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Value for Money in Road Traffic Noise Abatement

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REPORT TYRE AND VEHICLE NOISE

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Executive summary

Road traffic noise has become a significant problem in our society. The steady increase in noise levels is mainly due to the persistent growth in traffic. Urbanization, people moving from rural, quiet areas to noisier environments, also leads to increased exposure.

The purpose of this report is to provide support when strategies, plans and positions for future actions are discussed in order to reduce adverse noise effects more effectively. To give a recommendation on which strategy will be most beneficial for society in general, this report focuses on reduction in noise annoyance and the associated cost of implementing various noise abatement measures.

There are approximately 100 million inhabitants in Europe[1] annoyed by road traffic noise. Table 1 lists the main results when EUR 6 billion is invested in different noise mitigation measures, showing that the cost of reducing noise annoyance in a 20-year perspective varies from EUR 16 per person per year to EUR 4200 per year. Handling noise at source is by far the most cost-effective measure for reducing noise annoyance. There is on-going work in the European Union to update the current vehicle noise emission standards, and the present results illustrate that more stringent standards to reduce noise from vehicles will give very good value for money.

Table 1 Possible noise abatement measures, their potential for reduction in road traffic noise annoyance and the cost (per year) of making one person not annoyed anymore (reduce the noise annoyance by one)

Noise abatement measure	Reduction in annoyance	Cost of reducing annoyance by one (EUR per year)	Limitations on use
Vehicle noise reduction (5 dB)	31.5 mill	16	None
Vehicle noise reduction (3 dB) = EC proposal	19.7 mill	18	None
Thin Layer asphalt	2.4 mill	136	Not motorways (with high speed and density)
Porous asphalt single layer	1.1 mill	290	Only motorways (high speed and space for drainage)
Façade insulation (2 windows), same effect as outdoor measures	0.8 mill	360	None (indoor effect only)
Façade insulation (2 windows), effect 60 % of outdoor measures	0.5 mill	570	None (indoor effect only)
Porous asphalt double layer	0.3 mill	940	Only motorways (high speed and space for drainage)
Noise barriers	0.2 mill	4200	Not in narrow streets

[1]The 27 EU countries + Switzerland + Norway (2010)

Road authorities can work on three different noise abatement strategies:

a. International regulations on the noise sources

For society in general, it is important for road authorities to push for the vehicles to be quieter. Reducing noise from vehicles is more than seven times less expensive than any other measure outlined above. This could be undertaken by the following three actions.

1) Advising national governments to have a position on the proposal for Regulation on sound level of motor vehicles, COM(2011)856, which includes strict noise limits and long-term strategy for noise reduction.
2) Advising national governments to have a position when the Regulation concerning type-approval requirements for the general safety of motor vehicles, their trailers and systems, components and separate technical units intended therefore, (EC) No 661/2009, will be revised. Such position may include a long-term strategy in reduction of noise limits and paying particular attention to tyres for heavy vehicles.
3) Advising national governments to promote use of low noise tyres.

b. National measures to be fulfilled by road administrations

When following this strategy, the road administrations should exploit noise abatement measures in the following manner.

- Use thin layer asphalt as the preferred measure to reduce the general noise annoyance.
- Porous double layer asphalt is significantly more costly than single layer, even though the noise reduction is doubled. Porous double layer asphalt is probably more suitable as a local measure than a measure to reduce the general noise annoyance, because single layer gives more value for money.
- Continue research and testing in order to develop new, better and more cost effective low noise pavements.

c. Local measures - Reduce noise exposure at a specific location

There might be legal obligations to reduce the noise to a certain noise level and the local circumstances might alter the costs and benefits for each possible measure substantially. Noise barriers and façade insulation are examples of such local measures.

This report does not give further guidance related to these specific local cases.

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1 Mandate

This report was prepared by the CEDR Project Group Road Noise (CEDR PG Road Noise). CEDR, Conference of European Directors of Roads, is a non-profit organization with 24 member countries. 17 member countries participated in the Road Noise working group. The strategic goals for the work are listed in the CEDR Strategic Plan 2009-13 (CEDR, 2008). In SP2, the road noise topic is part of the Thematic Domain (TD) Construction. TD Construction shall focus on the role of the National Road Authorities in monitoring developments in the fields of standards and EU directives, as well as in environmental and road safety issues, and the goals are to:

- develop and share knowledge on a sustainable infrastructure;
- take appropriate action on EU directives;
- monitor European lawmaking;
- establish and update modern standards in line with the objectives of the National Road Authorities.

As representatives for the road authorities, the CEDR PG Road Noise has focused primarily on the noise information that was available in the TNO-report (TNO, 2011), commissioned by the EU Commission, DG Enterprise and Industry.

2 Introduction

Over the years noise from road traffic has become a significant problem in our society. Other traffic related health-sensitive issues such as traffic safety and air pollution seem to be gradually improving, however, the problems associated with road traffic noise continue to grow. The negative trend for road traffic noise is due to an increase in noise emissions and exposure to road traffic noise. The increase in noise emissions is mainly due to a constant growth in vehicular traffic and the fact that noise generated by each vehicle and its tyres has not been significantly reduced in recent years. Urbanization, people moving from rural quiet areas to noisier environments, and new roads also lead to an increase in exposure. The actions taken during the last decades against environmental noise are not adequate to compensate for these changes.

This report compares the effectiveness of different types of noise abatement measures to reduce noise annoyance in relation to the cost of each of these measures. The noise abatement measures investigated are noise barriers, facade insulation, quieter road surfaces and development and production of quieter vehicles. Also, tyre noise is considered in the report, but the lack of information on tyres has lead to a different approach been adopted for tyres than for the other measures. Information concerning noise barriers, facade insulation and quieter road surfaces is gathered and reviewed by the CEDR PG Road Noise to give the most updated information.

The purpose of this report is to provide support for strategies, plans and stakeholder positions for future actions for cost effective solutions to reduce adverse noise effects. This way, more noise reduction can be achieved for every euro spent on noise abatement.

3 Noise exposure in Europe

This report is based on noise exposure data obtained from the European Environmental Agency (EEA) and the European Topic Centre on Land Use and Spatial Information (ETC LUSI), on behalf of the European Commission. This is the latest noise exposure data for Europe.

For noise exposure affecting all people in Europe, we have adjusted the distribution of noise exposure of agglomerations (given in the EEA data) to reflect the fact that the total population of Europe is a little less noise exposed compared to people living in agglomerations. This approach is in accordance with the TNO report, where it is argued that 44 % of the people are exposed to noise levels above 55 dB L_{den}[2] in total, compared to data from EEA stating that 51 % of inhabitants in agglomerations are exposed to noise above 55 dB L_{den}. Some roads have restrictions or very low traffic flow and some dwellings are quite far from the nearest road, therefore, as a consequence approximately 10 % of the population in Europe is hardly exposed to any traffic noise (TNO, 2011). In this report no traffic noise exposure equate to exposure less than 40 dB L_{den}.

Accurate information on noise levels for all people in Europe exposed to road traffic noise is not available. Hence, a best estimate of noise exposure in 5 dB intervals has been used. As a point of reference, a representative value somewhat lower than the average for each interval is identified and used in the calculations, i.e., 67 dB L_{den} is the point of reference for the interval 65.0 – 69.9 dB. This simplifies the calculation of annoyance and gives a satisfactory accuracy for our purpose.

There is currently no information regarding the internal distribution between the three noise bands 40-44, 45-49 and 50-54 dB. Hence, the choice has been to use an even distribution, see Figure 1. It fits quite appropriately with the more substantial noise interval data and tends to be on the conservative side, therefore, it does not overestimate the noise exposure.

The noise exposure distribution (in percent) of people living in agglomerations is used for calculation of measures mainly implemented in agglomerations or densely populated areas. The noise exposure distribution for all people of Europe is used for the calculations of benefits for vehicles. This is because vehicles influence the entire road network and just not only people living in agglomerations.

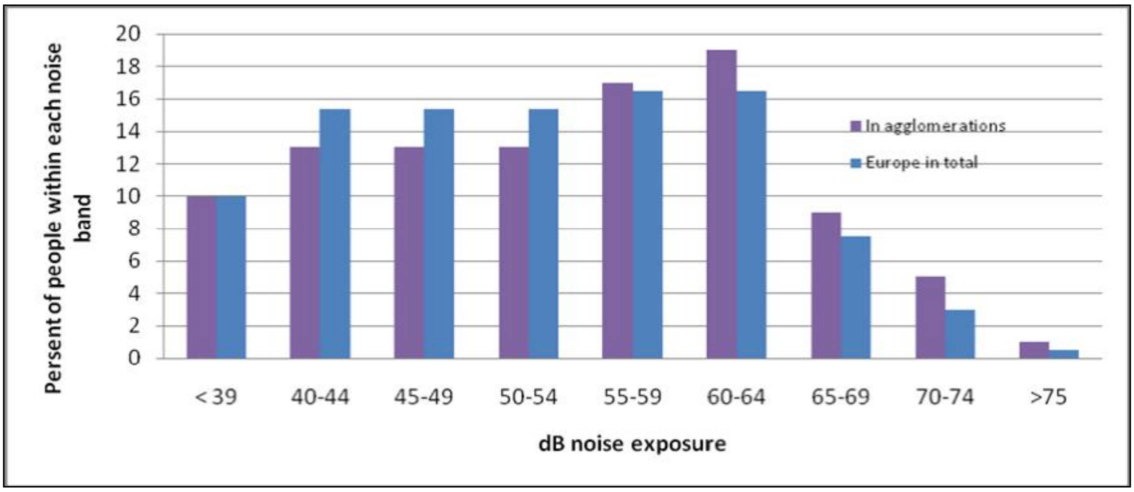

Figure 1 Distribution of people (in percent) in noise bands inside agglomerations and for Europe in total

[2] L_{den} is the A-weighted long-term average noise level, determined for all the day, evening and night periods of a year, as defined in the Directive 2002/49/EC.

4 Annoyance

To investigate possible strategies for governments to pursue noise abatement and give a recommendation on which strategy will be most beneficial for society at large, this report focuses on reduction in noise annoyance. Out of the 514 million people in Europe in 2010 (EU27 + CH + NO) there are 98 million people annoyed by road traffic noise (Annex A). Any measure implemented will change the number of annoyed people at a certain cost. This cost is divided by the number of people no longer "annoyed" as a result of implementing a certain measure. This is the cost of reducing the noise annoyance by one.

4.1 Why annoyance?

It is not easy to find an exact monetary value when calculating the benefit of noise reduction, as it varies a lot between different countries. However, the degree of annoyance is less discussed. According to the WHO (2011) noise annoyance is widely accepted as an end-point of environmental noise that can be used as a basis for evaluating the impact of noise on the exposed population. A definition of annoyance is given by the European Commission Noise Team (2000): *Annoyance is the scientific expression for the non-specific disturbance by noise, as reported in field surveys*. By choosing annoyance as our measurement for noise impact, we restrict the noise problem to concern only those negatively affected by noise at a given noise level.

