Current Pollution Reports

Analysis and management of current road traffic noise

--Manuscript Draft--

Manuscript Number:	
Full Title:	Analysis and management of current road traffic noise
Article Type:	Review Article
Section/Category:	Noise Pollution
Funding Information:	Consejería de Economía, Ciencia y Agenda Digital, Junta de Extremadura (ES) (TA18019) — Dr. Guillermo Rey Gozalo
Abstract:	Road traffic noise is one of the major environmental pollutants in cities around the world that continues to increase over the years despite the implementation of regulatory policies. The lack of engagement of national governments, the use of different or inadequate methodologies and the absence of implementation of measures to control road traffic noise are some of the causes why the population exposed to noise has not been reduced. There is a large number of recommendations, methodologies and procedures for adequate road traffic noise analysis and management in the scientific literature. The aim of this paper is to analyse the main findings of recent years with the objective of highlighting the current acoustic situation and to provide tools that can reverse it. Development of accurate noise analysis methods is close to reality. However, greater engagement and control by the authorities is needed for the implementation and efficiency of noise measures.
Corresponding Author:	Guillermo Rey Gozalo Universidad de Extremadura Cáceres, SPAIN
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Universidad de Extremadura
Corresponding Author's Secondary Institution:	
First Author:	Guillermo Rey Gozalo
First Author Secondary Information:	
Order of Authors:	Guillermo Rey Gozalo
	Juan Miguel Barrigón Morillas
	David Montes González
Order of Authors Secondary Information:	
Author Comments:	
Suggested Reviewers:	Eriberto Oliveira Do Nascimento Universidade Federal do Parana eriberto.on@gmail.com Researcher in the area of Acoustics with similar lines of research to the study
	Konstantinos Vogiatzis University of Thesally kvogiatz@uth.gr Researcher in the area of Acoustics with similar lines of research to the study presented in this paper.
	Mario Mateus Universidade de Coimbra mario.mateus@adai.pt

	Researcher involved in environmental acoustics
	Guillermo Quintero Universitat Politècnica de Catalunya: Universitat Politecnica de Catalunya guillermo.quintero@upc.edu Researcher involved in environmental acoustics and population noise exposure and he is cited in the manuscript.
	José Luis Barros Universidad Austral de Chile jbarros@uach.cl Researcher in the area of Acoustics with similar lines of research to the study presented in this paper.

Analysis and management of current road traffic noise

Guillermo Rey-Gozalo[1,2,*], Juan Miguel Barrigón Morillas[1], David Montes González[1]

[1] Laboratorio de Acústica (Lambda), Departamento de Física Aplicada, Instituto Universitario de Investigación para el Desarrollo Territorial Sostenible (INTERRA), Escuela Politécnica, Universidad de Extremadura, Avda. de la Universidad, s/n, 10003 Cáceres, Spain.

[2] Facultad de Ciencias de la Salud, Universidad Autónoma de Chile, 5 Poniente 1670, 3460000 Talca, Chile

[*] Corresponding author. Tel.: +34 927257233; fax: +34 927257203; E-mail address: guille@unex.es

Abstract

Road traffic noise is one of the major environmental pollutants in cities around the world that continues to increase over the years despite the implementation of regulatory policies. The lack of engagement of national governments, the use of different or inadequate methodologies and the absence of implementation of measures to control road traffic noise are some of the causes why the population exposed to noise has not been reduced. There is a large number of recommendations, methodologies and procedures for adequate road traffic noise analysis and management in the scientific literature. The aim of this paper is to analyse the main findings of recent years with the objective of highlighting the current acoustic situation and to provide tools that can reverse it. Development of accurate noise analysis methods is close to reality. However, greater engagement and control by the authorities is needed for the implementation and efficiency of noise measures.

Keywords: road traffic noise; road traffic modelling; noise assessment methodologies; CNOSSOS-EU; noise action plans

Introduction

Strategic noise maps (SNM) have been generated every 5 years in the European Union Member States (EU MS) since the establishment of the European Environmental Noise Directive (END) in 2002 [1]. Accordingly, three phases of noise map generation and updating have been performed (2007, 2012 and, 2017). A new update of the strategic noise maps will be available by the end of this year 2022. An overarching policy requiring noise mapping or city noise modelling is either lacking or difficult to find in other countries. In fact, environmental noise reports by the World Health Organisation (WHO) generally show the results obtained in European countries [2, 3].

The results obtained in the three phases show that the number of European people exposed to road traffic noise is much higher than exposure to other source of environmental noise. According to the 2017 data, the overall number of people exposed to $L_{den} \geq 55$ dB was estimated to be 113 million for road traffic noise, 22 million for railway noise, 4 million for aircraft noise and 1 million for noise caused by industry [4, 5]. Similar differences between the number of people exposed to the different sources of environmental noise were found to $L_{night} \geq 50$ dB. Therefore, road traffic is by far the biggest noise source in European cities, similarly in other cities around the world [6, 7] and villages [8, 9].

The number of people exposed to road traffic noise ($L_{den} \geq 55$ dB) inside urban areas has been increasing from 2007 to 2017 in Europe (73.8 million in 2007, 80.7 million in 2012 and 81.7 million in 2017) [4] and is even projected to increase in the coming years (83.6 million in 2020 and 84.3 million in 2030) [10]. Reducing the number of people exposed to $L_{den} \geq 55$ dB might be too ambitious. However, the percentage of people exposed to $L_{den} \geq 65$ dB has not decreased either (30% in 2007, 34% in 2012 and 30% in 2017) [11]. Urban areas whose $L_{den} \geq 65$ dB are considered black acoustic zones according to Organization for Economic Cooperation and Development (OECD) criteria [12]. The primary objective of significantly reducing noise pollution in Europe is not being met. This increase in road traffic noise has also been reported in other countries. The total United States population potentially exposed to road noise, defined by a 24-hour average sound level, increased by 2.4% from 2016 to 2018 [11]. Nascimiento et al. [14] show that 60% of the points sampled in 2016 in the city of Goiânia exceeded the daytime equivalent sound level of 60 dB. They estimate that all assessed points will exceed 60 dB after 2036.

The International Transport Forum for passenger transport in the world expects transport demand to almost triple by 2050, especially through private cars, as a result of population growth and increasing wellbeing [14]. Population growth and traffic in cities are some of the possible causes that have been able to offset actions to reduce noise levels [5, 15, 16]. However, missing and inconsistent data call into question the exposed population shown in the different phases of SNM, as highlighted by different researchers

[17, 18, 19]. Accuracy in results was not the main priority in the first phase of the noise mapping process, but rather to generate more effective noise policies [18, 20]. In this respect, the first phase (2007) was successful because it had a high media impact and a legislative framework for the regulation of environmental noise in the EU MS was developed. Cities with more than 250,000 inhabitants were mapped in the first phase but noise mapping was carried out in cities with more than 100,000 inhabitants in the following phases. The number of people noise exposed was lower in the second (2012) and third (2017) phases despite the increase in the number of agglomerations. These partial or incomplete figures for exposure and their consequent estimation increases the uncertainty of outputs. The quality of output is another problem and varies considerably between EU MS for the following reasons [17, 18, 19]: different calculation methods have been used, various methods used to calculate population exposed to noise, no specification of simulation parameter figures (reflection order, type of pavement, size of the grid, etc.), contradictions in the calculation of the L_{den} (dB), use of estimated noise source data instead of real-life scenario data, insufficient quality of geographical and topographical data, different criteria for mapping urban roads, etc. So, noise mapping seems to have become an obligation rather than an instrument to improve the health and quality of life of the population [18]. Inexperience of local authorities, deficiencies in management and administration in data collection, shortage of human and financial resources were possible causes of missing and inconsistent data [21, 22].

Different studies analysing the relationship between noise and health use the values shown in strategic noise maps. Therefore, poor data quality will significantly affect the results of disease burden studies [19]. In the last 5 years, the highest percentage of manuscripts using the keywords "urban traffic noise" in the SCOPUS database are related to the effects on people's quality of life and health as shown in Fig. 1.

Using the keywords "urban traffic noise" in the SCOPUS database, the highest percentage of manuscripts in the last 5 years are related to the negative effects on people's health and quality of life as shown in Fig. 1. Another significant percentage of papers are related to noise mapping, new methodologies and noise dynamics which will be discussed in the next section of this manuscript.

Fig. 1. Tag cloud of the frequency of road traffic noise topics reported in the last 5 years in the SCOPUS database.

Member states also have to draw up noise action plans and review them every 5 years according to the END [1]. Reducing noise exposure levels, which is the main objective of the END, depends on the development of appropriate action plans. Action plans have often had no effect in reducing noise levels either because they have not been properly implemented or reviewed. EU MS are not obliged to implement noise action plans and this is probably affecting their implementation and effectiveness. The absence or non-updating of noise maps in some countries has obviously influenced their non-obligatory drawing [23].

Considering the above, the aim of this study is to show the results or conclusions obtained in recent studies that can contribute to improve the accuracy of road traffic noise assessment and the implementation of appropriate action plans that can reduce the noise generated by vehicles.

