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# FUTURE BRIEF:
# **Noise abatement approaches**

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# Science for Environment Policy
**Noise abatement approaches**

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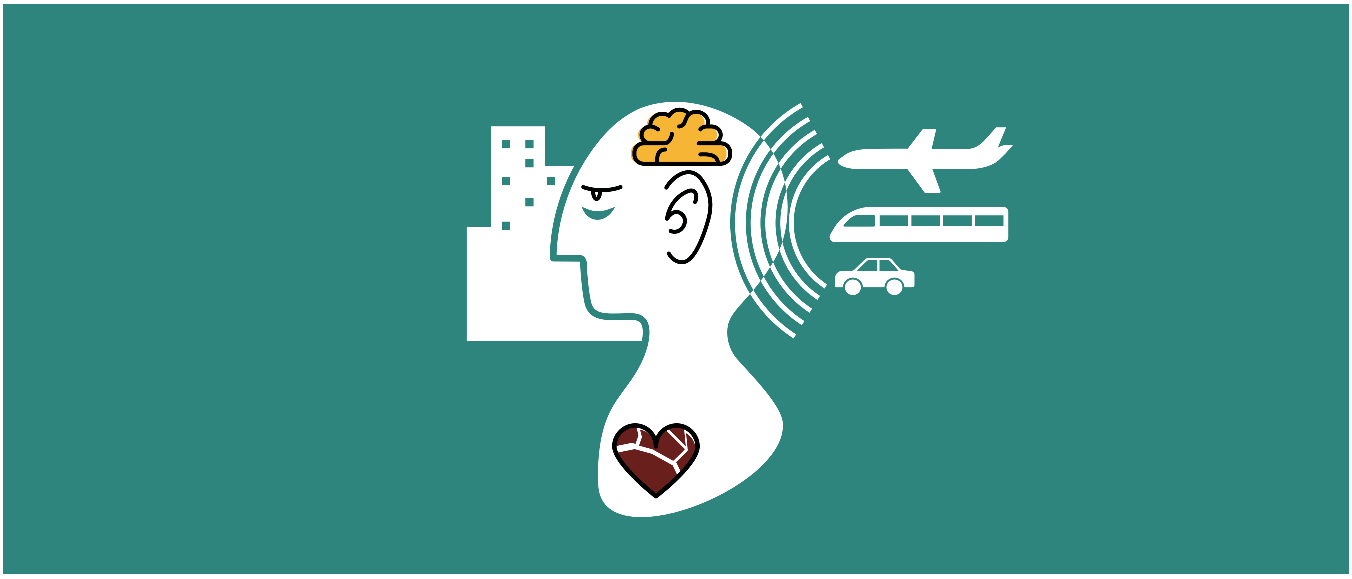
**Introduction**

# 1. Noise pollution: a growing environmental concern

*As the sources and severity of noise pollution continue to grow, there is a need for new approaches to reduce exposure. The complex and pervasive problem of noise pollution has no single solution; it requires a combination of short-, medium- and long-term approaches and careful consideration of the nature of the noise source. There are many sources of noise pollution, each requiring tailored abatement measures.*



## 1.1 Human health effects

Exposure to noise pollution is a bigger problem than ever before. As urbanisation proceeds, with more than half of the global population and three quarters of the EU now living in urban areas (European Environment Agency, 2017; World Health Organization, 2017), increasing numbers of people are being exposed to noise pollution.

Exposure to night-time noise causes sleep disturbance (Miedema and Vos, 2007), which has a multitude of negative effects on health (Colten and Altevogt, 2006; Newman *et al.*, 1997; Kawakami *et al.*, 2004). Noise exposure in the evening hours and during night-time is particularly important for health effects, as it affects relaxation and therefore stress. Furthermore, sleep is an important mediator of cardiovascular function (Babisch, 2011). Noise pollution has also been linked to impaired cognitive performance, hormonal disturbances, diabetes, stroke and psychological ill health (Isling and Kruppa, 2004; Goines and Hagler, 2007; Stansfeld and Matheson, 2003; Sørensen *et al.* 2011; Sørensen *et al.* 2013).

BOX 1.

**Effects of environmental noise in Europe**

In the EU, more than 100 million citizens are affected by noise levels above 55 dB $L_{den}$ (a threshold at which negative effects on human health can be observed).

Road traffic is the most prominent source for such noise, followed by noise from railways, airports and industry.

This means that around 14 million citizens are annoyed by environmental noise and around 6 million sleep disturbed. This is associated with an estimated 70 000 hospital admissions and 16 000 premature deaths per year.

Source: European Commission (2017).

The health impact of noise is being increasingly recognised, especially in terms of its cardiovascular effects. Evidence shows that environmental noise is associated with an increased incidence of high blood pressure, heart attack and stroke (Münzel *et al.*, 2014). According to noise and health scientist Wolfgang Babisch (2011):

> *"The question at present is no longer whether noise causes cardiovascular effects, it is rather: what is the magnitude of the effect..."*

A UK study (Harding *et al.*, 2013) estimated an additional 542 cases of hypertension-related acute myocardial infarctions (heart attacks), 788 cases of stroke and 1169 cases of dementia per year due to exposure to daytime noise,[1] at a cost to the UK economy of £1.09 billion (around €1.25 billion). A broader meta-analysis (Babisch, 2014) suggested that there is an 8% increase in risk of coronary heart disease per 10 dB(A) increase in road traffic noise.

Noise pollution causes adverse health effects by activating the autonomic nervous system and endocrine (hormonal) systems of the body, leading to changes in heart rate, blood pressure and the release of stress-associated hormones such as cortisol, which affects metabolism (Babisch, 2002; Babisch, 2011; Maschke *et al.*, 2000; Lusk *et al.*, 2004; Isling and Kruppa, 2004).

The World Health Organization (WHO) states that there is now sufficient evidence linking population exposure from environmental noise to adverse health effects, making environmental noise a major environmental health concern, second only to air pollution (WHO, 2011). They estimate the burden of disease due to environmental noise in disability adjusted life years (the sum of the potential years of life lost due to premature death and equivalent years of healthy life lost due to poor health or disability) to be: 61 000 years for ischaemic heart disease; 45 000 years for cognitive impairment in children; 903 000 years for sleep disturbance; 22 000 years for tinnitus; 654 000 years for annoyance. These figures are annual and for western Europe alone.