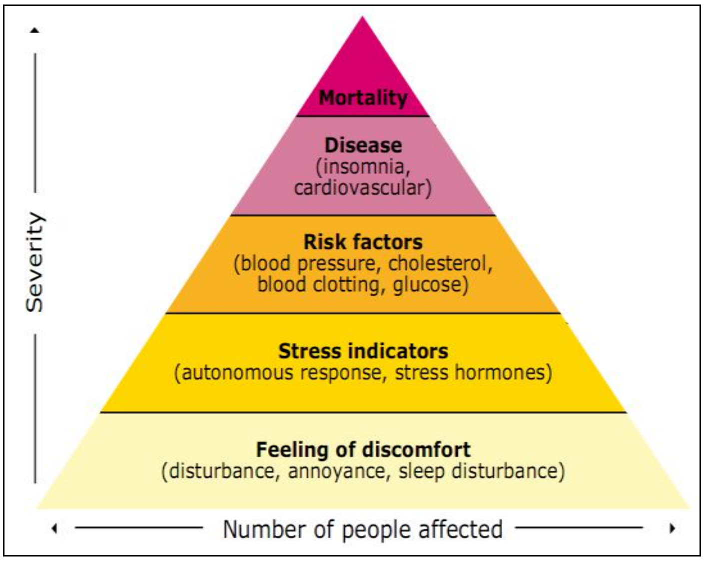

Figure 2 WHO pyramid of health effects of noise

A change in the number of people being annoyed has a value to each individual as well as to society at large. Looking at the reduction in noise annoyance reflects the value of a noise abatement measure. Both "annoyed" and "highly annoyed" are well accepted indicators. It could be argued that the indicator "highly annoyed" is likely to better reflect the direct health effects from noise exposure. It is assumed that people being highly annoyed to a larger extent will be disturbed and wake up in the night, be more exposed to increased blood pressure and reduction in DALYs (expected life years) as expressed by WHO (2011). Because of this both indicators have been investigated. The results of the calculations of reduction in "annoyed" and "highly annoyed" will be compared in the analysis.

4.2 How annoyance is calculated

Annoyance is calculated as a percentage of the population likely to be annoyed when exposed to a specific noise level L_{den}. There is a large variation in individual annoyance reaction. However, most policy is developed according to the overall reaction to exposure in the population. The annoyance curves that have been found by Miedema and Oudshoorn have rather narrow confidence intervals, which means that the curves are known rather accurately for the population as a whole (Miedema et al, 2001).The noise exposure data is used in the following annoyance equation for road traffic noise:

(1) $$\%A = 1.795 * 10^{-4}(L_{DEN} - 37)^3 + 2.11 * 10^{-2}(L_{DEN} - 37)^2 + 0.5353(L_{DEN} - 37)$$

where A is the percentage of the respondents who at a given noise level L_{den} will find traffic noise annoying.

(2) $$\%HA = 9.868 * 10^{-4}(L_{DEN} - 42)^3 - 1.436 * 10^{-2}(L_{DEN} - 42)^2 + 0.5118(L_{DEN} - 42)$$

where HA is the percentage of the respondents who at a given noise level L_{den} will find traffic noise highly annoying.

Figure 3 illustrates the difference between "annoyed" and "highly annoyed". For every measure evaluated we have first calculated the number of people affected by the noise reduction, and then the reduction in annoyance per noise band (as given in Figure 1).

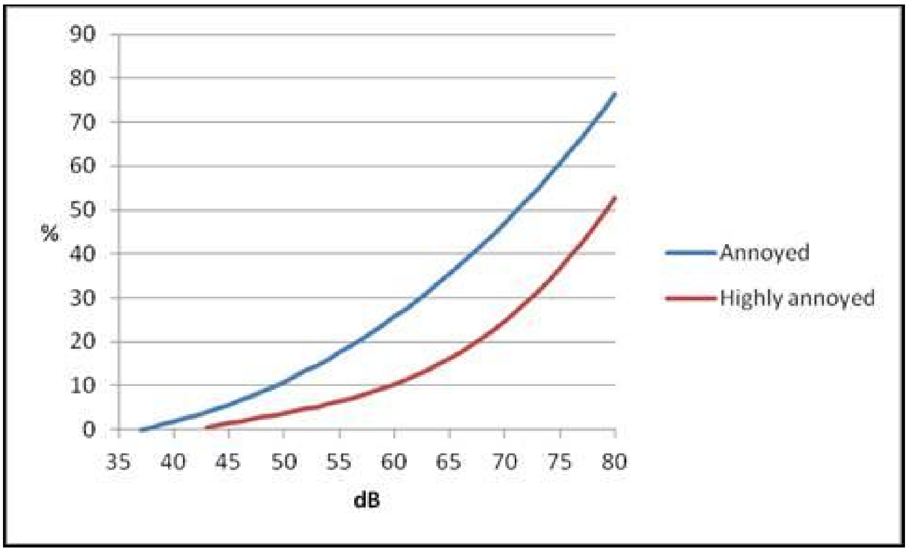

Figure 3 The likelihood of being annoyed and highly annoyed when exposed to road noise (expressed in percent)

5 People affected by reduction in road traffic noise

The reduction in calculated annoyance and the corresponding cost effectiveness of a noise barrier or a noise reducing road surface will depend on the number of people affected. This depends further on the type of road in close proximity to where they live. Table 2 illustrates the variation between different road categories and the number of inhabitants per km alongside each category of road. The numbers of exposed people per km are estimates from noise mapping and demographic data. The data in Table 2 is the basis when calculating how many people will be affected by a noise reducing measure. For example, noise barriers will be most effective when used on urban motorways, where there are about 1000 inhabitants per km.

Table 2 Type of roads and how they are categorized (TNO, 2011)

Road type	Residential urban/ suburban	Residential urban/ suburban	Main roads urban/ suburban	Main roads urban/ suburban	Arterial roads urban/ suburban	Urban motorways urban/ suburban	Rural motorways	Rural roads	Total
Traffic type	inter-mittent	free flow	inter-mittent	free flow	free flow	free flow	free flow	free flow	
Speed range (km/h)	<50	<50	<50	<50	50-70	70-120	80-130	50-100	
Full road length (km)	581 210	1 180 033	49 818	101 146	100 643	5032	95 610	2 918 633	5 032 125
Percentage of total road network	12 %	23 %	1 %	2 %	2 %	0.1 %	2 %	58 %	100 %
Estimated avg. exposed inhabitants (per km)	250	250	500	500	500	1000	40	20	

6 Cost calculations

To make the measures easily comparable, our approach has been to look at a total spending of EUR 6 billion in net present value for each type of measure. This amount of money is chosen since the "option 5" in the TNO report (2011) on vehicle noise is estimated to cost EUR 5.993 billion (rounded off to EUR 6 billion in this report). The "option 5" implies stricter noise limits for vehicles, giving an average noise reduction for the vehicle fleet of 3.1 dB when fully implemented. In spring 2011, "option 5" was presented to EU working groups on noise as the recommended suggestions for new type approval limits for vehicles. In December 2011, this option was implemented in Proposal for a Regulation of the European Parliament and of the Council on sound level of motor vehicles, COM(2011) 856 final.

6.1 Additional costs for investment and maintenance

The additional costs of implementing noise mitigation measures are compared to the changes in noise level and annoyance. In the case of resurfacing roads, only the additional cost of implementing a noise reducing surface, compared to normal asphalt, and the additional cost for maintenance are included in the calculations. In the case of façade insulation, only costs due to noise considerations in the refurbishing of a dwelling is used and matched with the reduction in annoyance for the people living in the dwelling.

When implementing the different measures, the investment costs are mostly due in year one (immediately). The maintenance costs are distributed over the 20 years calculation period. This planning horizon fits the data accessible from the TNO report (2011) and has been implemented when calculating all other measures. The cost distribution (investment and maintenance) over time is expected to vary. The measures without any maintenance costs or need for remaking in a 20 year period, will have all EUR 6 billion spent on the initial investment. For road surfaces, the cost distribution is calculated with an initial investment, annual maintenance as well as repaving after 13-14 years. For vehicles, it is expected to be a five year research and development period followed by a larger production cost per vehicle when the new technology enters production (TNO, 2011). Due to the large difference in cost profile between different measures, net present value (NPV) is calculated to make them comparable, using a discount rate of 4 %.

6.2 Is EUR 6 billion an unrealistic amount of money?

To establish if EUR 6 billion is an unrealistic amount of money to spend on noise abatement measures, the sum of money was divided among European countries weighted on the number of inhabitants in each country (see Annex B). As illustrated in the annex, the length of noise barriers one could get in each country is not unrealistic. Denmark would get 24 km of noise barriers, Estonia 6 km and Ireland 20 km. For bigger and more densely populated countries like Germany and France, the length of noise barriers would be 361 km and 275 km, respectively. Some countries probably spend an amount of money of this magnitude today on noise barriers and façade insulation. Increased awareness of the negative health effects of noise, higher expectations on quality of new roads, stricter regulations etc., can lead to even higher expenses for noise measures in the European countries.

7 Noise abatement measures

The most common noise abatement measures for road traffic noise have been investigated. In addition, noise reduction as a consequence of stricter sound limits for type approval of vehicles and tyres have also been considered. The following noise measures are included in this report:

1. Noise barriers
2. Facade insulation of dwellings
3. Porous road surfaces (single and double layer)
4. Thin layer surfaces (dense)
5. Vehicle noise limits for type approval (3 and 5 dB)
6. Tyre noise limits for type approval

The 17 European countries participating in the CEDR PG Road Noise were consulted, using a questionnaire about effects and costs of the different common measures (point 1-4). From the responses received, average or representative values for Europe were chosen. These figures were distributed to the same group for comments and afterward discussed in a CEDR PG Road Noise meeting. From this iterative process, final values where concluded, see Annex C and Annex D. The data for changes in noise exposures and annoyance from vehicles is derived from the TNO report (2011). The CEDR group has not changed any information in the TNO report, which deals with vehicle noise reduction.

7.1 Noise barriers

Noise barriers are commonly used in road construction to reduce exposure to road traffic noise. They are usually not suited in city centre locations due to the lack of space between the road and the receiver. Noise barriers are costly and are mainly used as a local abatement measure to meet legal obligations. When we consider the effect of noise barriers (i.e., how many people benefit from the measure), the distribution for noise exposure in agglomerations is used.
Noise barriers along state roads are often 3 to 4 m high and constructed along urban motorways. A noise barrier is in general most effective for dwellings close to the barrier. As a consequence, not all dwellings behind a noise screen have the same reduction in noise levels. In general, the greater the distance between the receiver and the noise barrier, the less effective the noise barrier will be. In the calculations, this is taken into account by assuming that the people living behind a noise barrier are distributed in different noise bands. Those in the highest noise band, closest to the barrier, has a reduction of 8 dB (see Figure 4), those in the next noise band (a little further away) have a reduction of 7 dB, then 6 dB, 5 dB etc., until you only have an effect of 1 dB in the lowest noise band (40-44 dB).