Road traffic noise assessment

CNOSSOS- EU method

The END modifies Annex II corresponding to the Assessment Methods for Noise Indicators in 2015. This new annex proposes common assessment methods (CNOSSOS-EU) that should be applied from 2019 in all EU MS [24]. Therefore, the CNOSSOS-EU method should be used in the next phase of noise mapping (2022) and perhaps solve the problems encountered in the previous phases regarding the use of different methodologies.

CNOSSOS-EU method includes different sound emission and propagation models depending on the type of sound source [25]. For the noise produced by road traffic, the emission model was obtained from experimental measurements carried out in the IMAGINE - Harmonoise project [26]. Sound power coefficients were determined from linear regression between Sound Exposure Levels (SEL per 1/3-octave band) and vehicle speed. The propagation model was generated from NMPB-ROUTES-2008 [27]. CNOSSOS-EU divides the noise source into corresponding equivalent point sources whose addition of sound waves is incoherent because they are energy-based models [28]. However, coherent point sources are assumed in the Harmonoise/IMAGINE projects [28]. Consequently, various studies showed that CNOSSOS gave an underestimation of the noise levels [29, 30, 31]. The studies by Kahn et al. [32, 33] showed this underestimation. However, they could not quantify it due to the lack of measured noise data. Rey Gozalo and Gómez Escobar [34] performed an extensive sampling of measurement points on different typologies of urban roads in two cities. The major urban roads, which have the highest road traffic flow and percentage of heavy vehicles, showed absolute underestimation errors of about 3 dB. This error was lower on residential streets (about 2 dB). In addition, the error was significantly correlated with the flow and percentage of heavy vehicles. Most of the measurements, from which the Harmonoise/IMAGINE algorithm was developed, registered light vehicles and therefore, Czyzewski and Ejsmont [35] found a significant overestimation of the propulsion noise or underestimation of the rolling noise. The reason for the 3 dB underestimation is that, when the propagation model was changed, the direct sound wave and the reflected sound wave on the ground were not added [28, 36]. The END has recently published a modification of Annex II to solve this error and for this purpose, new sound power coefficients are shown in Table F-1 [37].

Pallas and Dutilleux [38] also reported an underestimation of the CNOSSOS-EU method estimates. They point out the need to improve the rolling noise contribution of CNOSSOS-EU method for medium-heavy vehicles and consider that it is not appropriate to apply the same correction coefficients for respective road surface to both propulsion and rolling noise [38, 39]. The Netherlands National Institute for Public Health and the Environment carried out an analysis of CNOSSOS-EU method in 2017 before it was implemented [40]. Numerous issues were found in this study and were communicated to the EU commission. A report was drafted in 2019 with proposed amendments and possible improvements [41]. Relevant amendments include: the Rayleigh criterion is not defined, incorrect method for multiple diffractions in favourable conditions, large differences in ground attenuation between CNOSSOS-EU and ISO 9613 methods and attenuation due to industrial sites is absent in CNOSSOS-EU [40].

Regarding the assessment of population exposure, CNOSSOS-EU has implemented the VBEB model [42]. VBEB model distributes the noise receivers on the façades at different height levels depending on the number of floors. Each of these receivers will determine the noise level to which each dwelling is exposed considering the height parameter. Arana et al. [43] shows that the VBEB model is more accurate than the procedure of calculating the exposure of people at a height of 4 metres on the most exposed façade proposed by the END [1]. Vienneau et al. [44] analysed the relationship between road traffic noise and myocardial infarction mortality considering different methods to distribute the exposed population in the building and different spatial scales. Changes in spatial scale introduced more bias than changes in the method of distributing the exposed population.

All these uncertainties reported in the estimation of noise values by the CNOSSOS method prior to the new Annex II of the European Directive [37] call into question the results shown in studies that relate noise and negative health effects. The population exposed to road traffic noise varies significantly depending on the method used as shown in a study by Murphy and Douglas in Dublin [45]. Morley et al. [46] successfully implemented the CNOSSOS-EU road traffic prediction model for international epidemiological studies. So, several researchers have used the CNOSSOS-EU method in very recent epidemiological studies. They have used the UK Biobank cohort (502,490 citizens recruited from 2006 to 2010 in the UK) and estimated noise level data for 2009 with a search radius of 500 m [47, 48, 49, 50, 51]. They have analysed the relationship between road traffic noise and cardiovascular disease, mortality, sleep, mental health and obesity.

Quality of input parameters

The amendments implemented in the recent new version of the CNOSSOS-EU method will significantly improve the accuracy of the method [37]. However, despite the existence of guideline recommendations [52, 53], the quality of the estimates is strongly influenced by the modelling parameter configuration and the inputs [43, 54]. Arana et al. [43] pointed out the following simulation parameters: reflection order, type of pavement and size of the grid. Arana et al. [43] recommend using a second reflection order in urban areas with high building density. However, most noise maps only use one reflection order. Moreover, ISO 1996-2 corrections should be considered when *in situ* noise receivers are not located in free field [55, 56]. The consideration of horizontal and vertical diffractions in the calculation benefits the accuracy of the estimates although it entails a higher computational cost [41, 54]. The number of pavement types in the CNOSSOS-EU method has tripled compared to the NMPB-96 method [53] and this can lead to uncertainty about the correct assignment. In addition, the wear of the pavements significantly influences their acoustic properties. Recent research shows significant advances in pavement wear recognition and assessment [57, 58, 59]. Van Hauwermeiren et al. [57] propose an approach based on commodity sensors in a fleet of cars that label the pavement type using machine learning. Licitra et al. [58] and Freitas et al. [59] model and evaluate the acoustic ageing of pavements. Licitra et al. [58] apply regression models for acoustic ageing and Freitas et al. [59] uses data mining techniques. Regarding the grid size, noise maps of some Spanish cities use a 5x5 m resolution [43]. Cai et al. [60] developed a method based on high-resolution population and noise distributions with a cell size of 4x4 m.

The quality of the meteorological data determines the accuracy of the sound propagation model [54]. These parameters are introduced globally in the noise modelling. Humidity and sound pressure do not vary significantly over short distances between source and receiver. However, temperature can be variable from one city location to another. Barrigón Morillas et al. [61] find very significant relationships between temperature and L_{Aeq} (dB). Wind is also an influential variable on sound levels when the wind speed exceeds 5 m/s [62].

Quality of cartographic and topographic data (buildings, altitude…) is also considered by Arana et al [43] to be relevant to improve the quality of outputs. A mapping accuracy of 0.5 m in elevation is desirable to ensure accurate estimates of the exposed population [43]. Buildings or their heights are not always present in the public cartography of cities. This problem was encountered in the elaboration of the noise map of Santiago de Chile [63]. Google Street View or Google Earth are possible sources where this information can be obtained. However, there are methods that optimise the buildings extraction from high resolution satellite imagery using deep learning [64] and software that make 2D GIS data three-dimensional [65]. Building height is also important for estimating population noise exposure [66]. The most accurate methodologies place noise receivers at different heights from the façade [42]. 3D noise mapping is becoming increasingly common [67, 68]. The resolution of population data is important for the accuracy of noise exposure calculations as Cai et al. [60] and Vinneau et al. [69] show. Resident counts per dwelling or building are complex to obtain. Population data are most often provided by street or neighbourhood. Methodologies are now being developed that take into account the mobility of people and therefore noise exposure results are realistic and accurate. Methodologies are now being developed that take into account the mobility of people and therefore noise exposure results are realistic and accurate [70, 71]. People are not static and move in and out of their homes on a daily basis to get to work.

Despite the importance of the quality of the inputs mentioned above, the quality of the noise source data is the most influential on the accuracy of urban noise models [43, 72]. Road traffic flows come from major roads in many occasions because they are the ones that usually have traffic counters for their regulation in the city. These urban roads register high and constant noise levels. The noise estimates for these urban roads are usually the ones with the lowest error [34, 73]. So, new methodologies are often analysed in this type of urban roads [67, 74, 75]. However, the majority of the population lives on residential streets for which less information is available. In addition, vehicle speeds are often below 50 km/h on residential roads. The noise model algorithms have been developed on the basis of data collected on major or interurban roads where vehicle speeds are usually above 50 km/h [76, 77]. Therefore, the largest estimation errors are frequent on such urban roads [34, 73]. Rey Gozalo and Gomez Escobar show that an adequate *in situ* measurement strategy could be an alternative for assessing residential streets with low vehicle flow [73]. Vehicle speed is rarely available. Some researchers take the maximum regulated speed of the road as a reference [73]. There is no information on speed ranges or acceleration on urban roads [77]. The lack of this information generates uncertainties especially when the traffic flow is pulsed (intersections with traffic lights, roundabouts...). In fact, these zones have been the subject of interest for different microscopic traffic modelling [78, 79]. Another important aspect is that the CNOSSOS-EU method differentiates between 5 types of vehicles and many of the traffic registers only differentiate between light vehicles (cars and motorbikes) and heavy vehicles. Traffic counters usually classify vehicles according to their length using pavement sensors or Doppler radar. Therefore, differentiation between types of heavy vehicles or between types of two-wheeled vehicles on the basis of length may lead to uncertainties. These traffic sensors also record the speed of vehicles. Current studies show the identification of different vehicle typologies and their speed using machine learning from images collected by video cameras placed on urban roads [80, 81, 82]. Vehicle speed can also be determined from the sound spectrum as reported in the study by Zambon et al [83].