1. At levels at or above 55 dB(A).

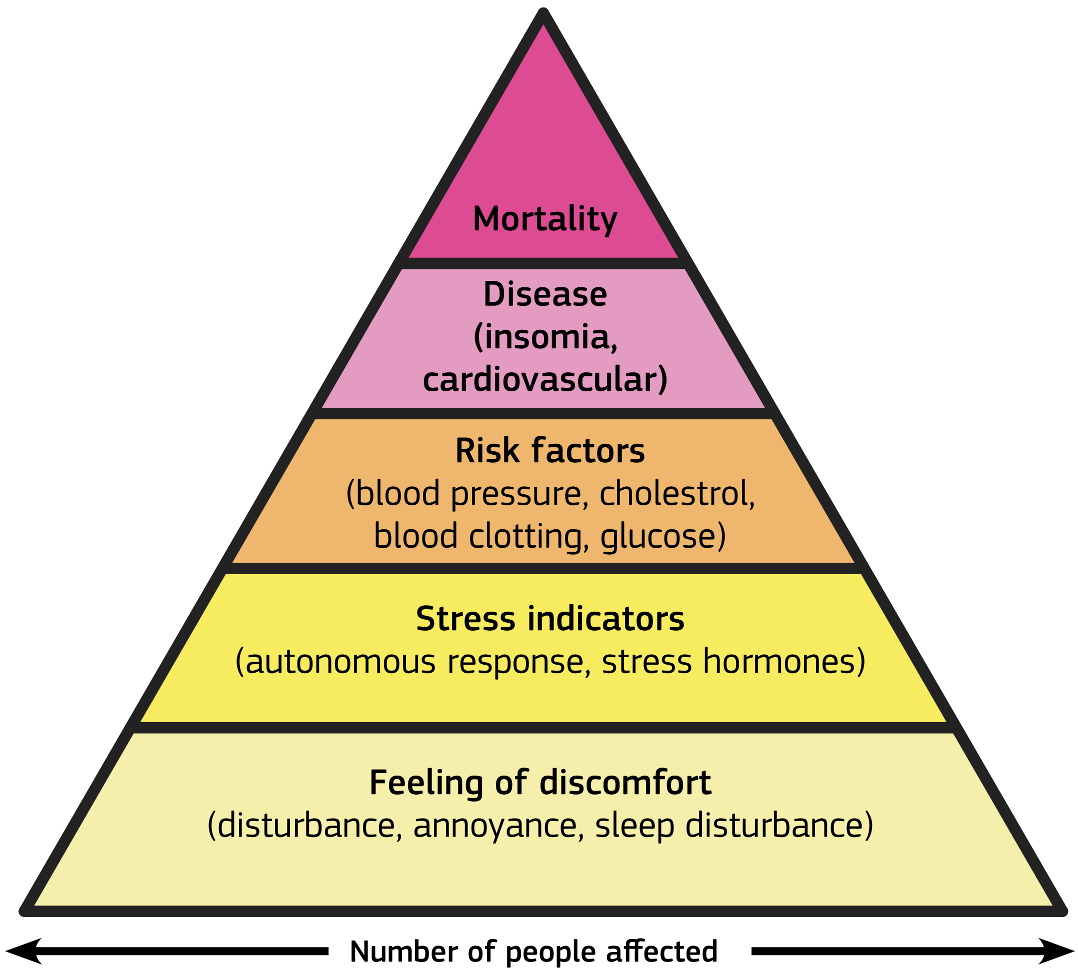



**Figure 1: The pyramid of noise-induced health effects.** Source: adapted from: Babisch, W (2002) The noise/stress concept, risk assessment and research needs. *Noise and Health* 4: 1-11.

## 1.2 Policy context

To mitigate these consequences, robust legislation will be key. The EU has been an important proponent of noise pollution policy. The 7th Environment Action Programme (7th EAP)[2] recognised that Europeans living in urban areas are being exposed to levels of noise that may affect their health and wellbeing, and set out to significantly decrease noise pollution in all EU Member States by 2020. This was the summation of over 20 years of work to develop a coordinated policy on noise in the EU, beginning with 1993's 5th EAP 'Towards Sustainability', which declared that "no person should be exposed to noise levels which endanger health and quality of life".[3] The subsequent Green Paper on Future Noise Policy made noise pollution an environmental priority and proposed a new framework for noise policy, which was further embellished in the 6th EAP 'Environment 2010: Our Future, Our Choice'.[4] It was here that the Environmental Noise Directive (END)[5] — the foundation of contemporary EU noise policy — was first proposed.

2. Decision No 1386/2013/EU of the European Parliament and of the Council of 20 November 2013 on a General Union Environment Action Programme to 2020 'Living well, within the limits of our planet': http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32013D1386
3. http://ec.europa.eu/environment/archives/action-programme/env-act5/pdf/5eap.pdf
4. http://eur-lex.europa.eu/legal-content/GA/TXT/?uri=URISERV:l28027
5. 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: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32002L0049

The END aims to establish a common approach to avoid, prevent or reduce the harmful effects of environmental noise and to provide a basis for developing measures to reduce the noise emitted by sources including roads, railways, aircraft and industrial equipment. This is to be achieved via three action areas:

- Determining exposure to environmental noise,
- Ensuring that information on environmental noise is available to the public,
- Preventing and reducing environmental noise and protecting good environmental noise quality areas.

As part of the Directive, Member States are required to publish noise maps and action plans for major roads, railways, airports, industrial sites and areas with over 100 000 inhabitants every five years. Based on the results of their strategic noise mapping, Member States draft action plans to reduce noise pollution where necessary. In doing so, the Directive provides the world's biggest programme of strategic noise reduction (Murphy and King, 2014).

After more than 10 years of operation, the END was recently evaluated in terms of its effectiveness, efficiency, coherence, relevance and value added for the EU. The evaluation, which was based on data from Member States, scientific literature, online surveys, interviews, workshops and a public consultation, concluded that the Directive is raising awareness of the harmful effects of noise and making progress towards a common approach to noise assessment and management, and was given a very favourable cost-benefit rating of 1:29 (European Commission, 2016). The Commission is due to publish a second report on the implementation of the END in 2017.

Alongside policy, innovative technological approaches to reducing noise pollution are essential to tackling this global environmental problem. This brief will describe diverse efforts to mitigate noise pollution, detailing the different types of noise abatement technology available for each of the major sources of noise pollution: roads, railways, airports and industry. It will also discuss broader means of reducing noise pollution, including improvements in city design, to equip the reader with a comprehensive overview of state-of-the-art approaches to noise mitigation.


Niveau de décibels est élevé, dB. © istock / olm26250

BOX 2.

## The decibel

Noise is measured in decibels (dB). It is also referred to in A-weighted decibels (dB(A)). The A-weighting filter is a method of summing sound energy across the frequency spectrum of sounds audible to humans, and is used to estimate the human ear's response to sound.

There are two important indicators of noise:

$\mathbf{L_{den}}$: The day, evening and night noise indicator. A measure of all the averaged (continuous equivalent) sound pressure level over a year, and

$\mathbf{L_{night}}$: The night time noise indicator, which averages (continuous equivalent) sound pressure level over one year, focussing on the hours between 23:00 and 07:00. This corresponds to 8 hours, the recommended period of sleep for adults.

A natural environment (birds, trees and wind) is associated with a typical average $\mathbf{L_{den}}$ value of **40 dB** and an $\mathbf{L_{night}}$ of **30 dB**.

An $\mathbf{L_{night}}$ value of **40 dB** is the limit suggested by the World Health Organization to avoid negative health effects on humans.

EU Member States are required to report noise above an $L_{den}$ of 55 dB and $L_{night}$ of 50 dB, under the Environmental Noise Directive.

3 dB is the minimum sound level typically considered perceptible by humans, and starting from 5–10 dB humans can clearly acknowledge a different acoustic environment.

# 2. Noise mitigation

## 2.1 Traffic Noise

The biggest source of environmental noise is road traffic (European Environment Agency, 2014), exposure to which far exceeds rail and aircraft sources combined (Murphy and King, 2014). In urban areas, road traffic is thought to account for 80% of all noise pollution (The SMILE Consortium, 2003).

Road traffic noise is caused by a combination of rolling noise (due to vibrations and interactions between the tyre of the vehicle and the road surface) and propulsion noise (emanating from the engine itself). Rolling noise dominates noise emissions when cars are travelling above approximately 30 kilometres per hour (km/h), while propulsion noise is the major source of noise below this speed.