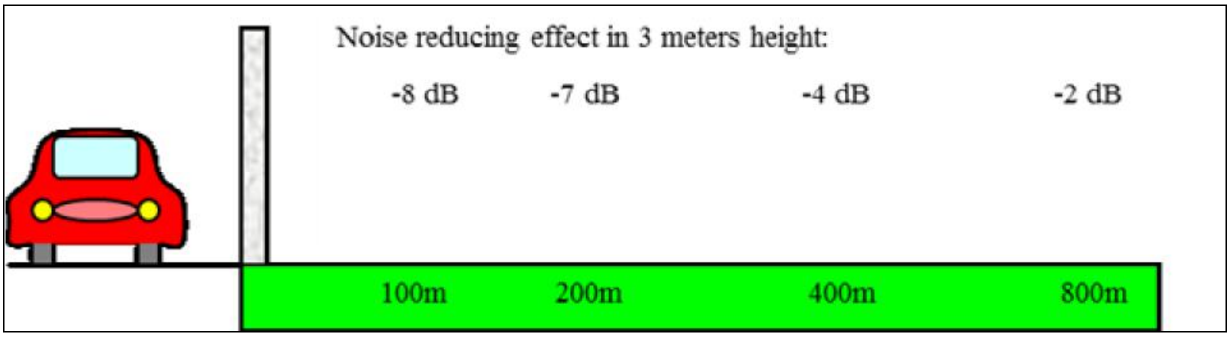

Figure 4 Example of noise reduction behind a 4 m high noise barrier (traffic volume 25 000, speed 80 km/h, heavy trucks 15 %, soft ground)

Costs

The average cost of a 4 m high noise barrier is EUR 1600 per linear m (EUR 400 per m²), and the annual cost for maintenance is EUR 77 per linear m. Investing EUR 6 billion in net present value in noise barriers will results in EUR 3.627 billion being used for investment in new noise barriers to be built in one year and having a lifetime of 20 years. This gives in total 2267 km of noise barriers, requiring an annual maintenance cost of EUR 175 million.

People affected

Noise barriers are assumed to be mostly used alongside urban motorways in agglomerations, which, according to Table 2, amounts to 1000 exposed people per km of road. To protect all these exposed people per km, there is a requirement to have noise barriers on both side of the road. Building 2267 km of noise barriers along 1134 km of roads will have an influence on 1 134 000 people. These affected inhabitants are distributed in noise bands according to the distribution for agglomerations. Those living closest to the road, with the highest noise exposure, will experience the largest noise reduction, in average 8 dB.

7.2 Facade insulation

Façade insulation can include new windows, doors, walls, ventilation etc., and it differs from country to country on how comprehensive this measure is. As result of the questionnaire to the CEDR PG Road Noise, the most effective and least costly option is used in our calculations: to replace two windows per dwelling.

Façade insulation is mainly used in urban areas. If the density of dwellings and people is low, façade insulation can also be the preferred choice alongside rural roads. Façade insulation will not improve the quality of outdoor recreational areas, as for example, the roadside noise barriers will. The exposure-response relationships for annoyance are based on outdoor noise levels.
A mitigation measure reducing only the inside noise level, and not the outside, is less likely to reduce the annoyance to the same extent. Due to lack of a methodology to calculate reduction of noise annoyance when only indoor noise level is reduced, we have used a simple approach and calculated two alternatives: (a) assuming full effect on annoyance reduction and (b) assuming 60 % effect on the annoyance reduction (WSP Analys&Strategi, 2012).

Costs

The cost of replacing two windows is set a EUR 3000 per dwelling. There are no maintenance costs and the windows will last for the entire calculation period of 20 years. Initially, all of the EUR 6 billion will be invested which will result in 2 million dwellings getting new windows.

People affected

Façade insulation is a measure used mainly for the highest noise levels, when other measures, like noise barriers, are not an option. Façade insulation is assumed to be a noise reducing measure for those exposed to the highest noise levels, and consequently only those with noise level greater than 65 dB is included in the calculation.
As calculated, 2 million dwellings will get new windows. Assuming 2.4 people living in each dwelling (Eurostat, 2010), 4.4 million people will get a noise reduction of 8 dB. The number of affected people will be the same regardless if we assume full effect on annoyance reduction or 60 % effect on the annoyance reduction, but the cost effectiveness will be less if the effect is only 60 %.

7.3 Porous road surfaces

In 65 % of the CEDR member states, noise is one parameter amongst a number of others that needs to be taken into account when choosing a new road surface. However, only 20 % of the member states include noise-reducing pavements in guidelines or similar documentation (CEDR, 2010). Porous asphalt is only used on a large scale on the motorways in the Netherlands. The Dutch "cost figures" for porous asphalt are used as a reference point for use of porous asphalt on a larger scale. Many countries would probably have to invest in development and test tracks, introduce procedures for testing the acoustic quality, the conformity of production etc., before starting to use porous asphalt on a regular basis. The costs for these adaptations are not taken into consideration.

The Netherlands use both one-and two-layer porous asphalt. One layer is less expensive, but also gives less noise reduction compared to the two-layer porous asphalt. Noise reduction of porous asphalt varies considerably during its lifetime, and a representative value for the average noise reduction is therefore chosen. The noise reduction as average for the lifetime is 2 dB and 4 dB, respectively for single and double layer, compared to dense asphalt concrete, DAC16, as a reference pavement. Cost and benefits have been calculated for both alternatives.

Costs

Spending EUR 6 billion on porous road surfaces will have to be split between investment and maintenance. For single layer porous road surface EUR 2.19 per m^2 is the additional cost compared to normal dense asphalt and a further spending of EUR 0.24 per m^2 on additional annual maintenance. For two-layer porous asphalt, the corresponding cost figures for investment are EUR 10.45 per m^2 and EUR 1.85 per m^2 for maintenance.

Roads that are identified to be appropriate for porous asphalt are assumed to be 25 m wide, 4 lanes with an additional emergency lane and the surface is expected in these calculations to give a life time expectancy of 13 years. To cover the time horizon of 20 years, a second resurfacing is included. This resurfacing will have half of its life time left at the end of the time horizon. Therefore, only half of the cost of the second resurfacing (EUR 1.095 and EUR 5.225 per m^2) is included.

Of the initial EUR 6 billion, EUR 2.20 billion will be available for the initial investment if single layer is chosen and EUR 1.67 billion if double layer is chosen. This will produce 40 232 km roads with single layer porous asphalt or 6 380 km double layer porous asphalt.

People affected

Porous asphalt is expected to be mainly used on urban motorways, which have high speed limits and a high density of inhabitants. If we assume that there are enough kilometres of urban motorways to spend EUR 6 billion (in total for investment and maintenance), a total number of 40.2 million people will experience a noise reduction if single layer is chosen, and 6.38 million people will experience a noise reduction if double layer is chosen. As for noise barriers, the affected inhabitants are distributed in noise bands according to the distribution for agglomerations. For porous asphalt the noise reduction is assumed to be the same for all inhabitants alongside the road, independent of the distance between dwelling and road, as long as the noise level is above 40 dB L_{den}.

7.4 Thin layer road surfaces

The noise reducing effect of thin layer surfaces is due to smaller aggregates size, sometimes with optimized mixes to make it semi-dense or have an open graded surface. Thin layer surfaces are used as noise reducing surfaces, but very few countries use these pavements to a large extent. Only Denmark and the Netherlands contributed with experience data. The CEDR PG Road Noise concluded that the Danish figures for costs, life time and noise reduction were representative of what could be expected with the use of such surfaces, therefore, these figures are used in the calculations.

In Denmark, a dense asphalt concrete with 11 mm aggregate (DAC11) is normally used as reference pavement. Compared to this reference pavement, thin layer surface has a noise reduction of 2 dB.

Costs

The additional cost for thin layer asphalt compared to normal DAC11 is EUR 1.5 EUR per m^2. Roads that are suitable for thin layers are assumed to be 18 m wide (4 lanes) with a lifetime expectancy of 14 years. The cost of the second resurfacing is only half (EUR 0.75 per m^2) since the second resurfacing will have half of its life time left at the end of the 20 year calculation period. There is no extra maintenance cost for thin layers. The roads are assumed to be 18 m wide, a normal two-line (sub)urban road. Out of the initial EUR 6 billion, EUR 4.799 billion will be available for the initial investment. This will produce 177 740 km road with noise reducing thin layer surface.

People affected

Noise reducing thin layer asphalt is expected to be used on suburban roads. Thin layers can be used on city streets where people live very close to the road. The affected inhabitants are distributed in noise bands according to the distribution for agglomerations. Assuming 500 people per km road, according to density alongside main roads in Table 2, spending EUR 6 billion would reduce noise exposure for 88.8 million people.

7.5 Vehicle noise limits for type approval

Noise limits for vehicles are under discussion in the EU. The European Commission DG Enterprise and Industry ordered a study which was undertaken by TNO Science and Industry on potential new noise limits and their associated effects on noise reduction and costs. Costs are calculated for society at large, but also for governments, auto industry and consumers. The TNO report (2011) gives the best available data on noise reduction of vehicles and the actual effect alongside roads.

As stated in paragraph 6, "option 5" in the TNO-report represents the ambition level in the Proposal for a Regulation of the European Parliament and of the Council on sound level of motor vehicles. The effect of limit changes on vehicle noise emission under real conditions depends on whether tyre or powertrain noise is dominant, which in turn depends on road surface, vehicle design, operating conditions, driving style and wear. In the TNO report, these factors are taken into consideration and the road traffic is distributed on different types of roads (Table 2). Depending on the type of road (speed, % heavy vehicles etc.) option 5 will reduce the L_{den} level by 2.7 to 4 dB alongside roads. The average noise reduction is 3.1 dB.

From a health perspective, it is desirable to have an even better noise reduction than 3 dB. The organisation Transport & Environment has commissioned an extension to the TNO report (2011) where a new option with 5 dB noise reduction is investigated (TNO, 2012). This alternative is added to the CEDR PG Road Noise calculations.

Costs

According to the TNO report (2011) the total cost for development and production of new vehicles which in real traffic gives a noise reduction of 3.1 dB is EUR 5.993 billion.
According to the TNO report (2012), commissioned for the European Federation for Transport and Environment[3], the total cost for development and production of new vehicles which in real traffic gives a noise reduction of 5 dB is EUR 10.2 billion.