Alternative methodologies for assessing road traffic noise

When *in situ* measurements are carried out to register different parameters of the road traffic source: noise levels emitted, flow and typologies of vehicles, speed... it is advisable to apply an appropriate methodology to reduce costs and ensure that the data accurately reflect the urban reality. Barrigón Morillas et al. [84] reviews different methodologies for assessing *in situ* urban noise. The stratification of streets according to their functionality, called the Categorisation Method [85], has proven its applicability and accuracy in different cities around the world [86]. Stratification of urban roads is also considered in dynamic noise mapping [87]. In addition, *in situ* measurements are recommended to verify the estimates made by noise models [52]. Calibration allows verification of the adequacy of the decisions regarding the configuration of the modelling parameters and the quality of the inputs. However, noise maps are not always calibrated with *in situ* measurements or measurements are only carried out on major roads. Inaccurate or uncertain estimates will affect the success of future action plans.

Most of the popular noise mapping software are expensive, although open-source noise modelling is becoming more and more common [88]. Considering the high influence of input data quality on prediction accuracy, many researchers choose to develop their own models or algorithms. Observation-based approaches generated the first algorithms, also called statistical methods. Despite their simplicity, they established significant relationships between sound levels and variables such as flow, type of vehicles or distance to the source [89]. These regression models give good results in urban areas with similar speeds and similar pavements and are used in educational apps [80]. A variety of studies are now developing multiple regression models that include other urban or land use variables to predict noise levels. These models are called land use regressions (LUR) and generally use GIS to register the different urban variables and estimate the results. Some of these models explain up to 80% of the noise variability but also incorporate some road traffic characteristics [90, 91]. Barrigón et al. [85] showed different studies where only the road traffic flow was able to explain 70% of the L_{Aeq} (dB) variability. Moreover, there is no prior selection of predictor variables in many of these models and, therefore, their effectiveness decreases, i.e. the models include many independent variables and some of them have no significant relationship with the noise variable [91, 92]. In fact, root-mean-square error (RMSE) is usually between 3 and 5 dB [90, 92]. However, LURs have also been developed that only include urban variables and present high explanations of noise variability [92, 93]. These models can be an alternative or complement to traditional noise models especially when analysing the applicability or effectiveness of action plans related to urban planning. Sensitivity of these models to variables that do not have a linear relationship with noise has led to the development of machine learning algorithms [75, 81, 82, 94]. Currently, deep learning is displacing other machine learning techniques (support vector machine (SVM), artificial neural network (ANN), adaptive neuro-fuzzy inference system (ANFIS)…) because they use a greater number of hidden layers favoring the learning of more linear patterns and, therefore, solving more complex interactions [94].

Road traffic noise maps made with the CNOSSOS-EU method are considered static because they only provide the annual average value of noise levels [95]. Some researchers consider them semi-dynamic because they include dynamic variables such as speed. Noise quantification in annual average values is not sufficient to assess the negative effects of noise on health and its variability also needs to be determined. Therefore, the development of new methodologies to assess noise dynamics has been an important focus of research in recent years.

DYNAMAP project based on dynamic road traffic noise mapping using low-cost sensors has been widely disseminated in the scientific community [87]. Noise maps in a ring road of Rome and a neighbourhood of Milan are periodically updated from data registered at noise monitoring stations [74]. In addition, urban road classification methods have been applied [96] and procedures have been developed for the identification and elimination of events anomalous to road traffic noise [97, 98]. Wei et al. [99] interpolates the results obtained from the measurements also considering the road typology. Better least squares fits are obtained for the observations than for the traffic data.

The computational and economic cost of temporarily registering the different characteristics associated with road traffic and the urban environment means that many of these studies are on a small scale. For this reason, they are also referred to as microscopic models. Some studies couple microscopic traffic models (SYMUVIA, VISSIM…) and noise prediction models [78, 79, 88]. Kinematic characteristics of vehicles in certain traffic control strategies are obtained from traffic models. Other studies use smart-phone microphone observations as a data source [100, 101, 102]. Ventura et al. [101] used this data to update a pre-calculated noise map. Picaut et al. [102] extends temporally and spatially the logging of sound data by mobile phones using the NoiseCapture app.

Dynamic noise maps require a large number of variables as shown above. Managing a large number of spatial and temporal variables increases the computational cost and can affect the efficiency of mathematical models due to the presence of interaction between variables. Sensitivity analyses can manage the influence of variables in models and only include those that contribute significantly by studying their uncertainty. Aumond et al. [103] shows the reduction of 40 input parameters required by the CNOSSOS-EU method to 15 input parameters. Using a sequential forecasting approach or meta-models also optimises and improves the accuracy of noise models [72, 104].

The accurate estimation of the variability of sound levels is an important advance but really the main objective of noise maps is to accurately assess the exposed population. In response, recent studies elaborate receiver-centric noise exposure sensitivity maps [105]. These maps consider the daily mobility of the population and are therefore also dynamic maps.

Noise management and abatement

Developing accurate urban noise assessment methodologies provides reliable information on the acoustic environment. If noise levels reach values that negatively affect the health of citizens, the objective is to reduce them. In addition, preservation of quiet areas is also a priority objective of the European Noise Directive. A review of current studies aimed at managing and abating road traffic noise is shown in this section. There are fewer studies on this topic as shown in Fig. 1.

Table 1 has been elaborated taking as a reference the figure "10 ways to combat noise pollution" produced by the European Commission [106]. They have been classified according to the priority order of action: source, propagation path and receiver. Nine of the ten ways to combat urban noise are related to the source of road traffic. Table 1 therefore reflects the importance of reducing road traffic noise.

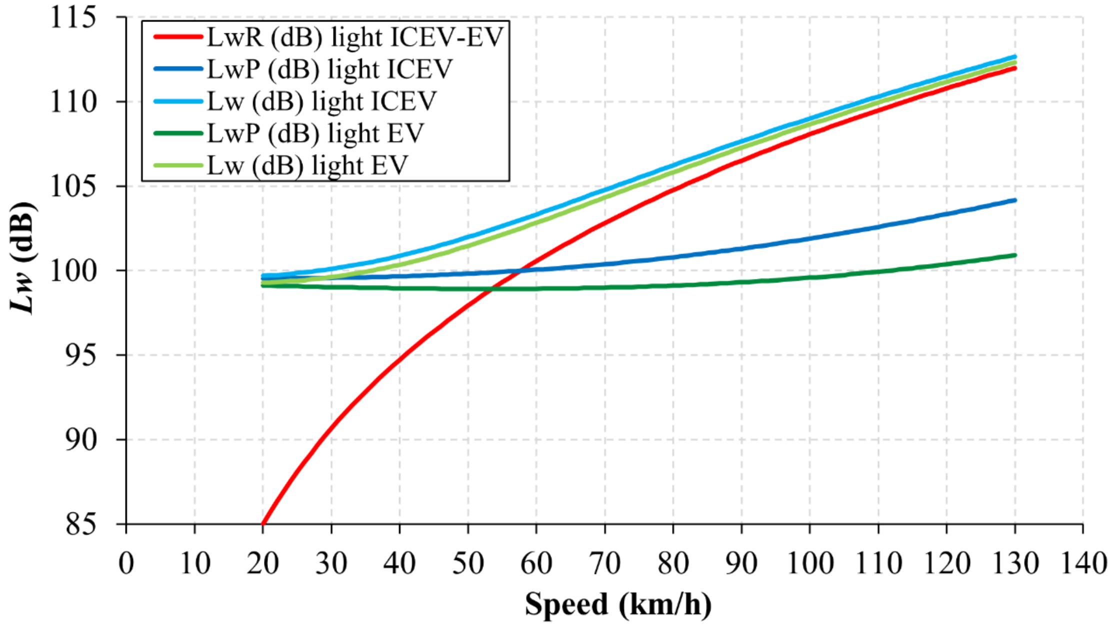
Table 1. Estimated sound reduction of the main noise actions developed in Europe. Source [106]

Category	Noise reduction actions	Estimated reduction (dB)
Source	Electric vehicles	1
	Low-noise tyres	3 – 4
	Quiet road surfaces	3 – 7
	Traffic management	1 – 4
Path	Noise barriers	3 – 20
Receiver	Building insulation	5 – 10
	Building design	2 – 15
Other	Land-use planning & design	Unknown
	Changing driving styles	5 – 7

Road traffic noise control measures at the source

Electric vehicles (EVs) were developed and promoted to reduce air pollution in cities. EVs currently represent 3% of the light vehicle fleet and are expected to reach 15-30% by 2030 in Europe [107]. Improvement in battery performance, increase in charging stations and financial support granted by the EU MS have contributed to the expansion of EVs [107]. Noise generated by EVs is lower than that of internal combustion engine vehicles (ICEVs), especially at speeds below 50 km/h as shown Fig. 2. Considering the sound power level in dBA (see Fig. 2 b), the difference between EVS and ICEVs is 1.5 dB at 30 km/h and 0.5 dB at 50 km/h. These differences may vary from those proposed by Pallas et al. [108] because the new sound power values (L_w (dB)) proposed by CNOSSOS-EU method [107] have been used.

a)



b)

