Chapter 6: Environmental noise pollution and sources

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Abstract
Environmental noise is a pollutant agent with a significant impact on the health and well-being of people and wildlife. Means of transport are the sources of noise to which the population is most exposed, with road traffic being the main sound source. Noise pollution is often associated with air pollution due to emissions from transportation. Other sources of noise such as industrial, construction, leisure and urban waste collection activities also generate annoyance and sleep disturbances, although to a lesser extent. In order to design and plan effective mitigation measures, it is essential to have an independent knowledge of both the impact of each noise source and the different physical mechanisms through which each source generates noise. Reducing the number of people exposed to adverse noise levels is a priority objective for many countries.

Keywords: urban noise; noise exposure; noise health effects; road traffic; train; aircraft; industrial noise; construction; noise action plans; green urban areas.

Introduction
Sounds that have adverse effects on the health of humans and animals are considered noise. This pollutant is in fact considered among the main environmental hazards by the World Health Organization (WHO) due to its significant impact on human health and well-being (*WHO*, 2018). Although roads, railways and airports positively contribute to the community by safely facilitating the movement of people and goods, they have become together with industries, the main sources of environmental noise (Fig. 1). The European Environmental Agency (EEA) estimated from data collected in the period 2013-2017 that the number of people in Europe who are exposed to day-evening-night noise levels of 55 dB or higher is approximately 139 million only due to these three noise sources (*EEA*, 2020). In this regard, one of the main goals of the Zero Pollution Action Plan is to reduce the number of people affected by transport noise by 30% between 2017 and 2030. This is an ambitious target which will require major efforts in terms of transport planning and the reduction of road traffic (*EEA*, 2022a). In addition, industrial noise, construction, leisure activities and urban waste collection are other annoying noise sources (Silva et al., 2021) (Mir et al., 2022b) (Quintero et al., 2019) (Zannin et al., 2018a).

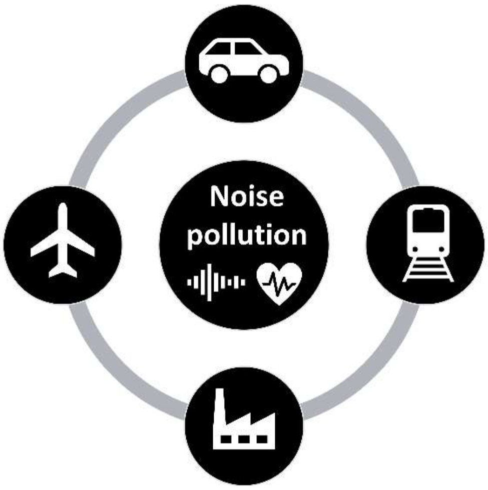

Fig. 1. Main sources of noise pollution

Despite the implementation of the European Noise Directive and the various phases of strategic noise mapping (END, 2002), there has generally not been a decrease in the number of people exposed to noise levels harmful to health (*EEA*, 2021). Table 1 shows the number of people exposed to an $L_{den} \geq 55$ dB in different European countries, where noise perception varies significantly. In the cities of Spain, Italy, Hungary, Malta, and Bulgaria, less than 50% of the respondents are satisfied with noise levels (*EC*, 2020). However, this percentage is higher than 80% in the cities of Finland, Germany, Ireland, Denmark, and Sweden. According to the European Environmental Agency, 22 million people in Europe are estimated to experience high chronic annoyance and 6.5 million have chronic high sleep disruption. It is important to take into account that noise exposure can induce stress and sleep disorder, so the impact on people's health and well-being can be broad. Extensive research associate environmental noise with effects such as annoyance, sleep disturbances, high blood pressure and other effects on the cardiovascular system, auditory alterations and cognition impairment (Itzkowitz et al., 2023) (Khomenko et al., 2022) (Romero Starke et al., 2023) (Veber et al., 2022) (Cerletti et al., 2020) (P. J. Lee et al., 2019) (*WHO*, 2018). Other investigations also raise hypotheses about the relationship of exposure to noise pollution with mental health disorders such as anxiety and depression (Jigeer et al., 2022) (Díaz et al., 2020) (Okokon et al., 2018), irritability and startle (Montes González et al., 2023), respiratory symptoms (Eze et al., 2018), metabolic diseases (Sørensen et al., 2023a) (Vincens and Persson Waye, 2022), cancer (Roswall et al., 2023) (Thacher et al., 2023) and mortality (Thacher et al., 2020) (Recio et al., 2017). In this regard, World Health Organization estimated the environmental burden of disease using the disability-adjusted life years (DALYs) indicator, which is the sum of the potential years of life lost due to premature death and the equivalent years of healthy life lost due to ill health or disability (*WHO*, 2011). This concept of years of healthy life lost is widely used in many countries to estimate the impact of environmental noise on the population (Aasvang et al., 2023) (Jephcote et al., 2023a).

Table 1. Number of people exposed to $L_{den} \geq 55$ dB for different types of environmental noise sources (*EEA*, 2021).

