Interest Group on Traffic Noise Abatement

European Network of the Heads of Environment Protection Agencies (EPA Network)

Final report of the Interest Group of Traffic Noise Abatement

Colophon

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Summary

The Interest Group of Traffic Noise Abatement (IGNA) of the EPA-network has studied the progress in the control of noise for road, rail and air traffic. The findings are laid down in a series of three progress reports. This study has updated the findings of the earlier studies and integrated them into a general scheme. This scheme, also in use by the European environmental Agency (EEA), defines the environmental impact of traffic noise as a series of relations between the drivers, the pressure and the state, leading to an impact. The responses to the impact of high noise levels are listed. This DPSIR framework is depicted in the figure below.

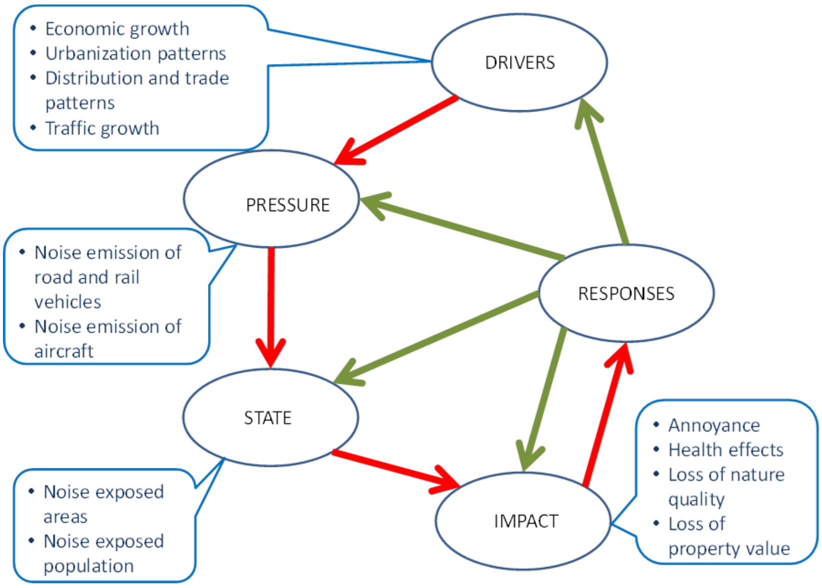

Figure: *DPSIR framework used in this report to define the cause, nature and control measures for traffic noise*

In this report the elements in the DPSIR framework are described. A summary of the findings is given below.

Drivers:

For road and rail traffic, the main driver is not so much the growth of transport, but the sprawling of urbanization along major road and railway lines. Air traffic does show strong volume growth combined with increasing urbanization around major airports.

Pressure:

The noise emission that is related to transport is for road and rail vehicles mainly caused by the wheel/rail and tyre/road interaction with an almost equal influencing part for the vehicle and for the infrastructure. For aircraft the engine is identified as main source. When noise emission is normalized to the goods and person capacity of the transport mode, modern rail transport is found to be the best option, assuming non-cast iron braking systems for freight wagons.

State:

The 2012 noise mapping showed that about 140 million inhabitants of the EU-28 are exposed to traffic noise levels exceeding 55 dB Lden, with road traffic responsible for 89% of the exposure, rail 8 and air traffic for 3%. Direct comparison with the figures of the 2007 mapping is hindered since the coverage is extended from agglomerations over 250.000 in 2007 to agglomerations over 100.000 in 2012.

Impact:

The effect of traffic noise depends strongly on the type of source. A certain level of air traffic noise gives a higher annoyance rating than the same level of road traffic noise. Rail causes the least annoyance. A similar trend is observed for sleep disturbance. In addition direct negative effects on health are observed and for children, higher noise levels are related to negative effects on their learning capabilities. Overall in Europe, each year, environmental noise causes the loss of more than 1,5 million disability adjusted life years (DALY's). In economic terms 45 billion euros of external costs are attributed to traffic noise.

Responses

Responses to reduce or compensate for the impact are organized at all levels. At the drivers level, a modal shift from air and road to rail traffic (assuming modern non-cast iron braking systems) is most effective. A reduction of total traffic as a whole is less effective: a 25% reduction in traffic volume has an effect of only 1 dB .

In the chain Drivers→Pressure, reduction of vehicle emission is found to be an effective and efficient approach to control the impact. For cars, emphasis is to be put on both the vehicle, through type approval tightening, and the infrastructure through road surface optimization. For rail vehicles the exchange of cast iron brake blocks with composite block is very effective (-10dB!) This development is stimulated by noise differentiation in the track access charge, later to be followed by ban on cast iron blocks for all international used wagons through an updated TSI noise. For air traffic tightening of certification levels and curfews/charges for less silent aircraft will improve the noise situation around airports.

Responses to the Pressure→State relation contain improvements of existing situations of high noise exposure. For road and rail traffic noise at the houses can be suppressed with barriers, or even tunneling. For aircraft and sometimes also rail, rerouting over/through less densely populated areas is applied. Such schemes, however, may jeopardize quiet areas that may soften the impact of high noise levels on the population.

Many of the mitigation measures that are applied to control noise exposure also show positive effects on other environmental themes such as air quality and CO2 emission. A clear indication of the positive combined effects is the aircraft fleet renewal that is driven by fuel efficiency, but also has very positive effects on noise. The exchange of cast iron blocks with composite brake blocks at the other hand, has no effect on the other themes. Such change can only be achieved by regulations and financial stimulation.

International aspects

Several parts of the DPSIR framework are more effectively approached at a European level. This is not only the type approval systems and regulations concerning international traffic, but also the R&D for noise control measures and the studies on health effects and annoyance due to noise. The European Noise Directive (2002/49) centralizes these developments by collecting European wide noise exposure data in a harmonized way, relating this to health and annoyance impact, raising awareness to this issue and indicating strategies to improve the situation.

Recommendations

Pressure on type approval regulations has to be continued, not only to lower limit values, but also to improve representativity of test methods and to prevent too many allowances. However, most effects are found in control of the existing car and rail fleet, by effective tyre regulations, extension of the TSI-noise to existing stock and the improvement of road and rail infrastructure.

The lower limits defined in the END to report noise exposure cause significant underestimation of sleep disturbance and annoyance, especially in the case of aircraft noise. Extending the END reporting to lower noise levels, down to 45 dB L_{den} and 40 dB L_{night}. is recommended.

It is regarded a good thing that in several regulations the obligation to apply mitigation measures shall be balanced with the costs. This will lead to a better distribution of available budgets, in order to maximize the health improvement within a certain budget. A standard procedure to perform such cost and benefits balancing, however, is needed. Transparent cost/benefit decisions will enhance the public acceptance.

Contents

1 Introduction

1.1 IGNA

In the September 2010 EPA-Network meeting in Krakow our Interest Group on Traffic Noise Abatement (IGNA) was created. IGNA is a great opportunity to exchange information on current and future developments and to establish proposals and reports containing concrete and helpful recommendations to successfully protect the population from traffic noise.

The main issues of the working program 2011 - 2016 were set to be:

- Harmonization of noise-monitoring: harmonization and standardization of methods for monitoring and evaluation of noise exposure and remedial measures;
- Noise abatement measures at source: Information and exchange of successful measures at the source, as well as common action plans with stringent regulatory and incentive measures for vehicles and machines;
- Critical levels: harmonized critical levels (limit values) that trigger specific remedial measures;
- Economic instruments: cost-benefit aspects and application of financial instruments in order to compensate external costs and to set incentives for measures at sources.

In a series of 8 meetings these subjects have been discussed with the members and with representatives from European institutions on road, rail and air traffic as well as NGOs.

The findings are reported in reports describing the progress in the field of abatement of road traffic noise, railway noise and air traffic noise as well as in a report that deals with decision and cost/benefit methods in Europe. The group observed lacking developments on road and rail vehicle noise and has informed the responsible authorities on the impacts caused by it and the necessity to take further steps.

1.2 DPSIR scheme for transportation noise and health effects

DPSIR represents the Drivers-Pressure-State-Impact-Responses relation in which the fundamental causes, the environmental pollutants and their effects and the reaction of society and legislation to control the adverse effects are fitted in a general framework. Application of this framework on different environmental issues leads to a better understanding of the underlying relations and components common to different environmental issues.

Drivers	growth of transportation due to economic development, work and settlement patterns, production and trade patterns, leisure patterns
Pressures	emission of sound from the vehicles used for transportation (other to transport related sources, such as workshops, power stations etc. are neglected)
State	transportation noise assessment, exposed population, exposed land area, measures Lden, Lmax, Lnight, quiet areas
Impact	effects of transport noise on the population[1] in terms of health, economic losses and urban settlement
Responses	responses from mainly supra national, national or local administrations, e.g.: ▪ tightening of certification noise limits ▪ taxation or curfew of noisy crafts, both road, rail and air (NDTAC, Night ban, CI-block ban,…) ▪ regulation of transport (vehicle speed, aircraft and rail routing) ▪ infrastructure (low noise pavement, noise barriers, rail dampers, rail grinding,..) ▪ planning (separation of noise producing and noise sensitive areas)

[1] Negative effects on fauna are not taken into account here

Drivers	growth of transportation due to economic development, work and settlement patterns, production and trade patterns, leisure patterns
	▪ public awareness

An overview of the system is given in figure 1 below, together with the identification of its components.

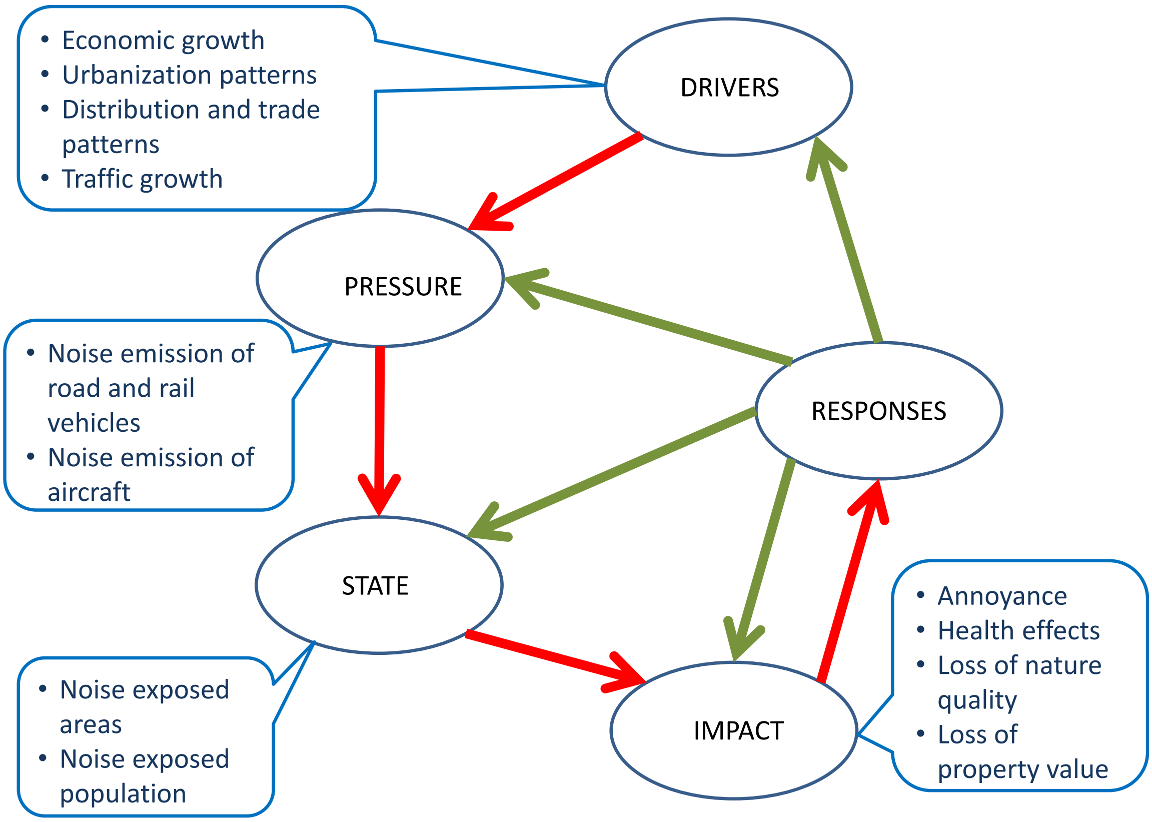

figure 1 *DPSIR model together with the identification of its components (ref.[3])*

2 Drivers

2.1 Transportation growth

The main drivers are the economic development of Europe with increased trade between member states and growing traveling needs for its inhabitants.

The EU statistical pocketbook for transport [26] illustrates the clear relation between the growth of the EU GDP and the development of passenger kilometers and tonne kilometers (see figure 2) . The trend for goods transport was discontinued due to the recession of 2008 and stabilized at a 10% lower level, reflecting probably the shift from hardware to software and services.

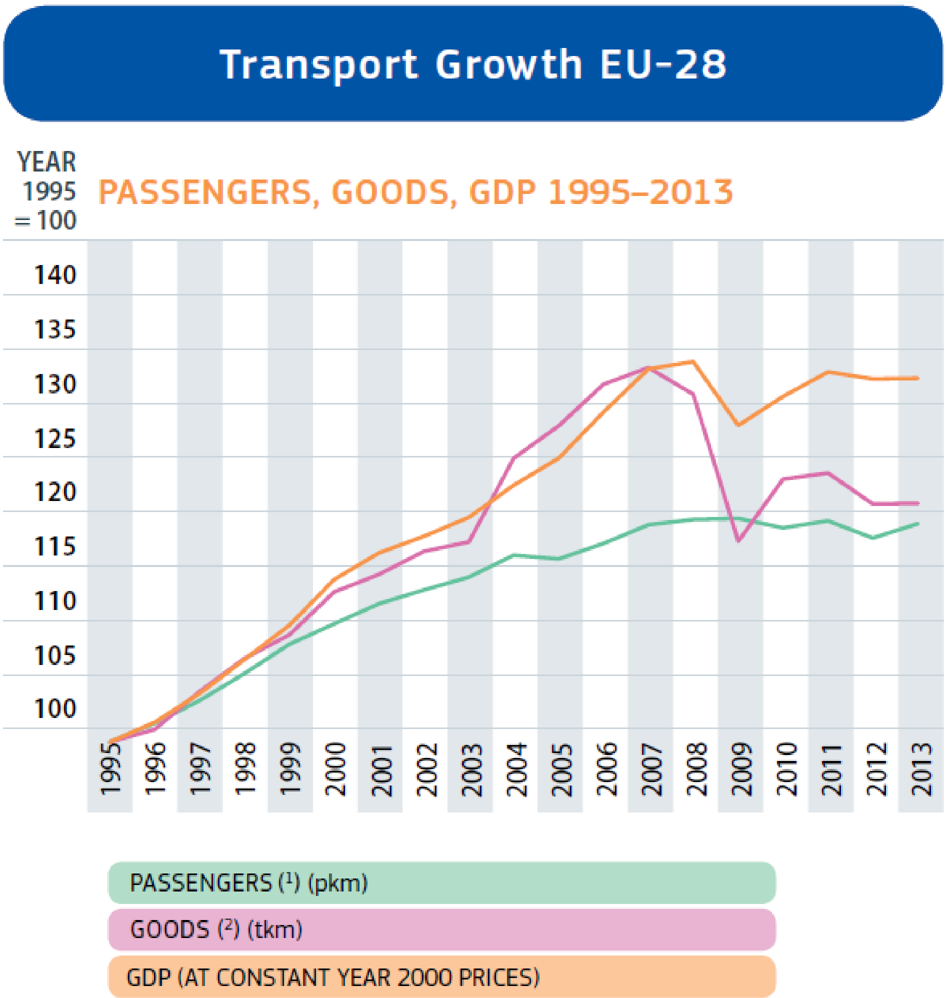

figure 2 *Growth of GDP and transportation of passengers and goods in EU28 [26].*

In figure 3 the goods and passenger transport is distributed over the transport modes. It shows that goods transport by road was the largest fraction already in 1995 and the road transport did grow fastest until 2008. From 2008, passenger transport stabilized. Goods transport dropped with about 10% and remained on that level (see figure 3). This level still represents a growth of 30% relative to 1995. Rail transport for goods remained at the same level in the 1995-2013 period, but passenger transport by rail increased with about 20%.

