delivery vans weighing less or equal to 3.5 tons, sport utility vehicles, and multi-purpose vehicles including trailers and caravans. Category 2 consists of medium-heavy vehicles, such as delivery vans over 3.5 tons, touring cars, and buses with two axles and twin tire mounting on the rear axle. Category 3 includes heavy-duty vehicles, such as buses and touring cars with three or more axles. Category 4 is for Powered Two-Wheelers, divided into subclasses 4a for mopeds, tricycles, and quads with a motor capacity less or equal to 50 cc, and 4b for motorcycles, tricycles, and quads with a motor capacity of more than 50cc, in addition to Category 5, being an open category for future needs and intended mostly for EVs [32].

To assess the influence of different road surfaces on noise emissions in different EU countries, the rolling noise $L_{\mathrm{WR},i,m}$ and propulsion noise $L_{\mathrm{WP},i,m}$ for each vehicle category for the Reference Road at a constant speed of 70 km/h were first calculated by utilizing the following mathematical expressions and A and B coefficients provided in Annex II of the CNOSSOS-EU document [32,39].

$$L_{\mathrm{WR},i,m}(v_m) = A_{R,i,m} + B_{R,i,m} \times \lg\left(\frac{v_m}{v_\mathrm{ref}}\right) \mathrm{d}B, \tag{1}$$

$$L_{\mathrm{WP},i,m}(v_m) = A_{P,i,m} + B_{P,i,m} \times \frac{(v_m - v_\mathrm{ref})}{v_\mathrm{ref}} \mathrm{d}B, \tag{2}$$

where i is the 1/1 octave band center frequencies from 63 to 8,000 Hz, m is the vehicle category based on the CNOSSOS-EU vehicle classification, v_m is the vehicle speed in km/h, while $v_\mathrm{ref} = 70$ km/h [32].

Then, the following formula was used to obtain the total sound power level $\mathrm{L}_{W,m}$ for each vehicle category for the Reference Road [32].

$$L_{W,i,m}(v_m) = 10 \times \lg\left(10^{\frac{L_{\mathrm{WR},i,m}(v_m)}{10}} + 10^{\frac{L_{\mathrm{WP},i,m}(v_m)}{10}}\right) \mathrm{d}B. \tag{3}$$

Since different road surface types can affect the noise emissions of vehicles [32], CNOSSOS-EU methodology introduced two correction coefficients for each road surface type: the $\alpha_{i,m}$ coefficient, which represents a pavement absorption correction for each vehicle category and varies with frequency [42], and the β_m coefficient that varies for each category only [32]. A large set of SPB measurements was collected to obtain these coefficients [45]. However, CPX method can also be used for that purpose [35]. Therefore, it was essential to calculate the road surface correction factors for rolling noise $\Delta L_{\mathrm{WR,road},\ i,m}$ and propulsion noise $\Delta L_{\mathrm{WP,road},i,m}$ using the following formulas:

$$\Delta L_{\mathrm{WR,road},i,m}(v_m) = \alpha_{i,m} + \beta_m \times \lg\left(\frac{v_m}{v_\mathrm{ref}}\right) \mathrm{d}B, \tag{4}$$

$$\Delta L_{\mathrm{WP,road},i,m}(v_m) = \min\{\alpha_{i,m};\ 0\}\ \mathrm{d}B, \tag{5}$$

where $\alpha_{i,m}$ is the spectral correction in dB at reference speed v_ref for category m (1, 2, or 3) and spectral band i (octave band from 125 to 4,000 Hz), and β_m is the speed effect on rolling noise reduction for category m (1, 2, or 3).

In theory, the β coefficient is frequency-dependent. However, in CNOSSOS-EU, a constant value was assumed since no spectral data were available in the literature [32].