Country	**Noise source**	**2007**	**2012**	**2017**	**Country**	**Noise source**	**2007**	**2012**	**2017**
Spain	Road	8,043,400	9,810,700	4,521,200	Finland	Road	237,500	646,900	482,500

	Rail	25,300	255,900	42,100		Rail	69,800	128,900	87,200
	Air	44,400	55,900	4,400		Air	500	700	800
	Industry	17,700	60,900	49,400		Industry		1,900	1,700
Italy	Road	4,267,000	8,244,100	8,529,400	Germany	Road	4,261,100	5,931,200	5,717,100
	Rail	237,800	526,700	602,600		Rail	1,952,400	3,220,800	3,131,800
	Air	31,800	423,600	140,500		Air	401,600	516,900	561,600
	Industry	84,800	35,900	40,300		Industry	32,200	44,800	49,000
Hungary	Road	1,268,000	1,560,200	1,607,100	Ireland	Road	1,092,500	809,200	686,400
	Rail	211,800	156,800	123,300		Rail	20,700	24,700	29,400
	Air	274,200	700	1,000		Air	3,100	21,400	28,500
	Industry	2,000	2,200	600		Industry			
Malta	Road		48,700	67,200	Denmark	Road	629,100	953,200	1,063,400
	Rail					Rail	30,500	29,400	
	Air		5,800	8,100		Air	600	3,200	3,400
	Industry					Industry	200	200	100
Bulgaria	Road	1,827,300	2,278,000	2,042,600	Sweden	Road	695,800	1,022,300	1,245,600
	Rail	24,800	26,300	44,400		Rail	143,300	237,700	263,300
	Air	105,600	105,600	5,200		Air	4,400	13,300	100
	Industry	2,900	4,700	1,800		Industry			500

In addition to the harmful effects on people, noise pollution also negatively affects wildlife. The European Environment Agency (*EEA*, 2020) points out that transport infrastructures generate noise levels above thresholds set in the European Noise Directive (END, 2002) in at least 19% of the natural areas protected under Natura 2000. Roads can generate a barrier effect for animals in natural areas due to the infrastructure itself, emissions (noise, light and dust) and avoidance of passing vehicles. This barrier effect extends to the vicinity of the infrastructure, but sometimes covers an even wider area as animals try to avoid vehicle emissions (D'Amico et al., 2016) (Chen and Koprowski, 2016). Several investigations were carried out on landscape fragmentation in natural environments due to terrestrial infrastructures (Sánchez-Fernández et al., 2022) (Bruschi et al., 2015). Some authors relate landscape fragmentation with negative effects on biodiversity such as the decrease in population and richness of some species (De Montis et al., 2017). These negative effects on wildlife do not only take place in natural areas, some species living in urban environments are also affected by noise pollution in terms of richness and behavior (Oliveira et al., 2021) (Fröhlich and Ciach, 2019).

Considering the large number of people exposed to environmental noise and the scientific evidence on its impact on the health and well-being of the population, the World Health Organization made a series of recommendations on maximum noise levels advisable for human exposure (*WHO*, 2018). They were specifically defined for each sound source and were classified as strong or conditional. While strong recommendations can be adopted as policy in most situations, conditional recommendations would need a policy-making process involving debate and participation of various stakeholders. As well as specific recommendations, four guiding principles were jointly defined to support the integration of the recommendations: reduce noise exposure, promote mitigating interventions, coordinate approaches to control noise sources and engage potentially affected communities.

In 2020, the results of the report on the quality of life in European cities were published, based on data from a survey that covered capital cities and other major cities in Europe (700 completed interviews per city). These results show an increase in satisfaction with noise levels from Mediterranean countries to Atlantic countries (*EC*, 2020). These high satisfaction percentages in some countries may appear contradictory to the number of people exposed to adverse noise levels (see Table 1). Therefore, as proposed in the Zero Pollution Action Plan, efforts must be increased and intensified to reduce urban noise, primarily from traffic sources. These traffic-related actions can also prove beneficial in reducing air pollution due to the relationship between these pollutants (Tremper et al., 2022) (Shu et al., 2014). Therefore, it makes sense to develop joint strategies to mitigate noise and air pollution and reduce the number of people exposed.

In the following sections of this chapter, we will analyze the main sources of urban noise: generation, assessment methodologies, impact, and effects on the population, action plans for their reduction, etc. To do this, we have compiled current studies that analyze and assess these noise sources and propose actions to reduce their impact on the health and well-being of citizens.