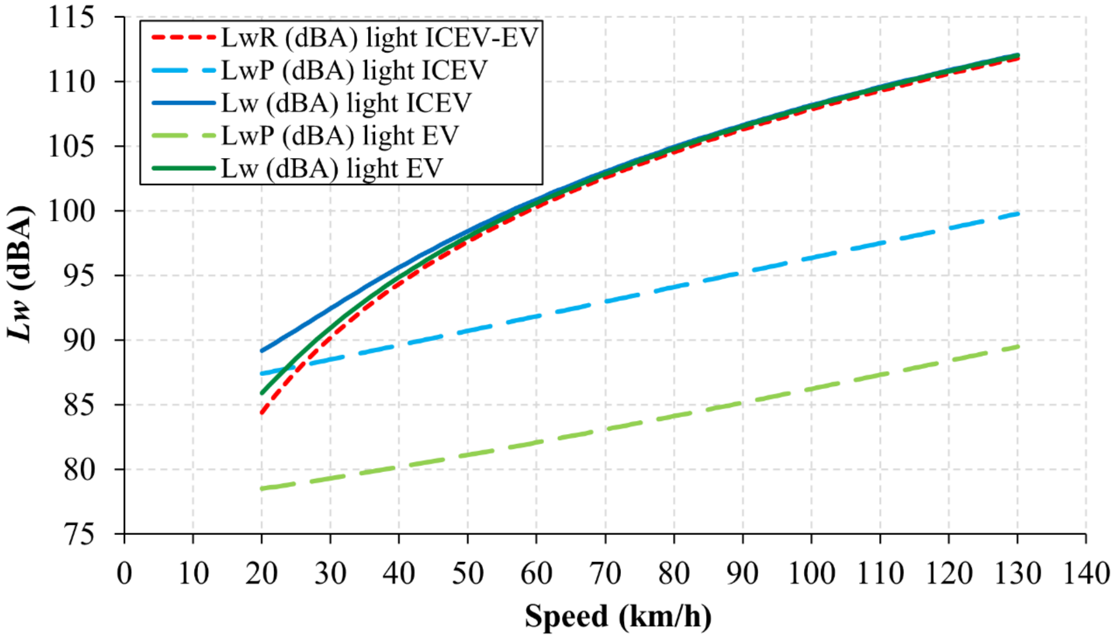


Fig. 2. Sound power level generated by rolling and propulsion of light internal combustion engine and electric vehicles in dB (a) and dBA (b) according to the CNOSSOS-EU method [37] and Pallas et al. [108], respectively.

Other studies obtain L_w (dBA) differences between ICEVs and EVs slightly higher than those shown in Fig. 2. Campello-Vicente et al. [109] obtain differences of 2 dB for a speed of 50 km/h and Yamauchi et al. [109] obtain differences of 2-4 dB for speeds of

20-30 km/h. Yamauchi et al. [110] also indicates that the artificial noise created by the Acoustic Vehicle Alerting System (AVAS) between speeds of 0-20 km/h was not negligible. Ibarra et al [111] found much larger differences between hybrid electric vehicles (HEVs) and EVs: 3 dBA on urban roads (50 km/h speed limit) and 7 dBA on interurban roads (80 km/h speed limit). Regarding to heavy vehicles, Laib et al. [112] evaluate the effect of using electric buses in the urban environment. Results show a decrease of 10 dB compared to internal combustion engine buses for 30 km/h. However, there are no differences in the noise levels emitted for 50 km/h.

Considering the vehicle flow registered in residential streets in previous studies [73, 86] and the sound power levels emitted by electric vehicles (Fig. 2), only if 100% of vehicles were electric and their speed was 30 km/h, the levels generated would be close to the limits proposed by the WHO [3]. Residential or neighbourhood streets (Category 4 and 5 according to [85]) have the lowest vehicle flows but also the highest percentage of the population living on them. Lower vehicle speeds would also reduce the number of traffic accidents [113] but would increase energy consumption [114]. Acceleration also influences noise levels [79] and therefore driving style is important. The future deployment of autonomous cars will benefit in this context [115].

Cesbron et al. [116] shows that the type of road surface can significantly decrease noise (overall a decrease of 6.2 dBA) in contrast to current electric vehicle traffic. Absorption and low texture are the main noise reduction properties of the road surface [116]. Praticò and Anfosso-Lédée [117] show different types of quiet pavements that have been developed: porous asphalt, rubberised asphalt, poroelastic road surface, very thin asphalt... Rubberised asphalt has shown a significant reduction of traffic noise (8-10 dB(A)) in current studies [118, 119]. Furthermore, these asphalts can be considered recyclable as crumb rubber from urban waste can be used [120]. Despite the good acoustic properties of these quiet asphalts, their sound absorption decreases with age. This decrease is influenced by many factors and different models have now been developed to estimate it [58, 59]. Another relevant current issue is the life cycle of low-noise pavements. Piao et al. [121] conclude that the use of semi-dense asphalt instead of stone-mastic asphalt reduces noise (thus benefiting human health) but increases energy demand and global warming.

Noise reduction provided by quiet pavement can be improved by optimising tyre properties. Tested tyres running on the smooth road surface in the QCITY project showed a noise reduction of 1.7 to 2.1 dB, for speeds of 40 km/h and 50 km/h [107]. This reduction was increased to 6.3 dBA with a prototype dualQ tyre. Once a real model of the Qdual tyre was created in the CityHush project, the reduction was 4.7 dBA for the EV and 4.1 dBA for the ICEV at 50 km/h [107].

In addition to speed reduction as part of traffic management actions, cities have limited private vehicle access to certain central areas [122, 123]. Efficient public transport and more bicycle lanes have also had a positive impact on the noise environment in some cities [124]. Limiting the access of heavy vehicles to central urban areas or not operating waste services at night also reduces noise levels.

Ögren et al [125] show future scenarios of Gothenburg using different road traffic reduction measures. Low-noise pavement all roads or low-noise tires (-5 dB) show similar decreases in the number of exposed population (from 210,000 inhabitants L_{den} > 55 dBA in 2015 to 150,000 inhabitants in 2035). Reducing vehicle speed (-10 km/h) has the most immediate effect, but reducing traffic flow provides a steady reduction in noise levels.

Road traffic noise control measures at the propagation path and the receiver

Noise barriers are the main propagation path noise reduction strategy. New waste for the construction of noise barriers appear every year: construction and demolition [126], palm tree pruning [127] … Innovative solutions that provide significant noise reductions are the use of sonic crystal and T-shaped acoustic barriers covered with oblique diffusers [128, 129]. Sustainability of the materials constituting the acoustic barrier should be considered [130]. Martinez-Orozco [131] and Halim [132] show results of the loss of effectiveness of different noise barriers.

The proposal for green noise barriers continues to spread despite low sound reduction values. Reductions between 5 and 10 dBA are achieved by combining depth and density of trees [133]. The great benefit of greenery is related to sound perception as indicated by Van Renterghem [134]. Van Renterghem and Botteldooren [135] also show the sound reduction provided by roadside embankments. Other alternatives to noise barriers that provide high noise reductions (>10 dBA) are the use of tunnels or underpass [136, 137].

Vegetation is also used in buildings to provide aesthetic and acoustic improvements. The water content of green roofs can lead to an improvement in acoustic reduction reaching values of 7 dBA [138]. Yang and Yeong [139] list the main design elements in today's building envelope with acoustic properties: balcony, protrusions, vegetation, materials, façade height, and façade profile. An average insertion loss of 7.8 dBA is provided by these elements for road traffic. Building morphology design, creating shielded side of dwellings produces greater reductions for road traffic noise (20 dBA) [140].

Regarding the insulation of buildings, EU MS have established *in situ* criteria to be assessed. There are building elements that provide high insulation but their effectiveness depends on their installation. In Spain, different levels of acoustic comfort have recently been established according to the UNE 74201 standard (2021).

Other road traffic noise control measures

Appropriate urban planning allows for long-term urban noise management by protecting those areas with good acoustic quality (quiet areas, green areas) and remediating those with high noise levels. Berlin and Hong Kong have used zoning plans to protect sensitive areas [106]. Madrid and Cáceres have developed actions to increase green areas, restrict road traffic in central areas and increase pedestrian streets [122, 123]. However, the efficiency of many of these proposals has not been evaluated as shown in Table 1.

Another possible measure is public education and awareness-raising. The dissemination of the negative effects of noise in the different media has contributed to the knowledge of this serious environmental problem. Also, it is important that there is public participation in decision-making in noise mapping. Macedo et al. [141] propose to develop a sustainable driving indicator that minimises noise and pollution emissions similar to the existing indicator for fuel consumption. Asensio et al. [142] create a useful tool that can help drivers avoid particularly noise-sensitive areas by estimating the noise emitted by a single vehicle.

Conclusions

Road traffic noise continues to increase in cities although environmental noise assessment and management policies have been successfully implemented in many countries. First, the lack of a common noise assessment method and then the shortcomings of the common method developed, create doubts about the figures of the exposed population. Improvements proposed in recent years will lead to the development of an accurate common noise method. A new detailed guide with recommendations for the configuration and measurement of the different parameters would be advisable. The engagement of countries is key to reducing the number of people exposed to noise levels that have negative effects on their health and quality of life. However, most of the road traffic control measures proposed in the action plans have not been implemented. The creation of policy frameworks that allow for greater interaction with the scientific community would benefit the actual implementation of findings.