It should be mentioned that the propulsion noise correction factor is identical to the rolling noise correction

Table 1: Road surface parameters

Parameter	Calculation standard	Air temperature	Tyres	Vehicle speed	Road surface conditions
Assumption	CNOSSOS-EU (2021)	20°C	Non-studded tyres	Constant, reference speed 70 km/h*	Dry flat road surface

*Except for road surfaces allowing a maximum speed of 60 km/h.

factor at reference speed with a maximum of zero. In other words, porous road surfaces will contribute to decreasing the propulsion noise while dense road surfaces will not increase it [32]. Moreover, all road surfaces were evaluated at a vehicle speed v_m = 70 km/h except for surfaces allowing a maximum speed of 60 km/h, such as paving block surfaces, which were evaluated at 60 km/h.

After obtaining the rolling and propulsion noise corrections, the total sound power level for each road surface $L_{W,\text{ road, }m}$ was calculated by adding the rolling and propulsion sound power-level corrections to the rolling and propulsion sound power levels calculated for the Reference Road, employing the following formulas.

$$L_{\text{WR,road},i,m}(v_m) = L_{\text{WR},i,m}(v_m) + \Delta L_{\text{WR, road},i,m}(v_m)\ \text{d}B, \tag{6}$$

$$L_{\text{WP,road},i,m}(v_m) = L_{\text{WP},i,m}(v_m) + \Delta L_{\text{WR, road},i,m}(v_m)\ \text{d}B, \tag{7}$$

$$L_{W,\text{road},i,m}(v_m) = 10 \times \lg\left(10^{\frac{L_{\text{WR,road},i,m}(v_m)}{10}} + 10^{\frac{L_{\text{WP,road},i,m}(v_m)}{10}}\right)\text{d}B. \tag{8}$$

The same procedure was used to calculate the sound power levels $L_{W,\text{road},m}$ for all different road surfaces, the arithmetic difference of each road surface's L_W from the CNOSSOS-EU Reference Road's L_W was calculated to obtain the noise emissions difference on the EU countries' road surfaces for each vehicle category ($\Delta L_{W,\text{road},m}$), where negative calculated values indicate lower noise emissions compared to the Reference Road Surface. However, exceptions were given to Categories 4a and 4b, where rolling noise is not affected. Thus, road surface types are not expected to influence the sound emissions [32,46]. The parameters considered for the road surface L_W calculations are summarized in Table 1.

This article assumes similar parameters and conditions for all road surface types. As such, it can be argued that the difference in the calculated noise emissions is only due to the effect of the road surface itself.

Figure 1 depicts the steps applied to calculate the noise emission difference of the road surface types from the Reference Road Surface.

2.2 Road surface types in EU countries

Road surface types and conditions in Europe vary significantly, which can lead to differences in their acoustic properties. For CNOSSOS-EU, no common procedure to assess the acoustic properties of all road surface types was found

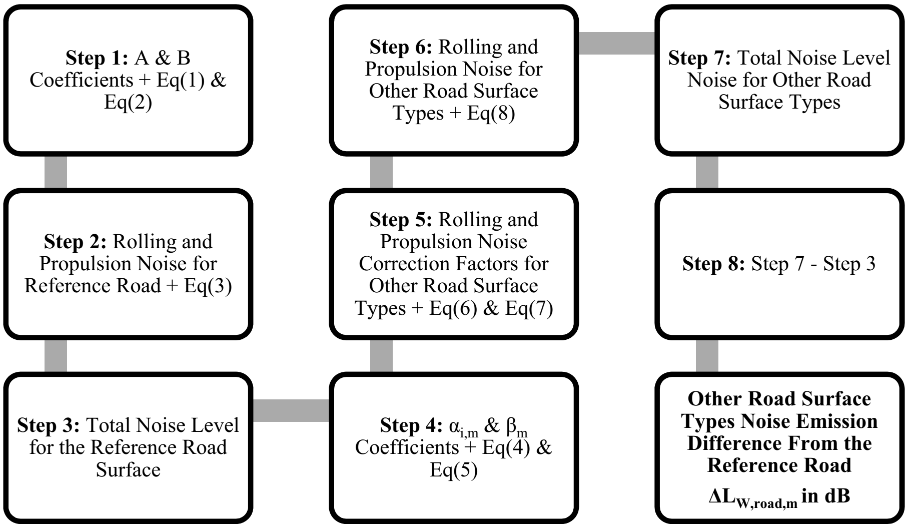

Figure 1: Noise emission difference calculation steps.