Road traffic noise

The World Health Organization (WHO) strongly recommends that the level of exposure to road traffic noise (L_{den}) be below 53 dB to prevent adverse health effects (*WHO*, 2018). Considering the population exposed to $L_{den} \geq 55$ dB in the last phase of available strategic noise mapping (2017), road traffic is the primary source of noise (*EEA*, 2020). One hundred and thirteen million European citizens are exposed to harmful levels of road traffic noise. This number of individuals is five times greater than those exposed to harmful noise levels from railway noise. The number of people exposed to road traffic noise has not generally decreased in European countries since the first phase of noise mapping was carried out in 2007 (see Table 1). In fact, it is estimated that the number of people exposed to noise within urban areas will increase by 14% by 2030 (*ETC/ATNI*, 2019). This projection contradicts the objective of the Zero Pollution Action Plan to reduce by 30% the number of people exposed to noise levels harmful to health by 2030 (*EC*, 2022). Moreover, this environmental pollutant also affects biodiversity. The expansion of road networks fragments natural areas, limiting the movement of wildlife and bringing these noise sources closer to their habitats. Therefore, the future scenario will be complex if effective measures to reduce road traffic noise are not implemented. The European Commission prepares reports every 5 years that analyze more comprehensively the implementation of the Environmental Noise Directive (*END*, 2002), including the adoption of noise management action plans. However, there is no obligation for EU member states to carry out the action plans to reduce noise. This recommendation may be a hindrance if the goal of the Zero Pollution Action Plan for 2030 is to be achieved.

Analyzing the sound environment accurately using a consistent methodology facilitates result comparison and the application of common proposals to reduce noise. For this reason, the European Commission has developed the Common Noise Assessment Methods for the European Union (CNOSSOS-EU) to assess major sources of urban noise: road, railway, airport, and industrial noise. The implementation of a common methodology for European Union member states in accordance with the Environmental Noise Directive appears to have been more successful than previous projects such as Harmonise/IMAGINE. Hence, the strategic noise maps for the latest phase (2022) must be prepared using CNOSSOS-EU. It's also important to highlight the advancements in the analysis of temporal variability of noise levels. Adverse health effects depend not only on the received sound energy but also on its temporal distribution. The DYNAMAP project used low-cost sensors to record traffic noise variability on main roads in Rome and a neighborhood in Milan (Bellucci et al., 2017). This project has gained significant international diffusion and influenced other research groups to advance in precision and modeling of this temporal variability (Aumond et al., 2021).

Despite these methodological advances, the main task is to increase the number and intensity of actions to reduce the number of people exposed to traffic noise (*EC*, 2022). The main actions concerning road traffic focus on air pollutants due to their adverse health effects and contribution to climate change. Designing more efficient engines and increasing the number of electric vehicles are among the primary objectives (*EEA*, 2022b). The increase in electric cars will benefit the reduction of vehicle traffic noise, primarily at speeds below 50 km/h, where vehicle engine noise is the primary source of the sound power emitted (Rey-Gozalo et al., 2022). However, this noise reduction can be compromised by the Acoustic Vehicle Alerting System (AVAS). There are other actions on the sound source that can lead to a greater noise reduction (*EC*, 2017). The combined use of quiet road surfaces and quiet tires can provide noise reductions of more than 5 dB (Pallas et al., 2020). Furthermore, the European Environment Agency prioritizes sustainable road transport with a focus on public transportation or cycling (*EEA*, 2022c). Recent studies conducted in European cities show a positive impact of efficient public transportation and cycling (Ögren et al., 2018) (Monazzam et al., 2021). The use of electric scooters and ride-hailing services in cities is growing, but walking, cycling, or using public transportation are the most significant contributors to sustainable mobility according to the EEA.

Awareness among urban planners about these environmental pollutants is leading to a shift in the planning of many cities worldwide, focusing on pedestrianization and green urban development. European cities such as Madrid, Oslo, Rome, Paris, and Thessaloniki have closed or restricted road traffic along significant stretches of urban roads. Small cities are also implementing similar programs. For example, the town of Cáceres (Spain) has restricted road traffic in tourist areas (Gozalo and Morillas, 2016), increased the number and extent of bike lanes, reduced the maximum speed on certain urban roads from 50 km/h to 30 km/h, and pedestrianized some streets while creating corridors connecting these streets to parks (G. Rey Gozalo et al., 2022). The environmental improvement resulting from these actions is evident in recent research. Moreover, pedestrianization generates economic benefits (Kim et al., 2021) (Yoshimura et al., 2022). Yoshimura et al. show that stores located in pedestrian areas of Spanish cities experience higher sales volumes than those not restricted to road traffic. In addition to these road traffic management measures, other actions such as the restriction of heavy traffic within cities also contribute to urban noise reduction.

There is lower urban transport flow during the nighttime, but there is also increased sensitivity to noise during this time. For this reason, the WHO recommends that nighttime road traffic noise levels should be below 45 dB. Anomalous noise events have a greater impact on health during the nighttime (Prieto Gajardo et al., 2014). A future concern is the use of the night for courier transportation. This type of transport mainly relies on road traffic within urban areas, and due to the increasing number of deliveries with a focus on reducing delivery times, freight traffic flow may increase during the night in the coming years (Can et al., 2020).