Funding

This work is funded by *Consejería de Economía, Ciencia y Agenda Digital* of *Junta de Extremadura* through grants for attracting and returning research talent to R&D&I centres belonging to the Extremadura Science, Technology and Innovation System (TA18019), where University of Extremadura was the beneficiary entity.

Compliance with Ethical Standards

Conflict of Interest

The authors declare no competing interests.

Human and Animal Rights and Informed Consent

This article does not contain any studies with human or animal subjects performed by any of the authors.

References

1. European Commission. Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise (END). Official Journal L 189 12–26, European Parliament and the Council of the European Union, Brussels, Belgium; 2002.
2. World Health Organization (WHO) Regional Office for Europe. Burden of disease from environmental noise: quantification of healthy life years lost in Europe. WHO Regional Office for Europe; 2011. https://apps.who.int/iris/handle/10665/326424 (accessed 26 July 2022).
3. World Health Organization (WHO) Regional Office for Europe. (2018). Environmental noise guidelines for the European Region. WHO Regional Office for Europe; 2018. https://apps.who.int/iris/handle/10665/279952 (accessed 26 July 2022).

4. European Environment Agency (EEA). Environmental Noise in Europe. Report No 22/2019. Luxembourg: Publications Office of the European Union; 2019. Doi: 10.2800/686249
5. European Environment Agency (EEA). The European environment — state and outlook 2020. Knowledge for transition to a sustainable Europe, European Environment Agency. Luxembourg: Publications Office of the European Union; 2019. Doi: 10.2800/96749
6. Alam P, Ahmad K, Afsar S, Akhter N. Noise Monitoring, Mapping, and Modelling Studies – A Review. J Ecol Eng. 2020;21(4):82–93. Doi: 10.12911/22998993/119804
7. United Nations Environment Programme (UNEP). Listening to Cities: From Noisy Environments to Positive Soundscapes. Frontiers 2022 Report: Emerging Issues of Environmental Concern Chapter 1; 2022. https://wedocs.unep.org/20.500.11822/38060 (accessed 26 July 2022).
8. Rey Gozalo G, Barrigón Morillas JM, Gómez Escobar V. Analysis of noise exposure in two small towns. Acta Acust United Acust. 2012;98(6):884–893. Doi: 10.3813/AAA.918572
9. Rey Gozalo G, Barrigón Morillas JM, Gómez Escobar V, Vílchez-Gómez R, Méndez Sierra JA, Carmona del Río FJ, Prieto Gajardo C. Study of the categorisation method using long-term measurements. Arch Acoust. 2013;38(3):397–405. Doi: 10.2478/aoa-2013-0047
10. European Topic Centre on Air pollution, transport, noise and industrial pollution. Noise exposure scenarios in 2020 and 2030 — outlooks for EU 28. Eionet Report - ETC/ATNI No. 2019/3; 2019. https://www.eionet.europa.eu/etcs/etcatni/products/etc-atni-reports/etc-atni-report-3-2019-noiseexposure-scenarios-in-2020-and-2030-outlooks-for-eu-28 (accessed 27 July 2022).
11. European Topic Centre on Air pollution, transport, noise and industrial pollution. Population exposure to noise from different sources in Europe. Eionet Report - ETC/ATNI; 2021. https://www.eea.europa.eu/data-and-maps/data/data-on-noise-exposure-8 (accessed 26 July 2022).
12. Organization for Economic Cooperation and Development. Fighting Noise in 1990s; Alexandre, A., Barde, J.-P., Eds.; OECD Publications: Paris, France; 1991.
13. U.S. Department of Transportation, Bureau of Transportation Statistics. National Transportation Noise Map 2016 – 2018. Washington, DC: U.S. Department of Transportation, Bureau of Transportation Statistics, 2020.

https://data.bts.gov/stories/s/National-Transportation-Noise-Map/ri89-bhxh/ (accessed 27 July 2022).

14. International Transport Forum (ITF). ITF Transport Outlook; 2019. Doi: 10.1787/9789282108000-en.

15. United Nations Department of Economic and Social Affairs, Population Division. World Population Prospects 2022: Summary of Results. UN DESA/POP/2022/TR/NO. 3; 2022. https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/wpp2022_summary_of_results.pdf (accessed 27 July 2022).

16. Rodrigue J.-P. The Geography of Transport Systems (5th ed.). Routledge; 2020. Doi: 10.4324/9780429346323

17. Arana M, San Martin R, Salinas JC. People exposed to traffic noise in european agglomerations from noise maps. A critical review. Noise Mapp. 2014;1:40–49. Doi: 10.2478/noise-2014-0005

18. King EA, Murphy E. Environmental noise – "Forgotten" or "Ignored" pollutant? Appl Acoust. 2016;112,211–215. Doi: 10.1016/j.apacoust.2016.05.023

19. Murphy E, Faulkner JP, Douglas O. Current State-of-the-Art and New Directions in Strategic Environmental Noise Mapping. Curr Pollut Rep. 2020;6(2):54–64. Doi: 10.1007/s40726-020-00141-9

20. Licitra G. (Ed.). Noise Mapping in the EU: Models and Procedures (1st ed.). CRC Press; 2012. Doi: 10.1201/b12885

21. Centre for Strategy and Evaluation Services (CSES). Evaluation of Directive 2002/49/EC relating to the assessment and management of environmental noise. Workshop working paper 1. The second implementation review of the END—emerging findings. Brussels: CEES, 2015. https://ec.europa.eu/environment/noise/pdf/Working%20Paper%201%20(implementation).pdf (accessed 27 July 2022).

22. Licitra G, Ascari E. Noise mapping in the EU: state of art and 2018 challenges. In: 47th International Congress and Exposition on Noise Control Engineering: Impact of Noise Control Engineering. Chicago, USA: INTER-NOISE 2018, 26–29 August; 2018.

23. Hinze B. Noise mapping in Australia: completed studies, goals and outcomes. In: 44th International Congress and Exposition on Noise Control Engineering. San Francisco, USA: INTER-NOISE 2015, 9–12 August; 2015.

24. Commission Directive (EU) 2015/996 of 19 May 2015 establishing common noise assessment methods according to Directive 2002/49/EC of the European Parliament and of the Council. Brussels: The European Parliament and the Council of the European Union; 2015.

25. Joint Research Centre, Institute for Health and Consumer Protection, Kephalopoulos S, Paviotti M, Anfosso-Lédée F. Common noise assessment methods in Europe (CNOSSOS-EU): to be used by the EU Member States for strategic noise mapping following adoption as specified in the Environmental Noise Directive 2002/49/EC. Luxembourg: Publications Office of the European Union; 2012. Doi: 10.2788/32029

26. Peeters B, Blokland GV. The noise emission model for European road traffic. Deliverable 11 of the IMAGINE project; 2007. http://www.imagine-project.org/ (accessed 30 July 2022)

27. Dutilleux G, Defrance J, Ecotière D, Gauvreau B, Bérengier M, Besnard F, et al. NMPB-ROUTES-2008: the revision of the French method for road traffic noise prediction. Acta Acust United Acust. 2010;96(3):452–462. Doi: 10.3813/AAA.918298

28. Peeters B, van Blokland G. Correcting the CNOSSOS-EU road noise emission values. In: 11th European Congress and Exposition on Noise Control Engineering. Crete, Greece: Euronoise 2018, 27–31 May; 2018.

29. Morley DW, de Hoogh K, Fecht D, Fabbri F, Bell M, Goodman PS, et al. International scale implementation of the CNOSSOS-EU road traffic noise prediction model for epidemiological studies. Environ Pollut. 2015;206:332–341. Doi: 10.1016/j.envpol.2015.07.031.

30. Guarnaccia C, Bandeira J, Coelho MC, Fernandes P, Teixeira J, Ioannidis G, et al. Statistical and semi-dynamical road traffic noise models comparison with field measurements. AIP Conf Proc. 2018;1982: 020039. Doi: 10.1063/1.5045445

31. Bertellino F, Cicoira P, Gerola F, Clementel M, Scaramuzza P, Nardelli M. Noise mapping of agglomerations: a comparision of interim standards vs new CNOSSOS-EU method in a real case study. In: 45th International Congress and Exposition on Noise Control Engineering: Towards a Quieter Future. Hamburg, Germany: INTER-NOISE 2016, 21–24 August, 1356–1366; 2016.

32. Khan J, Kakosimos K, Jensen SS, Hertel O, Sørensen M, Gulliver J, Ketzel M. The spatial relationship between traffic-related air pollution and noise in two Danish

cities: Implications for health-related studies. Sci Total Environ. 2020;726. Doi: 10.1016/j.scitotenv.2020.138577.

33. Khan J, Ketzel M, Jensen SS, Gulliver J, Thysell E, Hertel O. Comparison of Road Traffic Noise prediction models: CNOSSOS-EU, Nord2000 and TRANEX. Environ Pollut. 2021;270:116240. Doi: 10.1016/j.envpol.2020.116240

34. Rey Gozalo G, Gómez Escobar V. Uncertainty evaluation of road traffic noise models in two Ibero-American cities. Appl Acoust. 2021;180:108134. Doi: 10.1016/j.apacoust.2021.108134

35. Czyzewski A, Ejsmont JA. Validation of Harmonoise/IMAGE traffic noise prediction model by long term noise and traffic monitoring. In: Joint Baltic-Nordic Acoustics Meeting. Reykjavik, Iceland: 17–19 August; 2008.