Figure 4 indicates the development of the infrastructure. The growth of road transport was facilitated by the strong extension of the motorway network in Europe. At the same time the rail network slightly decreased. One could argue that notwithstanding the shrinking rail network, rail capacity might still increase due to better and more standardized guiding of the rail vehicles, such as the European Rail traffic management system that allows trains to drive closer to each other as the conventional block systems and facilitates international traffic. High speed rail lines for passenger transport extended significant from 600 km in 1985 to 7300 km in 2014 [26].

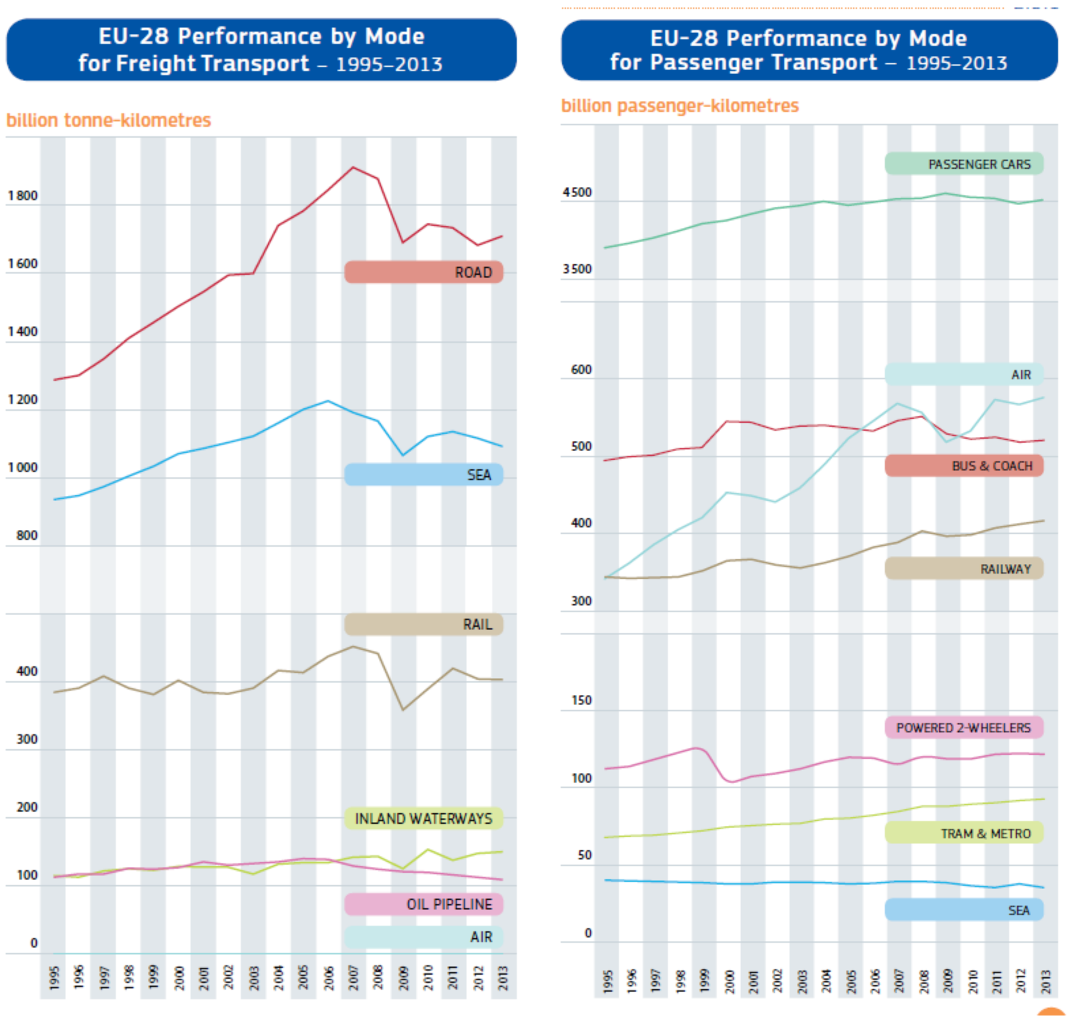

figure 3 *Modal split between transport modes for goods (in billion tonne km) and passengers (in billion passenger kilometers) [26]*

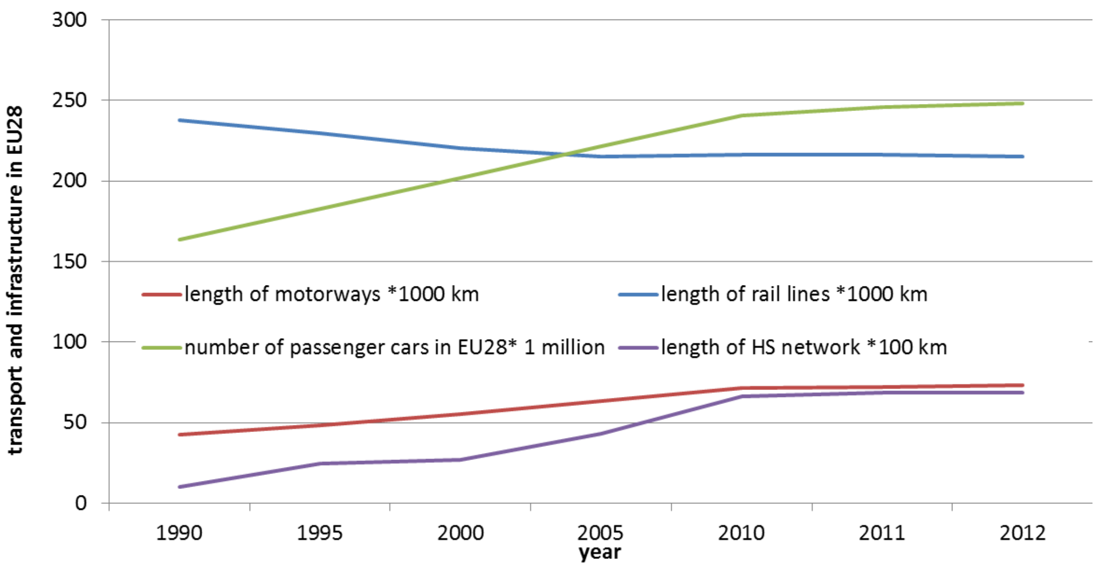

figure 4 *Increase in length of motorways and railway lines and number of passenger cars in EU 28 between 1995 and 2012 [26].*

2.2 Infrastructure and urbanization trends

The higher living standards and expending population in almost all EU-28 nations did cause a growth of area used for housing, which is often referred to as Urban Sprawl. Such developments are partly driven by increased transportation means, but, reversely, they also drive the growth of transportation. The general trend is pictured in figure 5. The specific nature of the expanding urban areas are illustrated with examples in figure 6 and figure 7. It shows a trend that expansion of built areas and infrastructure growth tend to line up.

Similar developments can be seen around airports. Urbanization slowly extends into the direction of airports that originally were built in rural only sparsely urbanized areas.

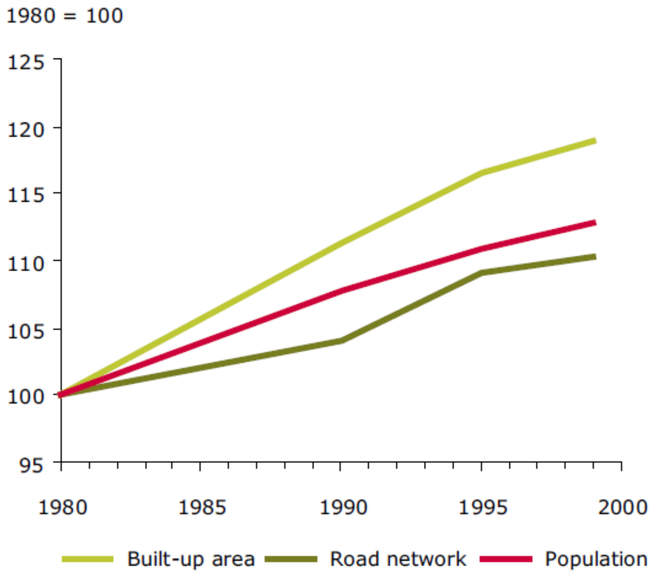

figure 5 *Built-up area, road network and population increases (B,CZ, DK, F, D, LT,NL, SLK, ES) [27]*

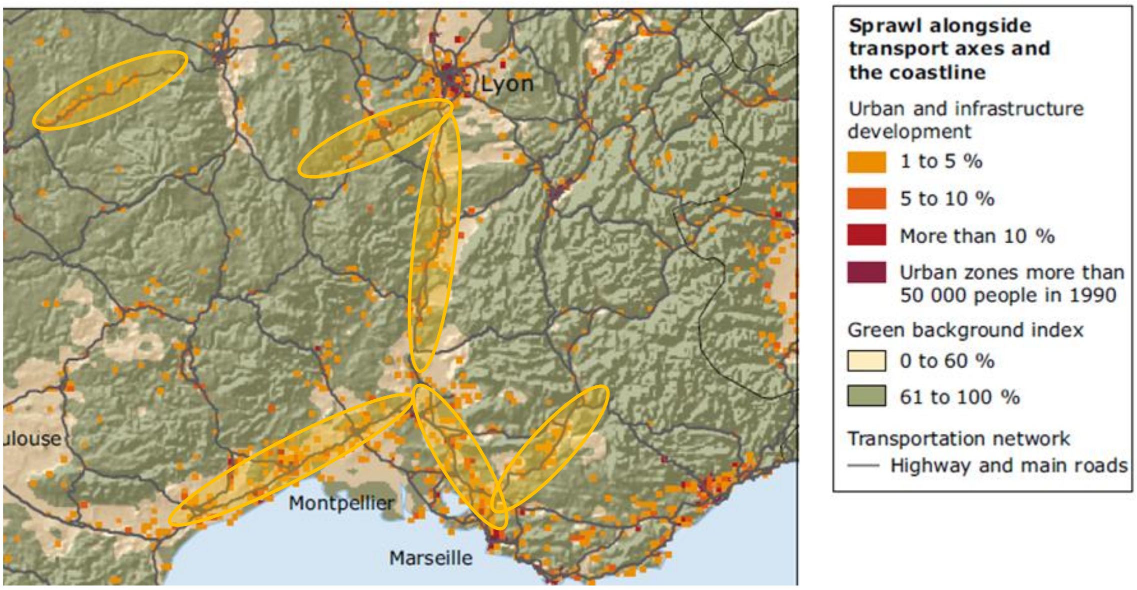

figure 6 *Urban sprawl in the Rhône corridor [27]. The urbanization along the same corridors as the main infrastructure is indicated.*

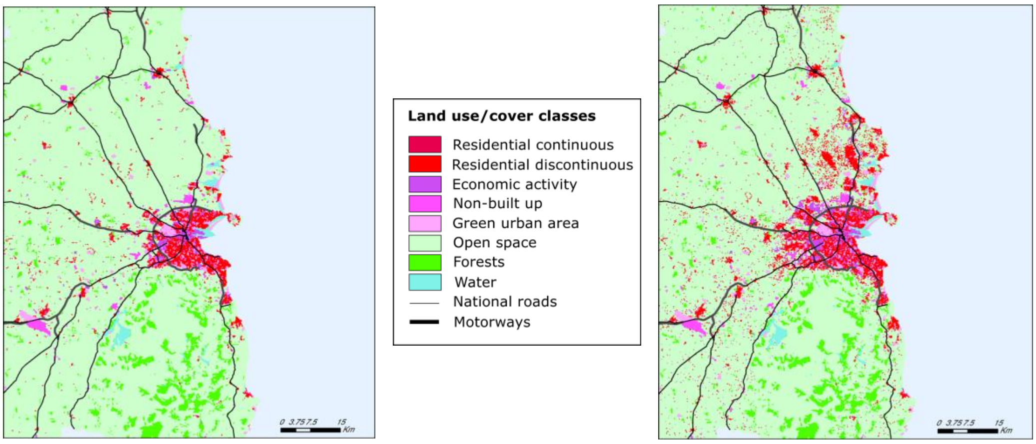

figure 7 *Urban sprawl case Dublin. Left situation 1990, right: scenario 2025 [27]. Expansion along infrastructure, although to a lesser extend then in figure 6. [27]*

3 Pressure

3.1 Noise emission of road and rail vehicles and aircraft

The intensive usage of road and rail vehicles and aircraft in the vicinity of urban areas can be noticed by the sound they emit. For cars and trucks, one might argue that in mixed areas with pedestrians and cyclists, the fact that these vehicles emit noise may increase safety, although this is questioned by experts. For regional roads, as well as for all rail and air traffic, the sound emission is a negative aspect and society presses on manufacturers and users to lower the noise emission.

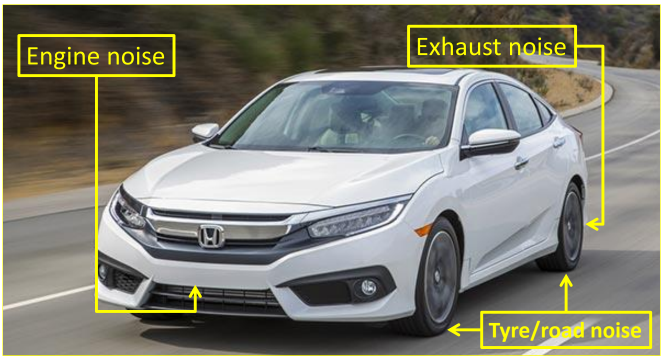

figure 9 *Noise sources of a passing road vehicle. The dominating noise source is the tyre/road interaction. Engine and exhaust noise are relevant in the low frequency range and at specific frequencies related to the firing*

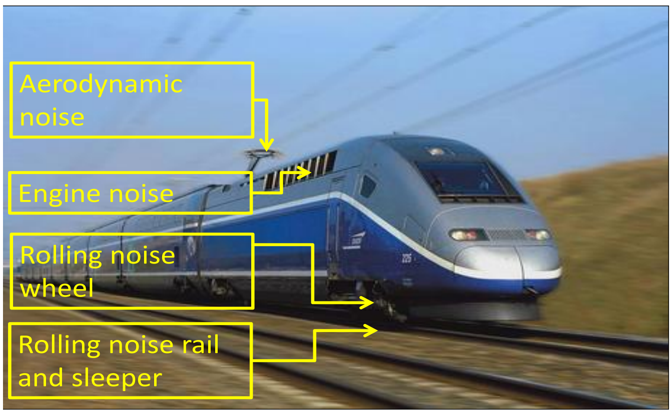

figure 10 *Noise sources of a passing rail vehicle. The dominating source is rolling noise with about even contribution from wheel and rail. Sleepers are relevant in the low frequency range.*

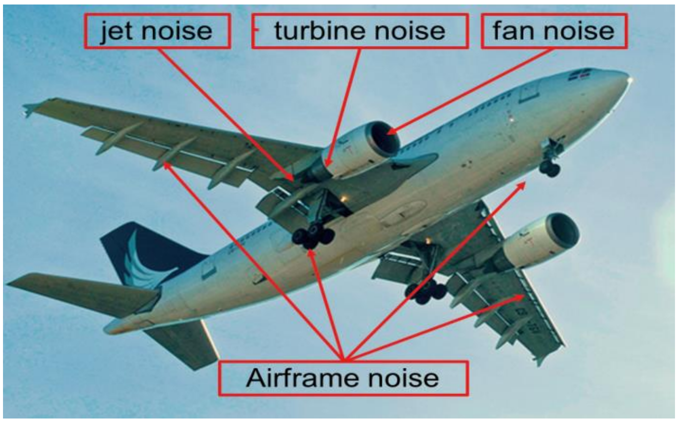

figure 11 *Noise sources of aircraft fly-over. Jet and turbine noise dominates at take-off. Fan noise dominates during approach with a relevant contribution from the air frame*

For cars the sound is produced by the vehicle and its tyres, but it is influenced by the infrastructure. Although the sound generating components are all part of the vehicle, it is observed that the quality of the infrastructure, e.g. road surface, bridge joints, etc., is an important parameter for the emission on regional roads and highways.