Other road traffic noise reduction measures focus on the sound propagation path or the receiver (*EC*, 2017). These alternative approaches are typically considered when it's not feasible to act on the noise source of road traffic. Sound barriers are among the most commonly used elements due to their high noise reduction potential (3 - 20 dB). Currently, there are European projects developing multifunctional barriers to reduce both road traffic noise and air pollution (Riesco García JI et al., 2023). In this context, especially for capturing air pollutants, nanotechnology will have a significant contribution. However, their development is still experimental, and most barriers serve only an acoustic function. They are primarily located on peri-urban roads to achieve greater efficiency. The materials used for sound barriers vary widely, but the current trend is to reuse waste materials (Amarilla et al., 2021). There is also a current trend of proposing green sound barriers. Although the noise reduction provided by these barriers is limited, from a subjective perspective, make the perception of reduction equivalent to actual insertion losses of up to 10 dB (Van Renterghem, 2019).

Urban green areas located between traffic roads and residential zones act as noise buffers. Many cities, for example, Madrid (Spain), have transformed the open spaces between major traffic roadways and residential areas into parks. The visibility of these green spaces has psychological benefits, and the green elements promote sound absorption (*WHO*, 2016). Furthermore, these green areas help reduce air pollution and regulate temperature. Therefore, the development of green spaces promotes urban sustainability. However, if these green areas are utilized as noise buffer elements and their size is not sufficiently large, which can be challenging in limited urban space, their potential to serve as quiet areas would be reduced (Rey-Gozalo et al., 2023). Therefore, the potential for these green areas to become quiet areas would be lost. The selection and preservation of quiet areas is also an objective of the Environmental Noise Directive, as these areas provide environmental and health benefits (*EEA*, 2016). Furthermore, protecting the soundscape is also important in these quiet areas. This entails not only reducing sound levels but also improving soundscape quality. The presence of mechanical sound sources, such as those from road traffic, does not guarantee this quality. But the presence of natural sources, such as birds and water, contributes to achieving a more pleasant soundscape. In summary, if one wishes to create a pleasant soundscape in green areas, it implies that these areas should not be used as noise buffer zones for road traffic unless they have a sufficiently large extent. These aspects are important to be considered in the design of green areas.

Ultimately, if interventions on the sound source of road traffic or the propagation path are not efficient, action should be taken on the receiver. The sound-absorbing and sound insulation properties of buildings have significantly improved in recent years. Furthermore, various regulations require the verification of these properties on-site. Therefore, proper construction execution is also important. Yang and Yeong estimate an average insertion loss of 7.8 dB, considering the most common design elements in building facades (Yang and Jeon, 2020).

Road education should not be forgotten in this set of actions. Awareness of the negative effects of noise can lead to greater driver awareness and, consequently, promote sustainable driving, using audible signals only in emergency situations. Recent studies are developing proposals for the implementation of devices in cars with sustainable driving indicators and alternative route suggestions to avoid noise-saturated areas (Macedo et al., 2022) (Asensio et al., 2021).

Railway noise

Railway noise is a source of environmental noise that is mostly present in large urban environments. In addition to the national interconnecting railways that cross the city, big cities often have an interurban railway network to enable the mobility of residents by collective means of transport, aligned with some of the Sustainable Development Goals set out by the United Nations as Goal 11*: make cities more inclusive, safe, resilient and sustainable* (*United Nations*, 2015). The European Environment Agency (*EEA*, 2020) ranks this source of environmental noise as the second most prevalent in Europe and points out a high correlation between the number of inhabitants of a city and the number of people exposed to railway noise. Based on data for the period 2012-2017 submitted by each country under the framework of European Noise Directive (*END*, 2002), it was estimated that 22 million European residents are exposed to railway traffic noise of at least 55 dB in the day-evening-night period (*EEA*, 2020).

In order to understand the effects caused by this sound source and to be able to plan control measures, it is necessary to analyze independently the different physical mechanisms through which this sound source generates noise. The Federal Transit Administration of United States Department of Transportation suggests some groups of sources (*FTA*, 2018). First, those associated with the propulsion unit are gear noise, engine exhaust noise, cooling fans noise and whine from electric control systems. The interaction of steel wheels and rails generates rolling noise, impact noise (discontinuities on contact surfaces) and noise generated by friction in sharp curves (squeal). Horns and bells for use in emergency situations comprises other group of sources, as well as the aerodynamic noise when the train is moving. Noise produced by moving trains depends on the speed of the train. At low speeds, engine and exhaust noise tends to predominate in the case of diesel-powered commuter rail trains. However, wheel-rail noise increases significantly with the third power of speed (*CALM*, 2003) and tends to be the main source of noise at regular travelling speeds (*FTA*, 2018). Considering also the current development of high-speed train networks in many countries around the world, it is also important to mention the relevance of aerodynamic noise. It should be considered that high-speed trains have speeds above 200 km/h and even, in some cases, exceeding 400 km/h and that the aerodynamic noise generated by trains depends on the sixth power of the speed (*CALM*, 2003). Experimental tests carried out in environments with non-reflective floors showed equivalent sound level values of up to 89 dBA for a distance of approximately 100 m between the microphone and the train running at approximately 250 km/h (Lee et al., 2014). However, not only the broadband sound level can vary with speed, but also the frequency spectrum of the sound generated (Mellet et al., 2006). The total mass of the train is another variable that can influence in this sense. Considering the variability in the emission sound spectrum as a function of variables such as speed, mass and type of train, some standards establishes a standardized railway noise spectrum in order to be able to take a standard spectrum as a starting point for the evaluation of the acoustic performance of noise barriers and noise reduction devices that act on the propagation of sound through the air in the vicinity of railroads (*EN 16272-3-1*, 2023)