36. de León G, Fidecaro F, Cerchiai M, Reggiani M, Ascari E, Licitra G. Implementation of CNOSSOS-EU method for road noise in Italy. In: 23rd International Congress on Acoustics: Integrating 4th EAA Euroregio, ICA 2019. Aachen, Germany, 9–23 September; 2019.

37. Commission Delegated Directive (EU) 2021/1226 of 21 December 2020 amending, for the purposes of adapting to scientific and technical progress, Annex II to Directive 2002/49/EC of the European Parliament and of the Council as regards common noise assessment methods. Brussels: The European Parliament and the Council of the European Union; 2021. http://data.europa.eu/eli/dir_del/2021/1226/oj (accessed 30 July 2022)

38. Pallas MA, Dutilleux G. Experimental confrontation of medium heavy vehicle noise emission to the CNOSSOS-EU prediction method. In: 11th European Congress and Exposition on Noise Control Engineering. Crete, Greece: Euronoise 2018, 27–31 May; 2018.

39. Faulkner J-P, Murphy E. Road traffic noise modelling and population exposure estimation using CNOSSOS-EU: Insights from Ireland. Appl Acoust. 2022;192:108692. Doi: 10.1016/j.apacoust.2022.108692

40. Kok A. Refining the CNOSSOS-EU calculation method for environmental noise. In: 48th International Congress and Exhibition on Noise Control Engineering. Madrid, Spain: INTER-NOISE 2019, 6–19 June; 2019.

41. Kok A, van Beek A. Amendments for CNOSSOS-EU: Description of issues and proposed solutions. Bilthoven, Netherlands: National Institute for Public Health and the Environment, 2019. Doi: 10.21945/RIVM-2019-0023

42. Umwelt Bundes Amt. Vorläufige Berechnungsmethode zur Ermittlung der Belastetenzahlen durch Umge-Bungslärm—VBEB. Dessau, Germany: Federal German Gazette; 2007.

43. Arana M, San Martin R, Salinas JC. People exposed to traffic noise in european agglomerations from noise maps. A critical review. Noise Mapping. 2014;1(1):40–49. Doi: 10.2478/noise-2014-0005

44. Vienneau D, Héritier H, Foraster M, Eze IC, Schaffner E, Thiesse L, … Röösli, M. Façades, floors and maps – Influence of exposure measurement error on the association between transportation noise and myocardial infarction. Environ Int. 2019;123:399–406. Doi:10.1016/j.envint.2018.12.015

45. Murphy E, Douglas O. Population exposure to road traffic noise: Experimental results from varying exposure estimation approaches. Transp Res D Transp Environ. 2018;58:70–79. Doi:10.1016/j.trd.2017.11.006

46. Morley DW, de Hoogh K, Fecht D, Fabbri F, Bell M, Goodman PS, … Gulliver J. International scale implementation of the CNOSSOS-EU road traffic noise prediction model for epidemiological studies. Environ Pollut. 2015;206:332–341. Doi:10.1016/j.envpol.2015.07.031

47. Cai Y, Hodgson S, Blangiardo M, Gulliver J, Morley D, Fecht D, … Hansell AL. Road traffic noise, air pollution and incident cardiovascular disease: A joint analysis of the HUNT, EPIC-Oxford and UK Biobank cohorts. Environment Int. 2018;114:191–201. Doi:10.1016/j.envint.2018.02.048

48. Cai Y, Zijlema WL, Sørgjerd EP, Doiron D, de Hoogh K, Hodgson S, … Kvaløy K. (2020). Impact of road traffic noise on obesity measures: observational study of three European cohorts. Environ Res. 2020;191:110013. Doi:10.1016/j.envres.2020.110013

49. Hao G, Zuo L, Xiong P, Chen L, Liang X, Jing C. Associations of PM2.5 and road traffic noise with mental health: Evidence from UK Biobank. Environ Res. 2022;207:112221. Doi: 10.1016/j.envres.2021.112221

50. Hao G, Zuo L, Weng X, Fei Q, Zhang Z, Chen L, Wang Z, Jing C. Associations of road traffic noise with cardiovascular diseases and mortality: Longitudinal results from UK Biobank and meta-analysis. Environ Res. 2022;212:113129. Doi: 10.1016/j.envres.2022.113129

51. Li D, Wang L, Yang Y, Hu Y, Wang Y, Tian Y, Wang F. Associations of long-term exposure to ambient air pollution and road traffic noise with sleep health in UK Biobank. J Affect Disord. 2022;310:1–9. Doi: 10.1016/j.jad.2022.04.136

52. European Commission Working Group Assessment of Exposure to (WG-AEN). Good Practice Guide for Strategic Noise Mapping and the Production of Associated Data on Noise Exposure. WG-AEN: version 2, 13th August; 2007.

53. Centro de Estudios y Experimentación de Obras Públicas (CEDEX), Ministerio para la Transición Ecológica y el Reto Demográfico. Guía básica de recomendaciones para la aplicación de los métodos comunes de evaluación del ruido en Europa (CNOSSOS-EU). Recomendaciones para su aplicación a la evaluación del ruido de fuentes industriales, carreteras, ferrocarriles y aglomeraciones. Madrid, Spain: CEDEX; 2022.

54. Aumond P, Can A, Mallet V, Gauvreau B, Guillaume G. Global sensitivity analysis for road traffic noise modelling. Appl Acoust. 2021;176:107899. Doi:10.1016/j.apacoust.2020.107899

55. Montes Gonzalez D., Barrigón Morillas JM, Rey Gozalo G. Acoustic behaviour of plates made of different materials for measurements with the microphone flush mounted. Appl Acoust. 2018;132:135–141. Doi: 10.1016/j.apacoust.2017.11.011

56. Montes González D, Barrigón Morillas JM, Rey Gozalo G, Atanasio Moraga P. Microphone position and noise exposure assessment of building façades. Appl Acoust. 2020;160:107157. Doi: 10.1016/j.apacoust.2019.107157

57. Van Hauwermeiren W, Filipan K, Botteldooren D, De Coensel B. Opportunistic monitoring of pavements for noise labeling and mitigation with machine learning. Transp Res D Transp Environ. 2021;90:102636. Doi: 10.1016/j.trd.2020.102636

58. Licitra G, Moro A, Teti L, Del Pizzo A, Bianco F. Modelling of acoustic ageing of rubberized pavements. Appl Acoust. 2019,146:237–245. Doi: 10.1016/j.apacoust.2018.11.009

59. Freitas EF, Martins FF, Oliveira A, Segundo IR, Torres H. Traffic noise and pavement distresses: Modelling and assessment of input parameters influence through data mining techniques. Appl Acoust. 2018;138:147–155. Doi: 10.1016/j.apacoust.2018.03.019

60. Cai M, Lan Z, Zhang Z, Wang H. Evaluation of road traffic noise exposure based on high-resolution population distribution and grid-level noise data. Build Environ. 2019;147:211–220. Doi: 10.1016/j.buildenv.2018.08.037

61. Barrigón Morillas JM, Rey Gozalo G, Montes González D, Sánchez-Fernández M, Bachiller León A. A comprehensive experimental study of the influence of temperature on urban road traffic noise under real-world conditions. Environ Poll. 2022; 309:119761. Doi: 10.1016/j.envpol.2022.119761

62. Trikootam SC, Hornikx M. The wind effect on sound propagation over urban areas: Experimental approach with an uncontrolled sound source. Build Environ. 2019;149:561–570. Doi:10.1016/j.buildenv.2018.11.037

63. Suárez E, Barros JL. Traffic noise mapping of the city of Santiago de Chile. Sci Total Environ. 2014;466-467:539–546. Doi: 10.1016/j.scitotenv.2013.07.013

64. Raghavan R, Verma DC, Pandey D, Anand R, Pandey BK, Singh H. Optimized building extraction from high-resolution satellite imagery using deep learning. Multimed Tools Appl. 2022. Doi: 10.1007/s11042-022-13493-9

65. Stoter J, Peters R, Commandeur T, Dukai B, Kumar K, Ledoux H. Automated reconstruction of 3D input data for noise simulation. Comput Environ Urban Syst. 2020;80:101424. Doi: 10.1016/j.compenvurbsys.2019.101424

66. Benocci R, Bisceglie A, Angelini F, Zambon G. Influence of traffic noise from local and surrounding areas on high-rise buildings. Appl Acoust. 2020;166:107362. Doi: 10.1016/j.apacoust.2020.107362

67. Alam P, Ahmad K, Afsar SS, Akhtar N. 3D noise mapping for preselected locations of urban area with and without noise barriers: A case study of Delhi, India. Noise Mapping. 2020;7(1):74–83. Doi: 10.1515/noise-2020-0006

68. Puyana-Romero V, Cueto JL, Gey R. A 3D GIS tool for the detection of noise hot-spots from major roads. Transp Res D Transp Environ. 2020;84:102376. Doi:10.1016/j.trd.2020.102376