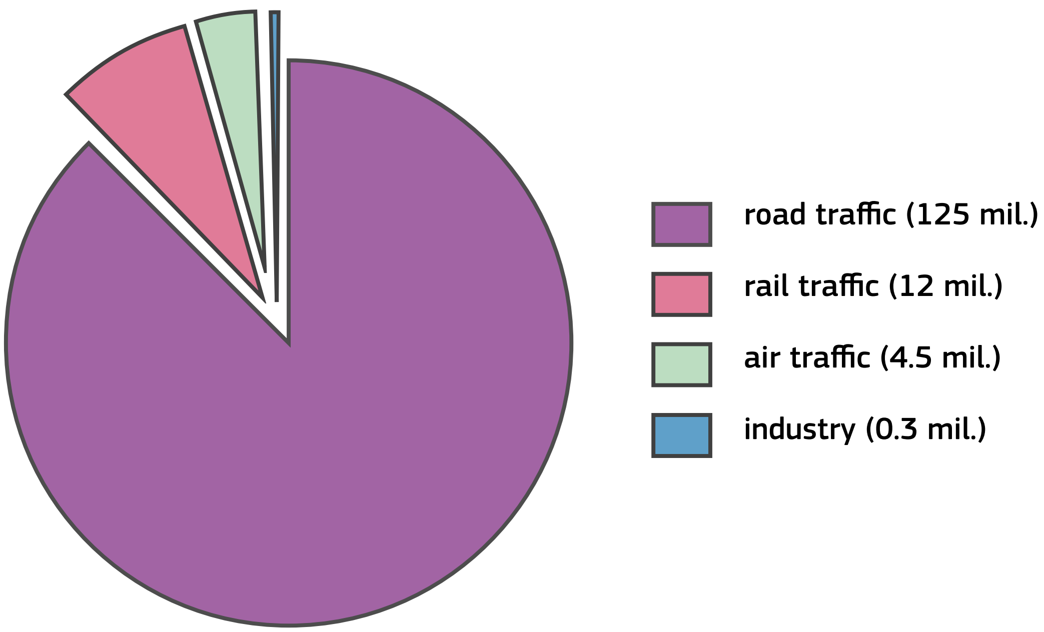



**Figure 2: Distribution of European population exposed to sound levels above 55 dB Lden, by noise source (millions). Includes populations living in large agglomerations (>100 000 inhabitants) and close to major infrastructure.** Source: adapted from Blokland and Peeters (2016) and based on noise mapping data from EEA (2014), extrapolated to 100% coverage over Europe.

There are various options available for mitigation of noise from traffic (European Environment Agency, 2014).

### *Quieter engines*

Most road vehicles are currently powered by internal combustion engines, which generate noise when fuel is burned as well as from the exhaust, air intake, fans and auxiliary equipment. Reducing noise at source is the most effective noise abatement approach for vehicle noise. Indeed, the biggest reductions in noise emissions from cars in recent years have come from improvements to engine technology (Murphy and King, 2014). Noise reduction technologies have been developed for internal combustion engines, which can reduce the noise level of the engine without affecting its power output (Ianetti, 1997). Electric and hybrid motor vehicles also offer reduced engine noise (Jabben *et al.*, 2012).

### *Low-noise road surfaces*

Road surfaces can have a significant influence on the sound produced by vehicles travelling on them. Low-noise road surfaces are an optimal solution to reduce noise because they act on the source and provide an acoustical benefit to the entire population living near to the road. Important characteristics of road surfaces include their roughness, porosity and elasticity. These factors can be influenced by the amount and type of binder used (asphalt or cement concrete, for example), the mix (such as the shape and type of stones used in the mineral aggregate) and the surface treatment (Kropp *et al.*, 2007). The most effective road surfaces for reducing traffic noise pollution are porous and thin-layer asphalt (Murphy and King, 2014).

Porous asphalt reduces the effect of 'air pumping' where, as the tread of the wheel hits the road, air is squeezed out as the tread is compressed (Murphy and King, 2014; Kropp *et al.*, 2007). Porous asphalt can also absorb noise coming from the engine (Murphy and King, 2014). Various European countries have shown that porous mixes can effectively reduce noise. In the Netherlands for example, where it is used on at least 60% of roads, research has shown that porous asphalt can reduce noise from passenger vehicles by 3 dB (Gibbs *et al.*, 2005).

Further results from the EU SILENCE project (Ripke *et al.*, 2005) suggest that single-layer porous road surfaces can reduce noise on main roads by up to 4 dB (compared to conventional dense asphalt concrete), while over 6 dB reductions can be achieved using the most absorptive, open porous surfaces (Kropp *et al.*, 2007), although these require bi-annual cleaning.

Thin-layer road surfaces have been specifically designed to reduce noise emissions. They incorporate small aggregates (6–8 mm), an open structure to reduce noise generated by air pumping and a smooth and even surface to reduce the vibrations of the tyre. These surfaces have been applied in a Danish noise abatement programme, generating a 3 dB reduction in noise from passenger cars (Bendtsen and Nielsen, 2008). These surfaces are also thought to be more suitable for urban areas as porous surfaces can become obstructed with dust, reducing their ability to mitigate noise (Murphy and King, 2014). Although they differ in composition, both types of surface have a low aggregate size, which increases the empty space (void) and aids noise absorption **(Table 1)**.

It is important to note that low-noise road surfaces are more impactful where rolling noise dominates. Where engine noise is the main culprit of noise pollution, their value is limited. The noise reduction effect also reduces with use; for porous asphalt road surfaces the noise reduction effect decreases by 0.4 dB/year for light vehicles at high speeds (Murphy and King, 2014). They can also be expensive (double-porous asphalt is almost twice as expensive per application than standard asphalt), yet relative to other noise abatement measures, such as noise barriers, the costs are relatively low (Guarinoni *et al.*, 2012; Murphy and King, 2014).

Low-noise road surfaces also have advantages over other mitigation approaches as they reduce noise for all buildings near to roads, as opposed to insulation for example, which only benefits the protected building (Murphy and King, 2014).

| Void content | Pavement group | Noise reduction (re. SPBcars 120km/h, reference pavement SMA 11) |
|---|---|---|
| 0 ... 7 % | dense surface | 0–2 dB |
| 7 ... 12 % | semi dense surface | 2–4 dB |
| 12 ... 18 % | semi porous surface | 4–6 dB |
| > 18 % | (open) porous surface | > 6 dB |

**Table 1: Pavement groups and noise reduction capacities.**
Source: Kropp *et al.*, 2007: 21.

Although many EU countries already use quiet road surfaces, the ultimate goal is to harmonise the type of road surfaces used across the EU. The European Committee for Standardisation (CEN) has started to work towards a standardisation of the noise characteristics of European road surfaces.

## *Low-noise tyres*

The other component of rolling noise, tyres, are also a valuable focus for noise mitigation efforts. Replacing tyres with quieter alternatives could reduce noise emissions by around 3 dB (Kropp *et al.*, 2007). There are already 'quiet' tyres available in the EU labelled 66-67 dB (the average value is 70-71 dB); however developing completely new tyres may have even more potential.

Important considerations in low noise tyre design include the *tread stiffness* (the texture of the rubber exterior that contacts the ground), lower levels of which can reduce excitation of tyre vibrations; *mass*, as tyres with higher mass generate reduced vibrations; *reduced tyre width* and increased *external diameter*; increased belt stiffness; and the *volume of grooves* in relation to the volume of rubber blocks in the tread, which influences air pumping. Each of these parameters can influence the rolling noise by a few decibels, but may negatively impact other tyre properties such as rolling resistance or friction. Thus, the optimisation of tyre parameters is important to obtain satisfactory noise emission levels, energy efficiency and other tyre properties.

More radical changes to tyre design include adding a porous tread, which could reduce noise emissions by 5 dB. A more futuristic idea is that of the 'TWEEL', first envisioned by Michelin, an airless tyre that could reduce noise emissions by up to 10 dB **(Figure 3)** (Kropp *et al.*, 2007).