in the literature [32]. However, a guide containing suggestions for monitoring and checking road surfaces' acoustic classifications was made [47]. The currently available version of CNOSSOS-EU contains tables in Annex II with $\alpha_{i,m}$ and β_m coefficients for 14 road surfaces, from quiet road surfaces, through asphalt to concrete and cobble surfaces, based on the Dutch road calculation method (RMG2012) [41,48].

All EU member states are required to implement the transposition of the CNOSSOS-EU method into their national law to comply with EU requirements for the upcoming round of strategic noise mapping. However, this section of the article focuses on the road surface types found in the widely used noise mapping software databases, such as SoundPLAN, IMMI, and CadnaA. Table 2 illustrates the collection of road surface types across Germany [49,50], Austria [50,51], and Finland [52], as well as the road surfaces in the CNOSSOS-EU document. The selection method is based on the type of road surface, such as asphalt concrete, cement concrete, or paving blocks [53,54]. However, no actual connection between the rows is made; the entries are simply listed sequentially under each surface type category. This means that each surface type is presented independently of others based on its classification, without regard to any hierarchical or relational order among the countries.

3 Results and discussion

The present section summarizes the results obtained from calculating $\Delta L_{W,\text{road},m}$ for light, medium heavy, and heavy vehicles for CNOSSOS-EU road surfaces in Germany, Austria, and Finland as depicted in Table 3. Negative values indicate lower noise emissions compared to the Reference Road Surface at a constant speed of 70 km/h, except for road surfaces that allow a maximum speed of 60 km/h, which were evaluated at that speed. As CNOSSOS-EU only considers propulsion noise in Categories 4a and 4b, different road surface types at the evaluated vehicle speeds are not expected to influence the noise emissions [32,33,46]. Therefore, they were not evaluated.

3.1 Sound power level difference for CNOSSOS-EU road surfaces

Figure 2 compares the noise reduction capabilities for light motor vehicles and medium to heavy motor vehicles of the road surfaces considered in the CNOSSOS-EU calculations. According to the results, Asphalt Concrete Surfaces were found to have the highest noise reduction capabilities compared to the Reference Road Surface. Moreover, they generate lower sound emissions from Category 1 vehicles, except for NL01. Road surfaces, such as NL13 and NL14 are more suitable for roads where the proportion of light motor vehicle traffic is higher, while NL07 can be installed on roads where more medium to heavy vehicle pass-bys are expected. Moreover, the best noise reduction capabilities were found to be for the "Two-layer porous asphalt (fine) ZOAB – NL03," which can decrease noise by 6.6 dB for light motor vehicles and an average of 5.75 dB for Category 2 and 3 vehicles. On the other hand, "Hard elements not in herringbone – NL11" can result in increasing Category 1 emissions by 6.1 dB and Category 2 and 3 emissions by 8.3 dB. However, since the maximum allowed speed on PBS is 60 km/h [32], it is recommended to avoid the use of such surfaces in urban areas with high populations in new development.