(*EN 16272-3-2*, 2014). This normalised railway noise spectrum shows the highest level of noise emission in the third octave frequency bands between 400 and 2500 Hz.

Several investigations have been carried out in the scientific literature on the effects of train noise exposure on human health, reaching different levels of quality of scientific evidence. World Health Organization conducted a detailed review on this topic in its report published in 2018 (*WHO*, 2018). For an average exposure to railway noise in the day-evening-night period, moderate quality evidence was found for relevant absolute risk of annoyance at 54 dB L_{den}. Whereas in the case of the night period, moderate quality evidence was reported for a relevant absolute risk of sleep disturbance related to night noise exposure from railways at 44 dB L_n. Based on these findings, World Health Organization established specific recommendations on the limit values of railway noise levels to minimize the impact of this noise source on the health of the exposed population: L_{den} = 54 dB L_{den} and L_n = 44 dB. In this respect, recent research has led to somewhat contradictory results. While in England Jephcote et al. (Jephcote et al., 2023a) estimated that some 13,000 disability-adjusted life years (DALYs) were lost due to this noise source, studies in Denmark found no association of railway noise with increased mortality (Sørensen et al., 2023b) and no association between residential exposure to railway noise and the incidence of diabetes (Roswall et al., 2018).

In order to reduce the level of exposure of the population to railway noise, different mitigation measures can be implemented. Depending on the scenario, actions can be carried out on the emitter, the propagation medium and the receiver. Operational methods to control noise such as speed reduction or re-routing can also be considered. When planning noise mitigation measures, it is also important to assess any cost that may be associated (Heutschi et al., 2016). On the emitter, wheel roughness is an important factor in noise emission. As it is dependent on the braking system, actions on the brake blocks have shown noise reductions of up to 10 dBA (*UIC-SBB*, 2012). In relation to the track, rail grinding to reduce surface degradation over time and the use of rail dampers have shown decreases in sound level that are generally around 3 dB (*UIC-SBB*, 2012). Regarding the propagation medium, the use of acoustic barriers is the most commonly employed method. The scientific literature shows many investigations carried out both experimentally and by computational methods on their configuration in terms of shape and absorbing and reflecting materials (Li et al., 2022) (Sousa et al., 2023) (Lee et al., 2021) (Peplow et al., 2021). Traditional continuous barriers typically show real insertion losses ranging from 5 to 15 dB (Heutschi et al., 2016). However, due to their visual impact in urban residential environments (Maffei et al., 2013) (Arenas, 2008), low height barriers are also studied as a possible solution in such scenarios to reduce mainly the noise generated by the interaction between wheel and rail. In particular, in some experimental in situ studies considering specific situations and different microphone positions, sound level reductions of even more than 10 dBA have been found in some experimental in situ studies considering different microphone positions (Vazquez et al., 2021) (Jolibois et al., 2015). When actions on the emitter or propagation medium are not possible for any circumstance or are not sufficient to mitigate the impact of noise on residents, actions can be carried out on the receiver. In this case, the measures generally carried out consist of reinforcing the acoustic insulation of the windows, which are usually the weakest element of the facades of buildings. Values of broadband insulation indicators between 10 and 30 dB can be found, but the insulation of windows in frequency bands can vary greatly between low and high frequencies depending on their characteristics (Yu, 2019) (Miskinis et al., 2015) (Heutschi et al., 2016).

Aircraft noise

The great mobility of people on both national and international routes in today's globalized world seems to point to expectations of growth in global air traffic (Flores et al., 2019) (Puliafito, 2023). This trend and the location of airports near urban areas leads, among other issues, to the exposure of residents to environmental noise caused by aircraft landings and take-offs. In addition, aircraft emissions also seriously impact the air quality in the vicinity of these transport infrastructures (Pandey et al., 2023) (Quadros et al., 2023). Approximately 3 million people in Europe are estimated to be exposed in urban environments to levels of at least 55 dB during the day-evening-night period. Although the amount of people exposed to aircraft noise is lower than in the case of road and rail traffic, aircraft noise often results more annoying to people and disturbs their sleep more than road or rail noise at the same noise level (*EEA*, 2020). In this regard, it is worth noting that aircraft noise events can cause sleep disruption and other physiological reactions (*WHO*, 2018).