For rail traffic, sound is emitted by both the vehicles and the rails. Just as with road vehicle noise, the quality of the rail influences the sound emission of the wheels, and vice versa.

For aircraft the sound emission is totally caused and due to the craft itself. For most of the operations the source is the engine, during approach and landing the contribution by airframe noise is becoming relevant.

3.2 Sound emission of single crafts normalized to capacity and speed

Both road and rail vehicles and aircraft will exercise pressure in the nearby environment due to the amount of sound they emit during their operations. A distinction is made between road and rail vehicles on one side and aircraft on the other side: aircraft noise is usually only relevant in the vicinity of the airport, while road and rail vehicles apply pressure during their total journey. A second relevant distinction is that aircraft follow less precisely defined paths, steered by origin/destination, local meteorological conditions, safety and environmental awareness. Road or rail vehicles are strictly bound to roads or railways, with roads generally having a finer mesh than rail.

The source power of these different types of vehicles can be estimated as follows:

- a 200-seater jet aircraft generates about 90 dB at 180 m distance (4700 rpm ≈ 90% of full power, according to the B737-400 data sheet), which corresponds roughly to a source power of 145 dB at 500 km/h;
- a disc braked rail vehicle at 100 km/h generates around 80 dB at 7,5 m distance with a vehicle length of 25 m this corresponds to a source power of about 110 dB.
- a passenger car, driving 100 km/h, produces approximately 80 dB at 7,5 m distance, corresponding to a source power of 105 dB; a heavy duty vehicle driving 90 km/h produces 88 dB, corresponding to source power of about 115 dB.

The sound immission is quantified in terms of time equivalent sound levels, such as L_{den}, L_{night} and L_{eq}. The contribution of a faster moving vehicle to the equivalent level is lower than that of a slower one, since it takes less time to move past the receiver. In this analyses, we will correct the sound power values for the passing speed v with $-10 \cdot \lg(v)$.

Furthermore, the capacity of an aircraft is larger than that of a passenger car or train wagon, so we correct also with $10 \cdot \lg(n)$, with n being either:

- the number of passengers: n = 2 for cars, 25 for train wagons and 150 for airplanes, or
- the load capacity in tonnes: n = 20 for a HDV, 50 for a freight wagon and 30 for a mid-size cargo plane.

If we use these estimated values, we can compare the typical amount of noise produced per person or per tonne for the different transport modes. The result is given in table I.

table I *Transport mode sound power levels: the second column presents the sound power of a standard vehicle at a representative speed on through roads, rail lines or during approach/departure operations around an airport; the last column presents the time-equivalent sound power level, normalized to a single passenger (PAX) or tons of freight and normalized for the normal operation speed.*

Vehicle type	Sound power at representative speed	Correction for speed and capacity	Normalized sound power
Passenger car	105 dB	-23 dB	82 dB/PAX
Train wagon passenger	110 dB	-34 dB	76 dB/PAX
Aircraft	145 dB	-49 dB	96 dB/PAX
Heavy Duty Vehicle	115 dB	-33 dB	82 dB/ton
Freight wagon (C.I. blocks)	125 dB	-37 dB	88 dB/ton
Freight wagon (K/LL blocks)	117 dB	-37 dB	80 dB/ton
Cargo plane	145 dB	-42 dB	103 dB/ton

3.3 Usage of vehicles

In addition to the normalized source power the usage of the vehicle, the nearness to noise sensitive areas and the specific annoyance due to that source, are relevant to evaluate the relevance of the specific transportation mode to the overall noise burden of society by transport.

The graphs presented in figure 3 and in figure 5 indicate negative trends of continuous increasing passenger and freight transport and continuous growth of urban areas, with indications that separation of the noise sensitive living areas and the noise emitting transport axes is in jeopardy.

The data on modal split in the EU-28 in 2013 reflect the dominance of road transport. It is also road transport that for a large part is interwoven with urbanization. Although rail lines traditionally cross cities, they are generally separated by shoulders and some free areas.

Airports are in almost all cases separated from living areas, but the flight paths (even with several hundred meters height difference to the housings) will have its effect on the ground due to the higher sound power of the source.

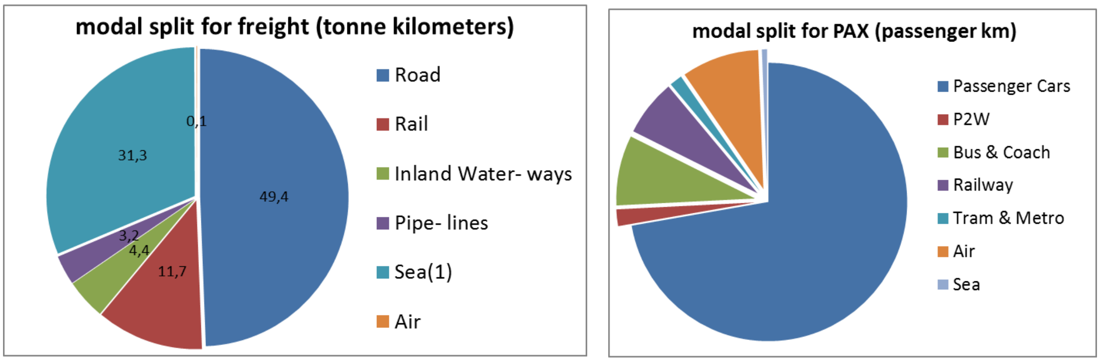

figure 12 *Modal split for freight and for passenger transport in 2013 in EU-28. Both transport types are dominated by road transport.*

4 State

In the EU-28 about 140 million inhabitants are exposed to traffic noise levels over 55 dB L_{den} levels and about 45 million to levels over 65 dB L_{den}. In the data provided for the END noise maps (2012), a separation is made between people living in the larger agglomerations (> 100.000 inhabitants) and people living outside the agglomerations but close to the major infrastructure (>4 M veh/yr , >30T trains/yr or >50T aircraft movements/yr).

Figure 13 shows that more than 2/3 of the annoyed people live in the larger agglomerations. The presented data do underestimate the expected impact. First because the exposure of the population in smaller agglomerations and smaller infrastructure is not included, secondly because the impact under the lower boundary of 55 dB Lden or 50 dB Lnight is not taken into account. The effect of the latter is treated in paragraph 5.5. The underestimation is specifically large for aircraft noise since severe impact is expected below the lower boundaries and the majority of airports in Europe are not taken into account. In the majority of countries only one airport is captured by the END specifications (ref. [8]).

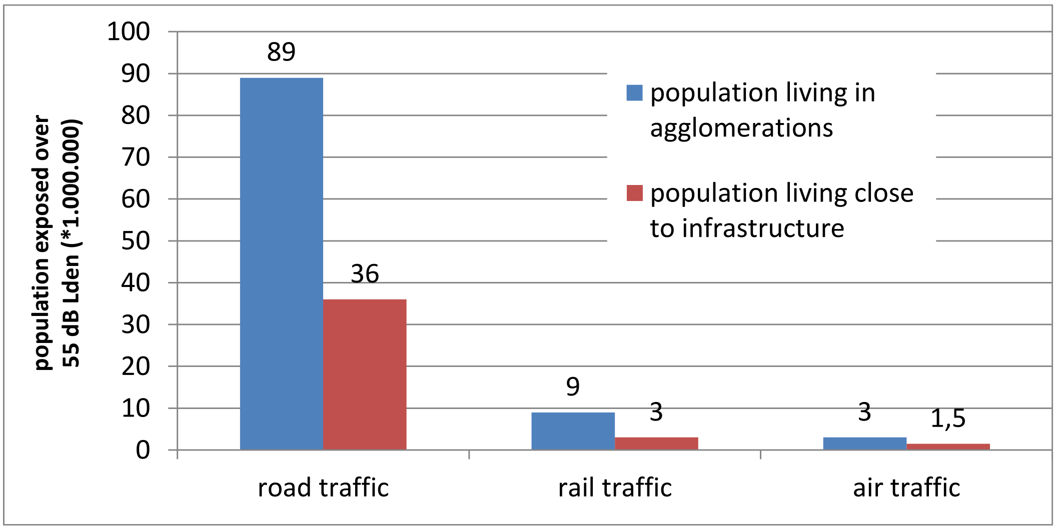

figure 13 *Estimated results of noise mapping in the framework of the European Noise Directive, reporting 2012. Displayed data present extrapolation to 100% of the areas to be mapped [15]. The exposure to industrial noise sources is not included (estimated about 0,3 M people)*

Road vehicles are the most relevant source of environmental noise in Europe, responsible for 89% of the population exposure. The contributions of rail and air traffic to the total number of people exposed are 8 and 3 %, respectively. These numbers, however, are based on the objective noise levels and do not necessarily reflect the importance of each traffic category, since it is known that the impact of the same noise level is higher for air traffic and lower for rail traffic. More details are given in chapter 5.

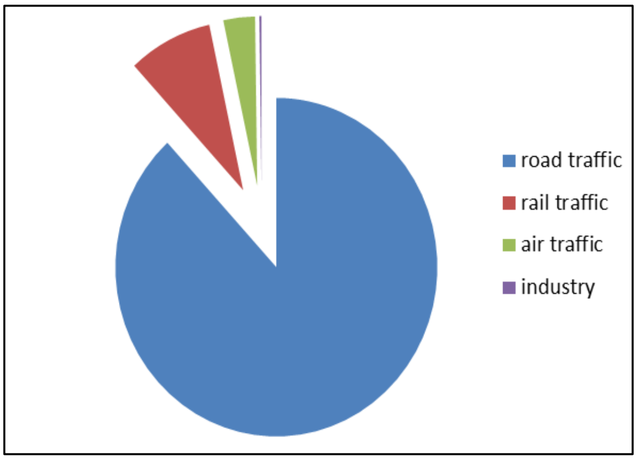

figure 14 *Distribution of exposed population >55 dB Lden over noise sources (data EEA extrapolated to 100% coverage) [8].*

5 Impact of noise on people

5.1 Effects of noise on health and wellbeing

Exposure to environmental noise due to transport has a negative impact on people. The World health Organization Regional office for Europe published an overview in which four main effects are distinguished:

- general annoyance due to the disturbing effect of noise on the wellbeing
- interruption of sleep during the night
- stress-related effects on the cardio vascular system of humans
- cognitive impairment on children.

Tinnitus is reported as fifth effect, but is related to exposure to very high sound levels, not found in transportation noise.

The WHO defines 'health' as a total state of mental and physical well-being, so all these effects are considered as a negative health impact. In this chapter, we separate annoyance and sleep disturbance, which are conscious effects that people are actually aware of and complain about, from the other effects, which the people affected generally will not relate to the environmental noise.

At this moment, the WHO is undertaking an extensive review of more new as well as existing studies on the health impacts of environmental noise (including leisure noise). This review is expected to result in an update to their noise guidelines in 2017 (ref. [36]). Some preliminary presentations by WHO in 2016 indicated that in addition to the already known effects, relations, both statistical and biological, with environmental noise have been found for obesity and diabetes, as well as some forms of stress-related breast cancer in women.

5.2 Annoyance and sleep disturbance

The relation between exposure levels and impact, in terms of annoyance and sleep disturbance is given in figure 15. The graphs show that apart from the level, also the source type defines the impact. Railways cause lower and air transport higher impacts then road transport noise at the same level.

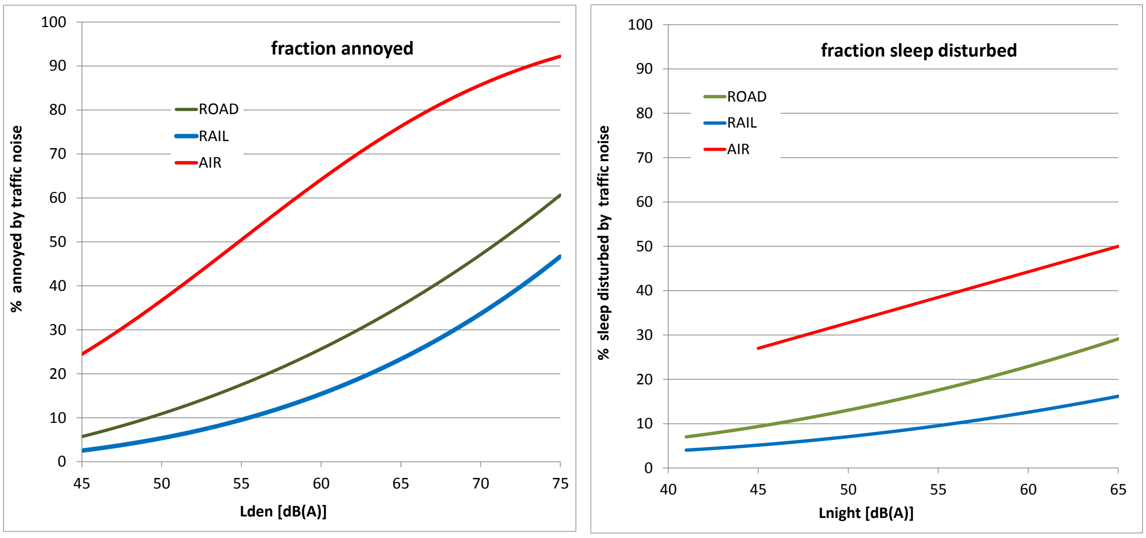

figure 15 *Fraction of population that is annoyed and sleep disturbed as a function of L_{den} or L_{night}. For road and rail, data originate from the EU position papers [1][2] . The data for air traffic are updated with post 1996 findings. The background to this update is explained in [4].*

In 2015 an extensive study in the Main Rhine region in Germany has been finalized, the NORAH study [17]. This study covers the effects on annoyance, sleep disturbance, health effects and cognitive impairment of children due to traffic noise. The results point into the same direction as the studies that served as basis for the standard dose-effect curves presented in figure 15. The NORAH study shows that traffic-noise related annoyance, at least for aircraft noise, is increasing with time. For the Frankfurt airport, the recent NORAH studies in 2011, 2012 and 2013 find that for the same noise level, 10 to 20% more people are highly or extremely annoyed than measured in 2005. Interesting is that the lower impact of rail noise compared to road noise, was not observed in this study. Road and rail are found to be about equal annoying. The area covered by the survey does include two noise hot-spots; the Frankfurt airport and the Rhine valley rail connection, that might explain the higher impact. Stuttgart and Berlin findings are slightly lower, but still above the curves presented in figure 15.