3.2 Sound power level difference for German road surfaces

In Germany, "Open-pored asphalt PA 0/8 – G-ACS-2" was found to have the highest noise reduction capabilities for all vehicle categories, while "Hard elements with $b > 5$ mm or $f > 2$ mm or other hard elements – G-PBS-12" increases the sound emissions significantly. On the other hand, and unlike CNOSSOS-EU road surfaces, G-CCS-10 can result in increasing the sound emissions of medium to heavy motor vehicles. However, road surfaces in Germany showed noticeable fluctuations between Category 2 and Category 3 vehicles compared to other countries, with higher emission increase from Category 2 vehicles. This trend was mainly, but not exclusively, observed on road surfaces allowing a maximum speed of 60 km/h, which can be attributed to the fact that rolling noise becomes dominant at lower speeds in Category 2 vehicles compared to Category 3 vehicles. This difference may contribute to the larger variations between Categories 2 and 3, based on the acoustic properties of the respective road surface types. As a result, the average noise reduction of both categories is not representative of each category's reduction. The difference in the emissions of Category 2 and 3 vehicles is related to the $\alpha_{i,m}$ and β_m coefficients provided from the measurements conducted in Germany. It was observed that both coefficients vary significantly from each other in both categories. Given that the β_m coefficient is a frequency-independent assumed constant [32,49], further research is advised to investigate those fluctuations. Figure 3a and b below depict a comparison of the noise reduction capabilities of German road surfaces for light motor vehicles against medium-heavy vehicles, and light motor vehicles against heavy vehicles, respectively.

Table 2: Road surface types in the examined countries

Surface type\Country	CNOSSOS-EU	Germany	Austria	Finland
Reference	Reference surface – 0	National reference (non-fluted mastic asphalt) – G0	Reference surface – A0	Reference surface – F0
Bituminous Mixes/Asphalt Concrete Surface – ACS	Single layer porous asphalt ZOAB – NL01	Open-pored asphalt PA 0/11 – G-ACS-1	Open porous asphalt – A-ACS-1	SMA/DAC 16 – F-ACS-1
	Two-layer porous asphalt ZOAB – NL02	Open-pored asphalt PA 0/8 – G-ACS-2	Noise-reducing stone mastic asphalt – A-ACS-2	SMA 8 – F-ACS-2
	Two-layer porous asphalt (fine) ZOAB – NL03	Stone mastic asphalt SMA 0/5 and SMA 0/8 – G-ACS-3	Stone mastic asphalt – A-ACS-3	
	Stone mastic asphalt SMA-NL5 – NL04	Stone mastic asphalt SMA 0/8 and SMA 0/11 – G-ACS-4	Asphalt concrete – A-ACS-4	
	Stone mastic asphalt SMA-NL8 – NL05	Low-noise mastic asphalt – G-ACS-5		
	Thin layer A – NL13	Noise-optimised asphalt SMA LA 0/8 – G-ACS-6		
	Thin layer B – NL14	Thin asphalt wearing courses in hot application (≥70 km/h) – G-ACS-7		
		Asphalt concrete AC 11 (≥70 km/h) – G-ACS-8		
		Noise-optimised asphalt AC D LOA – G-ACS-9		
Cement Concrete Surface – CCS	Brushed down concrete – NL06	Concretes according to ZTV Beton-StB 07 with washed concrete – G-CCS-10	washed concrete – A-CCS-5	
	Optimized brushed down concrete – NL07		Noise-reducing washed concrete GK8 – A-CCS-6	
	Fine broomed concrete – NL08		Noise-reducing washed concrete GK11 (2019) – A-CCS-7	
	Worked surface – NL09			
Paving Block Surface or Setts – PBS	Hard elements in herring bone – NL10	Hard elements with flat surface with $b \leq 5$ mm and $b + 2f \leq 9$ mm – G-PBS-11		Even paving stones – F-PBS-3
	Hard elements not in herring bone – NL11	Hard elements with $b > 5$ mm or $f > 2$ mm or other hard elements – G-PBS-12		Uneven paving stones – F-PBS-4
	Quiet hard elements – NL12			