Different noise sources can be identified in aircraft noise, which are generally grouped into two clusters: engine and airframe noise within the first group, exhaust and fan are usually the predominant sources. While for airframe noise, slats, flaps and landing gear can be considered the main sources. But the level of noise generated may also depend on other factors such as the kind of operation (take-off or landing), the type of aircraft, aircraft conditions (speed, weight, etc.), the airport runway conditions (length, surface, etc.) and the plane's trajectory (Zhao et al., 2020) (Sadeghian and Gorji-Bandpy, 2020) (Gagliardi et al., 2018) (Qiao and Michel, 2008). All these aspects related to these sound sources are significant in determining the incident sound level at the façade of residential buildings near airports and should therefore be considered in the calculation models. In fact, experimental studies showed that parameters such as different angles of inclination in aircraft trajectories, airport runway materials and different types of flights can be relevant to accurately determine the sound level on the facades of buildings in the surroundings (Flores et al., 2019). This degree of precision can be relevant in estimating the number of people exposed to the values of noise levels recommended in international references and, therefore, also for the design of noise mitigation action plans. In this regard, some studies have experimentally observed high sound exposure level values of up to approximately 95 dBA in residential urban neighbourhoods (Gagliardi et al., 2018). Other investigations suggested a variation of sound levels and sound spectrum depending on some characteristics of the source, and even refer to tonal components (Qiao and Michel, 2008).

These aspects could be related to a higher degree of annoyance or sleep disruption in the case of aircraft noise. But in addition to these effects due to this source of environmental noise, WHO also pointed to cardiovascular disease, cognitive impairment, hearing impairment and tinnitus, adverse birth outcomes, quality of life, well-being and mental health and metabolic outcomes (*WHO*, 2018). The scientific literature shows recent studies on the association of aircraft noise with some these effects. Itzkowitz et al. showed possible evidence of an association of increased risk of cardiovascular hospitalizations and deaths in residents near a major airport with the level of aircraft noise both in the evening and night periods (Itzkowitz et al., 2023). Nearly 17,000 disability-adjusted life years (DALYs) lost were estimated in England due to aircraft noise (Jephcote et al., 2023b). Based on scientific evidence of the impact of aircraft noise on human health, the World Health Organization strongly recommended reducing aircraft noise levels and suggested limit values of 45 dB in the day-evening-night period and 40 dB in the night period (*WHO*, 2018). It is of interest to note that the recommended values for this sound source are lower than in the case of traffic and railway noise.

Considering the huge impact of aircraft traffic, strategies have been developed in the European Union to try to reduce noise emissions by 65% by 2050 (*EC*, 2011). If goals of this nature are addressed in any country in the world, it may be of interest to approach the question by considering different types of noise mitigation measures. When possible and feasible, interventions on the emitter are often more effective than on the propagation medium and the receptor. The World Health Organization recommends in fact that changes are made in the infrastructure (*WHO*, 2011). It is also important to bear in mind that some measures could be associated with increased costs for airlines. Some researchers have proposed specific interventions for noise reduction on aircraft landing gear by means of fairings, acoustic treatment of the landing gear wheel bay, component optimisation, hole coverings, flow blowing and plasma actuators (Zhao et al., 2020). Gagliardi et al. also suggested the feasibility of shortening the take-off ground run distance by enhancing the engine thrust, as well as future study of a similar approach for possible application to landing operations (Gagliardi et al., 2018). Initiatives based on computer modelling are also useful to evaluate the effectiveness of possible aircraft noise mitigation action plans by studying possible scenarios. Vogiatzis recommends regulating land use in the surroundings of airport infrastructures in urban development plans of cities based on the noise levels estimated in the strategic noise maps (Vogiatzis, 2012). Licitra et al. predicted a noise reduction of up to 7.7 dBA for individual flights at Pisa airport (Italy) in the case of moving the runways 400 m backwards and correctly applying take-off and landing procedures (Licitra et al., 2014). Xie et al. investigated the effectiveness of measures related to the regulation of the number of night flights and the optimization of flight procedures in a noise model of Guangzhou Baiyun International Airport (China), foreseeing a relevant decrease in the number of people exposed to aircraft noise (Xie et al., 2023).But when corrective measures cannot be implemented at the sound source, sometimes action programs are applied to improve the acoustic insulation of dwellings in order to reduce the noise level indoors (Asensio et al., 2012).

Other noise sources

In addition to transport, there are other sources of environmental noise that can also have an impact on people's health and well-being. The most relevant in terms of their impact on the population are: industrial activities, construction, leisure activities and night-time urban waste collection. Since these are usually more localized sources of noise, the number of people exposed is usually lower than in the case of roads, rail and airport infrastructures. However, given the characteristics of the noise generated by these sources in terms of noise emission level, impulsivity, tonal components, low frequency energy and period of the day, their impact on people living in the surroundings can also be significant.