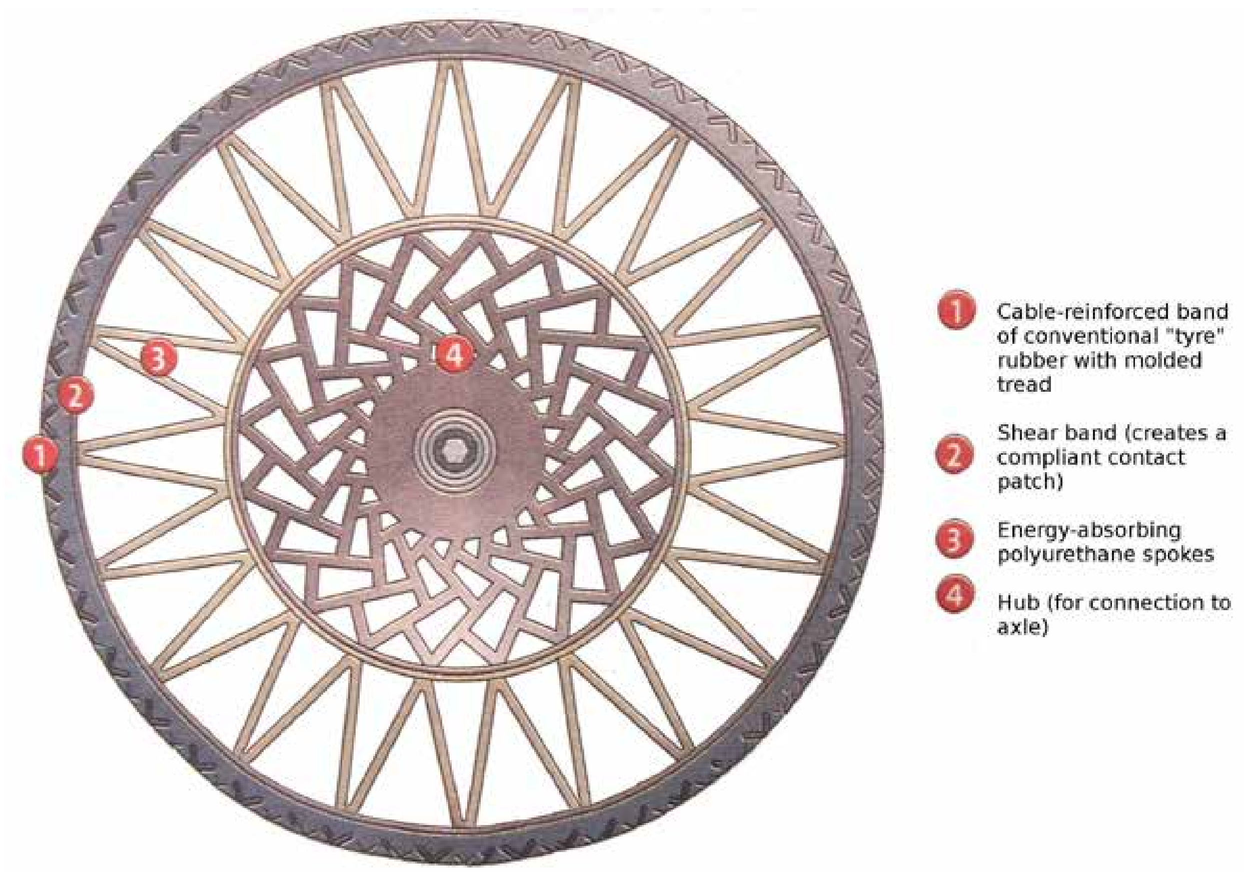



**Figure 3: The Michelin TWEEL.** Source: Public domain. https://commons.wikimedia.org/wiki/File:Tweel.JPG

The benefits of low noise tyres are amplified when applied on noise-reducing road surfaces. The potential of quieter tyres could also be enhanced by the use of speed limits. It has been estimated that speed limits of 130 km/h could enhance noise reduction by an extra 2 dB (Sandberg, 2006). Legislation to promote low-noise tyres will be another important element. In the EU, current legislation on tyres establishes a framework for providing consistent information on tyre parameters, including their external rolling noise. This system helps consumers to make an informed choice when purchasing tyres. The label provides ratings of noise both in decibels and in more general terms for those unfamiliar with the decibel system – black waves indicating whether the tyres are 'quiet', 'moderate' or 'noisy' (**Figure 4**). Unlike the other major source of vehicle noise (the engine) however, there are currently no manufacturer limits on the sound that can be emitted by tyres in the EU.

Quieter tyres are generally no more expensive than standard tyres and perform similarly in terms of wet grip and rolling resistance. Several have been developed and are already on sale on the European market.

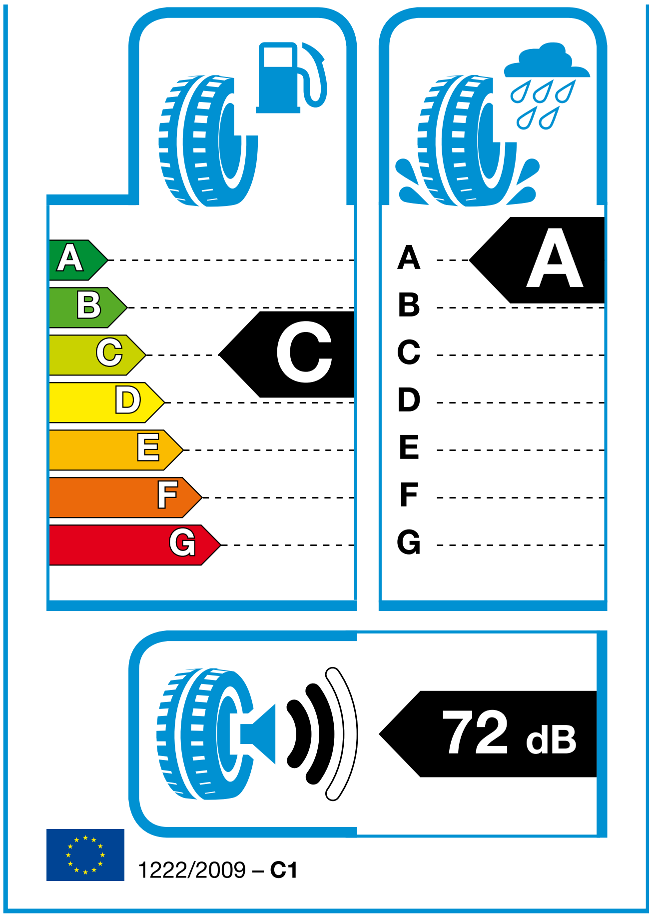



**Figure 4: EU Tyre Label.** Source: Public domain. https://commons.wikimedia.org/wiki/File:EC_tyre_label_CA.svg

## *Electric vehicles*

A more transformative means of reducing traffic noise is the adoption of electric vehicles. Hybrid electric vehicles have been produced since the 1990s and more recently all-electric vehicles have been introduced, which operate using electricity at all speeds.

When in electric mode, at least at low speeds, these vehicles are quieter than traditional gasoline or diesel-powered cars (Kropp *et al.*, 2007). This has even led to concerns that they may be dangerously quiet for cyclists or the visually impaired, who rely on the sounds produced by vehicles as warning signals (Kaliski, 2012). In 2014, the European Parliament approved legislation requiring 'Acoustic Vehicle Alerting Systems' for all new electric and hybrid electric vehicles (European Commission, 2014). Likewise, under US legislation, hybrid and electric vehicles are required to make audible noise when travelling at speeds up to 20 km/h (NHTSA, 2016). However, because the difference in noise emissions is negligible at high speeds, studies have shown non-significant benefits.