Table 3: Sound power level difference from the reference surface in dB

Country	Pavement type	Road surface	$\Delta L_{W,\mathrm{road},m}$ in dB		
			$m = 1$	$m = 2$	$m = 3$
CNOSSOS-EU	Reference	0	0	0	0
	ACS	NL01	−1.1	−3.1	−2.8
		NL02	−4.5	−5.3	−5.3
		NL03	−6.6	−5.8	−5.7
		NL04	−1.8	0	0
		NL05	−0.8	0	0
		NL13	−3.3	−1.3	−1.2
		NL14	−4.9	−1.3	−1.2
	CCS	NL06	1.8	−0.2	−0.2
		NL07	0.2	−1.9	−1.7
		NL08	1.7	2	2
		NL09	2.8	−0.4	−0.2
	PBS	NL10*	2.3	4.4	4.8
		NL11*	6.1	8.2	8.4
		NL12*	−1.4	2.2	2.2
Germany	National Reference	G0	0.9	3.5	3
	ACS	G-ACS-1	−4	−1.9	−3.1
		G-ACS-2	−5.3	−4.4	−5.2
		G-ACS-3*	−1.5	1.0	0.1
		G-ACS-4	−1	1.6	0.7
		G-ACS-5	−1.2	2	1.3
		G-ACS-6	−2.1	-2	-3.2
		G-ACS-7	−2	1.1	0.2
		G-ACS-8	−1.1	1.5	0.5
		G-ACS-9*	−2.4	1.5	0.2
	CCS	G-CCS-10	−0.4	1.1	0.5
	PBS	G-PBS-11*	3	4.1	3.1
		G-PBS-12*	7	7.8	6.9
Austria	Reference	A0	0	0	0
	ACS	A-ACS-1	−3.7	−3.1	−3.3
		A-ACS-2	−3	−1.1	−1.1
		A-ACS-3	0	0.8	0.9
		A-ACS-4	−0.5	1.3	1.5
	CCS	A-CCS-5	0.9	0.9	0.9
		A-CCS-6	−0.1	0.1	0.1
		A-CCS-7	2.3	3.8	4.1
Finland	Reference	F0	0	0	0
	ACS	F-ACS-1	1.5	0.9	1
		F-ACS-2	−0.5	−0.5	−0.5
	PBS	F-PBS-3*	2.7	1.0	1.1
		F-PBS-4*	5.6	2.2	2.4

*Surfaces allowing a maximum speed of 60 km/h.

3.3 Sound power level difference for Austrian and Finnish road surfaces

In Austria and Finland, fewer road surfaces were evaluated in the process of transposing CNOSSOS-EU into the national law, with no Paving Block Surfaces in Austria and no Cement Concrete Surfaces in Finland [50–52].

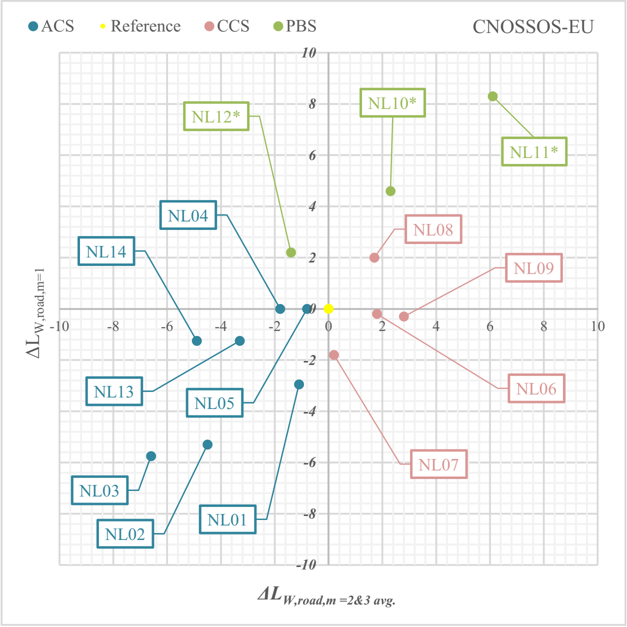

Figure 2: Noise reduction capabilities of CNOSSOS-EU road surfaces.