69. Vienneau D, Héritier H, Foraster M, Eze I C, Schaffner E, Thiesse L, … Röösli M. Façades, floors and maps – Influence of exposure measurement error on the association between transportation noise and myocardial infarction. Environ Int. 2019;123:399–406. Doi: 10.1016/j.envint.2018.12.015

70. Kaddoura I, Kröger L, Nagel K. An activity-based and dynamic approach to calculate road traffic noise damages. Transp Res D Transp Environ. 2017;54:335–347. Doi: 10.1016/j.trd.2017.06.005

71. Sampaio C, Bandeira JM, Macedo E, Vilaça M, Guarnaccia C, Friedrich B, … Coelho MC. A Dynamic Link-based Eco-indicator for supporting equitable traffic

management strategies. Transp Res Proc. 2019;37:43–50. Doi: 10.1016/j.trpro.2018.12.164

72. Lesieur A, Mallet V, Aumond P, Can A. Data assimilation for urban noise mapping with a meta-model. Appl Acoust. 2021;178:107938. Doi: 10.1016/j.apacoust.2021.107938

73. Rey Gozalo G, Gómez Escobar V, Barrigón Morillas JM, Montes González D, Atanasio Moraga P. Statistical attribution of errors in urban noise modeling. Appl Acoust. 2019; 153:20–29. Doi: 10.1016/j.apacoust.2019.04.001

74. Bellucci P, Peruzzi L, Zambon G. LIFE DYNAMAP project: The case study of Rome. Appl Acoust. 2017;117:193–206. Doi: 10.1016/j.apacoust.2016.04.022

75. Nourani V, Gökçekuş H, Umar IK, Najafi H. An emotional artificial neural network for prediction of vehicular traffic noise. Sci Total Environ. 2020;707:136134. Doi: 10.1016/j.scitotenv.2019.136134

76. Melo, R. A., Pimentel, R. L., Lacerda, D. M., & Silva, W. M. (2015). Applicability of models to estimate traffic noise for urban roads. Journal of Environmental Health Science and Engineering, 13:83. doi:10.1186/s40201-015-0240-9

77. Hammer E, Egger S, Saurer T, Bühlmann E. Traffic noise emission modelling at lower speeds. In: 23rd International Congress on Sound and Vibration. Greece, Athens: ICSV23, 10-14 July; 2016.

78. Estévez-Mauriz L. Forssén J. Dynamic traffic noise assessment tool: A comparative study between a roundabout and a signalised intersection. Appl Acoust. 2018;130:71–86. Doi: 10.1016/j.apacoust.2017.09.003

79. Can A, Aumond P. Estimation of road traffic noise emissions: The influence of speed and acceleration. Transp Res D Transp Environ. 2018;58:155–171. Doi: 10.1016/j.trd.2017.12.002

80. Vergara Elgueda DI. Elaboración de mapa de ruido dinámico de viales basado en sistema de medición de flujo vehicular en tiempo real. Chile, Valdivia: Final degree thesis, Universidad Austral de Chile, September; 2019.

81. AlKheder S, Almutairi R. Roadway traffic noise modelling in the hot hyper-arid Arabian Gulf region using adaptive neuro-fuzzy interference system. Transp Res D Transp Environ. 2021;97:102917. Doi: 10.1016/j.trd.2021.102917

82. Guarnaccia C. EAgLE: Equivalent Acoustic Level Estimator Proposal. Sensors 2020; 20(3):701. Doi: 10.3390/s20030701

83. Zambon G, Roman HE, Benocci R. Scaling model for a speed-dependent vehicle noise spectrum. J Traffic Transport Engin (EE). 2017; 4(3): 230–239. Doi: 10.1016/j.jtte.2017.05.001

84. Barrigón Morillas JM, Rey Gozalo G, Montes González D, Atanasio Moraga P, Vílchez-Gómez R. Noise Pollution and Urban Planning. Curr Pollut Rep. 2018;4(3): 208–219. Doi: 10.1007/s40726-018-0095-7

85. Barrigón Morillas JM, Gómez Escobar V, Méndez Sierra JA, Vílchez-Gómez R, Trujillo Carmona J. An environmental noise study in the city of Cáceres, Spain. Appl Acoust. 2002;63:1061–1070. Doi: 10.1016/S0003-682X(02)00030-0

86. Rey Gozalo G, Barrigón Morillas JM, Gómez Escobar V. Urban streets functionality as a tool for urban pollution management. Sci Total Environ. 2013;461–462:453–461. Doi: 10.1016/j.scitotenv.2013.05.017

87. Zambon G, Benocci R, Bisceglie A, Roman HE, Bellucci P. The LIFE DYNAMAP project: Towards a procedure for dynamic noise mapping in urban areas. Appl Acoust. 2017;124:52–60. Doi: 10.1016/j.apacoust.2016.10.022

88. Le Bescond V, Can A, Aumond P, Gastineau P. Open-source modeling chain for the dynamic assessment of road traffic noise exposure. Transp Res D Transp Environ. 2021;94:102793. Doi: 10.1016/j.trd.2021.102793

89. Quartieri J, Mastorakis NE, Iannone G, Guarnaccia C, Ambrosio SD, Troisi A, Lenza TLL. A review of traffic noise predictive noise models. Recent Adv Appl Theor Mech. 2009:72–80.

90. Ahmed Adulaimi AA, Pradhan B, Chakraborty S, Abdullah Alamri A. Traffic Noise Modelling Using Land Use Regression Model Based on Machine Learning, Statistical Regression and GIS. Energies 2021;14:5095. Doi: 10.3390/en14165095

91. Harouvi O, Ben-Elia E, Factor R, de Hoogh K, Kloog I. Noise estimation model development using high-resolution transportation and land use regression. J Expo Sci Environ Epidemiol 2018. Doi: 10.1038/s41370-018-0035-z

92. Xu X, Ge Y, Wang W, Lei X, Kan H, Cai J. Application of land use regression to map environmental noise in Shanghai, China. Environ Int. 2022;161:107111. Doi: 10.1016/j.envint.2022.107111

93. Rey Gozalo G, Suárez E, Montenegro AL, Arenas JP, Barrigón Morillas JM, Montes González D. Noise estimation using road and urban features. Sustainability 2020;12: 9217. Doi: 10.3390/su12219217

94. Tiwari SK, Kumaraswamidhas LA, Gautam C, Garg N. An auto-encoder based LSTM model for prediction of ambient noise levels. Appl Acoust. 2022;195:108849. Doi: 10.1016/j.apacoust.2022.108849
95. Rey Gozalo G, Aumond P, Can A. Variability in sound power levels: Implications for static and dynamic traffic models. Transp Res D Transp Environ. 2020;84:102339. Doi: 10.1016/j.trd.2020.102339
96. Brambilla G, Benocci R, Confalonieri C, Roman HE, Zambon G. Classification of Urban Road Traffic Noise based on Sound Energy and Eventfulness Indicators. Applied Sciences 2020;10(7):2451. Doi: 10.3390/app10072451
97. Alsina-Pagès RM, Alías F, Socoró JC, Orga F, Benocci R, Zambon G. Anomalous events removal for automated traffic noise maps generation. Appl Acoust. 2019;151:183–192. Doi: 10.1016/j.apacoust.2019.03.007
98. Alsina-Pagès R, Garcia Almazán R, Vilella M, Pons M. Noise Events Monitoring for Urban and Mobility Planning in Andorra la Vella and Escaldes-Engordany. Environments 2019;6(2):24. Doi: 10.3390/environments6020024
99. Wei W, Van Renterghem T, De Coensel B, Botteldooren D. Dynamic noise mapping: A map-based interpolation between noise measurements with high temporal resolution. Appl Acoust. 2016;101:127–140. Doi: 10.1016/j.apacoust.2015.08.0
100. Aumond P, Can A, Rey Gozalo G, Fortin N, Suárez E. Method for in situ acoustic calibration of smartphone-based sound measurement applications. Appl Acoust. 2020;166:107337. Doi: 10.1016/j.apacoust.2020.1073
101. Ventura R, Mallet V, Issarny V. Assimilation of mobile phone measurements for noise mapping of a neighborhood. J Acoust Soc Am. 2018;144(3):1279–1292. Doi: 10.1121/1.5052173
102. Picaut J, Fortin N, Bocher E, Petit G, Aumond P, & Guillaume G. An open-science crowdsourcing approach for producing community noise maps using smartphones. Build Environ 2019;148:20-33. Doi:10.1016/j.buildenv.2018.10.049
103. Aumond P, Can A, Mallet V, Gauvreau B, Guillaume G. Global sensitivity analysis for road traffic noise modelling. Appl Acoust. 2021;176:107899. Doi: 10.1016/j.apacoust.2020.107899
104. Van Der Eerden F, Graafland F, Wessels P, Segers A, Salomons E. Model based monitoring of traffic noise in an urban district. In: 43rd International Congress on Noise Control Engineering: Improving the World Through Noise Control. Australia, Melbourne: INTERNOISE 2014, 16-19 November; 2014.