[3] Transport and Environment is an international non-profit organization which represents, and is supported by about 50 organisations across Europe.

The authors are aware that a report written by UTAC and TUV Nord Mobilität on behalf of European Automobile Manufacturers' Association, ACEA (Pardo and Steven, 2010), estimates the costs to be much higher than given above. The production costs found in the report for ACEA are similar to those quoted in the TNO report (2011). In contrast, estimates of investment costs vary widely. The report for ACEA concludes that a 3 dB noise effective reduction of the limit values for M1 vehicles[4] would cost EUR 26 million for each vehicle type, whilst a 4 dB reduction would cost EUR 59 million. There are reasons to believe that the estimate from ACEA is far too high (Experts letter, 2012).

People affected

All people considered to be exposed to road traffic noise in Europe (90 % of the inhabitants) are also considered to be affected by the vehicle noise reduction. Therefore, we have used the distribution in noise bands to be representative for the whole of Europe and not only for the agglomerations. The people being exposed to road traffic noise will all have the same reduction in their noise exposure level. This measure takes effect gradually and will only be fully in place after all vehicles are replaced 12 years after coming into force of the new noise limits (TNO, 2011).

The number of annoyed people are based on the calculated L_{den} levels and exposed number of people alongside the different road types (Table 2). A 3.1 dB noise reduction for vehicles will, according to our calculations, give a reduction in annoyance for 19.7 million inhabitants. This is a little less than given in the TNO report itself (24 million), which is probably due to the extrapolation of inhabitants in TNO (2011). A 5 dB reduction in road traffic noise will affect the same people, and yield an even bigger reduction in annoyance.

7.6 Tyre noise limits for type approval

Tyres have a great impact on road traffic noise. Depending on the speed and gear, tyre/road noise can cause higher noise levels than the noise produced from the power train. For light vehicles, tyre/road noise is equal to power unit noise, or dominates, at speeds higher than 30-40 km/h. For heavy vehicles, the tyre/road noise dominates at speeds above 60-70 km/h. Differences in noise properties between different tyres indicate that there could be an important potential to mitigate noise from tyres in a cost effective way.

Both the FERHL report (2006) and TNO report (2011) have tried to establish the relationship between costs and benefits from investing in less noisy tyres. The FEHRL report concluded that the cost estimate figures the tyre industry, ETRTO, had offered to their investigation were considered to be very significant overestimates. According to the TNO report (2011), the tyre industry claims that the accumulated cost for a 3.1 dB noise reduction for vehicles, would result in a EUR 10.8 billion cost for the tyre industry (tyre noise also influence the type approval noise level for vehicles). In their conclusions, TNO has highlighted this cost for the tyre industry, but chosen not to take tyre cost into account when calculating the cost-benefit ratio. The authors of this CEDR report assume this is due to scepticism about the cost data.

Since there is a lack of data for costs connected to less noisy tyres, we have not been able to use the same approach for tyre noise reduction as for the other measures. Tyre noise is further discussed in chapter 10.

[4] Category M1 vehicles are used for the carriage of passengers and have no more than eight seats in addition to the driver's seat

8 Results

By dividing Net Present Value (NPV) of each measure by the change in number of people annoyed or highly annoyed, the cost of making one person not annoyed any more is derived. The initial investment for each measure depends on the spending needed for maintenance and repaving to maintain the noise characteristics of the measure in the 20-year period used for comparison. The initial investment available is divided by the cost per unit to implement the measure. Then, the volume of each measure is multiplied by the number of people affected per unit of volume, to get the total number of people affected. A summary of the results is given in Table 3.

Table 3 The initial investment costs for the different abatement measures leads to a given amount of noise barriers, new windows etc., and from this the number of people who gets a noise reduction is calculated.

	Initial investment in billion EUR	Cost per unit	Volume of abatement measure	People affected per unit
Noise barrier	3.627	EUR 400 per m^2	2 238 km (4 m high)	500 per km*
Façade	6	EUR 3000 per dwelling	2 mill dwellings	2.4 per dwelling
Porous asphalt single layer	2.082	EUR 2.14 per m^2	38 825 km	1000 per km
Porous asphalt double layer	1.610	EUR 10.45 per m^2	6 155 km	1000 per km
Thin layer	4.418	EUR 1.5 per m^2	163 632 km	500 per km
Vehicle (3 dB)	5.993**		All vehicles	All people exposed to traffic noise (> 40 dB)
Vehicle (5 dB)	10.2**		All vehicles	All people exposed to traffic noise (> 40 dB)

* 1 km noise barriers cover 0.5 km road (need screens on both sides of the road)
** The costs for vehicles include both R&D and extra production costs due to stricter noise limits

Reduction in noise annoyance

From Table 3, the number of people affected by each type of noise abatement measure can be derived, distributed in noise bands and the reduction in annoyance can be calculated. Table 4 sums up the calculated change in annoyance, and the cost of reducing the annoyance score by one, if EUR 6 billion in net present value is spent on any of the given measures.

Table 4 Overview of how an investment of EUR 6 billion will reduce the number of people annoyed by road traffic noise, and the cost of making one person not annoyed anymore (reduce the noise annoyance by one).

Measure	Noise reduction (dB)	People affected (million)	Reduction in annoyance	Cost of reducing annoyance by one (per year in EUR)
Noise barrier	8 – 1	1.12	71 500	4200
Façade insulation	8	4.8	834 000	360
Façade insulation (60 % effect)	8	4.8	500 000	570
Porous double layer	4	6.2	320 000	940
Porous single layer	2	38.8	1 050 000	290
Thin layer asphalt	2	81.8	2 200 000	136
Vehicle noise (3 dB)	3.1	463.0	19 664 000	18
Vehicle noise (5 dB)	5.2	463.0	31 525 000	16

Table 5 summarizes the calculated change in highly annoyed, and the cost of reducing the "highly annoyed" score by one if EUR 6 billion in net present value is spent on any of the given measures.

Table 5 Overview of how an investment of EUR 6 billion will reduce the number of people highly annoyed by road traffic noise, and the cost per year of making one person not "highly annoyed" anymore (reducing "highly annoyed" by one)

Measure	Noise reduction (dB)	People affected (million)	Reduction in highly annoyed	Cost of reducing one person from highly annoyed (per year in EUR)
Noise barrier	8 – 1	0.86	40 000	7500
Façade insulation	8	4.8	345 000	870
Façade insulation (60 % effect)	8	4.8	230 000	1300
Porous double layer	4	4.9	165 000	1800
Porous single layer	2	29.9	553 000	540
Thin layer asphalt	2	63.0	1 266 000	260
Vehicle noise (3 dB)	3.1	384.0	9 616 000	36
Vehicle noise (5 dB)	5.2	384.0	15 244 000	34

The difference in the number of "people affected" in Table 4 and Table 5 is caused by the people in the noise band between 40 and 42 dB. In the calculations we have a cut-off at 40 dB, and all dwellings above 40 dB are counted as affected. The graph for "highly annoyed", however, starts at

42 dB. Hence, there are less people affected when we count only those above 42 dB. These people may be annoyed, but by definition never highly annoyed, and they are not included in the calculation of affected people.

Difference between annoyed and highly annoyed

As illustrated in Figure 2, there are less people highly annoyed than annoyed for a given noise level. Table 4 and Table 5 confirm this, and the cost per person "highly annoyed" is higher than for "annoyed" for all measures. The measures are in general doubled in cost. The relative difference between the costs is least for façade insulation and biggest for vehicle noise. Still, the same order of cost effectiveness is achieved for the annoyed and highly annoyed. The sensitivity analysis, discussion and conclusion will focus on the annoyed.

9 Sensitivity analysis

In order to get a better understanding of the robustness of the results and to get a second opinion of our calculations, an external run of sensitivity analysis has been conducted by the Institute of Transport Economics in Norway. They have performed a sensitivity analysis, but they have not reviewed the input factors used in this report. Their conclusion is that the calculations appear reasonable and the sensitivity analysis underlines the results in this report.

For running the sensitivity analysis, a web based tool developed in the EU project HOSANNA, has been used. Uncertainty is set at plus and minus 30 % on all costs and benefits. The uncertainty analysis is performed by making 10 000 Monte Carlo simulations. The results of the sensitivity analysis are illustrated in Figure 5, and the report is given as Annex F.

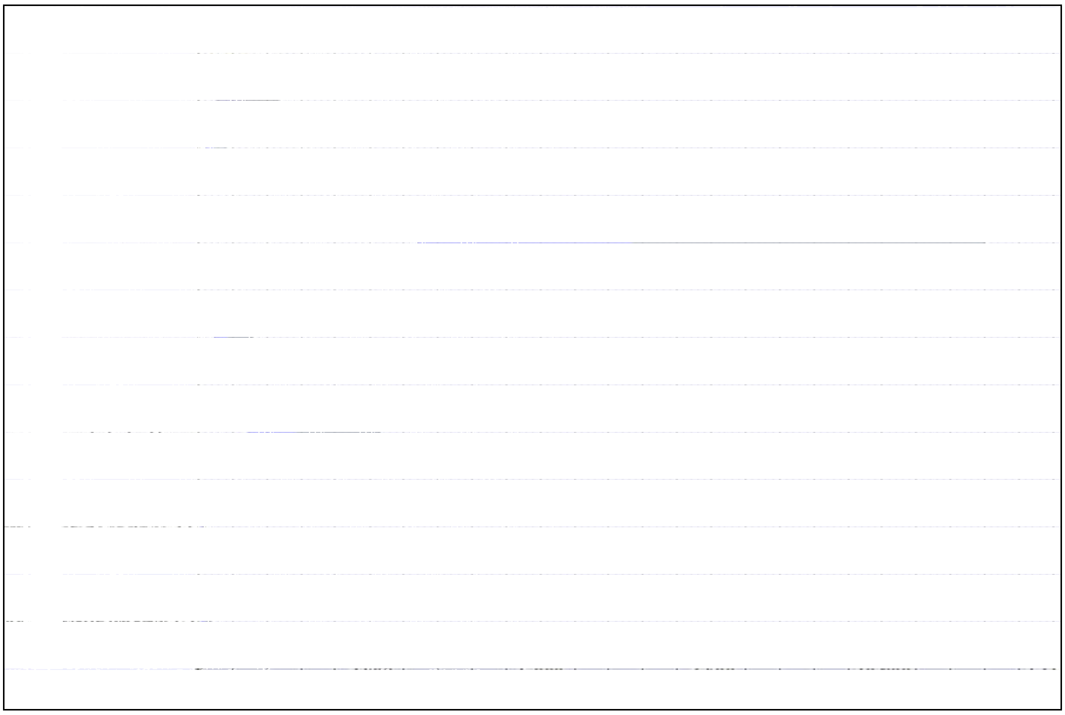

Figure 5 The abscissa axis shows the simulated cost effectiveness results (costs of reducing annoyance by one) and the uncertainty (lilac to the left and grey to the right of the simulated point estimate); which are comparable to 90 % confidence intervals (5 % to either side).