“Open porous asphalt – A-ACS-1” has the highest noise reduction capabilities in all categories in Austria, while A-CCS-7 is the least in terms of noise reduction. Moreover, the Finnish ACS road surfaces were found to have slight to no influence on noise emissions compared to the Reference Road Surface in all categories. However, both PBS proved that they are not capable of reducing sound emissions; on the contrary, they increase noise emissions in all categories. Figure 4 shows the comparison of the noise reduction capabilities for light motor vehicles and medium to heavy motor vehicles of the road surfaces considered representative in Austria and Finland for strategic noise mapping purposes.

3.4 General discussion

The results presented in Table 3 indicate that road surface types have a significant influence on noise levels calculated from the Reference Road Surface for all categories. Furthermore, noise levels for the same road surface type vary in the evaluated countries. For instance, $\Delta L_{W,\mathrm{SMA}\ 0/8,1}$ varies from −1.0 to −0.5 dB, $\Delta L_{W,\mathrm{SMA}\ 0/8,2}$ varies from −0.5 to 1.6 dB, and $\Delta L_{W,\mathrm{SMA}0/8,3}$ varies from −0.5 to 0.7 dB. These deviations can be linked to the different acoustical characteristics among similar road surface types in EU countries [32]. Alternatively, porous asphalt pavements were found to have the highest noise reduction capabilities, contributed by many factors, such as the number of surface layers, air–void ratio,

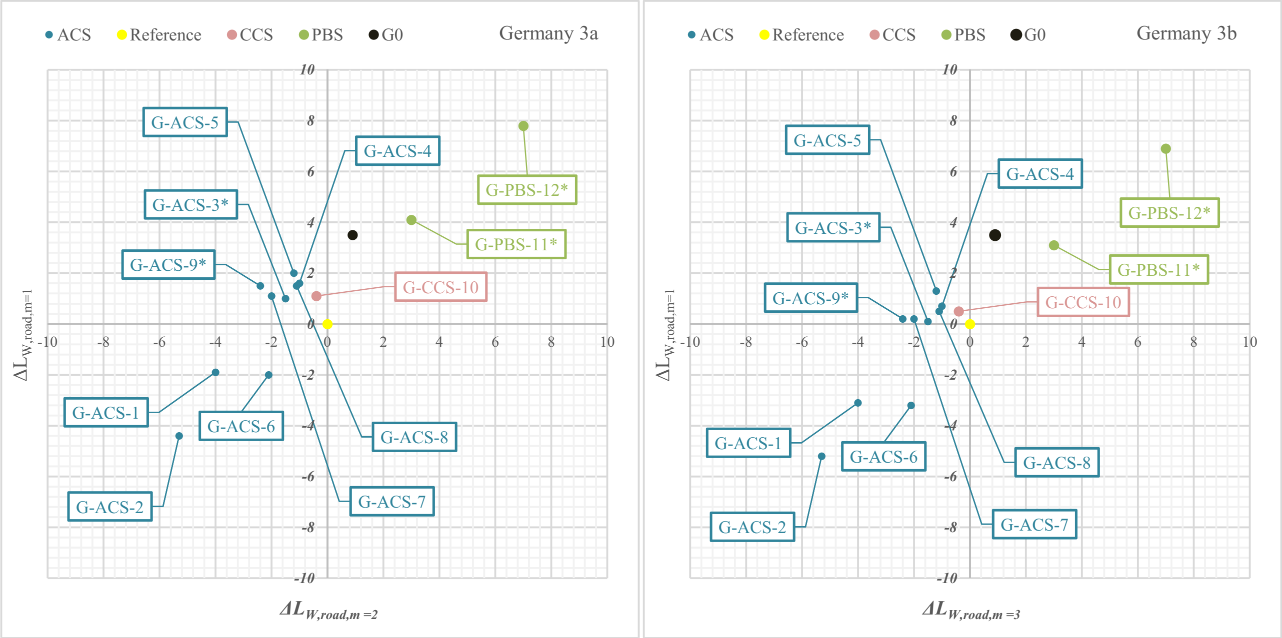

Figure 3: (a) and (b) Noise reduction capabilities of German road surfaces.