5.3 Cardiovascular diseases

The physiological arousal caused by external sounds has also a negative impact on the physical health of human beings. The WHO reports that exposure to noise cause increased risks of hypertension and ischaemic heart diseases that results in loss of healthy life years.

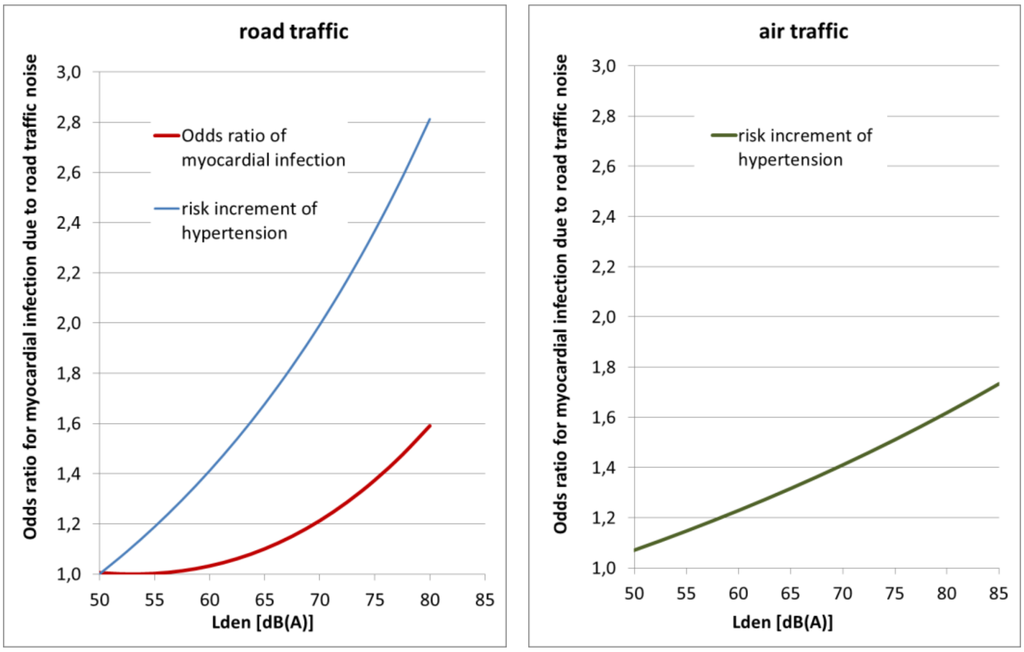

figure 16 *Effect of road traffic noise on the relative risk for myocardial infections and of road and air traffic on the relative risk for hypertension [6]*

5.4 Cognitive impairment in children

For children, cognitive impairments are reported due to aircraft noise. Several studies have shown the negative effects of noise on the reading and memory abilities of children. A very clear demonstration of this effect is observed in Munich when air traffic was relocated from the old airport near Riem, to the new airport near Freising in the north-east of Munich. Until 1992 the old airport was in operation and the effect of resulting high noise exposure was studied on 362 children in the age of 9-10 years. Indications of cognitive impairment were found caused by air traffic noise. When the study was repeated 2 years after closure of the airport the negative cognitive effects were gone while in the vicinity of the new airport similar cognitive deficits started to develop (ref [6], chapter 3).

Similar but less clear effects were found in other studies where road and rail traffic were dominant sources. This suggests that the characteristics of air traffic noise with its high peak level has a more detrimental effect.

The NORAH study [17] also covered cognitive impairment. The findings are presented in figure 17. The study extended to other issues of wellbeing, health and disturbances in school. For all three issues clear relations were found with the noise level of air traffic. This type was also mentioned as the most disturbing source of noise in class rooms.

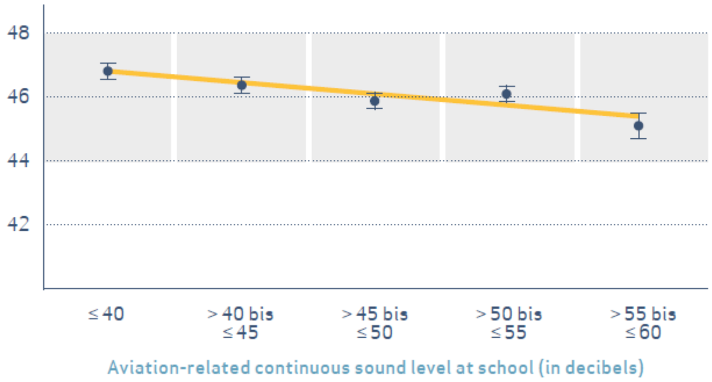

figure 17 *Reading performance in adjusted T-values. A T-value corresponds to the improvement in reading in one month [17].*

5.5 Overall impact on EU population

An attempt to map the full impact of traffic noise on the EU27 population was performed by the RIVM in 2015 [15].The study extended the noise exposure range beyond the lower limits set in the END (to Lden levels below 55 dB and Lnight levels below 50 dB) where, especially in the case of aircraft noise, still significant annoyance and sleep disturbance occurs as is illustrated in figure 15.

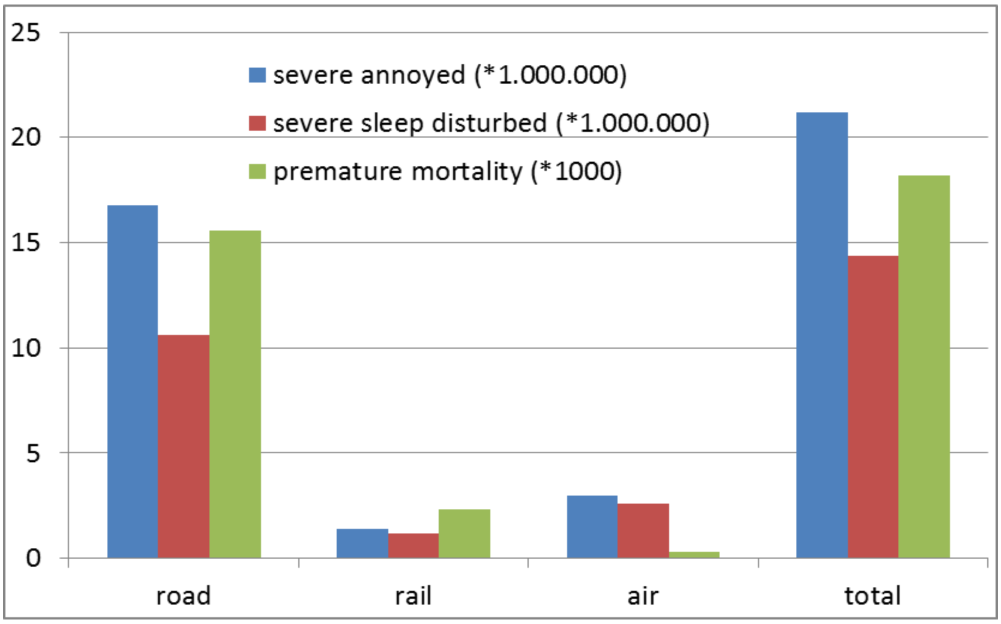

figure 18 *Impact of traffic noise on the European population. Estimates of number of people affected in the EU27 based on extrapolation to 100% coverage of the areas intended by the END and on extending the estimated impacts below the reporting threshold of Lden 55 en Lnight 50 dB [15]*

5.6 Dalys

The burden of diseases in a population is defined with the quantity DALY, which stands for Disability-Adjusted Life-Years. This quantity combines the amount of lost life years due to early mortality and the number of years burdened with a disease:

$$DALY = YLL + YLD$$

The number of life years lost (*YLL*) is calculated by

$$YLL = \sum \left(N_i^m \cdot L_i^m + N_i^f \cdot L_i^f \right)$$

where *N* is the number of male (*m*) of female (*f*) deaths in age group *i* multiplied by the life expectancy *L* for females or males in the age group *i*.

The number of disabled life years is estimated with the formula

$$YLD = I \cdot DW \cdot D$$

Where *I* is the number of incident cases, *DW* the disability weight and *D* the average duration. Annoyance is included in the definition of diseases, according to the WHO broader definition of health and thus DALY's are attributed to it.

The total number of DALY's for Europe is estimated in the WHO report [6] based on:

- the available data on the exposure of the EU population to different sources of traffic noise
- dose-effect relations for the different types of noise related health impacts
- the value of DW for each noise related health impact.

From the available statistics the figures shown in figure 19 were estimated.

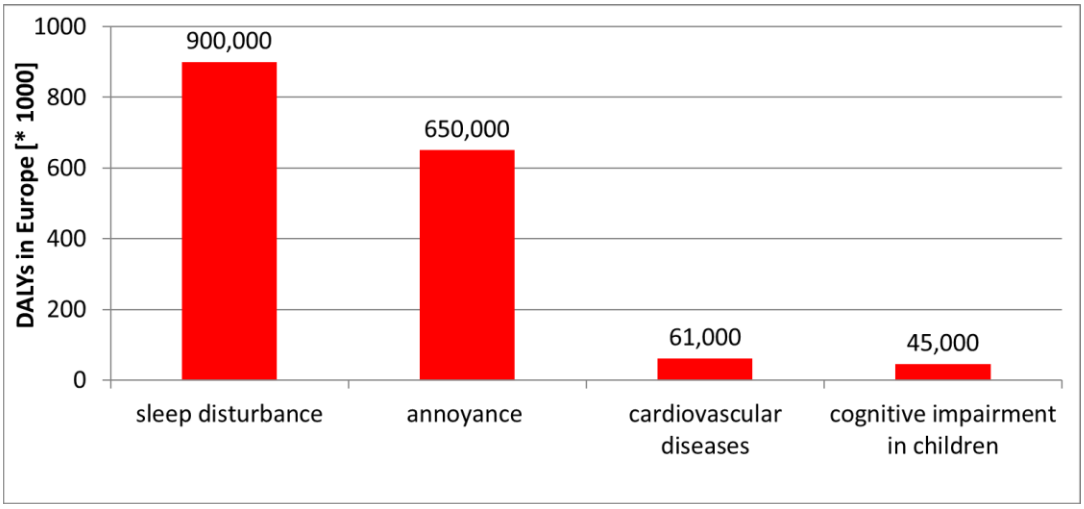

figure 19 *Yearly loss of Disability Adjusted Life Years (DALY's) in Europe due to exposure to environmental noise based on available data from the END noise mapping. Data are based on best. Refer to [6] for background data, including uncertainty, on the presented values.*

5.7 Effects of noise on settlements

Though direct proof is not available, one may expect negative effects of high traffic noise levels on urban developments. The clearly stated willingness to pay for a less noisy environment and the hedonic pricing, reflected in the dependence of value of houses on the environmental levels, will have an impact on the social classes. People with higher income are expected to move away and those with lower income will migrate into the noisy and thus cheaper parts.

5.8 External costs due to traffic noise

The economic impact of traffic noise on the European population is composed of the willingness to pay for a less annoying environment (or the willingness to pay extra for a residence in a less noisy area) and the health related costs such as the absentee of employees and costs involved in the treatment.

A study performed by IWW and INFRAS in 2004 [18] reports that the costs of traffic noise for the EU17 in total may be in the order of 46 billion Euros. The largest share is caused by road traffic (40 B€); for rail and air traffic, figures are in the range of 2 to 3 billion Euros.

These figures refer to exposure to noise levels above 55 dB for annoyance and 65 dB for medical costs. However, the annoyance below 55 dB and medical impact below 65 dB cannot be neglected since some annoyance (as shown in figure 15) and medical risk still exists at those levels. Since the number of exposed people in the 45-55 dB L_{den} range is much larger that for the higher levels, the contribution on the total annoyance will still be significant [15], and the same applies for medical costs.

More detailed information on the external costs of traffic noise can be found in [32].

6 Responses

6.1 General

The serious impact of environmental noise exposure of the European population has initiated a series of responses. Measures are taken at local levels, national levels and international levels. Measures are taken at all components in the DPSI chain, but not so much at the D, P, S, I elements themselves. Rather, measures are taken on the level of the relations between successive components in the DPSI system. In the figure below the responses on the level of the links are indicated.

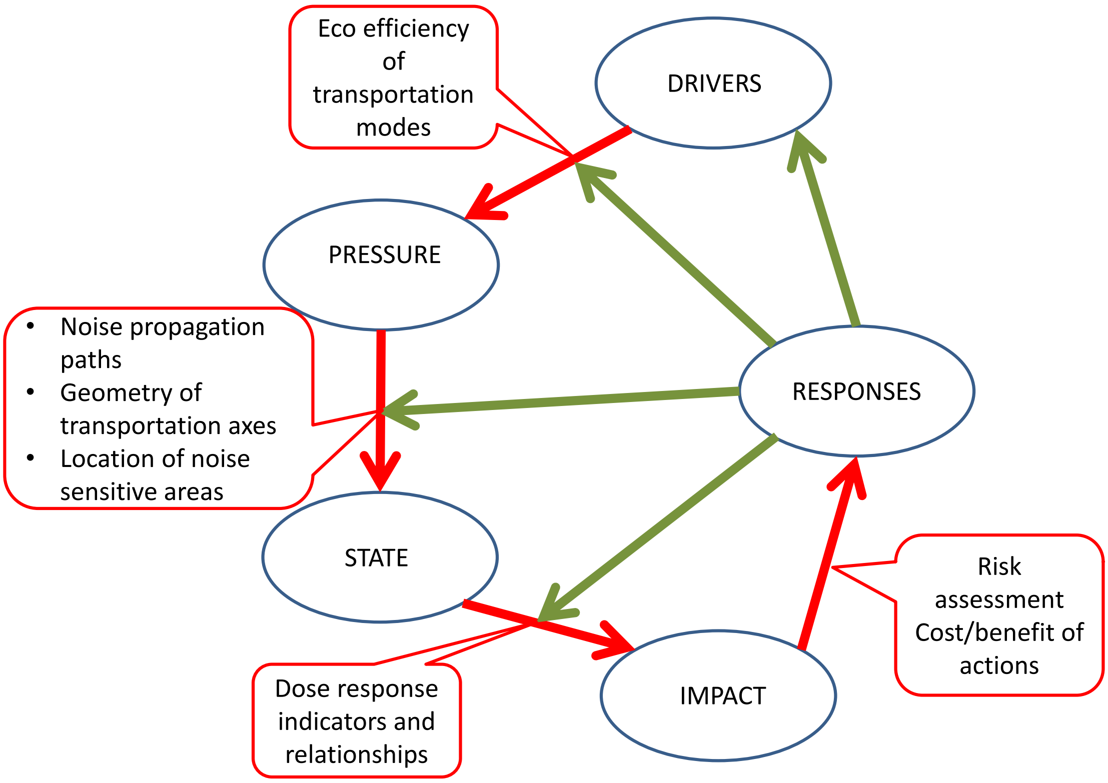

figure 20 *Responses in the DPSI diagram. In contrast to the diagram given in figure 1, the responses are here focused on the links between the DPSI elements.*

table II *Description of the links between the DPSI elements [3]*

DPSI relation	description
Driver → Pressure	Indicates the amount of noise generated during operation of the road or rail vehicle or aircraft
Pressure → State	Indicates how effective emitted noise from roadways, rail lines and aircraft routes is propagated into the living, working and leisure areas
State → Impact	Indicates how intrusive the exposure of transportation noise is to the health and wellbeing of humans
Impact → Response	Indicates to which responses from society the Environmental burden leads. Key issues are the assessment of the risk and ratio of the costs verses the benefits of actions.