A US source showed that, even if all cars were replaced with electric ones, the average sound level would only be reduced by 1 dB during the day (Kaliski, 2012), while an assessment in the Netherlands suggests that replacing the conventional car fleet with hybrid or fully electric cars could reduce noise emissions in urban areas by 3–4 dB (Jabben, 2012). A more recent study (Campello-Vicente *et al.*, 2017) evaluated the effect of introducing a flow of electric vehicles into urban traffic in Spain, describing the expected effects on noise maps. The study showed that at high speeds (above 50 km/h) the benefits of electric vehicles are minimal due to the overriding contribution of rolling noise. However, when a flow of electric vehicles running at 30 km/h was studied, the authors estimated a reduction in sound levels of 2 dB. A simulated noise map showed that the substitution of internal combustion engine vehicles with electric vehicles could improve the acoustic environment for 10% of citizens.

## *Traffic management and engineering*

Less frequently used measures to mitigate traffic noise include banning private cars in city centre areas. Several studies (King *et al.*, 2011; Nieuwenhuijsen and Khreis, 2016) suggest that banning private cars in certain areas can significantly reduce noise levels. A similar sentiment was stressed in the 2010 White Paper on European Transport Policy:[6]

> *"The big problem that urban authorities will have to resolve is that of traffic management, and in particular the role of the private car in large urban centres.... The lack of an integrated policy approach to town planning and transport is allowing the private car an almost total monopoly".*

A major study in Dublin, Ireland (King *et al.*, 2011) introduced a public transport (bus and taxi) only area in the city centre which restricted private vehicles from accessing the area during peak traffic times. Over a 24-hour period, levels of noise in the city centre were not significantly reduced. The authors suggest that the effectiveness of the ban would be enhanced if the scheme was expanded to only allow quiet buses into the centre, and that the benefits of the ban may have been felt in areas that were not considered part of the scheme. More recently, Hamburg, Helsinki, Madrid and Oslo have also announced plans to become, at least partly, private car-free (Nieuwenhuijsen and Khreis, 2016).

Other measures to reduce motorised traffic include 'car-free days', restricting the number of parking spaces in city centres and investing in cycling infrastructure and public transport (Nieuwenhuijsen and Khreis, 2016). Brussels holds an annual 'car-free Sunday' event, when car traffic is banned between the hours of 9am and 7pm. Acoustic assessments of this initiative suggests it reduces noise by over 10 dB (Brussels Environment, 2012). Paris began a similar initiative in 2016, banning car traffic along 10 routes, including the Champs Elysées, on the first Sunday of each month (Anzilotti, 2016).

Assessments of the impacts of such initiatives on noise levels though are rare, and instead tend to focus on the air pollution benefits although the reduction of traffic noise can also

Trafic de Bruxelles. With 559 vehicles per 1000 people Belgium is the 25th most motorised country in the world. © istock / tupungato

6. *European transport policy for 2010: time to decide.* White Paper. COM(2001) 370.

BOX 3.

**A piece of HEAVEN: Healthier Environment through Abatement of Vehicle Emission and Noise**

The HEAVEN project, which involved Berlin, Leicester, Paris, Prague, Rome and Rotterdam, set out to reduce transport-related noise and air pollution by developing a decision support tool to assess the emissions associated with different forms of vehicle management.

As part of this remit, the project considered the role of different traffic regulation measures on reducing noise pollution. In an area of Berlin used by many goods vehicles, a speed limit of 30 km/h was introduced, followed by a three week ban on heavy goods vehicles (HGVs) weighing over 3.5 tonnes.

The lower speed limit reduced noise levels by over 2 dB(A), but could have reduced noise by 3 dB(A) if it had been complied with in full. The HGV ban reduced noise slightly less, around 1 dB(A) during the day, but could have been more effective if applied to vehicles of other weights.

Sources: Transport Research & Innovation Portal, 2003; The SMILE Consortium, 2003.

have significant benefits for health (Nieuwenhuijsen and Khreis, 2016). These measures can contribute to noise abatement as part of a wider traffic management strategy. They indirectly benefit the acoustic environment and are important for promoting quieter cities.

Other measures that can feed into a traffic management strategy include speed limits (which can reduce noise emissions by several decibels), one way streets and restricting access to heavy vehicles in residential areas (Nieuwenhuijsen and Khreis, 2016).

Aspects of driver behaviour can also be important for reducing noise emissions. More passive driving styles are suggested to reduce noise levels by up to 5 dB for cars (Kloth *et al.*, 2008). Rapid acceleration and re-starting the engine in traffic can result in emissions up to 15 dB higher than 'smooth driving' in urban areas (Singh and Davar, 2004). Quieter driving styles could also be promoted through the greater use of automatic gears, which facilitate gradual transitions between gears at low engine speeds. Public campaigns to raise awareness of the negative effects of 'aggressive' driving styles could also be beneficial (Murphy and King, 2014).

Finally, integrating concerns over noise pollution into plans for upgrading transport networks could be beneficial on a large scale. It has been suggested for example that road surfaces could be upgraded to low-noise alternatives when roads are routinely re-surfaced. Likewise, when public transport vehicles are upgraded, lower noise alternatives could be selected. Valencia for example has applied low-noise asphalt road surfaces and purchased quieter hybrid buses for use in the city centre, in a move co-financed by the EU. Parma has also introduced low-noise buses in its city centre, which is also a 'limited traffic area' (The SMILE Consortium, 2008).

## 2.2 Railway Noise

Although road traffic is the most important source of noise pollution in Europe (nine times as many people are exposed to road traffic as railway traffic), the sound levels produced by railway lines can often be higher (European Commission, 2011).

While rail is generally considered the most environmentally friendly transport mode, reducing noise levels is an important objective for the sector (de Vos, 2016). Indeed, the EU's Future Noise Policy Green paper (European Commission, 1996) noted that the public's main criticism of rail transport is its associated noise pollution. Soon after, the EURailNoise study was set up to review European legislation on railway noise and document technical measures to reduce railway noise (Kalivoda *et al.*, 2003).

Rolling noise is the major source of noise emissions from trains when they are travelling, while engine noise takes over when trains are stationary or moving slowly. Above 300 km/h, aerodynamic noise dominates. Overall, the main source of train noise is the interaction of the wheels with the rails, which leads to vibration that is perceived as noise (de Vos, 2016; Murphy and King, 2014).

As rolling noise is the major source of railway noise, abatement efforts tend to focus on the vehicle (including the wheels, brakes and body) and the track (including the rail itself, rail pads, sleeper and the ballast). The roughness of the contact area between the wheel and the rail causes the vibrations that are responsible for rolling noise, so it is important that this surface is as smooth as possible (de Vos, 2016).

The most effective strategy to tackle this is to reduce the wheel roughness, for example by replacing cast iron brake blocks. A new type of low-noise brake block (LL-blocks) can easily replace noisy, cast iron blocks and can reduce noise from freight trains by up to 12 dB (on a well-maintained track). In 5-10 years, most freight trains in international traffic are expected to use these brake blocks, making their noise emissions similar to those of passenger coaches. It can also be beneficial to isolate the wheel tread from the wheel web and optimise the size and shape of the wheel to reduce vibration, although this is only possible for new vehicles.

On the track side, the roughness of the rail line can be reduced using acoustic grinding, which has been shown to reduce sound levels by 2.5–5 dB. Using firmer rail pads can also reduce the vibration of the rail, while adding a rail damper can further reduce noise by up to 3 dB(A) — although concerns remain regarding their cost and safety (de Vos, 2016).