From the sensitivity analysis we can conclude that stricter noise limits for vehicles, reduction of 3.1 dB, will perform economically better than the competing alternatives – given that actual costs and benefits lie within the specified uncertainties.

From the vehicle industry it is claimed that real life noise level will not be reduced by 3.1 dB, as stated in the TNO report (2011), but only by 1.5 dB. As a worst case scenario, the sensitivity analysis is also performed with only 1.5 dB noise reduction. With a noise reduction of 1.5 dB instead of 3.1 dB, there is a very slight chance that thin layer asphalt could perform economically better than the integrated vehicle package.

10 What about tyres?

Two methods can be used to compare reduction of tyre noise with other noise mitigation measures:

a) To calculate costs to make one person not annoyed with estimated noise reduction and estimated extra costs for development and production. This is the same approach as for the other measures in this report. However, the result will have very high uncertainty, based on very poor information of extra costs, as stated in paragraph 7.6.

b) To calculate how much extra cost one could accept on tyres compared to other noise abatement measures. This is the reverse way of calculating the costs; a given cost per person not annoyed will lead to a given cost per tyre. The results will illustrate what extra costs will yield the same effectiveness as for the other measures.

Since we have not found reliable cost figures for noise reduction of tyres, we choose to reverse the calculations, as described in b). We turn the question "up-side-down" and ask: If society requires equal cost effectiveness for tyres, as for other measures, how much extra could society (producer and/or consumer) pay per tyre?

The following assumptions are made:

- There are about 243 122 000 vehicles in Europe today. If these vehicles change tyres every fourth years, the associated annual sales of tyres will be 243 122 000.
- The average price for one tyre is EUR 80 (based on prices given in figures in Annex E)
- The potential for noise reduction from tyres are assumed to be 1-2 dB (on the road), and calculations are made for 1 dB and for 2 dB.

Example of the calculations made:

Using thin layer asphalt, the cost of reducing annoyance by one is EUR 136 per year, and the Net Present Cost (NPC) of keeping one person not annoyed anymore for 20 years is EUR 2720. If tyres could reduce noise by 1 dB (compared to 2 dB for thin layers), and all people being annoyed gets a noise reduction, since tyres affect the whole population, this will reduce the number of people annoyed by 6.6 million. To be as cost effective as thin layers, the cost per annoyed can be up to EUR 2720, which is <u>the break even point</u> between thin layer asphalt and less noisy tyres.

Multiplying number of reduction in annoyance (6 631 400 inhabitants) with EUR 2720 gives us the total cost, NPC. The total cost is divided by the total amount of tyres bought in the 20-year period (243 122 000 tyres*20). This gives us the accepted additional cost per tyre of EUR 3.71.

Hence, if the tyre cost EUR 80 without noise reducing effect, society should accept a 5 % increase in tyre cost due to noise reductions if the same cost effectiveness as with thin layer asphalt is required.

This calculation is repeated for all measures and for 1 and 2 dB noise reduction for the tyres and it is displayed in Table 6.

Table 6 How much tyres can increase in price to equal the cost of other noise measures

	Tires - 1 dB reduction		Tyres - 2 dB reduction	
Measure to be equalized	Extra cost per tyre (EUR)	Percent increase in tyre price	Extra cost per tyre (EUR)	Percent increase in tyre price
Vehicle, 3.1 dB	0.5	0.6 %	0.9	1 %
Thin-layer asphalt	3.7	5 %	7.3	9 %
Porous, single-layer asphalt	5.8	7 %	11.3	14 %
Façade insulation	10.7	13 %	21.0	26 %
Porous, double-layer asphalt	25.7	32 %	50.2	63 %
Noise barriers	113	141 %	221.3	277 %

As Table 6 illustrates, the society can accept a significant increase in tyre price to reach the same reduction in noise annoyance as façade insulation, noise reducing porous double layer asphalt or noise barriers. But less noisy tyres can only have an extra cost of 0.6-1 % to be as cost effective as stricter noise limits for vehicles.

Example 1: If tyres can be produced with noise levels 2 dB lower than the average today, and we want the tyre noise reduction to be an abatement measure just as cost effective as façade insulations, then the tyre price can be 26 % higher than it is today.

Example 2: If tyres can be produced with noise levels 1 dB lower than the average today, and we want tyre noise reduction to be as cost effective as thin-layer asphalt, then we can accept a 5 % increase in tyre price.

An area requiring more work is noise emission from heavy vehicle tyres, since these tyres appear to have very liberal noise emission limits as outlined in Regulation (EC) No 661/2009. In addition, re-treaded tyres are not included in the Regulations, although they represent a significant part of the tyre fleet for heavy vehicles in some countries.

Currently trucks are a significant source of night time noise emission on motorways and this will probably become more pronounced in the future. A substantial increase in heavy vehicle traffic is expected to occur in Europe in the next couple of decades. Originally, the EU Commission proposed more stringent and quite effective noise limits for truck and bus tyres, but later decisions in the EU Parliament and in the Council almost entirely eliminated these improvements.

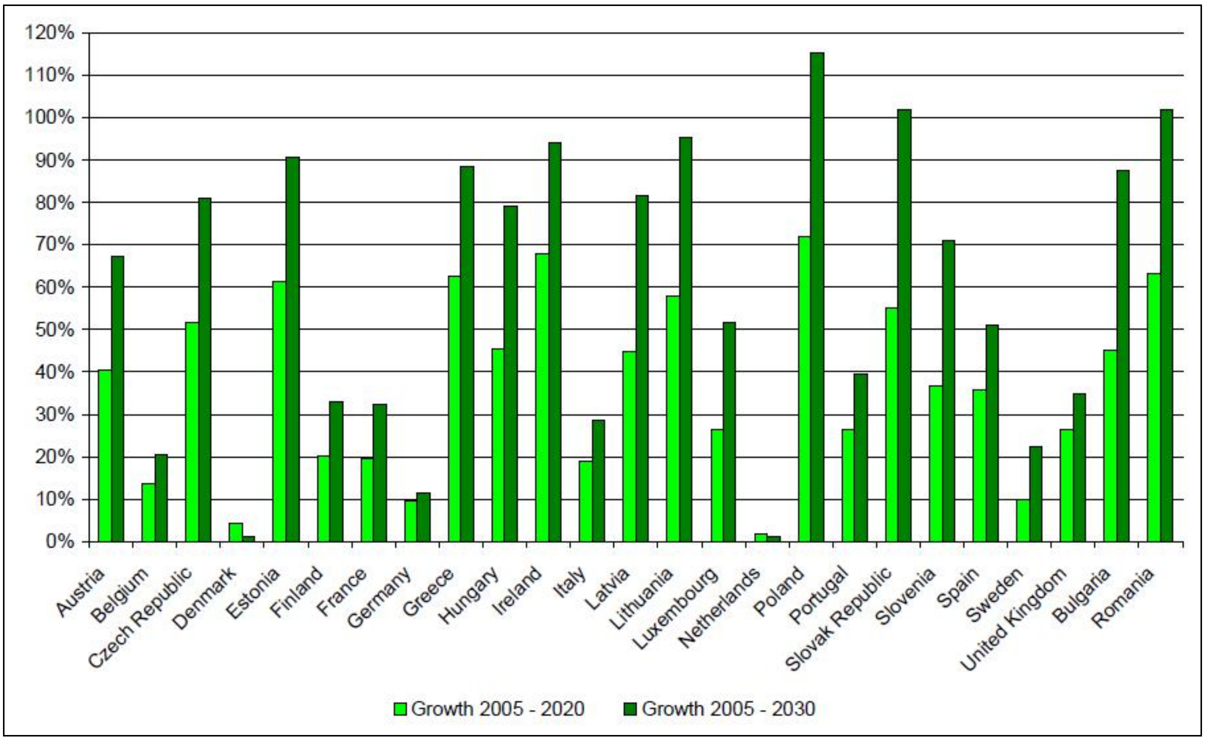

Figure 6 Predicted growth in tonne-km transported by trucks in EU27 from 2005 to 2020 and 2030 [Rich & Hansen, 2009]

Do strict noise limits result in bad performing tyres?

During the hearing on the Regulation that includes noise limits for tyres, *Regulation (EC) No 661/2009 concerning type-approval requirements for the general safety of motor vehicles, their trailers and systems, components and separate technical units intended therefor*, the consequences of stricter noise limits were considered. The relationships and trade-offs between noise and the other parameters, wet grip, rolling resistance and price, were investigated. Annex E gives a brief summary of findings. The data in Annex E relates to car tyres (C1 tyres). It seems sufficient data for C2 and C3 tyres (vans and heavy vehicles) have not been available. Lack of available data for truck tyres may have been one reason why the most lenient noise limit reductions were applied to truck tyres in 2009.

11 Discussion

The trends of increasing urbanization and traffic growth are anticipated to continue into the future. Today, approximately 100 million inhabitants in Europe are annoyed by road traffic noise. To date, the extensive (and costly) noise mitigation measures have not been adequate to counteract the negative trend in general, however, local noise measures on hot spots have had a good effect. A recent Danish study observes that the road traffic noise level has been increasing by 0.5 dB every 5^{th} year since 1988 (Mette Sørensen et al., 2012). Trucks are a significant source of night time noise emission, and this will probably become more pronounced in the future. In addition, urbanization, people moving from rural, quiet areas to noisier environments, also leads to increased exposure.

Because of the elevated and growing costs associated with mitigating severe noise problems, it is important to explore the most cost effective measures that can be used regardless of who is in a position to undertake such measures and who is liable to fund such measures. This survey has been undertaken by comparing data from a report on vehicle noise limits and noise emission from vehicles (TNO report, 2011) with the experience of noise abatement costs and effectiveness of measures traditionally employed by road authorities (represented by CEDR project group Road Noise). This information was then used together with noise exposure data and formulae for calculating noise annoyance.

Measures taken at the noise source are the most effective measures and result in the best reduction in respects of noise-exposed people and noise annoyance. The most cost-effective measure to reduce noise annoyance is to mitigate vehicle noise because it is seven times more costly to improve road surfaces. Noise-reducing road surfaces, with the exception of double layer porous asphalt, are about half the price of facade insulation, in the form of window upgrade. The most expensive measure is the introduction of noise barriers. However, noise barriers, in contrast to façade insulation, also help to reduce noise in outdoor areas.