7 Response at the level of ***Drivers***

7.1 Traffic volume control

One might argue that measures at the start of the chain, namely the *Drivers*, are the most effective, since all negative consequences are driven by the transport itself. The characteristic of noise reception does however frustrate this approach. The impact of noise on humans is defined in Decibels which has a logarithmic relation with the magnitude of the sound when expressed in physics terms, such as energy or energy density. The reason is found in the reception characteristics of the human which is rather insensitive to variations in sound energy, but has a tremendous dynamic range of $1:10^{13}$ between the energy at the lowest noticeable level and the level where it really starts to become unbearable after a short while.

A noticeable difference is in the order of 1 dB that is equivalent to an energy change of 25%. A traffic decrease of 25%, which is quite a challenge, will only lead to a barely observed reduction of noise.

A similar deduction can be observed for the closeness of infrastructure and urban areas. A 25% increase in distance between road/rail and houses leads to an approximate 1 dB lower immission level. Increasing distance is effective for houses close to the road. A shift from 25 m to 100 m is a 6 dB reduction, the next 6 dB implies a shift from 100 to 400 m.

7.2 Modal shift

Road → rail

On base of the normalized noise emissions given in table I an estimate can be made of the effect of shifting from road to rail or from air to rail. For the assumed 2 person occupation of a car the shift to a well occupied rail carriage reduces emission with 3 dB. For single occupation in cars such shift would lead to 6 dB. Shifting from a fully occupied 4 seat car to a rail carriage has no noise effect on the immission levels. The effect of shifting freight from road to rail traffic though is negative. The same amount of freight transported with conventional wagons emits 6 dB more noise, but with the TSI compliant wagons about 2 dB less.

Nevertheless one may expect an improvement due to the lower annoyance and sleep disturbance associated with rail traffic noise when compared to the same level of road traffic noise. (see figure 15).

Air → rail

The positive effect of a modal shift from air to rail is for the same reason unambiguous. Although the normalized emission in dB/PAX[2] for air is much higher, the distance to the houses is also much larger. In fact a 1000 km air travel is noticeable on the ground for about 20% of the distance and will be

[2] PAX is short for 'passenger' in travelling industry

closer to the ground than 1000 m for only about 3% of the distance. This 3% neutralizes the increase of 15 dB in normalized emission of aircraft versus train. So for this common type of traveling distance in Europe air and rail are comparable in terms of noise level.

However, the impact in terms of annoyance and sleep disturbance is very distinctive. At 60 dB of aircraft noise 40% of the population is highly annoyed, while the same level of railway noise only leads to a 5% annoyance rating (figure 15). An even larger effect can be deduced from the data on sleep disturbance. It is clear that, although effect on the noise levels is limited, a large improvement in annoyance and sleep disturbance can be expected by shifting from air to rail.

7.3 Short summary

The effect of Responses on the level of Drivers was found to be small: only a few dB's for rigorous measures such as halving traffic. Improvements in terms of annoyance and sleep disturbances can be expected from modal shifts due to the distinctive dose-response relationships for the different transport modes.

8 Response to the relation ***Drivers → Pressure***

In contrast to the limited effect on drivers reported in chapter 7, it will be shown that action at the level of *Drivers → Pressure* relationship is highly effective.

8.1 Road traffic

On the *Driver → Pressure* level various actions are feasible to control the sources depicted in figure 9:

1 Improving the source emission of cars and trucks, by tightening type approval procedures and limits for vehicles and their tyres.
2 Stimulating the buying and usage of low noise vehicles and tyres, and taxing noisy ones.
3 Application of noise reducing road surfaces
4 Reducing the driving speed
5 Improving driving style by suppressing high engine loads and avoiding high engine speeds through gearing up quicker.

Standard vehicle emission

Although vehicle technology has advanced considerably in the last 25 years, leading to improved mileage and gaseous emissions, the noise emission has not improved. For cars at high speed, the situation has even worsened, as is shown in figure 21. Only for heavy duty vehicles under urban driving situations improvements are found. This trend is in clear contradiction to the continuous tightening of type approval limit values from 82 dB in the early eighties to 72 dB from July 1st, 2016. This paradox can be explained by the fact that the 82 dB presented a relaxed limit value, which did not have much effect in terms of shifting the noise emission of the vehicle fleet. Then, additional tightening of limit values where often bypassed with a change in test procedure or added allowances for specific vehicles (such as the “Lex Ferrari” giving high powered sport cars an 2 dB higher limit value).

The most important effect is that under conditions of normal driving the tyres contribute most of the emission, while in the test procedure it used to be a much smaller part. Refer to [28] for more extensive comments on this topic.

Tyre type approval for noise was introduced in the EU in 2001, but again with very relaxed limit values. A tightening took place in 2012, but the complete enforcement for all new tyres on the market will be accomplished only in 2019.

Effect of vehicle speed and driving style

In the graphs in figure 21 the effect of vehicle speed on the noise emission can be deduced. When going from 50 to 120 km/h the sound emission increases about 10 dB. The effect on the time-averaged road side level however has to be corrected for the shorter passing time at high speed (with a factor 10·lg(120/50) dB) resulting in a net effect of 6 dB on equivalent road side levels.

In order to achieve environmental goals on noise, air quality and CO2 reduction, speed reduction has frequently been studied as a potential measure. Although the environmental effects are undisputed, authorities are reluctant to apply the measure since the costs of longer travelling time is found to exceed the environmental benefits. In a recent Dutch study even an further raising of the maximum speed exhibited positive societal benefits [37].

There exists an effect of driving style but that is mainly noticeable in cities where the more frequent driving with higher acceleration and higher engine speeds is a noise issue. On main roads tyre noise is dominant for the overall emission; the influence of driving style on the tyre noise is negligible.

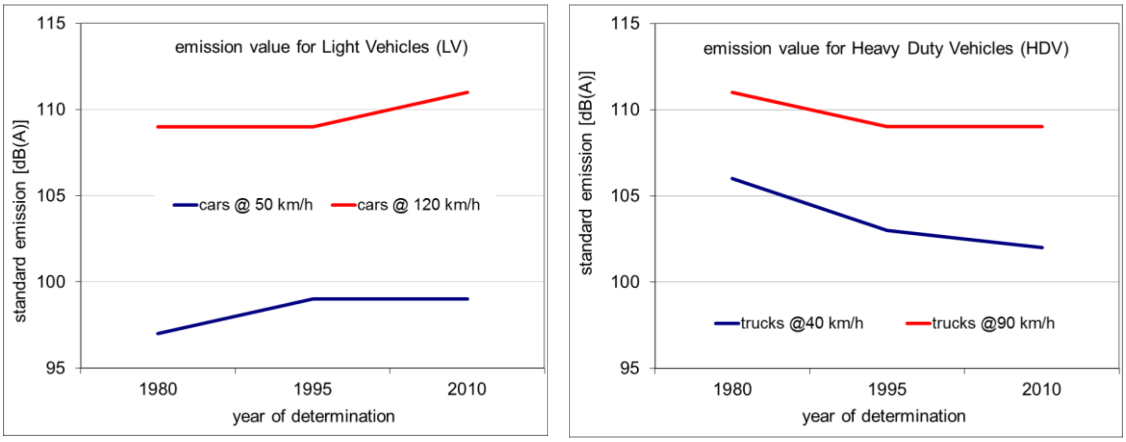

figure 21 *Noise emission of the average Dutch vehicle over the last twenty years. Road surface type is a standard Dense Asphalt Concrete 11 in all tested conditions. Each data point presents the average over 10 different test sections on highways and through roads.*

Effect of road surface

It is generally acknowledged that the surface type the vehicle runs on is an important factor in the overall noise emission. In “Progress report on measures on road traffic noise in the EU”, [28] data are presented of the noise emission of several vehicles running at speeds between 50 and 150 km/h. The pass-by levels show a spread in noise values due to the varying characteristics of the vehicles and the mounted tyres. The measurement campaign was performed on a series of transversely brushed concrete surfaces and a series 2 layer porous asphalt surfaces (NL recipe). A schematic presentation of the data is given in the figure below (figure 22). It shows that the spread between cars on a specific surface (due to tyre and vehicle influences) is smaller than the difference found between the average values on the surfaces. In fact the most noisy passage on the 2L PAC surface is below the most silent passage on the concrete surface.

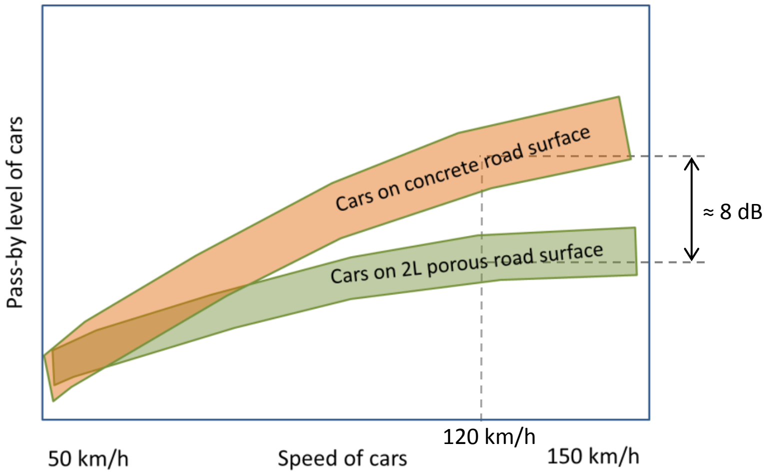

figure 22 *Schematic presentation of pass-by measurements on cars on a concrete road surface and cars on a 2-layere porous asphalt surface (data presented in figure 14 of [28]). It shows the dominance of the road surface type over the vehicle and tyre characteristics.*

8.2 Rail traffic

Rail traffic gives a very clear example of how improvement in the technology results in a significant lowering of the noise emission values. In the progress report on railway noise (ref. [29]) it was demonstrated that the noise emission of railway stock can for the larger part be explained by the roughness of the rolling surface of the wheel. The braking system has a close relation with this wheel roughness level: block brakes with cast iron blocks have the worst effect on wheel roughness; much better are composite blocks and best are disc brakes, which do not touch the rolling surface of the wheel at all.

The most important is therefore remove cast iron blocks from the market and replace them by composite blocks or disc brakes.

For rail traffic noise, possible actions on the *Driver* → *Pressure* level are:

1. Improving the source emission of railway stock by tightening approval procedures and limits for new railway stock
2. Stimulating the usage of low noise railway stock by taxing noisy ones
3. Improving the acoustic characteristics of the railway tracks

As explained above, actions nr.1 and 2 can be narrowed down to enforcing or stimulating the application of composite brake blocks or disc brakes. Only when improved braking systems are applied, the effect of improving the track (action 3) becomes relevant. Furthermore, it was demonstrated that the ratio of the costs to the benefits is superior for retrofitting of these improved braking systems and that other measures such as noise barriers or track damping exhibit less optimal C/B ratio's.

Tightening approval procedures

Railway vehicles are not subject to European type approval regulations as is the case for road vehicles. Although, a similar system exists: the Technical Specifications for Interoperability for Noise (TSI). All new railway stock that might cross borders has to fulfill the TSI requirements. For noise, vehicles are tested under stationary, starting and passing-by conditions and limit values are defined depending on the type of vehicle. The limits, although not very technology forcing are so strict that cast iron brakes are effectively banned on new vehicles. The graph below (figure 23) shows that the effect of the most recent update on the pass-by values for freight wagons merely consists of smoothing the function for axle density without tightening overall levels (see also ref. [29]).

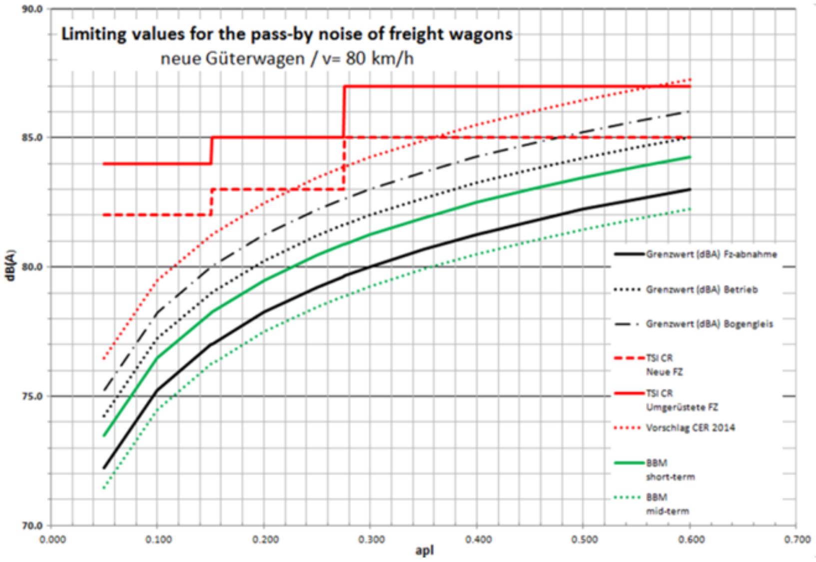

figure 23 *Pass-by levels as a function of axis per length. The red curves present the former TSI and the present TSI (from 2014). The green curves present the UBA short term and mid-term proposals and the black drawn line the Swiss requirement for the extra quiet freight wagon subsidies [29].*

Additionally the effectivity of the TSI for improving the total railway stock is limited. Due to the long service life of stock and the resulting low renewal rate, it would take several decades for a noticeable effect to appear. Only when about 50% of the fleet is exchanged for a silent wagon, a noticeable effect of 2,5 dB results. With a renewal rate of 3 % (33 year service life) that will take 17 years.

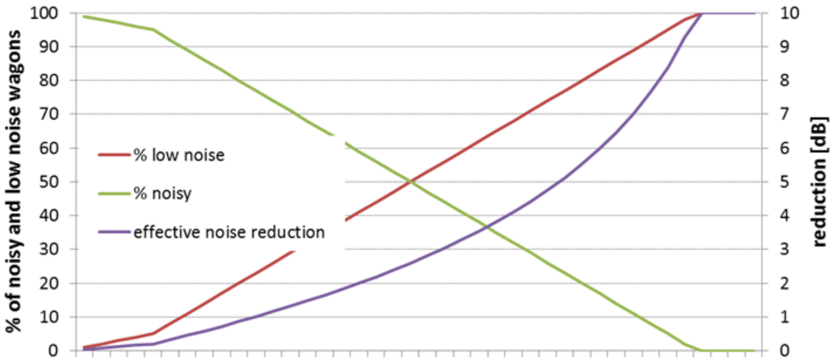

figure 24 *Effect of a 3% fleet renewal rate on average noise emission of vehicle fleet. Clearly illustrated is the low effectiveness in the beginning (23% new for 1 dB effect) and the high ratio in the final phase (6% new for 1 dB).*

Policies to stimulate and enforce the refitting of existing stock

Faster renewal is enforced by introducing noise limits to existing stock and by stimulating financial incentives, e.g. lower rates for silent wagons or subsidies to partly cover the costs of the refitting.

CO-FUNDING FOR RETROFITTING

The EU has initiated actions to stimulate and enforce refitting of freight wagons. Regulation 1316/2013 allows co-funding of retrofitting up to 20% of the eligible costs. A first call in 2014 with a budget of 20 million euro was not that successful (only 6 million spend), probably because increased maintenance costs are not covered. A second call in 2016 has been launched.

TAXATION OF NOISY VEHICLES

Improvement is found in stimulating the refitting of cast iron blocks by composite blocks and the usage of lower noise vehicles by a noise based bonus/malus system in the determination of the usage fee for tracks, often referred to as the Noise Differentiated Track Access Charge (NDTAC). The principle of this system is that the operator of a train (mainly freight trains) will invest in retrofitting its wagons in order to save money when using a track. The effectivity of the system is however severely limited, partly due to the height of the bonus, but for the greater part due to the difficulty in identifying low noise stock as well as the complex ownership relations in the rail freight operations. No general system is available at the moment that allows on track identification of low noise stock; most of the systems in use are based on self-declaration of the operator. Secondly, the organization receiving the bonus differs from the organization owning the vehicle and responsible for the investment in retrofit.