Switzerland offers a valuable case study of railway noise abatement. Over 7% of the national budget for railway investment between 2000–2015 was dedicated to noise abatement, aiming to reduce noise exposure by two thirds. The programme was funded by taxes on heavy vehicles, VAT and fuel taxes and involved retrofitting of trains with low-noise brake blocks, installing noise barriers and improving insulation of windows. The approach, although requiring significant resources, was supported by the public through a referendum. More recently, the Swiss government announced plans to ban cast-iron brakes by 2020, which will encourage foreign trains using Swiss railway lines to do the same (Murphy and King, 2014).

## 2.3 Aircraft Noise

Although fewer people are exposed to air traffic noise than that from road or rail, it is reported to cause greater annoyance (Guarinoni *et al.*, 2012; ISO, 2016; Münzel et *al.*, 2014) (**Figure 5**).

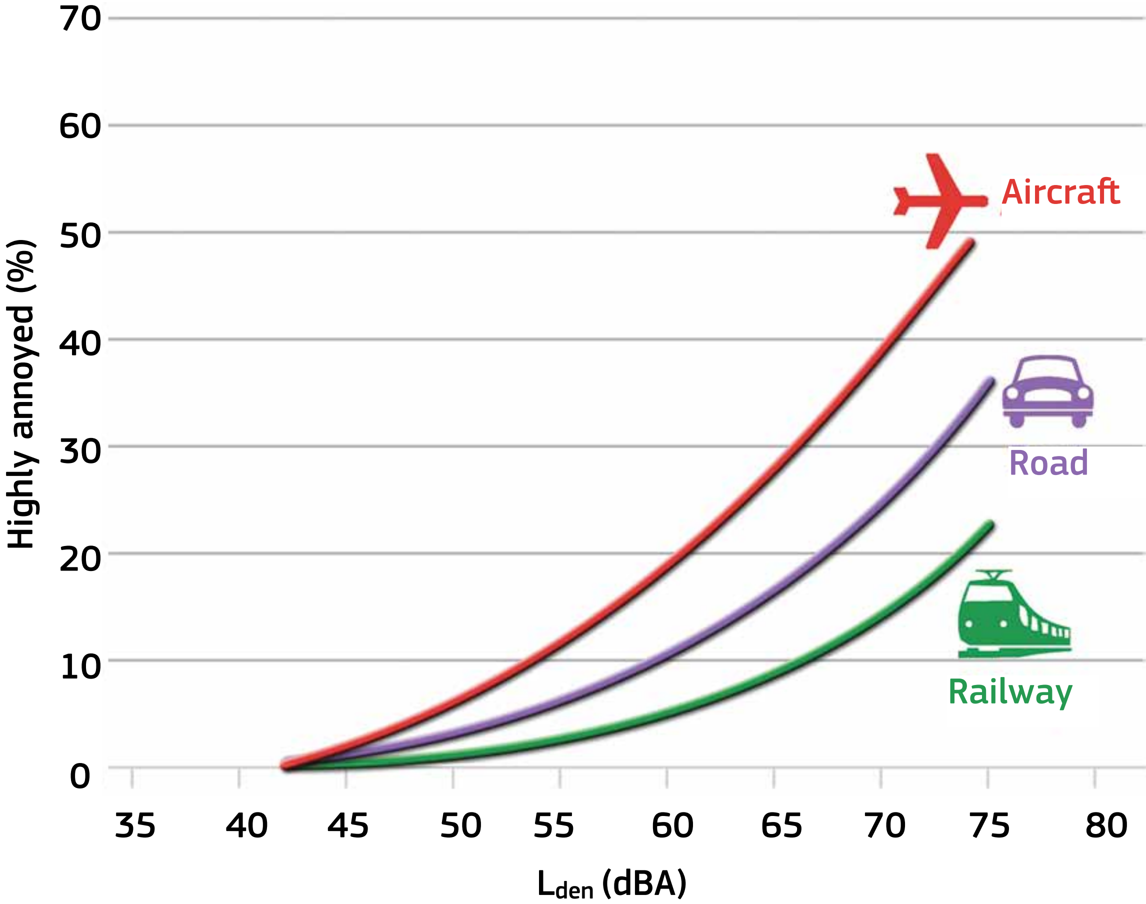



**Figure 5: Percentage of people highly annoyed by aircraft, road and rail noise.** The curves were derived for adults on the basis of surveys (26 for aircraft noise, 19 for road noise, and 8 for railways noise) distributed over 11 countries. Source: adapted from Münzel *et al.*, 2014 .

Although individual aircraft have become quieter in recent decades, increases in air transport mean many in Europe remain exposed to high levels of aircraft noise (Guarinoni *et al.*, 2012). The main sources of airport noise are from the aircraft itself, which generates noise on the ground while parked, while taxiing, during run-up, take-off, flight and landing. Noise originates from three major sources: aerodynamic noise (due to the airflow around the main body of the aircraft, increasing with speed and at low altitudes), engine/mechanical noise (due to the jet engines, which predominates during take-off and climb), and noise from aircraft systems (from the auxiliary power unit, which is used to start the main engines and provide power while the aircraft is on the ground).

The International Civil Aviation Organization (ICAO) Balanced Approach to Aircraft Noise Management was developed in 2004 to address growing concerns about airport noise. It aims to tackle noise issues at individual airports in an environmentally and economically responsible manner. Following an assessment of noise levels, the ICAO Balanced Approach suggests four approaches to management (ICAO, 2016):

**1) Reduction of noise at source**

- New technologies.
- Noise standards.
- Fleet evolution.
- Air traffic management.

**2) Land-use planning and management**

- Zoning: controlling development, such as preventing noise-sensitive land-uses (e.g. residential buildings, schools, hospitals) near to an airport or flight path.
- Mitigation: e.g. facade insulation of nearby noise sensitive buildings.
- Tax incentives and financial charges.

**3) Noise abatement operational procedures**

- Noise-preferential routes or runways.
- Limited engine running while on the ground.
- Displaced landing thresholds: Changing where on a runway planes can land to reduce noise emissions for sensitive areas.
- Reducing power/drag.
- The continuous descent approach (CDA), whereby the aircraft is at a higher altitude throughout most of the descent than the conventional 'stair-step' approach, which reduces noise pollution for communities below.

**4) Operating restrictions on aircraft (last resort)**

- Movement caps.
- Noise quotas.
- Curfews.

Other mitigation approaches include aircraft modifications, such as the use of high-bypass turbofan engines and aerodynamic construction changes to reduce drag and therefore airframe noise. Larger-scale approaches include creating 'noise contour overlap maps' which represent sound emissions in lines and outline the area around an airport in which noise levels exceed a given dB threshold, and zoning policies to site new airports away from populated and noise-sensitive areas. Financial charges are also important. Encouragingly, over 100 airports in Europe have deployed noise charging schemes in the past 25 years (EASA, EEA and EUROCONTROL, 2016; Ganic *et al.*, 2015).

Despite this suite of measures, there remains a need for new efforts to mitigate aircraft noise. Although jet aircraft noise levels have reduced, the number of people exposed to noise from European airports is forecast to increase by 15% by 2035 (from 2014 levels). However, a continued 0.1 dB reduction per year for new aircraft could halt the growth of overall noise exposure by 2035. This could be further enhanced by new technology development (EASA, EEA and EUROCONTROL, 2016).

Route asphaltée. © istock / bjdlzx

BOX 4.