11.1 Limitations of the survey

In this report, each noise measure is evaluated separately and combined effects are not considered. Noise reducing effects from vehicles and road surfaces cannot be added without further investigation of how these measures interact. One exception is the noise reduction from vehicles, where tyre noise is included in the calculations of the actual effects of stricter noise limits for vehicles (TNO report 2011).

In this report other topics than noise are not considered. Traffic safety, climate and aesthetics are elements which can influence the choice of noise abatement measure, but such elements are not taken into account in our evaluation of preferred noise abatement measures. An example is porous asphalt which gives better traffic handling and reduces risk of aquaplaning. This is positive for traffic safety, and a factor one could also put a value on.

The chosen parameter to evaluate the benefit of noise reduction is reduction in annoyance. This is not always the most appropriate indicator to use when choosing noise abatement measures. Sometimes a severe noise reduction is required and local measures are the only alternative. Such measures are of importance for adapting to local needs. Local measures, like noise barriers and façade insulation, will always be of great importance when helping those exposed to the highest noise levels, where for example, 2 dB is not enough to yield a satisfactory noise level and/or comply with a regulation.

It should be stressed that assumptions have been made to simplify the calculations. Sensitivity analysis has therefore been performed to assess the veracity of the results. The findings are robust and the uncertainties, simplifications and limitations are not enough to invalidate the conclusions.

11.2 Annoyed versus Highly annoyed

Noise annoyance is an end-point of environmental noise that can be used as a basis for evaluating the impact of noise on the exposed population. Both "annoyed" and "highly annoyed" are calculated as a percentage of the population likely to be annoyed/highly annoyed when exposed to a specific noise level. To control the consequence of our choice of metric for evaluation of noise impacts, we made calculations for cost effectiveness for both "annoyed" and "highly annoyed". As shown in Table 4 and Table 5, most measures are doubled in cost when changing from reduction in "annoyed" to reduction in "highly annoyed", but the ranking of measures are exactly the same. Changing the metric for impact evaluation will not change the preference of the noise abatement measure.

11.3 Variations in cost in European countries

The cost for noise abatement measures varies significantly between member states. The costs chosen in our calculations are assumed to be representative as European averages when the measures are in common use. For many countries, porous asphalt is not an alternative within their normal road surfaces, and therefore, the cost per m^2 is significantly higher, making this measure more costly than shown in our calculations. Material and building costs also vary, and the CEDR members gave values from EUR 100 (Ireland) to EUR 1000 (Finland) per m^2 for noise barriers. By assessing each measure individually, the CEDR PG Road Noise has managed to agree upon representative values, which are used in the calculations of costs. The sensitivity analyses, Figure 5, demonstrate that a variation of +/- 30 % in the cost figures will not change the ranking of the different measures.

11.4 On-going discussion in Europe on regulations and directives

Noise emissions from four-wheel motor vehicles are addressed by Directive 70/157/EEC and the equivalent UN/ECE Regulation No. 51. These regulations are now under revision, after almost 20 years of no changes to the limit values. It has also been recognised that the latest reduction in 1995 did not produce the expected benefits, mainly because current test method do not reflect real world driving behaviour (CARS 21 High Level Group, 2012).

A proposal for a new EC regulation on sound level of motor vehicles was released in December 2011. At a meeting in Brussels in March 2011, the Commission presented a proposal for the CARS 21 working group 4 which is in line with "option 5" in the TNO report (2011). Hence, this option has been the basis for the work in CEDR PG Road Noise. By December 2012 the proposal for the new regulation has not yet been decided on in the European Parliament and the Council, and the discussions will continue in 2013.

Advising national governments to have a position on the proposal for Regulation on sound level of motor vehicles, COM(2011)856, which includes strict noise limits and long-term strategy for noise reduction, could be a way to go to for road authorities to push for vehicles to become quieter. The original proposal from the Commission has been opposed by the vehicle industry, trying to water down the proposed noise limits. Examples of arguments from industry and answers found in research and reports are given in Annex G.

Tyre noise is treated in Regulation (EC) No 661/2009. Lack of available data for truck tyres may have been one reason why truck tyres got very lenient noise limits in 2009. When speeds exceed 30-40 km/h for cars, and 60-70 km/h for heavy vehicles, tyre noise is the dominant noise source. According to the regulation, the Commission "…*should continue to assess the technical and* *economic feasibility and market maturity of other advanced safety features, and present a report, including, if appropriate, proposals for amendment to this Regulation, by 1 December 2012, and every three years thereafter*". To ensure that there will be a reduction in tyre noise which will consequently result in a reduction in general road traffic noise, it is important to urge national governments to have a position when the Regulations are being revised.

11.5 Summary of discussion

Road traffic noise is the most common cause of environmental noise in Europe, and WHO findings confirm causal links between noise and annoyance, sleep disturbance and stress responses, which can lead to increased risk of high blood pressure and cardiovascular diseases (WHO, 2011). The CEDR PG Road Noise believes that multiple measures are necessary to lower noise to acceptable levels for those highly exposed to traffic noise in accordance with recommendations from WHO (1999, 2009).

When the purpose is to reduce noise annoyance for as many people as possible for a given sum of money, or reduce the number of people annoyed by a certain number as economically as possible, this report concludes.

- Measures taken at the noise source are in general the most cost effective measures and result in the best reduction in respects of noise exposed people and noise annoyance.
- Stricter noise limits for vehicles are in particular the most cost-effective measures to reduce noise annoyance.
- To reduce noise annoyance, noise barriers are the most expensive of the measures investigated. This is a local measure to be used in special situations, but not a cost effective measure when it comes to reducing general noise annoyance problems on a national level.
- Low noise tyres are as safe as normal tyres, they do not wear any faster than normal tyres or result in higher CO_2 emissions.
- Multiple measures are necessary to bring the general road traffic noise level closer to acceptable levels in accordance with recommendations from WHO and to achieve significant reduction in noise annoyance.

12 Recommendations

In keeping with the central theme of the Environmental Noise Directive, national and community policies should aim to achieve high levels of health and environmental protection. The CEDR PG Road Noise believes the most cost effective actions to mitigate noise should be exploited. Road authorities can work on three different noise abatement strategies. Our recommendations are organised according to these strategies.

a. International regulations on noise sources

For society at large, it is important for road authorities to push for road vehicles and tyres to become quieter. Reducing noise from vehicles is the most cost effective abatement measure, and more than seven times less costly than any other abatement measure outlined in this report. This could be done by:

1) Advising national governments to have a position on the proposal for Regulation on sound level of motor vehicles, COM(2011)856, which includes strict noise limits and long-term strategy for noise reduction. More specific this might be:
   - Significantly stricter noise limits for cars and heavy vehicles, in accordance with the original proposal from the Commission.
   - A long-term strategy in noise limit reductions, i.e. a multistep/3-step approach with tightening of limits 2, 5 and 8 years after the Regulation enter into force. This will reduce noise and be predictable for the industry, and
   - A "not-to-exceed" maximum noise limit for all vehicles of 90 dB, for highly intrusive peak noise levels, such as when an engine is revved.
2) Advising national governments to have a position when the Regulation concerning type-approval requirements for the general safety of motor vehicles, their trailers and systems, components and separate technical units intended therefore, (EC) No 661/2009, will be revised which may include:
   - A long-term strategy in reduction of noise limits, which over time gives significantly stricter noise limits for all tyres,
   - Paying particular attention to tyres for heavy vehicles, as these tyres had the most lenient noise limit reduction in 2009, and
   - Include re-treaded tyres in the Regulation (EC) No 661/2009.
3) Advising national governments to promote use of low noise tyres. This can be done on a national level by i.e. incentive schemes.

b. National measures to be fulfilled by road administrations

When focusing on reducing noise annoyance, road administrations should exploit noise abatement measures in the following manner:

- Use thin layer asphalt as the preferred measure to reduce general noise annoyance.
- Porous double layer asphalt is significantly more costly than single layer, even though the noise reduction is doubled. Porous double layer asphalt is more cost effective than noise barriers, but probably more suitable as a local measure than a measure to reduce the general noise annoyance.
- Continue research and testing in order to develop new, better and more cost effective low noise pavements.

c. Local measures: Reduce noise exposure at a specific location

There might be legal obligations to reduce the noise to a certain noise level, i.e. when building a new road. Demand for a significant noise reduction and local circumstances might alter the costs and benefits for each possible measure substantially. Noise barriers and façade insulation are often such local measures.
This report does not give further guidance related to these specific cases.

13 Dissemination

The results from the CEDR PG Road Noise on comparison of different noise abatement measures have been presented in different forums.

- 23 November 2011. STOA-ERF workshop, Brussels. Paving the way for a quieter Europe. Preliminary results were presented. http://www.erf.be/
- 11 April 2012. Workshop on Sound level of motor vehicles, European Parliament, Brussels. Policy Department A: Economy & Science, Committee on the Environment, Public Health and Food Safety (ENVI) (Results presented in contribution from Nina Renshaw, Transport and Environment).
- 24 April 2012. TRA2012, Athens, Greece. Poster presentation by Ingunn Milford, Norwegian Public Roads Administration.
- 4-6 July 2012. AIA 2012, Italian Acoustic Association Annual Conference, Rome, Italy. Oral presentation by Patrizia Bellucci, ANAS S.p.A.
- 18 December 2012. Seminar concerning the Regulation on sound level of motor vehicles, COM(2011)856, Brussels. Presentation of draft report and results. (Summary in Annex H)

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Annex A Calculation of annoyance

The calculation of annoyance is done by using the annoyance formula as described in chapter 4. The likelihood of being annoyed depends on the level of noise people are exposed to. The distribution of people being exposed to noise is according to chapter 3.

We have calculated the likelihood of being annoyed, being in a specific noise band. Taking this likelihood and multiplying it with the number of people in Europe exposed to noise in this noise band, the number of annoyed people in this noise band is calculated. By summing up all annoyed people in the different noise bands the total number of people being annoyed is found.

This is done for populations in European agglomerations as well as the European population in total.

The TNO report (2011) presumes that 10 % of the population is not exposed to road traffic. The table below includes EU27 plus Norway and Switzerland.

		In agglomerations (2007)				Total (2007)			
		Exposed people		People annoyed		Exposed people		People annoyed	
Noise band (dB)	Mean of noise band (dB)	% of population	Million people	% per noise band	Million people	% of population	Million people	% per noise band	Million people
<39	37	10	51.40	0.0	0.00	10	51.40	0.0	0.00
40-44	42	13	66.82	3.2	2.16	14.5	74.53	3.2	2.40
45-49	47	13	66.82	7.6	5.11	14.5	74.53	7.6	5.70
50-54	52	13	66.82	13.4	8.94	14.5	74.53	13.4	9.97
55-59	57	17	87.38	20.6	17.99	16	82.24	20.6	16.93
60-64	62	19	97.66	29.4	28.69	18	92.52	29.4	27.18
65-69	67	9	46.26	39.9	18.46	8	41.12	39.9	16.41
70-74	72	5	25.70	52.3	13.44	4	20.56	52.3	10.75
< 75	77	1	5.14	66.7	3.43	0.5	2.57	66.7	1.71
Sum		100	514.00		98.19	100	514.00		91.05

Annex B Investment divided between European countries

The invested amount of money in noise abatement measures are divided by country and population.