Therefore the Swiss authorities have decided a total ban on cast-iron braked vehicles by 2022 at the latest. The German authorities are presently evaluating similar steps.

TSI NOISE LIMITS FOR EXISTING STOCK

Revision of the TSI-noise with the objective to include existing freight wagons, is initiated. In a first stage, scheduled in 2022, wagons that are used for international transport are subjected to noise limits. In a later stage all wagons, with the exception of track machines, special wagons and wagons not in operation after the deadline, have to fulfill the TSI noise limits. A working party for the revision has started in 2016.

A technical issue to be covered is that not all composite brake blocks are acoustically proven or have not yet passed the TSI-WAG procedure. Validation through track side monitoring or controlling acoustic performance on a test bench are in development.

PRESENT STATUS OF LOW NOISE FREIGHT STOCK

Although the influx of low noise stock increases strongly the last years, the majority of stock is still equipped with noisy CI blocks. The status for Germany (over 150,000 registered wagons) is given in figure 25.

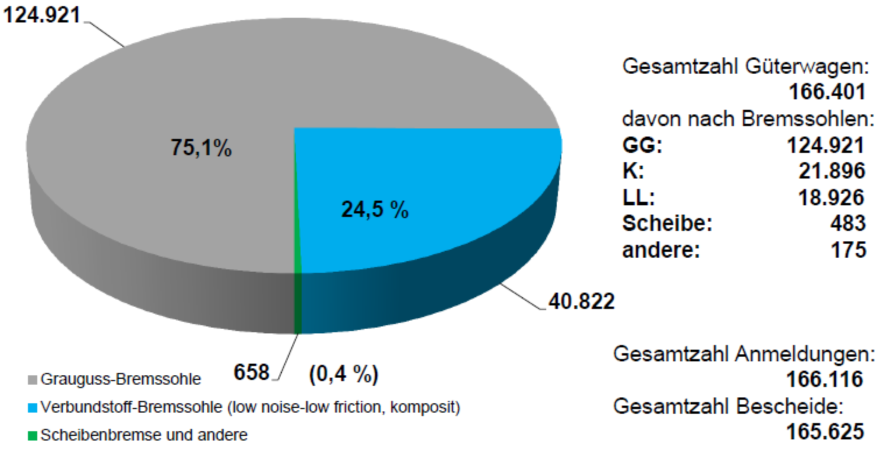

figure 25 *Fraction of freight wagons equipped with silent brake blocks (LL or K) data from Eisenbahn-Bundesambt, status August 2016.*

The data present the registered vehicles and do not take into account the usage.

Given the pressure on the market by the ban on CI blocks in Switzerland, the expected ban in Germany, the stimulation by the bonus for low noise stock and the expected enforcement by the EU of the TSI-noise for existing stock, it is to be expected that the usage of composite blocks will continue to increase. This is corroborated by the observations from the Netherlands. Data from on actual usage of low noise wagons on the dedicated freight line from the harbor of Rotterdam to Germany showed that about 60% of the wagons are equipped with low noise brake blocks. It is estimated that in 2020 the fraction will increase to 80% (information from the Dutch rail authority ProRail).

Improving track characteristics

Only when braking systems are optimized, track related measures, such as more intensive grinding or rail damping become relevant and can reduce the overall emission with a few dB's. Refer to [29] for an overview of possible measures.

8.3 Air traffic

The system for aircraft shows similarity with the system for rail stock. Improving the noise characteristics of the fleet is pursued through tightening the approval system for new aircraft and taxation of the usage of noisy existing aircraft.

Approval procedures

All aircraft needs to pass certification tests that includes noise emission. Since aircraft noise is mainly an issue around airports the noise tests are based on two noise measurements made on the ground when the aircraft is taking-off (fly-over and side-line) and one measurement when the aircraft is landing (approach).

In the first, and now outdated, classification of a low noise aircraft (Chapter 3) a maximum allowed noise level is defined at each of these positions. The noise values are expressed as EPNdB's a measure that is defined slightly different from the generally used dB(A) value.

The limit levels are made dependent on the maximum allowed take–off weight and for fly-over also on the number of engines. Chapter 3 limits are introduced in 1972 and in 2001 a tightening was introduced with a 10 dB lowering cumulative over all measuring positions, referred to as Chapter 4. These values became mandatory in 2006 for all new aircraft. In 2020 an additional tightening of 7 dB (cumulative over all measuring positions) will come into force. The time-line is shown in figure 26 together with the certification results of actual aircraft of varying types [13].

At the moment aircraft that, cumulated over all three measurement positions, have a cumulative margin of less than 7 dB to Chapter 3 limits, are considered as noisy and eligible to be restricted in their use on European airports [30].

Taxation and restricting of noisy aircraft

Although the service life of aircraft is shorter than for rail wagons, it is longer than of road vehicles. So in addition to improving the noise emission of new aircraft, the replacement of existing noisier aircraft is also stimulated. Apart from a total ban on Chapter 2 aircraft in Europe, in about 40% of the airports the landing and take-off charges are (for a part) based on the noise category of the aircraft. No general categorization of the noisiness of aircraft exists. In many cases the certification values are used but the definition of the categories differs, in other cases (Germany and Switzerland in particular) the classification is based on own measurements.

For several airports, restrictions exist for the usage of noisy aircraft in the noise-sensitive night period. Also at quite a few airports there exists a limit to the total number of operations (or more effective for noise control, the total noise emission) over a yearly period.

The freedom to introduce such restrictions is however limited due to European law. Only after following the Balanced Approach procedure (see [30]), including a cost/benefit analysis and consultation with all stakeholders, such measures can be introduced.

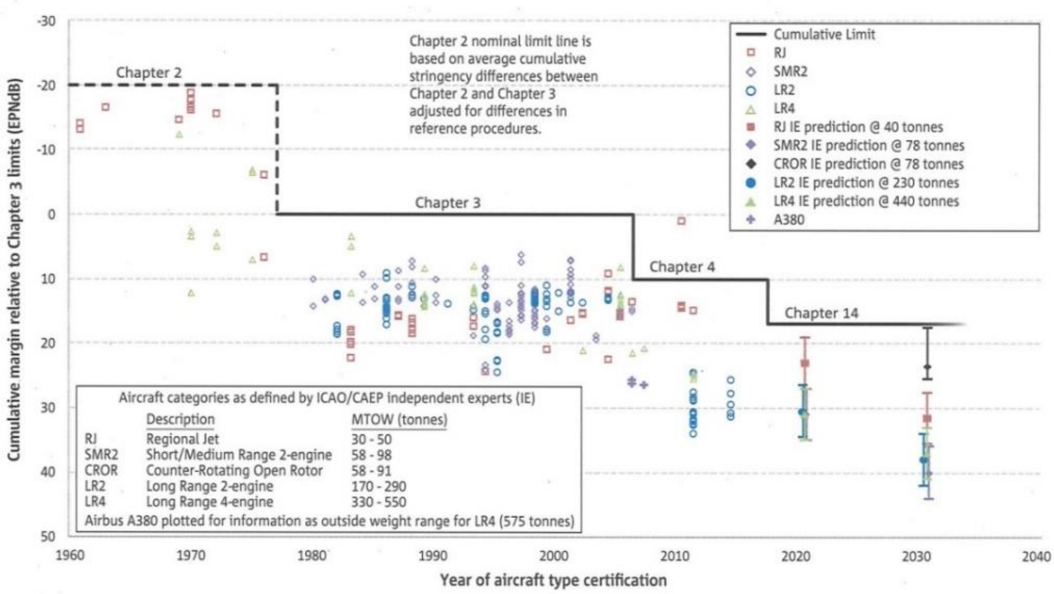

figure 26 *Development of noise standards for commercial jet aircraft (source EASA). The y-axis represents the cumulative value over all three measurement positions relative to the values for Chapter 3 aircraft [13].*

Noise Abatement Operational Procedures

Noise abatement operational procedures include a series of measures aiming at reducing the immission levels on the ground by optimization of the flight procedures during take-off and landing. Modern aircraft and airport navigation, including GPS-based steering, enable more controlled routing both in horizontal as in vertical sense, compared to the conventional instrument-based flight procedures. For instance with reduced drag procedures (faster retraction of flaps in take-off and reduced flap settings during approach), Noise Abatement Departure Procedures (NADP) and Continuous Descent Approach (CDA), take-off and landing operations can be performed with less noise impact on the ground. Specific nuisance is suppressed by restricting the use of reverse thrust after touch down and the engine run-up before take-off. The application of such procedures must not jeopardize safety and have to be balanced against the capacity. However, with capacity very often fixed priorly and with safety as inflexible condition, there is usually very little space for to noise optimized operational procedures.

8.4 Short summary

The Responses to Drivers → Pressure relation were found to be very effective. The shift to composite braking blocks suppresses noise levels around freight lines with 10 dB. Less effective but still significant is a further type approval tightening for vehicles and tyres. Improving the road surface will have a direct effect on environmental noise levels of 3 dB in general and over 10 dB in certain situations. Shift from chapter 3 to chapter 14 aircraft has on average a 5 dB effect. It must be acknowledged though that such shifts already take place, driven by the improved fuel efficiency of modern aircraft.

9 Response to the relation ***Pressure → State***

In order to limit the environmental impact of the usage of noise emitting vehicles, several procedures and mitigation measures are available to the acting authorities. Measures that affect the *Pressure → State* relation aim to prevent the emitted noise from reaching the people. In this type of measures, one can distinguish between road and rail traffic, which take place on fixed infrastructure, and air traffic, where vehicles travel more or less freely and no infrastructure measures exist.

In this chapter, we combine road and rail traffic, since the noise abatement measures for these modes are the same.

9.1 Road and rail traffic

Noise barriers

Noise barriers shield the environment from the noise emitted by vehicles on the roads or railways. Basically, the barrier efficiency is defined by its height and relative distance to the source and the receiver. If chances are that noise reflected against the barrier may contribute to noise sensitive areas at the other side of the road, the barrier surface is made acoustically absorptive which will prevent these reflections. For rail traffic, almost all noise barriers are made acoustically absorptive, to suppress multiple reflections between wagon body and barrier.

figure 27 *Examples of noise barriers in the Netherlands (photos: beeldbank.rws.nl)*

In cases where large reductions are required, barriers may fall short and full coverage of road or rail lines is applied. The high costs of such measures are sometimes partly covered by using the area on top of the tunnel for building activities. Especially for rail care must be taken to not introduce vibration problems.

Road and rail traffic - rerouting

For road (and in a limited way also for rail) moving the source farther away from the noise sensitive areas is a frequently used measure. While in earlier times roads and railway lines were planned to go through cities, nowadays such city crossings do cause major problems in terms of safety, air quality and noise impacts. Redirecting the traffic by ring roads or bypasses significantly improves the urban environment, although at the cost of the quiet environment in the rural area.

Such ring roads, planned in the last century, now form major obstructions in the expansion of cities and may lead to an even higher exposure than what would be the situation without redirecting. The fierce opposition from the population in cases where ring roads are planned nowadays has the effect that extensive measures are to be taken, such as very high noise barriers or even, as is the case in the Munich A99 west, several long tunnels.

figure 28 *Example of complete covering of a highway for environmental purposes, A99 Munich (photo: Simon Klopp)*

Rail rerouting by financial stimulation

Redirecting the traffic from a shorter faster route to a longer, but in terms of noise exposure, better route is not straightforward. Although on society level the advantages of lower noise exposure outweigh the higher costs of longer traveling time, the actual decision to take that route is taken by the operator who usually does not benefit from the better environmental situation.

Examples where the external costs on society are (partially) brought upon the rail operators do exist. In Austria, for instance, the freight cars using the rail connection through the heavy populated Inn valley are taxed heavier than when they use the slightly longer but less populated alternative.

9.2 Air traffic

Rerouting

It is clear that noise barriers are not useful for air traffic noise (apart from ground applications, e.g. for testing of engines). An effective response to the link between *Pressure* and *State* is found in separating the traffic from the noise sensitive areas. This may be done either by preventing the development of living areas close to the flight paths or by redirecting flights away from living areas.

Improved avionics allow careful avoiding of noise sensitive areas without jeopardizing safety and capacity aspects. Rerouting, however, involves redistribution of the noise impact on the ground and care must be taken to interpret a minimum in exposed persons as an objective. The negative effect of a small noise increase cannot be fully compensated by the positive effect of a small decrease, even if a larger population benefits from it. An evenly spreading of the noise burden on a wider area is sometimes preferred by the population over a concentration, even if the net exposure may be lower, as experiences around Heathrow airport have learned [35] although a similar policy caused wider complaints in Frankfurt.

9.3 Short summary

The effect of Responses on the Pressure → State relation was found to be limited. Noise barriers do have positive effects on the living areas behind them but spoil the landscape and are considerably expensive to build and to maintain. In many situations they show inferior cost/benefit ratios than source related measures. A similar evaluation is observed to rerouting. Longer traveling distances add costs and though populated areas may be saved, not much trafficked areas are exposed to higher noise loads.

10 Response to the relation ***State → Impact***

Mitigation measures on the link between state and impact will have partly a technical nature and partly a non-technical nature. Technical measures improve the personal noise exposure people are exposed to, given a certain level of environmental noise. Non-technical measures aim to alter the way persons experience a certain exposure to noise.

10.1 Technical measures

Facade insulation

The most common technical measure that affects the *State → Impact* relation is the application of facade insulation. This might be the most frequently applied measure in cities and around large infrastructures crossing densely populated areas with high rise buildings. With improved window insulation, heavier facade elements and noise insulating ventilation devices one can achieve an indoor level of 30 dB in situations where the outdoor levels are 70 dB.

Noise optimized urban planning

Even if the urban area is traversed with very noisy through roads, very agreeable areas are found in the noise shadow zones of large buildings. In urban planning such zones can be intentionally developed by positioning long, non-interrupted buildings; the use of these buildings themselves will be restricted to activities that are not sensitive to external noise from these roads. Behind these buildings, relative quiet areas can be created that are well suited for living and recreation.

10.2 Non-Technical measures

Quiet areas

The dose-response curves in figure 15 are presented as clear functions, but in reality will show an ensemble of curves, with different dose-response relations depending on the specific situations. If one knows in which situation the response to a certain dose is lower, then one might create such a situation, resulting in lower response, even when lowering the dose is not feasible.

The availability of quiet areas is known to be such a situation. It is therefore that the preservation of Quiet areas is high on the list in the Green Paper on Future Noise Policy [31] and is included in the aims of the END.

These areas can be identified within agglomerations in the END noise mapping. Outside agglomerations the potential quiet areas are identified by the EEA using the Quietness Suitability Index (QSI) that uses, besides noise contours, also other input such as type of land use and socio-economic data to evaluate potential quietness. In [8] a European coverage of QSI is presented. Low QSI values are found in the densely populated areas and along the main transport arteries in Europe.