## Project portfolio

The European Commission has funded a number of projects to tackle noise pollution, a selection of which are presented here:

### HARMONICA

This LIFE-funded project developed novel tools to increase public awareness of noise pollution and to assist local decision making on the issue. These included a simple 'noise index' and information platform about noise in major European cities.

www.noiseineu.eu

### SILENCE

This three-year research project developed a new method for controlling transport noise, including from road and rail, in urban areas of Europe. The project produced a toolkit for noise reduction including traffic management strategies, driver support tools and a roadside monitoring system for vehicle noise.

www.silence-ip.org

### OPENAIR

OPENAIR (Optimisation for low Environmental Noise Impact Aircraft) aims to reduce aircraft noise by 2.5 dB at the source, on top of the 5 dB noise reduction achieved by previous EU project SILENCE(R). It is focused on developing new technologies, such as aeroacoustics, sound absorbent materials and methods to reduce airframe noise.

http://www.xnoise.eu/index.php?id=387

## 2.4 Industrial noise

Although transportation is the major contributor to environmental noise pollution, there are many other, more localised sources of environmental noise, such as industrial sites, shipping ports, construction sites, landfills and even wind turbines.

Industrial-type noise can cause particular annoyance due to its intermittent and low-frequency nature (Murphy and King, 2014). Mechanical noises, which can produce a sensation of vibration, are considered especially annoying by people (Morel *et al.*, 2012).

The mitigation options for industrial noise include many of those mentioned in previous sections, including noise barriers, sound proofing and restricted operation periods. Legislation is particularly important in this regard, such as stringent noise limits during the evening and night-time.

There are also more specific noise mitigation approaches for industry, including shock mounting equipment and damping to reduce vibrations, acrylic glass barriers and machine guards. A more pro-active approach to noise abatement is to design machinery with reduced sound emissions. In the EU, the Outdoor Noise Directive (2000/14/EC) imposes noise limits for 22 different types of equipment and requires noise marking for a total of 57 equipment types (Guaranoni *et al.*, 2012). There is also legislation regulating noise emitted by household appliances and recreational craft. Initiatives have also been launched in the US to promote the purchase of quieter equipment.[7]

BOX 5.

### Industrial noise abatement case studies

Noise control at a:

**Power station**

A combined heat and power plant was to be built 200 metres from residential buildings. To attenuate noise, the plant and associated elements (e.g. turbines) were enclosed in a building especially designed to reduce noise emissions. As a result, noise surveys after building showed no detectable increase in noise levels in the residential buildings nearby.

**Landfill site**

A landfill site located in a noise sensitive area was generating concerns among local people. To address this, two embankments were constructed of soil removed from the site during its construction. Alongside the noise barriers, a suite of noise management practices including restricted operating times and noise monitoring led to an overall noise reduction of 10 dB(A).

Sources: HSE, 2016; Mitchell, 2001.

7. https://www.cdc.gov/niosh/topics/buyquiet/default.html

## 2.5 Cross-functional noise abatement approaches

Although some noise abatement approaches are specific to particular noise sources, several can be applied across noise types:

### *Noise barriers*

A popular noise abatement strategy is the use of noise barriers. Noise barriers are an effective means of significantly reducing high noise levels, such as those near to large roads. They limit noise by preventing direct propagation between the source and the receiver.

The level of noise reduction provided by a noise barrier depends on: its *height* (an effective barrier must be tall enough to block the line of sight between the noise source and the receiver); *length* (it should be long enough to cover at least 160 degrees from the receiver); *design* (barriers should be solid and continuous and contain no holes or gaps); *position* relative to the source and receiver (ideally the barrier should be as close as possible to one or the other); and the *soil* on which the barrier is placed (Murphy and King, 2014; Renterghem and Botteldooren, 2012).

Workers during the installation of noise barriers on the railway. © istock / fotoember

BOX 6.

## Types of noise barrier

**Absorbing barriers** have absorbing materials on the side facing the noise. Although slightly more effective and commonly used to mitigate traffic noise, they are also relatively expensive.

**Angled barriers** reflect sound away from the receiver and can be a useful alternative to absorbing barriers.

**Capped barriers** have a specially designed top section to attenuate sound waves.

**Covering barriers** offer significant noise reduction. Examples include a grid set over a road or a complete cover over a road, such as a tunnel.

These types of barriers are all more effective than simple reflecting barriers (Kloth *et al.*, 2008).

Noise barriers can be made from a range of materials, typical building materials such as concrete, steel and aluminium but also natural materials including earth mounds and wood. While **vegetation** may have useful psychological effects, it is one of the least effective noise barrier types. Although visually 'hiding' a noise source with greenery has been linked to a subjective reduction in annoyance, a vegetation barrier of 10 metres depth results in only 1 dB noise reduction (Dzhambov and Dimitrova, 2014; Gidlöf-Gunnarsson and Öhrström, 2007; Murphy and King, 2014; Yang *et al.*, 2011).

**Buildings** can also be used as noise barriers. Noise-insensitive buildings can be placed between a road and residential buildings for example. This can be a cost and space-effective solution.

More advanced types of barrier include longitudinal profiled barriers (which have a different height along their length) and double barriers which consist of two barriers installed in parallel along one side of a road, although the performance of these barrier types requires more testing (Kloth *et al.*, 2008).

Noise barriers can reduce noise levels by up to 10 dB(A). However, performance varies and they are generally an expensive way to reduce noise levels. Noise barriers may also interfere with local air circulation and obstruct views (Kloth *et al.*, 2008), thus, sometimes leading to resistance from local people.

## Building design

During the planning stages, architects can make significant improvements to the noise levels within a building. One way of achieving this is to locate less noise-sensitive rooms, such as the kitchen or a storage room, towards a potential noise source such as a road, and more noise-sensitive rooms such as bedrooms and the living room away from the noise source. It can also be beneficial to consider noise interactions when designing the geometry of entire buildings. Certain orientations can reduce reflections of noise onto a building (Murphy and King, 2014).

Extra design features can also aid noise abatement. For example, orientating windows away from the noise source and protecting them with wing walls can significantly cut internal noise exposure. Balconies also have a significant noise reduction potential (5–14 dB), depending on their parameters (Murphy and King, 2014; Kloth *et al.*, 2008).

## Land-use planning

Land-use planning is an important long-term approach for noise management. Land-use planning or ‘zoning’ involves considering the location of future developments in the context of other areas, such as residential areas and green space. Proper planning can help to identify noise-sensitive and quiet areas that should be protected against noise in the future. This could mean designing a large enough distance between areas to prevent noise transmission, or implementing noise abatement as part of new development programmes (for example using noise insensitive buildings as ‘barriers’) (Murphy and King, 2014).

Determining the sound levels in an area by noise mapping is important for making zoning decisions. The EU Noise Directive requires the creation of strategic noise maps and action plans, in addition to local Member State zoning and land planning activities (European Commission, 2015). In Berlin, the 'Flächennutzungsplan' (land use plan) is the preparatory urban plan for the city, stipulating the type and extent of land use for the whole area resulting from urban development. Combined with existing urban development objectives, Berlin applies various strategies for low-noise development, including appropriate allocation of land-use, controlling inner city development to avoid an increase in passenger car traffic and defining acoustic exposure limits in residential areas (Senatsverwaltung für Gesundheit, 2008).

Other parts of the world also use zoning plans to minimise the impact of environmental noise. In Hong Kong for example, Outline Zoning Plans (OZPs) ensure the compatibility of nearby land-uses, providing separate zones for industrial developments and residential buildings for example, including planning buffer areas for non-noise sensitive use between the two zones (The Government of the Hong Kong Special Administrative Region, n.d.).