If EUR 6 billions are spent on noise abatement in Europe, in net present value over a 20 year period, it can result in measures as illustrated in the table. For each measure we have assumed the same amount of money, so it is either road barriers or façade insulation (new windows) or porous asphalt etc., but not a mix of several different measures.

		Cost per country		Noise reduction volume per country if Europe spend EUR 6 billion in NPV over 20 years			
Country	Population (million)	EUR 6 bill/ population in Europe	EUR investment per year (for 20 years)	Noise barriers (km)	Window upgrade (number of dwellings)	Porous asphalt (km)	Thin layer asphalt (km)
Austria	8.4	97 234 339	4 861 717	37	32 411	652	2 880
Belgium	10.8	125 015 579	6 250 779	47	41 672	838	3 703
Bulgaria	7.6	87 973 926	4 398 696	33	29 325	590	2 606
Croatia	4.4	50 932 273	2 546 614	19	16 977	342	1 509
Cyprus	0.8	9 260 413	463 021	4	3 087	62	274
Czech Republic	10.4	120 385 372	6 019 269	46	40 128	807	3 566
Denmark	5.5	63 665 341	3 183 267	24	21 222	427	1 886
Estonia	1.3	15 048 172	752 409	6	5 016	101	446
Finland	5.3	61 350 238	3 067 512	23	20 450	411	1 817
FYR of Macedonia	2	23 151 033	1 157 552	9	7 717	155	686
France	62.6	724 627 336	36 231 367	275	241 542	4 859	21 466
Germany	82.1	950 349 909	47 517 495	361	316 783	6 372	28 153
Greece	11.3	130 803 337	6 540 167	50	43 601	877	3 875
Hungary	10	115 755 165	5 787 758	44	38 585	776	3 429
Iceland	0.3	3 472 655	173 633	1	1 158	23	103
Ireland	4.6	53 247 376	2 662 369	20	17 749	357	1 577
Italy	60	694 530 993	34 726 550	264	231 510	4 657	20 574
Latvia	2.2	25 466 136	1 273 307	10	8 489	171	754
Liechtenstein	0.0354	409 773	20 489	0	137	3	12
Lithuania	3.3	38 199 205	1 909 960	14	12 733	256	1 132
Luxembourg	0.5	5 787 758	289 388	2	1 929	39	171
Malta	0.4	4 630 207	231 510	2	1 543	31	137
Netherlands	16.5	190 996 023	9 549 801	72	63 665	1 281	5 658
Norway	4.80	55 562 479	2 778 124	21	18 521	373	1 646
Poland	38.1	441 027 180	22 051 359	167	147 009	2 957	13 065
Portugal	10.70	123 858 027	6 192 901	47	41 286	831	3 669

		Cost per country		Noise reduction volume per country if Europe spend EUR 6 billion in NPV over 20 years			
Romania	21.3	246 558 502	12 327 925	94	82 186	1 653	7 304
Slovakia	5.4	62 507 789	3 125 389	24	20 836	419	1 852
Slovenia	2	23 151 033	1 157 552	9	7 717	155	686
Spain	46.7	540 576 623	27 028 831	205	180 192	3 625	16 014
Sweden	9.3	107 652 304	5 382 615	41	35 884	722	3 189
Switzerland	7.7	89 131 477	4 456 574	34	29 710	598	2 640
UK	62	717 682 026	35 884 101	272	239 227	4 812	21 260
Sum	518.34			2 277	2 000 000	40 232	177 740
Sum EUR net present value		6 bill	0.3 bill	6 bill	6 bill	6 bill	6 bill

Annex C Quality control on noise reduction potential

After having an initial questionnaire and presenting the data, each country got the opportunity to comment on the figures proposed for the calculations. The initial level is the noise reduction chosen after an initial questionnaire to the CEDR Road Noise Group countries. The new level is the noise reduction used in the calculations in this document. Be aware that agreement does not always mean the figure is representative for the country in question, but an agreement of using the noise reduction value as a representative European value.

Table C.1 Noise reduction potential in dB. Comments from the CEDR PG Road Noise countries after initial values were set.

	Noise barriers	Porous Asphalt (single layer)*	Porous Asphalt (double layer)*	Thin layer asphalt*	Façade insulation
Initial level	8	2	4	2	8
Austria	Agree	Agree/NIU	Agree/NIU	Agree	Agree
Belgium	Agree	Agree	-	-	-
Cyprus	-	-	-	-	-
Denmark	6	NIU	NIU	Agree	Agree
Estonia	Agree	NIU	NIU	NIU	NIU
Finland	Agree	Agree	NIU	NIU	NIU
France**	-	-	-	-	-
Germany	Agree	3 in Germany	3 in Germany	Agree	-
Greece	Agree	-	-	-	Agree
Ireland	Agree	Agree	Agree	Agree	Agree
Italy	Up to 8	4-6	6-7	3-6	Agree
Latvia	Agree	Agree	Agree	Agree	Agree
Netherlands	Agree	Agree	3 to 4	Agree	Agree
Norway	Agree	Agree	Agree	Agree	Agree
Poland	Agree	NIU	NIU	NIU	Agree
Spain	5	Agree	Agree	Agree	10
Sweden	Agree	Agree	Agree	Agree	Agree
New level	1-8	2	4	2	8

*The noise reduction is the relative noise reduction compared to the reference pavement. The figures for porous asphalt are from the Netherlands, where DAC16 is used as reference. The thin layer data are from Denmark, where DAC11 is used as reference pavement.
**The representative from France was not present at this stage of the project
NIU = not in use
\- = have not answered (could be because the noise measure is not in use)

Annex D Quality control on costs of noise mitigating measures

After having the initial questionnaire and presenting the data, each country got the opportunity to comment on the figures proposed for the calculations. The initial cost level was chosen after an initial questionnaire to the CEDR Road Noise Group countries. The new level is the value (in EUR) used in the calculations in this document. Be aware that agreement does not always mean the figure is representative for the country in question, but an agreement of using the noise reduction value as a representative European value.

Table D.1 The cost (in EUR) for different noise abatement measures. Comments from the CEDR PG Road Noise countries after initial cost values were set.

	Noise barriers per m²	Porous Asphalt (single layer)* per m²	Porous Asphalt (double layer)* per m²	Thin layer asphalt* per m²	Façade insulation per dwelling
Initial cost level (EUR)	595	2.14	10.45	1.5	4100
Austria	200	Agree/NIU	Agree/NIU	EUR 2-4	EUR 2000 (if L_n > 60 dB)
Belgium	300	0 EUR/m² compared with SMA 0/10	NIU	NIU	-
Cyprus	-	-	-	-	-
Denmark	Agree	NIU	NIU	Agree	Agree
Estonia	190	NIU	NIU	NIU	NIU
Finland	Agree	Agree	NIU	NIU	NIU
France**					
Germany	309 (2009)	12.9			
Greece	200	2001 pilot: 3.52			700
Ireland	Agree	Agree	Agree	Agree	Agree
Italy	283+foundation	Agree	Agree		Agree
Latvia	600/m	NIU	NIU	NIU	90 000-170 000
Netherlands	Agree	Agree	Agree		-
Norway	Agree	NIU	NIU	Agree	Agree (but much more expensive in N)
Poland	140-200	NIU	NIU	NIU	1200-1800
Spain	400				6000
Sweden	450	4	25	Agree	3000
New level (EUR)	400	2.14	10.45	1.5	3000

*The cost is the additional cost compared to a normal dense asphalt concrete. The lifetime for porous asphalt is 13 years (based on Dutch experience), and 14 years for thin layers (based on Danish experience)
** The representative from France was not present at this stage of the project
NIU = not in use
\- = have not answered (could be because the noise measure is not in use)

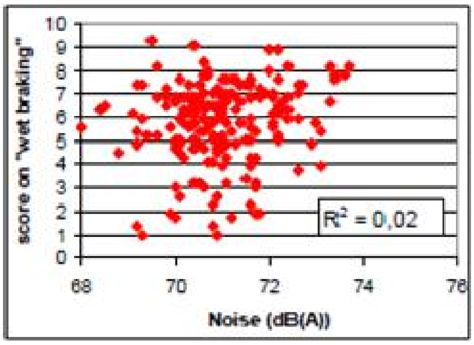
Annex E Trade-offs between noise and other parameters

A short summary of trade-offs between noise, rolling resistance, wet grip and price for car tyres is presented here. The diagrams and text are based on the following sources:

1. FEHRL Study SI2.408210 (2005).
2. Type approval requirements for the general safety of motor vehicles, Fundación CIDAUT (investigation commissioned by the IMCO committee).
3. Open letter on the update of EU tyre noise requirements. To: L. de Prada, Cidaut, consultant undertaking study for the EP, Dr A. Schwab, rapporteur EP. From: various independent European experts on tyres and road noise.
4. Factsheet tyre noise. Limit values proposals and measurements. 10 October 2008. Issued by the Netherlands.

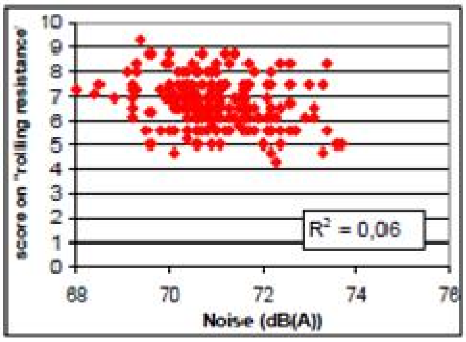
Noise and wet grip

The relationship between noise and wet grip is given in the figure to the right. As the figure illustrates, it is not a correlation between noise and wet grip for normal car tyres.