Industrial noise is a source of environmental noise commonly present in urban environments. The European Noise Directive (*END*, 2002) establishes the need to consider this noise source in strategic noise maps, considering ports as part of this source. Based on noise mapping data in Europe for the period 2013-2017, industrial noise in urban areas is estimated to impact 0.15% of the European population during the day-evening-night period and 0.08% during the night period. This means that about 800,000 urban residents are exposed to industrial noise levels of 55 dB or more during the day-evening-night period and about 400,000 to levels of at least 50 dB at night (*EEA*, 2020). In this regard, the location of industrial areas and ports with respect to residential areas is an important factor. Silva et al. (Silva et al., 2021) points to the need to regulate urban land uses in such a way that residential areas are sufficiently distant from industrial areas to avoid the immission of industrial noise into dwellings. This study shows the case of Guimarães, (Portugal), where not carefully planned urban development led to the construction of dwellings in the vicinity of industrial areas built decades ago. Makarewicz and Gołębiewski (Makarewicz and Gołębiewski, 2017) suggest that the level of noise emission in industrial areas is associated with their size and points out that, consequently, this variable, together with the distance from the sensitive area to be protected, should be factors to be taken into account in determining the emission limits to be set in industrial areas. Solutions based on acoustic barriers are proposed in some cases to try to reduce the noise transmitted from industries to nearby residential buildings. However, the location, distribution and characteristics of the main noise sources in industrial plants can make the problem so complex that solutions based on noise barriers may either be an ineffective measure or require a high economic cost to be sufficiently effective. Some research has also been carried out on the relationship between visual and sound aspects in the perception of industrial plant noise when vegetation screening is used. The results obtained by Haapakangas et al. (Haapakangas et al., 2020) in a study carried out in laboratory conditions show that the degree of visual masking of the industrial area by trees and shrubs did not affect the subjective perception of industrial noise nuisance. And as in industrial plants, maritime ports are very complex environments to assess from the point of view of noise pollution due to the presence of numerous noise sources (ships, straddle carriers, front lifts, container cranes, transtainers, dock tractors) and the different types of operations (sailing, loading/unloading, mooring) (Fredianelli et al., 2022). The use of acoustic cameras is a technique that can be useful and feasible to identify and characterize the main noise sources in terms of position, emission level, sound spectrum and time duration (Bocanegra et al., 2022). This may make it easier to identify sound sources with low frequencies, tonal components and impulsivity, which are factors that can have a negative impact on the population living near these types of environments (Murphy and King, 2014).

Other frequent source of noise pollution in cities is construction. The concentration of population in cities leads to the need to build new dwellings to meet the demand. At the same time, urban development requires the construction of new educational, health and transport infrastructures, as well as the maintenance of existing ones. When these works are carried out in the vicinity of residential areas, the noise and vibrations generated during the execution phase of these projects often have an associated impact on the well-being and health of residents. A large number of activities are carried out in the construction of buildings and infrastructure such as demolition, earth moving, excavation, tunnelling, concreting of structures, loading/unloading, pile driving, etc., which involve the presence of a wide variety of heavy machinery as cranes, excavators, hammers, trucks, etc (Lee et al., 2019). Each of these activities involves variable noise levels that can exceed values of the equivalent sound level of 100 dBA and peak noise level of 140 dBC (Mir et al., 2022b). Taking into account this complexity regarding the different phases of a construction project, which involve multiple operations and cover different time periods, Mir et al. suggested that construction noise management to minimize the impact on the population can be structured in two different phases: the pre-construction phase and the construction phase (Mir et al., 2022b). In the former, a noise assessment should be carried out initially to determine the noise associated for each task and the construction noise on a full day basis. For this purpose, in addition to the usual procedure using class

1 sound level meters-spectral analyzers, other authors suggest the use of an acoustic array or an acoustic camera to determine the emission levels, the sound spectrum and possible tonal or low frequency components (Lee et al., 2017). Based on the data of noise assessment, the proposal of Mir et al. then suggests making a forecast of the noise generated in nearby buildings using prediction models in order not to exceed the established noise limits. This aspect is especially of interest at noise-sensitive locations such as hospitals and schools. Once the construction execution phase starts, two important tasks should be carried out in parallel to try to reduce the noise impact: noise monitoring and noise control. In the first case, noise level monitoring in the vicinity of the buildings located on the perimeter of the construction site can be carried out to verify if they are below the established limits. If not, noise measurements near each task can be performed to determine the noisiest source. But in addition to monitoring construction airborne noise levels, it is important to monitor transmitted vibrations. Vogiatzis et al. (Vogiatzis et al., 2018) show an example of how vibration monitoring can be carried out in a construction project with a high impact on the population, such as a subway line in a residential environment. From this screening, a noise control phase can be implemented by corrective measures on each task that can involve the substitution of some tools or organizational measures in which several noisy activities do not overlap at the same time. In this regard, some investigations have been carried out on the influence of individual and combined noise from various construction noise sources on annoyance. Lee et al. (Lee et al., 2015) selected various machines for foundation and demolition operations and designed auditory test to quantify the annoyance. The findings show that the annoyance caused by combined noise was significantly higher than that caused by individual noise when the equivalent sound level exceeds 65 dBA. In addition to considering subjective parameters on the health effects of noise, another interesting approach to the issue may be to monitor objective physiological variables to try to understand the response of the human body to an undesired stimulus such as noise. Through laboratory studies, some research found significant effects of different types of construction noise, its sound level and duration on heart rate and brain signals (Mir et al., 2023) (Mir et al., 2022a).