thickness, and texture. Generally, when the air-void ratio increases, the noise reduction increases [55]. That being said, the air-void ratio is recommended to be controlled at 20% [56]. Moreover, it was observed that for a 6 cm-thick surface with double layering, noise reduction capabilities are reduced when the bottom layer is thinner than the top layer. Additionally, the increase in the texture depth of pavements with very thin surfacing with small aggregates contributes to enhancing the sound absorption performance but extends the vibration distances of the layers which leads to generating more vibration noise. On the other hand, smooth surfaces generate less noise than surfaces with few and small texture patterns [55].

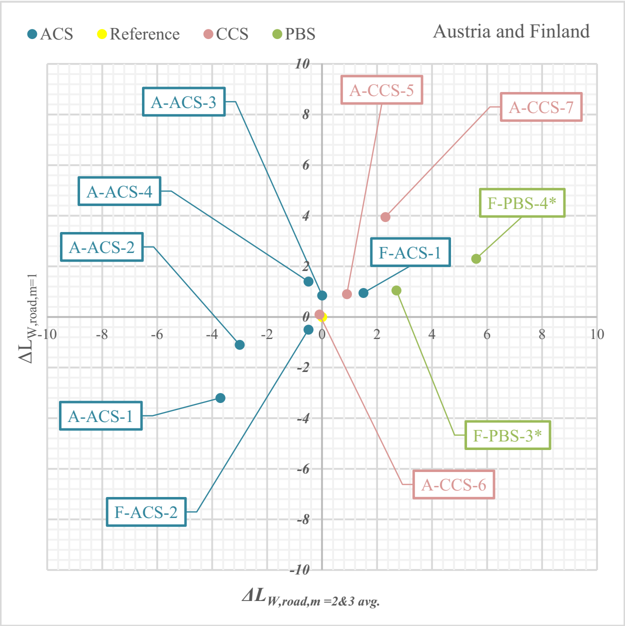

Figure 4: Noise reduction capabilities of Austrian and Finnish road surfaces.

However, the recommended scope of application for porous asphalt pavements is roads with low traffic flow, without junctions, narrow curvatures, or turning lanes. This is due to durability issues of porous roads when the traffic load is high. When the weight on the porous surface increases, the voids tend to compress which increases the necessity of rehabilitation and maintenance and reduces cost-efficiency [57].

In general, Paving Block Surfaces or Setts exhibit higher noise levels compared to the Reference Road Surface across all categories, which can be linked to the low air-void ratio that negatively affects the noise levels. For instance, light motor vehicles showed the same behavior on CNOSSOS-EU, German, and Finnish herringbone surfaces with noise levels increasing by 2.5–2.8 dB. However, heavy vehicles are expected to increase noise levels by 1.3–5.3 dB on the same surfaces compared to the Reference Road. Therefore, the variations in the calculated noise levels may pose challenges in adopting CNOSSOS-EU without aligning national laws with the CNOSSOS-EU methodology. To further support this observation, relevant literature was reviewed to compare the noise reduction capabilities of different pavements. Generally, porous sound absorption, resonance sound absorption, control of the sound propagation path, vibration damping, and connected pore excretion or a combination of these, are the mechanisms used to reduce the pavement noise [58]. For example, Porous Asphalt Pavements can effectively reduce noise levels by up to 6 dB [59], while noise levels measured on Rubber Asphalt Pavements were less by 1–3 dB in comparison with ordinary asphalt pavements [60]. Moreover, Porous Elastic Road Surfaces were found to be capable of reducing noise levels by 7–12 dB in comparison with Dense Asphalt Pavements [61–63]. Additionally, low-noise pavements have proven to be among the most effective measures for mitigating road traffic noise. However, accurately estimating their health benefits poses a challenge, as their acoustical characteristics are yet to be fully assessed [43]. In general, different techniques were used to evaluate the noise reduction capabilities of different pavement types [58]. Therefore, the results obtained from previous research may vary if they were evaluated using the CNOSSOS-EU methodology.