The Nordic countries exhibit about 85% of their area with a QSI >0,5 while for Belgium this is only the case for 8% while 70% of its surface has a QSI< 0,1.

figure 29 *Potential quiet areas in Europe based upon Quietness Suitability Index QSI [8] (see also http://www.eea.europa.eu/publications/quiet-areas-in-europe)*

Soundscape: acoustic quality of public spaces

In a wider sense than quiet areas, *sound scaping* refers to understanding the acoustic environment not only in terms of average noise levels but in terms of subjective evaluation. It tries to define the acoustic quality of the environment in such terms that it presents the pleasant or unpleasant rating by humans. It can be that an objectively noisy environment can be rated more pleasant than a more silent environment, just because the character of the sound is more natural or in better harmony with its environment. A commonly used example of such situation is the creek that produces a lot of noise of running water that might be louder than that from a road but is experienced less disturbing. This example may be put into practice by placing a fountain near a noisy road, so the road traffic noise is masked by a different source with a lower annoyance rating. An example from Sheffield station is given in figure 30.

Listen to “Feel yourself become relaxed while listening to this 15 minute meditation music” with flowing sounds of water in the background. The sounds of nature is very calming, a great form of music therapy, https://www.youtube.com/watch?v=50gN2vDxAYI.

figure 30 *Sheffield, station sculpture, which serves as a noise barrier against the roads behind the barrier and at the same time the water installation brings quality back to the square.*

10.3 Short summary

Responses on the State → Impact relation are relatively ineffective in specific cases. Façade insulation suppresses indoor levels but windows cannot be opened and the direct living area outside is still exposed. At the level of urban planning higher potential is available. By careful orientation of building blocks non-exposed facades and shielded areas can be created that for a part can compensate for the noise exposed facades. On a larger scale the availability of quiet or relaxing areas do improve living quality, despite average high noise loads in the city.

11 Relation with other environmental topics

It may be advantageous to approach environmental noise not as an isolated issue, but to consider it in relation with other environmental topics. At one hand to prevent that mitigation measures for noise result in worsening of other environmental issues. At the other hand to be aware of possible win-win situations where measures for noise might also improve other environmental issues. The two relevant topics in this view are the air quality and the CO2 emission.

Other benefits and disadvantages exist. One could argue that safety shall be included in the rating. At the other hand, it is not common that safety is jeopardized in favour of environmental improvements, so the assumption is that for all measures safety is secured. Another issue that is of interest is costs and traffic capacity (which are closely related). Some measures such as CDA for air traffic might reduce the capacity and consequently cannot be applied in rush hours. At the other hand a measure such as application of a porous road surface, improves capacity during rainy periods (by suppressing splash and spray) but might at the other hand reduce capacity due to lane closure caused by the more frequent maintenance and resurfacing. These issues and other criteria that influence the decision making for noise abatement measures, as well as an evaluation of methods to incorporate these criteria in an integral decision, are treated in a parallel study [32].

For the series of mitigation measures, proposed in this report, the possible positive or negative effect on the air quality and on CO2 emission are given. The table below (table III) presents an overview of the estimated effects. The green rows indicate clear combined positive effects on all three environmental issues.

table III *Overview of positive or negative impact of noise mitigation measures on air quality (mainly PM10/2,5 and NOX) and on CO2 emission.*

Mitigation measure	Air Quality	CO2 emission	Noise
Modal shift (road → rail)	++	++	-/0
Modal shift (air → rail)	+	++	+
Road: noise reducing road surface	+	+	++
Road: fleet renewal (incl. tyres)	+	+	+
Road/Rail/Air: Volume control	++	++	0/+
Road/Rail: noise barriers	0	0	+
Road: traffic calming	+	+	+
Rail: fleet renewal (mainly block → disc brakes)	0	0	++
Rail: low noise tracks	0	0	+
Rerouting (road/rail/air)	+	-	+
Facade insulation	0	+	+
Road/rail: noise optimized urban planning	+	0	+
Air: fleet renewal	+	++	+
Air: NADP and CDA	0	+	+
Soundscape	0	0	0/+
Quiet areas	+	+	+

The data in the table shows that for most of the measures, the effect on CO2 emission and air quality is either neutral or positive. An exception is rerouting that in most of the cases implies a larger travelling distance. The tabled values assume that the measure is designed for noise purpose only. If one could focus on all three topics, then very effective measures may result as the following examples show.

- The modest effect for electric vehicles for noise, is due to the dominance of the tyres in the overall noise emission and the assumption that for such vehicles the rolling resistance is the tyre design criterion. If also rolling noise is included in the design an excellent overall rating will result.
- Some types of noise reducing road surfaces, especially the ones where trucks are included in the optimization, lack the smooth texture, required for low rolling resistance. It is demonstrated that better designs are available that show superior rolling resistance properties (2L-PAC-fine in use in NL). When combined with traffic calming as is done on the A2 between Amsterdam and Utrecht the measures deserves ++ for all environmental topics.
- Air fleet renewal shows very positive performance on noise and CO2 emission. Unfortunately improved burn efficiency implies higher temperatures with chance of increasing NOX emission. Increasing by-pass ratios to improve fuel efficiency may limit noise reduction potential. Trade-offs may lead to improvements on all topics [33], but may also result in excellent performance on CO2 while jeopardizing noise, as the technology of unducted fans shows [30].
- Noise optimized urban planning commonly involves separation of living areas from transport arteries that improves noise and air quality, but may increase CO2 due to longer traveling distances. An alternative approach is that mobility is included in the concept resulting in reduced private traffic and improved usage of cycles and public transport, with the need for private transport supplied through rented electric/hybrid vehicles. One can notice such developments already in cities, where car ownership is becoming less important for the citizens.
- Climate change adaptation policies have a lot in common with the improvement of public spaces in cities and therefore are close to the idea of quiet areas. Both purposes need green spaces.

Combined optimization for more than one environmental topic will reduce cost/benefit ratios for the measures and thus improving the scale of application, eventually leading to an improved overall environmental quality for the European inhabitants.

12 European key players

12.1 General

Environmental noise is generally regarded as a local problem that has to be solved by the local authorities. Nevertheless, the listing of mitigation measures shows several ones that can only be solved on an international scale. Moreover, especially those measures that work on the source are regarded more cost efficient than local measures on propagation and on the receiver.

The international scale can be identified as the European Union, where several technical specifications for road and rail vehicles are developed and for aircraft a supra European scale.

The key players in the structure of the European Union are the following.

EUROPEAN COMMISSION DG-ENV

DG Environment is responsible for the European Noise Directive and works on developing a common method for evaluating environmental noise levels in Europe. The EU does not impose noise limits in individual countries (such as is the case with air quality). The relevant document is: EC 2002/49 (END) [22]. The END will be revised on two relevant topics:

- The method to be applied for assessing the noise indicator specified in Annex II, is to be based on the EU harmonized calculation procedure CNOSSOS-EU [14]. This will improve the comparability of data obtained in different countries. This procedure will be mandatory from 2019.
- The method to be applied for assessing harmful effects, indicated in Annex III, will be updated based on the information from the WHO and JRC on the annoyance and health effects from environmental noise. A draft version available for voting might be available in 2017.

The END is at the same time evaluated in terms of its “fitness for the job”. This REFIT procedure looks at the implementation aspects and evaluates how effective and efficient the objective of the END is achieved, is it coherent with other EU legislation and matches it current needs. The general outcome is that the END functions reasonably well but needs some fine tuning in the implementation part.

EUROPEAN ENVIRONMENT AGENCY

The European Environment Agency (EEA) in Copenhagen is a key organization in the collecting, interpreting and providing of environmental data to all involved in developing, adopting, implementing and evaluating environmental policy in Europe. In chapter 12.2 the activities and available data from the EEA are presented in more detail.

EUROPEAN COMMISSION DG-MOVE

The aim of DG Mobility and Transport is to promote a mobility that is efficient, safe, secure and environmentally friendly and to create the conditions for a competitive industry generating growth and jobs.

EUROPEAN RAILWAY AGENCY (ERA) AND EUROPEAN AVIATION SAFETY AGENCY (EASA)

Organizations involved in specifying the technical specifications for interoperability of rail stock (TSI) and of aircraft certification. The TSI and the aircraft certification also stipulates maximum allowed sound levels.

EUROPEAN COMMISSION DG-ENT

The Directorate-General (DG) for Internal Market, Industry, Entrepreneurship and SMEs is the European Commission service among others responsible for the completing of the Internal Market for goods and services. Its relevance for transport noise control lies in the activities to harmonize the technical requirements for road vehicles and its tyres with respect to noise emission.

WHO The World Health Organization / Europe.

The European branch of the WHO shows activities on the topic of transportation and health. The WHO/Europe has issued several publications on the health issues related to exposure on traffic noise and exhaust emission. Based on this it works on risks assessment on exposure to traffic noise and on the definition of safe levels.

ICBEN International Commission on Biological Effects of Noise

Its goal is to promote a high level of scientific research concerning all the aspects of noise-induced effects on human beings and on animals including preventive regulatory measures and to keep alive a vivid communication among the scientists working in that field. ICBEN is a non-profit organization that has no legal identity of its own and entirely depends on its members and its officers that voluntarily work for the organization. ICBEN is an affiliate member of the International Commission for Acoustics (ICA). The main activity of ICBEN evolves within its congresses that are organized every 3 years and regularly attract between 200 and 300 researchers and policy makers from across the globe. The next congress will take place in Zurich, Switzerland, from June 18 to June 22, 2017.

EPA network:

The EPA Network is an informal grouping bringing together the heads and directors of environment protection agencies and similar bodies across Europe. The Network exchanges views and experiences on issues of common interest to organizations involved in the practical day-to-day implementation of environmental policy (see http://epanet.pbe.eea.europa.eu/)

ICAO / ECAC

International Civil Aviation Organization and its subsidiary for environment, CAEP (Committee on Aviation Environmental Protection) . On a European level (44 member states) ECAC (European Civil Aviation Congress) functions as a platform for development of safe and sustainable air transport in Europe.

12.2 European Environment Agency

Introduction

The European Environment Agency (EEA) is one of the prime sources of environmental noise information on a European scale. The EEA raises conscience on the seriousness of environmental noise for the health and wellbeing of the European citizens by structuring, making available and analyzing the level of noise exposure and the impact on the population.

The data provided to the commission and to member states on noise exposure is very much based on the outcome of the 5 year obligation of EU member states to determine the noise exposure around major road, rail and air traffic infrastructure and in major agglomerations. Member states communicate the number of exposed people in the different noise bands, using strategic noise maps, and inform the EEA on the intended measures to control exposure on high noise levels through their noise action plans. The EU helps in harmonization of the evaluation by encouraging the adoption of common calculation procedures in the next noise mapping exercise in 2022. This calculation procedure has been published as EC directive 2015/996 and is known as the “CNOSSOS-EU” method.

The EEA furthermore informs the stakeholders, EU institutions and general audience on the impact of high noise levels on the health and wellbeing and the costs involved in these negative effects on society (see for instance [8] and [4]).

Recently interest is developing on not so much controlling areas with high noise levels, but preserving areas with low levels. The preserving of quiet areas was identified as aim in the Annex V of the END (see [7] and [9]).

figure 31 *Member countries and cooperating countries of the EEA.*

Reporting of noise data in Europe

Information on the status of European exposure on noise is obtained through the member countries following the requirements of the European Noise Directive EC2002/49 (END). The EEA facilitates the process of gathering the data through an online portal where member states can upload their results. The relevant information is processed and where necessary completed by the European Topic Center on Air Pollution and Climate Change Mitigation (ETC/ACM) led by the Netherlands Institute for Public Health and the Environment (RIVM).

Noise exposure and impact of noise on health and wellbeing and its implication to the European economy are reported in several ways. The EEA analyses and compares the data from all member states and publishes technical reports on issues such as the exposure and possible health effects [4], the noise exposure in Europe [8], the relevance and identification of quiet areas [7] and [9]. General public is approached with video message [11]. Other European or national studies on environmental noise are welcomed by the EEA, as reference material for their findings and conclusions.

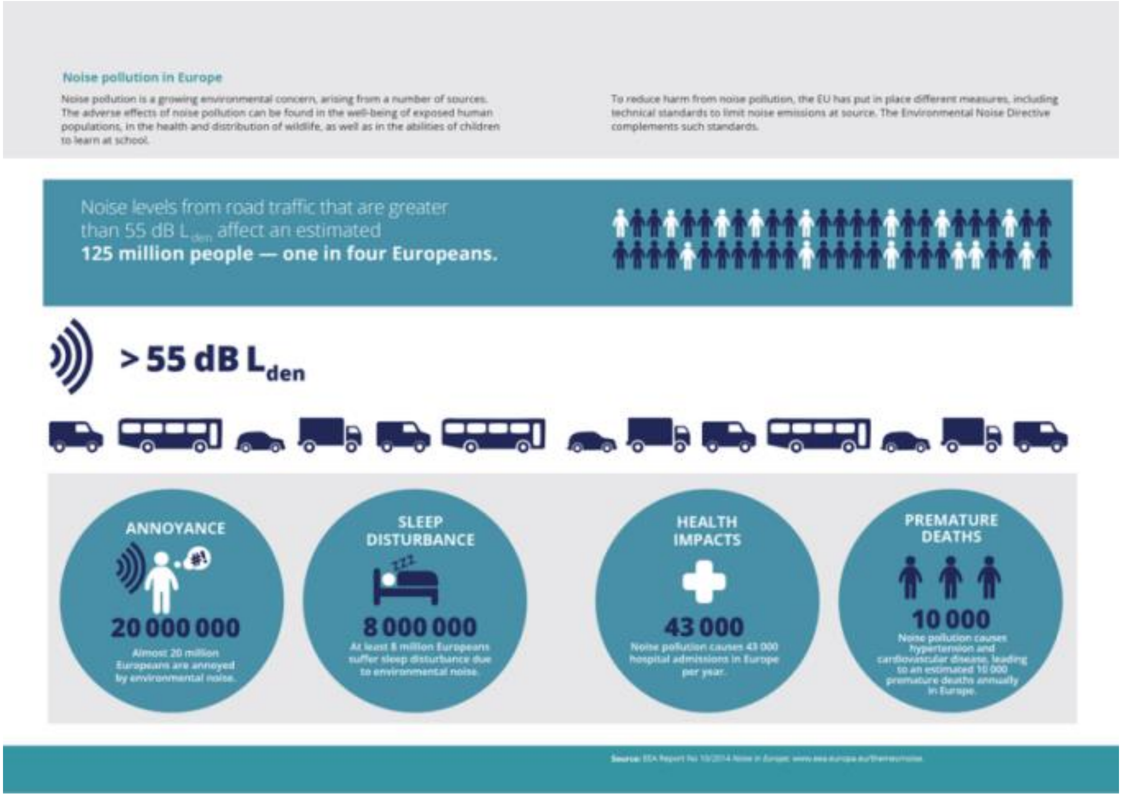

figure 32 *EEA Infographic for Noise pollution in Europe (from http://www.eea.europa.eu/)*

Through its data service the EEA publishes detailed quantitative data on noise exposure of different sources in the member states by means of the “noise viewer” (see [12]).

A very interesting and appealing instrument to raise awareness with the public was NoiseWatch. People could present their own noise experience by making recordings with their smartphones and share that with others through the NoiseWatch app. The application also allowed this citizen data to be directly compared to data from official measurements stations and modelled noise contour map. Unfortunately it is not supported anymore by the major app stores.