## Building sound insulation

Sound insulation of windows and walls is an expensive option and generally less preferable than reducing sound at the source. However, it can be very effective. Sound-insulated windows can achieve reductions in the order of 30 dB, which is around the same as solid doors. Special sound reducing windows can reduce emissions by up to 40 dB, although this depends on the characteristics of the building and the windows, and of course is only effective when the windows are closed. Overall, façade insulation has been shown to have a significant effect on noise levels and annoyance ratings, but can be costly and only benefits the building being treated (Murphy and King, 2014; Kloth *et al.*, 2008).

## *Sonic crystals*

Sonic crystals can prevent the transmission of sound waves at specific frequencies, which can be tailored by changing the size and geometry of the crystals. The original sonic crystal device was made up of 1 cm solid lead balls surrounded by silicone, arranged into a crystal lattice cube, and could absorb sounds that usually require much thicker materials. Researchers are currently working to create noise barriers from sonic crystals to abate road traffic noise. Although in the early stages of development, in the future sonic crystals could be used to build 'acoustic cloaks' which could theoretically make large objects, including entire buildings, sound proof (Krynkin *et al.*, 2013; Ding *et al.*, 2007; Liu *et al.*, 2000).

**Figure 6: Sonic crystal noise barrier created by the Wave Phenomena Group, Polytechnic University of Valencia, Spain.** Source: Reprinted from García-Chocano, V., Cabrera, S. & Sánchez-Dehesa, J. (2012) Broadband sound absorption by lattices of microperforated cylindrical shells. Applied Physics Letters. 101 (18), pp. 184101, with the permission of AIP Publishing.

BOX 7.

## A ‘quiet’ European city: the case of Annecy, France

The French city of Annecy provides a valuable example of how to achieve urban noise reduction. The city has recently experienced a significant increase in population size, associated with concerns regarding noise pollution. Noise abatement has been a political priority in Annecy from the earliest emergence of the problem, beginning by banning heavy goods vehicles from the city centre in the 1970s and reducing speed limits from 50 km/h to 30 km/h. The local authority has also invested in **lower-noise public service vehicles** and **moved glass recycling facilities underground** (The SMILE Consortium, 2003), although the major focus has been on traffic noise.

Analysis in the 1990s revealed that 75% of journeys relied on cars and that a significant proportion of city centre traffic was transit-based. As a result, several targets were set in Annecy, including to reduce transit traffic and promote cycling, walking and public transport use. To achieve this, **private vehicles were banned** from the city centre, **one-way streets** and **bus lanes** were developed and **pedestrianised areas** were expanded. Benefits were soon observed, including reduced travel time for buses, reduced car traffic, improved road safety and increased pedestrian access to the city centre (The SMILE Consortium, 2003).

The city was nominated for a **‘Golden Decibel’** award by the French National Council for Noise Reduction in 1992 and has since had a progressive noise policy (Murphy and King, 2014). More recently, the **LIFE+Urbannecy** project was launched to reduce the environmental impact of deliveries and improve quality of life in Annecy, partly by reducing traffic noise in the city centre (Pure Annecy, 2016).

While Annecy has adopted a wide range of noise abatement measures to successfully reduce noise pollution in the city centre, some of the noise has essentially been shifted to other areas (Murphy and King, 2014; The SMILE Consortium, 2003). This emphasises the importance of a holistic approach to noise abatement, involving a comprehensive suite of mitigation approaches and careful planning to consider the knock-on effects of measures.

# 3. Cost-effectiveness issues

As well as their ability to reduce noise pollution, the cost-efficiency of abatement approaches is a critical consideration for decision makers, who are often operating within tight budgetary limits. Important considerations include the cost of implementation, as well as the cost of maintenance/renewal, the availability of resources and relevant funding schemes. An important decision-support tool is cost-benefit analysis, which can help to prioritise different noise abatement options and ensure that limited funds are spent to greatest effect (Kloth *et al.*, 2008). The EPA Network Interest Group on Traffic Noise Abatement (Blokland and Peeters, 2016) recently made a suite of recommendations for traffic noise abatement, including developing a standard procedure for cost-benefit assessment and making decisions on investment open to the public.

Cost varies widely between local noise abatement measures. Noise barriers have an estimated cost of €300 per $m^2$ (Kloth *et al.*, 2008), with a varying cost to benefit ratio depending on the specifics of the site, such as the population density and the type of barrier. Tunnels are both the most expensive and most effective form of noise barrier. Overall, noise barriers are considered the least cost-effective approach, despite their significant noise abatement ability (Guarinoni *et al.*, 2012).

For façade insulation, costs are generally high compared to other measures, but comparatively little when implemented in new buildings with high thermal insulation standards (Kloth *et al.*, 2008). It has been estimated that the average cost, per apartment, for insulation is around €28 000 (Klæboe *et al.*, 2011). Façade insulation may be more cost-effective than low-noise road surfaces (Klæboe *et al.*, 2011), which have an estimated cost of €3.5 per m*2* (Nijland *et al.*, 2003). Their respective benefit however depends on how densely populated an area is (with insulation being more effective in less densely populated areas). Low-noise tyres are considered particularly cost-effective, due to their significant noise abatement but minimal side effects. Quiet tyres can reduce noise by around 4 dB at no additional cost (Nijland *et al.*, 2003).

Traffic management measures are some of the most affordable measures. Static signs to impose speed limits or ban heavy goods vehicles for example are relatively cheap, with an estimated cost of €300 per sign (Kloth et al., 2008).

For railway noise, using quieter brake blocks on existing freight trains could reduce noise emissions by 10 dB at an estimated installation cost of €2,000 per wagon and additional life-cycle costs of €1,000 per wagon and year. In particular, LL-blocks are recommended, as they perform equally effectively as K-blocks but are considered more cost-efficient. On the track side, polishing existing train tracks would cost €2 700/km/year, while implementing quiet tracks on planned new lines has an estimated cost of €11 000/km (Nijland *et al.*, 2003). Broadly speaking, however, the most cost-effective approach is often to use a combination of strategies.

Boules Quiès © istock / MikePanic

Overall, comparisons of the (discounted) costs and benefits of road and rail traffic noise abatement measures suggest that the benefits are higher than the costs in all cases (Nijland *et al.*, 2003).

# 4. Summary and conclusions

Noise is one of the most pervasive and complex environmental pollutants, driven by a combination of factors including urbanisation, economic growth, expanding transport networks and increasing industrial output (European Environment Agency, 2014). As recognition of its public health implications grew at the end of the 20th Century, dedicated European legislation was developed and the European Environmental Noise Directive was adopted in 2002.

Alongside legislation, noise abatement measures will be an important component of a comprehensive noise strategy for the EU. As this brief shows, there are a wide variety of noise abatement techniques available. Important considerations when selecting a technique include the type of noise, the location of the noise source and the receiver population, and cost.

The most effective and cost-efficient approaches to mitigate noise are those at source, such as legislation demanding quieter engines. However, these methods are often difficult to put into practice, making local strategies equally important as part of a wider strategy (den Boer and Schroten, 2007; the HOSANNA project, 2012). There are a range of approaches available to reduce exposure to noise locally, from well-established methods such as insulation and speed limits to more novel strategies such as low-noise road surfaces.

In conclusion, a mix of mitigation at source and noise abatement at the receiver end will be important to target noise hotspots in Europe (Guarinoni *et al.*, 2012). Although there remains room for improvement in terms of technical capability and cost-efficiency, important progress has been made in developing noise abatement technologies in recent years, which — together with robust legislation — will pave the way to a quieter Europe.

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