105. Baclet S, Venkataraman S, Rumpler R, Billsjö R, Horvath J, Österlund PE. From strategic noise maps to receiver-centric noise exposure sensitivity mapping. Transp Res D Transp Environ. 2022;102:103114. Doi: 10.1016/j.trd.2021.103114

106. European Commission. Science for Environment Policy. Future Brief: Noise abatement approaches. Bristol, UK: European Commission DG Environment by the Science Communication Unit, UWE; 2017. https://data.europa.eu/doi/10.2779/016648

107. Pallas M-A, Cesbron J, Luzzi S, Busa L, Colucci G, Bellomini R. Electric Vehicle noIse control by Assessment and optimisation of tyre/road interaction. LIFE E-VIA, LIFE18 ENV/IT/000201, version 1.1; 2020.

108. Pallas M-A, Bérengier M, Chatagnon R, Czuka M, Conter M, Muirhead M. Towards a model for electric vehicle noise emission in the European prediction method CNOSSOS-EU. Appl Acoust. 2016;113:89–101. Doi: 10.1016/j.apacoust.2016.06.012

109. Campello-Vicente H, Peral-Orts R, Campillo-Davo N, Velasco-Sanchez E. The effect of electric vehicles on urban noise maps. Appl Acoust. 2017;116:59–64. Doi: 10.1016/j.apacoust.2016.09.018

110. Yamauchi k, Yabuno m, Yamasaki R. Sound power level of electric vehicles running in steady low speed. Acoust Sci & Tech. 2020;41(3):626–629. Doi: 10.1250/ast.41.626

111. Ibarra D, Ramírez-Mendoza R, López E. Noise emission from alternative fuel vehicles: Study case. Appl Acoust. 2017;118:58–65. Doi: 10.1016/j.apacoust.2016.11.010

112. Laib F, Braun A, Rid W. Modelling noise reductions using electric buses in urban traffic. A case study from Stuttgart, Germany. Transp Res Procedia. 2018;2019(37):377–384. Doi: 10.1016/j.trpro.2018.12.206

113. Rossi IA, Vienneau D, Ragettli MS, Flückiger B, Röösli M. Estimating the health benefits associated with a speed limit reduction to thirty kilometres per hour: A health impact assessment of noise and road traffic crashes for the Swiss city of Lausanne. Environ Int. 2020;145:106126. Doi:10.1016/j.envint.2020.106126

114. Rodrigues RC. Traffic noise and energy. Energy Reports 2020;6:177–183. Doi: 10.1016/j.egyr.2019.08.039

115. Coelho MC, Guarnaccia C. Driving information in a transition to a connected and autonomous vehicle environment: Impacts on pollutants, noise and safety. Transp Res Proc. 2020;45:740–746. Doi: 10.1016/j.trpro.2020.02.103

116. Cesbron J, Bianchetti S, Pallas M-A, Le Bellec A, Gary V, Klein P. Road surface influence on electric vehicle noise emission at urban speed. Noise Mapping 2021;8(1):217–227. Doi: 10.1515/noise-2021-0017

117. Praticò FG, Anfosso-Lédée F. Trends and issues in mitigating traffic noise through quiet pavements. Proc Soc Behav Sci. 2012;53:203–212. Doi: 10.1016/j.sbspro.2012.09.873

118. Praticò FG. "Noisy" issues in road acoustics: A white paper. J. Road Eng. 2022;2:61–69. Doi: 10.1016/j.jreng.2022.03.001

119. Del Pizzo A, Teti L, Moro A, Bianco F, Fredianelli L, Licitra G. Influence of texture on tyre road noise spectra in rubberized pavements. Appl Acoust. 2020;159:107080. Doi: 10.1016/j.apacoust.2019.107080

120. Poulikakos LD, Athari S, Mikhailenko P, ..., Pieren R, Heutschi K. Effect of waste materials on acoustical properties of semi-dense asphalt mixtures. Transp Res D Transp Environ. 2022;102:103154. Doi: 10.1016/j.trd.2021.103154

121. Piao Z, Heutschi K, Pieren R, ..., Poulikakos LD, Hellweg S. Environmental trade-offs for using low-noise pavements: Life cycle assessment with noise considerations. Science of the Total Environment 2022;842:156846. Doi: 10.1016/j.scitotenv.2022.156846

122. Barrigón Morillas JM, Gómez Escobar V, Rey Gozalo G. Noise source analyses in the acoustical environment of the medieval centre of Cáceres (Spain). Appl Acoust 2013;74(4):526-534. Doi: 10.1016/j.apacoust.2012.10.001

123. Rey Gozalo G, Barrigón Morillas JM. Perceptions and effects of the acoustic environment in quiet residential areas. J Acoust Soc Am. 2017;141(4):2418–2429. Doi: 10.1121/1.4979335

124. Monazzam MR, Karimi E, Shahbazi H, Shahidzadeh H. Effect of cycling development as a non-motorized transport on reducing air and noise pollution-case study: Central districts of Tehran. Urban Clim. 2021;38:100887. Doi: 10.1016/j.uclim.2021.100887

125. Ögren M, Molnár P, Barregard L. Road traffic noise abatement scenarios in Gothenburg 2015 – 2035. Environ Res. 2018, 164, 516–521. Doi: 10.1016/j.envres.2018.03.011

126. Amarilla RSD, Scoczynski Ribeiro R, Henrique de Avelar Gomes M, Pereira Sousa R, Henrique Sant'Ana L, Eduardo Catai R. Acoustic barrier simulation of construction and demolition waste: A sustainable approach to the control of environmental noise. Appl Acoust. 2021;182:108201. Doi: 10.1016/j.apacoust.2021.108201

127. Gil-Lopez T, Medina-Molina M, Verdu-Vazquez A, Martel-Rodriguez B. Acoustic and economic analysis of the use of palm tree pruning waste in noise barriers to mitigate the environmental impact of motorways. Sci Total Environ. 2017;584-585:1066–1076. Doi: 10.1016/j.scitotenv.2017.01.162

128. Monazzam MR, Abbasi M, Yazdanirad S. Performance evaluation of T-shaped noise barriers covered with oblique diffusers using boundary element method. Arch Acoust. 2019;44(3):521-531. Doi: 10.24425/aoa.2019.129267

129. Peiró-Torres MP, Ferri M, Godinho LM, Amado-Méndes, Jose Vea Folch, F., Redondo J. Normal incidence sound insulation provided by Sonic Crystal Acoustic Screens made from rigid scatterers - Assessment of different simulation methods. Acta Acustica. 2021;5:28. Doi: 10.1051/aacus/2021021

130. Ahac M, Ahac S, Lakušić S. Long-Term Sustainability approach in road traffic noise wall design. Sustainability 2021;13(2):536. Doi: 10.3390/su13020536

131. Martinez-Orozco JM, Barba A. Determination of Insertion Loss of noise barriers in Spanish roads. Appl Acoust. 2022;186:108435. Doi: 10.1016/j.apacoust.2021.108435

132. Halim H, Abdullah R, Ali AA, Nor MJ. Effectiveness of existing noise barriers: Comparison between vegetation, concrete hollow block, and panel concrete. Procedia Environ Sci. 2015;30:217–221. Doi: 10.1016/j.proenv.2015.10.039

133. Ow LF, Ghosh S. Urban cities and road traffic noise: Reduction through vegetation. Appl Acoust. 2017;120:15–20. Doi: 10.1016/j.apacoust.2017.01.007

134. Van Renterghem T. Towards explaining the positive effect of vegetation on the perception of environmental noise. Urban For Urban Green. 2019;40:133–144. Doi: 10.1016/j.ufug.2018.03.007

135. Van Renterghem T, Botteldooren D. Landscaping for road traffic noise abatement: Model validation. Environ Model Softw. 2018;109,17–31. Doi: 10.1016/j.envsoft.2018.08.012

136. Jang D-J, Kim S-A. Optimization design method for noise barrier tunnel junction on merging lanes using quad meshes. J Asian Archit Build. 2022;21(2):211-223. Doi: 10.1080/13467581.2020.1869011

137. Medeiros, A.F.D.D., Pimentel, R.L., Melo, R.A.D., Araújo, B.C.D.D., Brasileiro, T.D.C. Investigation of traffic noise attenuation potential of an urban highway underpass. Appl Acoust. 2022;191:108682. Doi: 10.1016/j.apacoust.2022.108682

138. Liu C, Hornikx M. Effect of water content on noise attenuation over vegetated roofs: results from two field studies. Build Environ. 2018;146:1–11. Doi: 10.1016/j.buildenv.2018.09.022

139. Yang W, Jeon JY. Design strategies and elements of building envelope for urban acoustic environment. Build Environ 2020;182:107121. Doi: 10.1016/j.buildenv.2020.107121

140. Forssén J, Estévez-Mauriz L, Gustafson A, Kropp W. How can we plan for a good urban sound environment, focusing on road traffic noise? IOP Conference Series: Earth and Environmental Science 2020;588(5):052037. Doi: 10.1088/1755-1315/588/5/052037

141. Macedo E, Pascale A, Ferreira E, Guarnaccia C, Coelho MC. Experimental evaluation of gear-shift and internal-combustion engine variables on fuel consumption, noise and pollutant emissions. Transp Res Proc. 2022;62:703-710. Doi: 10.1016/j.trpro.2022.02.087

142. Asensio C, Pavón I, Ramos C, López JM, Pamiés Y, Moreno D, de Arcas G. Estimation of the noise emissions generated by a single vehicle while driving. Transp Res D Transp Environ. 2021;95:102865. Doi: 10.1016/j.trd.2021.102865