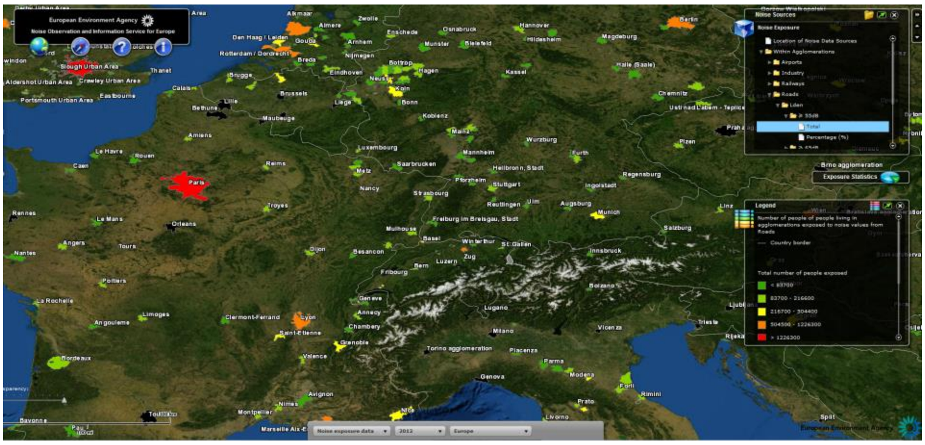

figure 33 *Example of noise exposure data made available NOISE – Noise Observation & Information Service for Europe and presented by the “noise viewer” [12]. Displayed is the total number of people within agglomerations exposed to >55 dB Lden, state 2012 .*

After the 2022 noise mapping exercise the EEA will be able to further improve the quality of noise exposure data in Europe since then the common CNOSSOS-EU noise assessment method will be applied (see [14]).

13 Discussion and conclusions

13.1 Underestimation of the issue

Although health issues in the European population are high on governments agendas and administrations are prepared to take measures to prevent negative health effects, the impression exists that the health issue of traffic noise is not taken seriously enough in many European nations compared to, for example, air quality. Exceeding European air quality limits is addressed by closing cities for older vehicles, installing state of the art air cleaning devices (such as electric particle filters) and implying European type approval legislation that require the application of complex exhaust treatment devices in road vehicles.

For traffic noise immission values no European limit values are defined and on national scales only in a few cases limit values are enforced by serious mitigation measures, and then only in cases of new roads or railways where resistance by the public may otherwise prevent the construction. Selective allowance of quiet vehicles was last applied by Austria in the nineties (and proved to be a great success, leading to a big step in low noise truck technology). There exists no acoustic version of the Euro 5, 6 or EEV vehicles. The most recent tightening of type approval limits for road vehicles was in 1992 for cars and 1996 for trucks. For tyres a latest tightening did however show a slight shift in noise values, although non-complying tyres can be sold up to 2019.

Public awareness is expected to be raised by the mandatory reporting of noise exposure in the EU within the framework of the European Noise Directive. Unfortunately the completion of the data moves very slow (in 2014 only about 50% of the total data set from the 2012 mapping was available at the EEA). In addition to this the defined lower thresholds obscures a large population still exposed to annoying and harmful noise levels. It is estimated that the reported data presents only a third of the actual impact of environmental noise. Especially for aircraft noise the defined thresholds are the cause of a large under estimation of the actual impacts (0,1M reported, 0,2M gap-filled, 2,6M actually sleep disturbed).

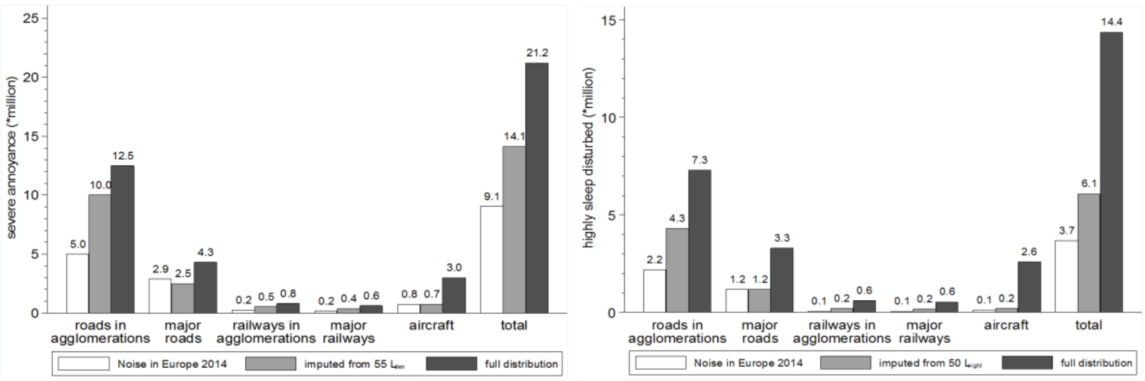

figure 34 *Number of highly annoyed and highly sleep disturbed people in EEA member countries. Comparison of reported data (noise in Europe 2014), data extrapolated to threshold values in END (imputed from 55 Lden and 50 Lnight) and estimated number when effects below thresholds are taken into account (full distribution) [15]*

13.2 Measures to quieten the source

Measures to the source are considered very effective in controlling environmental noise. Such developments are pursued in two ways:

1 Take care that new vehicles reflect state-of-the-art acoustic quality with respect to exterior noise

2 Stimulate the replacement of older noisy products by new products.

In addition, bringing the acoustic quality of the infrastructure to a higher level will significantly reduce environmental noise from road and rail traffic.

The quality of new vehicles is traditionally a topic covered by type approval regulations for road vehicles, TSI's for rail vehicles and airworthiness certification for aircraft. The stimulation to replace old by new is nowadays mainly done on a local or national scale although supra-national institutions safeguard the used methods against arbitrariness and friction with free transport between EU countries.

Improving infrastructure is in all cases a national or local topic and no supra national organization is yet established to harmonize developments.

European type approval legislation

Traffic noise is an underestimated burden for the European population. The impact due to annoyance and health problems, defined in terms of DALY's, is only slightly less than the burden of air quality while at the other hand the relevance attributed to the problem is far below that of air quality. This is for instance reflected in the stringency of European type approval systems that for exhaust emission are *technology forcing* and really force manufacturers to introduce special technology for emission treatment (both legal and illegal as recent publications show), while the stringency for external noise of the vehicle and its tyres is *technology following*. No new technology is required to comply with the limit values and furthermore extensive time periods are allowed before all new road and vehicles and aircraft has to fulfill the already presently achievable requirements.

This report and the related progress reports for road, rail and air traffic noise ([28], [29] and [30]) have clearly shown that there is a wide margin between the certification requirements valid at present or in the near future and the already available technology.

- While CAEP/8 expert panel advised a future target limit for noise certification of *Chapter 4 - 20dB*, CAEP/9 decided on a *Chapter 4 - 7dB* limit value in 2017/2020. Airport data shows that Chapter 4 - 15dB is already widely used on the market (A 320, 330, 340, 380, B737, B747, B767, B777, B787, …)
- The UBA study investigated noise emission from existing railway stock [29]. On base of their findings the IGNA recommended for freight wagons a TSI limit on short term of 80dB and mid-term of 78 dB, the actual chosen limit is 83dB, presenting no improvement compared to the earlier TSI limit value.
- For road vehicles, the stringency of type approval has not been tightened for more than 20 years. For tyres, after a relaxed series of limit values at the introduction of tyre noise regulations, the first tightening will be totally effective only in 2019. In the meantime the actual noise emission of road vehicles has become higher between 2000 and 2010 (see figure 21), while regulations on emission established in the same period is found to be effective).

Taxation and restrictions

Besides the relative relaxed limit values for new rail stock and aircraft, the long service life of these crafts create an additional issue. Through taxation and restrictions in usage, the authorities try to remove the noisy types out of service, at least in specific areas and at specific times where extra nuisance and health problems are to be expected. One does notice a European-wide lack in the harmonization of the criteria these systems are based on.

For rail, the European-wide variation exists in the definition of the emission category, either based on direct measurements or based of self-definition, to the level of individual wagons or trains, and to the financial arrangements. For rail only three European nations have introduced such schemes: Switzerland, Germany and the Netherlands.

Compared to rail, restrictions for noisy aircraft are implemented in many more European nations. For about 50% of the European airports, some type of noise-dependent taxation or restriction is in place. The noise categorization of aircraft, however, varies significantly. A proposal from the ACI (Airport Council International) has not (yet) been implemented. One may assume that the effectivity in terms of stimulating companies to use lower noise aircraft will be limited due to this lack of harmonized categories. The largest incentive for air fleet renewal might be the savings in fuel and maintenance of newer aircraft.

The introduction of new restrictions for EU airports is regulated through EU/598/2014 that stipulates that new restriction may only introduced after following the balanced Approach and assessing the costs verses the benefits.

Evaluation of source measures

The effectivity of source related measures in the EU for road and rail vehicles is limited. This can be explained for road vehicles by the absence of technology forcing specifications in the regulations, for rail vehicles the long service life of exiting stock limits the impact of TSI's only for the small number of new vehicles. For aircraft a similar picture is the case but positive is that fleet renewal rate to low noise aircraft is comparably high due to the much better economic performance of new types.

Infrastructure improvements for road and rail traffic can be very effective. But especially for rail traffic, infrastructure improvements are only effective when the vehicles are of an acoustic better type.

13.3 Measures in the propagation and reception area

Noise barriers and facade insulation

Conventional measures to mitigate traffic noise are shielding the noise by barriers and by insulating the facade. Such measures are attractive since they can be applied without interfering with the vehicle or traffic systems and work instantly. Its disadvantage lies in the limited applicability of barriers in cities and in the rather negative ratios of benefits to costs. Facade insulation requires closed windows and although indoor levels are low, the subjective rating of the inhabitants is more closely related to the outdoor levels [34].

Non-exposed facades and quiet areas

The availability of relative quiet areas for the noise exposed population may result in lower annoyance and health effects. This is why preserving quiet areas is included in the aims of the European Noise Directive. These areas can be found in urban areas where due to shielding of surrounding buildings and the absence of local traffic, noise values can be quite moderate. These can even be the existence of non-exposed facades at the rear of houses aligned along heavy traffic loaded roads. Outside agglomerations where human activities are not present, vast areas are found in Europe, in the Nordic countries and in the rural areas of southern and mid Europe.

While most legislation is aiming at preventing or controlling the existence of high noise levels, the preservation of areas with low noise levels needs to be addressed more clearly and with more mandatory regulations. Preserving or creating those areas may ease the negative effects of traffic noise exposure in modern agglomerations. In addition creating an acoustic friendly atmosphere by sound scaping may even improve the situation in high noise areas

13.4 Recommendations

1 Road traffic:
- a Tightening of type approval regulations for road vehicles and its tyres on limit values, test procedures and quicker coming into force.
- b Improve effectivity by the introduction of more representative test surfaces in the type approval schemes
- c Infrastructure improvements by technical developments of durable noise reducing pavements both for urban areas and for regional and long distance roads.

2 Rail traffic:
- a Introduction of noise requirements for existing freight wagons
- b Further tightening of limit values for new vehicles in the TSI
- c EU wide stimulation of low noise freight wagons by means of a NDTAC

3 Air traffic:
- a More ambitious limit values in scheduled update of noise certification levels (CAEP/8 proposals versus CAEP/9 decision)
- b Harmonization of noise categories of aircraft and quicker introduction of Chapter 3+10 EPNdB as definition for the marginal aircraft within the framework of the balanced approach.
- c Establishing a permanent incentive to optimize flight procedures in terms of noise.
- d Extending the Lden lower boundary in the END to 50 dB.

4 General
- a Extending the lower boundary in the END for Lnight from 50 to 45 dB for road and rail traffic and 40 dB for air traffic.
- b Developing a harmonized methods to determine and internalize the costs and benefits of measures to reduce traffic noise.

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15 Annex: Acoustic terms used in the report

The terms used in the acoustic field are often not familiar to non-acousticians. This annex is possibly helpful to have a better understanding.

15.1 Sound (pressure) level

This term, expressed by *Lp* refers to the strength of the sound at a certain moment. It is expressed in Decibels (dB's), which presents the logarithm of the ratio of the sound pressure (P) to the sound pressure at the hearing threshold (P_0). Wikipedia supplies a clear explanation of the definition (see https://en.wikipedia.org/wiki/Sound_pressure#Sound_pressure_level). The logarithmic nature reflects the high dynamic range of the human ear (factor of 10^{14} between hearing threshold and threshold of pain) but shows the peculiar effect that volume control has only a minor effect in dB terms. At levels of 65 dB halving the traffic flow only reduces levels with $\Delta L[dB] = 10.\log(0{,}5) = -3\ dB$ to 62 dB. A tenfold reduction or increase relates to a + or -10 dB effect.

Although not always expressed explicitly, one may assume that all values for Lp, expressed in dB, are subjected to a frequency filtering that accounts for the sensitivity of the human ear. This filter is standardized by the A-weighting curve (see Wikipedia).

15.2 Sound power level

This term, refers to the amount of sound energy emitted per second by a source (car, train, aircraft,…). It is also expressed in decibels, but refers to the ratio of the total emitted power to the energy flow at the hearing threshold ($10^{-12}W/m^2$). Wikipedia give a nice explanation. For sound power applies the same rules for halving or 10-fold increase or decrease.

Also sound power levels can be assumed to be A-weighted.

15.3 Equivalent level

The effective noise dose is derived from equivalent level times the duration. The equivalent level over a time period T of a time varying signal Lp(t) of for instance passing vehicles on a road is defined as follows:

$$Leq = 10.log\left(\frac{1}{T}\int_T 10^{Lp(t)/10}.dt\right)$$

It expresses the sound level of a constant source with the same energy content.

15.4 Lden and Lnight

The generally used measure to define effective noise exposure is the Lden, which is the equivalent sound level averaged over a year. To account for the more sensitive evening and night periods, before averaging, the equivalent levels in the 4 hour evening period ($L_{evening}$) are increased with 5 dB and in the 8 hour night period (L_{night}) with 10 dB.

$$L_{DEN} = 10 \times \lg\left[\frac{12}{24}10^{L_{day}/10} + \frac{4}{24}10^{(L_{evening}+5)/10} + \frac{8}{24}10^{(L_{night}+10)/10}\right]$$

Since the night period is so essential for the health, an additional metric is used that only gives the equivalent level during the night period without the 10 dB correction factor. In the evaluation this higher sensitivity is of course included.

$$Lnight = 10.log\left(\frac{1}{8h}\int_{23:00}^{07:00} 10^{Lp(t)/10}.dt\right)$$

15.5 Basic calculation

The logarithmic nature is convenient for expressing sound levels, but make adding sources complicated as the rule of halving or doubling sound levels already indicates. One cannot just add the values.

$$L_{a+b} \neq L_a + L_b$$

The total effect of two sources with the same level is the same as doubling the source, i.e. +3dB. If levels are not the same has to calculate an energy related level, add them up and then taking the logarithm again:

$$L_{a+b} = 10.\log\left(10^{L_a/10} + 10^{L_b/10}\right)$$

Adding two signals with a 10 dB difference thus only increase the highest level with 0,4 dB.

$$53{,}0dB + 63{,}0dB = 10.\log\left(10^{53/10} + 10^{63/10}\right) = 63{,}4dB$$

So adding a source with the same frequency distribution but with a 10 dB lower level is not noticeable. However, if the source has another frequency distribution, then the human ear can detect much smaller changes. This feature is explained by the spectral integration area of the human ear, the critical band (see https://en.wikipedia.org/wiki/Critical_band)

The rules of addition applies for in coherent sources, i.e. sources emitting waves that has no fixed relation with each other. A special case are coherent sources, where waves have a fixed relation in phase. In certain cases adding two identical coherent sources can lead to complete cancelation of the sound (destructive interference). This effect is used in active sound cancelation (see https://en.wikipedia.org/wiki/Active_noise_control). Headphones with this technology are popular in aircrafts.

Similar technology finds its way in modern vehicles to improve the interior sound quality. For instance, when some cylinders of a 6 or 8 cylinder engine are shut down for fuel efficiency reasons, the degraded sound experience is restored by artificially adding the missing acoustic components into the interior.