Furthermore, it is necessary to keep an eye on future modifications on the road surface types in the CNOSSOS-EU document. For instance, if a new pavement is widespread in Europe, such as new formations of low-noise pavements, the affected countries should evaluate the new pavement's influence on road traffic noise emissions and update their regulations accordingly. Low-noise pavements are typically implemented during road resurfacing or when required by law. However, the END's 2023 evaluation recommended that member states consider them as a key mitigation measure, in addition to quiet tyres and road speed limits reduction [25]. The EU has enabled member states to define new surfaces in the CNOSSOS-EU road traffic model by introducing their specific $\alpha_{i,m}$ and β_m correction coefficients [32]. While the process of determining the correction coefficients is still not established, a recent study estimated the correction coefficients for two low-noise pavement surfaces. The study concluded that the Urban SPB method is effective for defining new surfaces in the CNOSSOS-EU road traffic noise model [43].

The comparison presented in this article is limited to countries that have their national road surface types and their coefficients accessible in the noise mapping software after adopting CNOSSOS-EU at the national level, specifically Germany, Austria, and Finland. The results from this work can serve as a valuable foundation for other EU countries that are currently transitioning the CNOSSOS-EU method to their national law for comparison purposes.

This groundwork will support further investigations into a broader range of road surfaces, addressing the deviations in noise levels across different road surfaces. Consequently, the outcome of this work is expected to be useful for noise mapping experts in the industrial field, as it provides a summary of the difference in noise levels on various road surface types across different countries.

Therefore, when selecting the applicable road surface type from the noise mapping software database for road traffic noise mapping projects that employ the CNOSSOS-EU calculation method, it is crucial to consider that similar road surface types can vary from one country to another. To achieve accurate results, the CNOSSOS-EU method should only be applied to countries whose data is already available in the noise mapping software databases. This approach ensures consistency and reliability in noise mapping across different regions and road surfaces in the EU.

4 Conclusion

In this article, the influence of road surface types in Europe on the total sound power levels of light, medium heavy, and heavy vehicles was evaluated by excluding all other parameters indicated in CNOSSOS-EU such as temperature, studded tires, *etc.* A virtual road with an average of stone mastic asphalt 0/11 and dense asphalt concrete 0/11 between 2 and 7 years old and in representative maintenance condition was selected to be the base for the road traffic noise calculations, and is referred to as "Reference Road."

Data in the literature are available in 1/1 octave bands for rolling and propulsion noise separately. Therefore, the summation of both noise sources was calculated by utilizing the CNOSSOS-EU formulas to obtain the total sound power level for each road surface type, and then, the obtained value was subtracted from the total sound power level of the Reference Road, which is referred to in this article as $\Delta L_{W,\mathrm{road},m}$. A negative difference indicates that the noise level for the evaluated surface is expected to be lower than that for the Reference Road. Based on the results, it was observed that $\Delta L_{W,\mathrm{road},m}$ for the same road surface type in different countries varies significantly in some cases from CNOSSOS-EU road surface types, which can be related to the uneven sound characteristics of the similar road surface types in Europe.

Although this article focuses on highlighting the differences between accessible coefficients in the noise mapping software for different road surfaces at the national level, in Germany, Austria, and Finland, it paves the way for future possible comparisons. This will become feasible once all EU member states publish their road surface coefficients officially, following the transposition of CNOSSOS-EU into their respective laws.

In summary, the results show that road surface type correction factors presented in the CNOSSOS-EU documentation do not apply to all EU countries' road surface types despite being in the same pavement category. However, the approach and methodology utilized in CNOSSOS-EU for road traffic noise calculations shall be adopted in all European countries to calculate their national road surface correction factors which urges the necessity of the transposition of CNOSSOS-EU in all EU member states to serve several purposes such as the preparation of strategic maps.

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