Noise associated with leisure activities is another source of environmental noise that disturbs citizens at home. This is a rather controversial question and its management has become a real challenge for authorities, as it is often difficult to harmonize the rest of residents with certain leisure activities in the same urban area. Nightlife activities often take place in very specific areas of the city. And, although they involve a mobility of people that affects the whole city, the specific noise environment associated with these activities often implies important differences between these areas and the rest of the city. A rresearch carried out in Barcelona (Spain) showed that the temporal and spatial variability of night-time noise in urban environments can be affected by leisure activities (Quintero et al., 2019). These differences often affect both the sound level values and their temporal structure as well as the annoyance perceived by citizens. For example, studies carried out in Cáceres (Spain) by Barrigón et al. (Barrigón Morillas et al., 2005) using measurements on building balconies and surveys of people's residences demonstrate this. They showed that noise associated with night-time leisure activities is the most annoying source of noise for 60% of residents in these areas, while in the city as a whole it was only mentioned as a source of annoyance by 1.5% of respondents. Leisure noise at night is usually associated with commercial activities such as pubs and nightclubs. However, the noise that is transmitted to adjacent dwellings does not always come from inside these activities, but rather the affluence of many people to these areas and their accumulation outdoors at a sensitive period such as at night is often on of the main source of noise (Ballesteros et al., 2014). Other investigations report that the celebration of large sport, religious or recreational events are also a source of sleep disturbances and complaints (Silva Passos et al., 2021) (Ballesteros et al., 2015). Some possible interventions to address this issue and mitigate the impact on people's well-being and health may involve urban planning and land use management, management planning of the movement of people to sensitive areas and periodic inspections of the most annoying noise sources.

Collection of solid waste is other source of environmental noise inherent to urban environments and which often cause disruptions on people's sleep. This activity is usually carried out using trucks with a large storage capacity for materials and the planned routes usually cover part of the night period (Zannin et al., 2018b) (Rey Gozalo et al., 2013). Although it is a noise source with a duration of some minutes at each urban collection point, the noise level emitted can reach 100 dBA (Radetić et al., 2016). In addition, the impulsive characteristics of the noise generated when moving waste containers make it annoying in a sensitive period for people's rest such as the night. This noise source can be particularly annoying when waste collection is carried out in noise-sensitive buildings such as hospitals and nursing homes. It is therefore recommended to plan and design truck routes in such a way that they drive through the most sensitive areas in the evening, where they do not have a high impact on people's sleep. In the same line, other noise mitigation measures that can be considered are the replacement of waste collection vehicles with electric or hybrid engines, as well as improving the procedure for dumping the contents of the containers in the truck.

Conclusions

Noise pollution is an increasing environmental problem in European countries, as indicated by the sound exposure data obtained from strategic noise mapping conducted every 5 years since 2007. The five-year reports on the implementation of the Environmental Noise Directive, which provide a more thorough analysis of the effectiveness of action plans, along with the implementation of the Zero Pollution Action Plan, are some of the initiatives aimed at reversing the current situation.

Road traffic noise is the sound source negatively affecting a larger number of citizens. Common methodological proposals for sound assessment among European member states, along with consideration of its dynamics, aim to enhance both the evaluation and data comparability, with the goal of proposing efficient common actions. The consideration of soundscape leads to not only reducing sound levels but also improving soundscape quality. Creating and preserving quiet areas with a pleasant soundscape is a key objective. In this regard, green spaces are potential quiet areas with a quality soundscape that also reduce air pollution and regulate temperature.

The promotion of public transportation will lead to an increase in the frequency and number of train and airplane journeys. Although currently, the number of people exposed to high noise levels from trains and airplanes is lower than that from road traffic, their numbers are significant and possibly increasing if these infrastructures are not properly planned and designed. The location of these infrastructures plays a crucial role since corrective measures at the receiver end may be ineffective due to the high noise levels generated by these sound sources.

In addition to traffic noise sources, cities also have other noise sources which, although some times more localized and punctual, can generate significant levels of annoyance in the population due to their energetic (high emission power), spectral (tonal characteristics) or temporal (impulsivity or time period in which they are present) characteristics. Industries, construction sites, leisure activities and waste collection are among these noise sources. Their measurement and localization are generally carried out through in-situ measurements, with the current trend being the use of acoustic cameras. Zoning and urban isolation of these activities, differentiation of various construction phases, compliance with regulatory requirements for entertainment venues, and changes in operating hours or noise reduction in waste collection systems are some of the current measures to mitigate the negative effects of these noise sources.

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