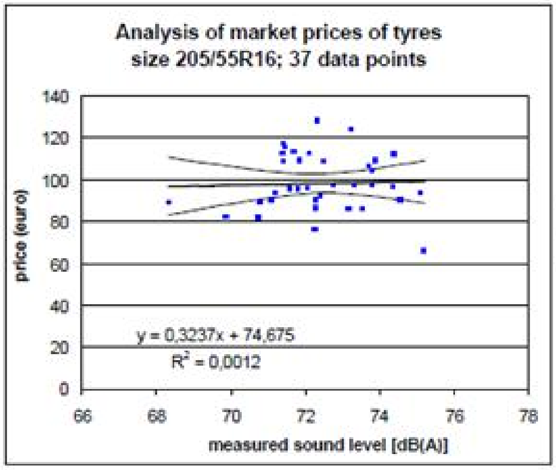
Noise and rolling resistance

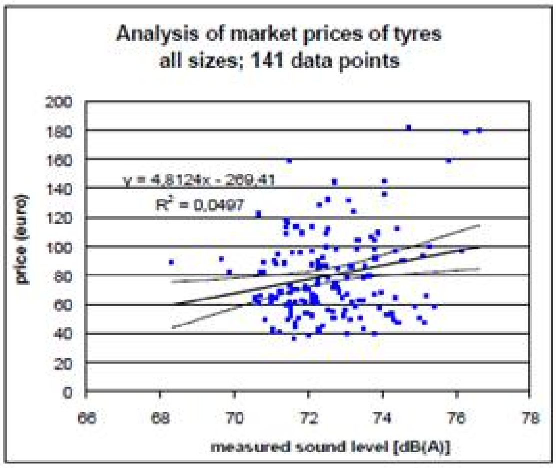
The relationship between noise and rolling resistance is given in the figure to the right. As the figure illustrates, it is not a correlation between noise and rolling resistance for normal car tyres.



Noise and price of tyres

The relationship between noise and price of tyres is given below. As for the other parameters, there is no correlation between noise and price of tyres for normal car tyres.





Annex F Sensitivity analysis

Working paper of 3 July 2012
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SM/50148/2012
Revised version 20 Sept 2012

Sensitivity analysis on the assessment of estimated values for money in road traffic noise abatement

1 Stricter noise limits for new vehicles

Before addressing sensitivity analysis, we first establish the discounted noise-reduction effect of a measure targeting vehicle noise, adapting the noise-reduction effect over the project period to the description by Roo *et al.* (2011). This is one among several assessed measures for noise abatement at the European level. For the potential implementation of stricter noise limits it is assumed that new cars, in production from the fourth year of the project period, will have 3.1 dB lower noise level (de Roo *et al.* 2011, Milford *et al.* 2012). We calculate average noise reductions on roads by separating out two sound sources:

a) New generation silent vehicles emitting 3.1 dB less
b) Old generation of vehicles

The proportion of new vehicles is *p* which, given strict regulation, is allowing only vehicles of the new silent type to be sold. Given an average vehicle life length of 12 years, it translates into an additional 8.3% (approximately) of new more silent vehicles each additional year. We can then add the sound energy for each year of the 12 year transition period using:

$$L_{\Sigma} = 10 \bullet \log_{10}\left(p_{new} \bullet 10^{\frac{L_a}{10}} + \left(1 - p_{new}\right) \bullet 10^{\frac{L_b}{10}} \right)$$

1.1 Main Scenario (Scenario 1) – Vehicle fleet 3.1 dBA less noisy than previously

We have assumed that the new vehicle fleet *a)* emits 72 dB(A), and the old fleet *b)* 75.1 dB(A. (For this type of calculations it is not the absolute numbers, but differences in total sound pressure levels from each vehicle category that are important and that determine the resulting improvement). Table 1 shows the calculation of noise reductions over the project period, from the implementation of stricter noise limits for vehicles that makes these 3.1 dB(A) less noisy than they would have been given no such regulation.

The nominal noise reduction each year in the project period is given by the column "delta dBA", in Table 1. However, since it can be seen as unreasonable to count the benefit of a noise reduction that one first can enjoy after a period of 20 year as equally valuable as one that is enjoyed immediately, the noise reduction benefits should be discounted. We use the same discount factor as are used for discounting future costs 3%. The third last column of Table 1 describes how much a unit value is discounted relative to the first year. We multiply the nominal noise reduction with the discount factors to calculate the equivalent immediate noise reduction benefit of a noise reduction achieved each year of the project period. If we enjoy a noise reduction benefit in the third year, the benefit is assed to be equal to 92.5% of a noise reduction benefit you don't have to wait to enjoy but benefit from immediately.

Table 1 Simple and discounted noise reduction from phasing in a new generation of vehicles 3.1 dBA less noisy than the previous fleet. Transition period (noise reduction effect) starting in the fourth year, and completed after 12 years (in year 16).

		dBA new= 72		dbA old= 75.1					Noise	Discount		1.31
		New fleet		Old fleet					reduction	Adjustment	delta dBA ad	Annuity
		Proportion	(10^7.2)	Proportion	(10^7.5)	weighted sum	Year	Noise level	delta dBA			
1	2010	**0%**	15848931.9	**100%**	32,359,366	32,359,366	1	75.10	0.00	1	0.00	**1.31**
2	2011	**0%**	15848931.9	**100%**	32,359,366	32,359,366	2	75.10	0.00	0.96153846	0.00	**1.26**
3	2012	**0%**	15848931.9	**100%**	32,359,366	32,359,366	3	75.10	0.00	0.92455621	0.00	**1.21**
4	2013	**0%**	15848931.9	**100%**	32,359,366	32,359,366	4	75.10	0.00	0.88899636	0.00	**1.17**
5	2014	**8%**	15848931.9	**92%**	32,359,366	30,983,496	5	74.91	0.19	0.85480419	0.16	**1.12**
6	2015	**17%**	15848931.9	**83%**	32,359,366	29,607,627	6	74.71	0.39	0.82192711	0.32	**1.08**
7	2016	**25%**	15848931.9	**75%**	32,359,366	28,231,757	7	74.51	0.59	0.79031453	0.47	**1.04**
8	2017	**33%**	15848931.9	**67%**	32,359,366	26,855,888	8	74.29	0.81	0.75991781	0.62	**1.00**
9	2018	**42%**	15848931.9	**58%**	32,359,366	25,480,018	9	74.06	1.04	0.73069021	0.76	**0.96**
10	2019	**50%**	15848931.9	**50%**	32,359,366	24,104,149	10	73.82	1.28	0.70258674	0.90	**0.92**
11	2020	**58%**	15848931.9	**42%**	32,359,366	22,728,279	11	73.57	1.53	0.67556417	1.04	**0.89**
12	2021	**67%**	15848931.9	**33%**	32,359,366	21,352,410	12	73.29	1.81	0.64958093	1.17	**0.85**
13	2022	**75%**	15848931.9	**25%**	32,359,366	19,976,540	13	73.01	2.09	0.62459705	1.31	**0.82**
14	2023	**83%**	15848931.9	**17%**	32,359,366	18,600,671	14	72.70	2.40	0.60057409	1.44	**0.79**
15	2024	**92%**	15848931.9	**8%**	32,359,366	17,224,801	15	72.36	2.74	0.57747508	1.58	**0.76**
16	2025	**100%**	15848931.9	**0%**	32,359,366	15,848,932	16	72.00	3.10	0.5552645	1.72	**0.73**
17	2026	**100%**	15848931.9	**0%**	32,359,366	15,848,932	17	72.00	3.10	0.53390818	1.66	**0.70**
18	2027	**100%**	15848931.9	**0%**	32,359,366	15,848,932	18	72.00	3.10	0.51337325	1.59	**0.67**
19	2028	**100%**	15848931.9	**0%**	32,359,366	15,848,932	19	72.00	3.10	0.49362812	1.53	**0.65**
20	2029	**100%**	15848931.9	**0%**	32,359,366	15,848,932	20	72.00	3.10	0.47464242	1.47	**0.62**
21	2030	**100%**	15848931.9	**0%**	32,359,366	15,848,932	21	72.00	3.10	0.45638695	1.41	**0.60**
									33.47	**Adjusted=**	**19.15**	**19.15**

Note: $10^{\frac{L_N}{10}}$ is described as (10^72/10=10^7.2 in the spreadsheet), $\overline{10^{\frac{L_O}{10}}}$ is described as (10^75/10=10^7.5
$p_{new} \cdot 10^{\frac{L_N}{10}} + (1 - p_{new}) \cdot 10^{\frac{L_O}{10}}$ is described as the "weighted sum", and the resulting logarithmic decibel values "noise level" are 10 $\log_{10}$ (weighted sum).

When we sum the discounted benefits ("delta dBA ad") (=19.15) and divide by the annuity factor (14.59, for a project period of 21 years), we obtain the equivalent constant noise reduction (1.31) that over the project period produces the same (discounted) sum. The last column of Table 1 is simply a check that we arrive at the same aggregated discounted benefit.

1.2 Conclusion from calculations in Scenario 1.

The arithmetic average of the noise savings over the project horizon (2010-2030) is ca. 1.59 dBA. However, most of the noise savings come towards the end of the project period. We usually prefer noise savings that occur immediately over those coming late in a project. If one wants to compare the results of implementing a measure where the effects follow this type of time-profile against measures providing an immediate noise reduction from day one, it is reasonable to discount future noise and noise annoyance savings.

For our project horizon (counting 21 years, from 2010 to 2030), using the given discount rate 4%, we get an accumulated noise benefit of 19.15 dBA. As seen from the last column in Table 1, the integrated vehicle package provides discounted benefits equivalent to that produced by an annual constant noise reduction of 1.31 dBA, , when the average over vehicle types and road types is 3.1 dB(A) at full implementation. (1.31 dBA is the noise reduction each year that over the project horizon produces an accumulated discounted noise reduction of 19.15 dBA.)[1]

1.3 Secondary Scenario (Scenario 2) – Vehicle fleet 1.5 dBA less noisy than previously

The motivation for including this scenario is to show the robustness of the economic assessment of the integrated vehicle alternative. We follow the same procedure as explained above but with 1.5 dBA instead of 3.1 dBA (see Table 2).

Table 2: Simple and discounted noise reduction from phasing in a new generation of vehicles 1.5 dBA less noisy than the previous fleet. Transition period (noise reduction effect) starting in the fourth year, and completed after 12 years.

		dBA new- 73.6		dbA old- 75.1					Noise	Discount		0.66
		New fleet		Old fleet					reduction	Adjustment	delta	
		Proportion	(10^7.2)	Proportion	(10^7.5)	weighted sum	Year	Noise level	delta dBA		dBA adj	Annuity
1	2010	0%	22908676.53	100%	32,359,366	32,359,366	1	75.10	0.00	1	0.00	0.66
2	2011	0%	22908676.53	100%	32,359,366	32,359,366	2	75.10	0.00	0.961538462	0.00	0.64
3	2012	0%	22908676.53	100%	32,359,366	32,359,366	3	75.10	0.00	0.924556213	0.00	0.61
4	2013	0%	22908676.53	100%	32,359,366	32,359,366	4	75.10	0.00	0.888996359	0.00	0.59
5	2014	8%	22908676.53	92%	32,359,366	31,571,808	5	74.99	0.11	0.854804191	0.09	0.56
6	2015	17%	22908676.53	83%	32,359,366	30,784,251	6	74.88	0.22	0.821927107	0.18	0.54
7	2016	25%	22908676.53	75%	32,359,366	29,996,693	7	74.77	0.33	0.790314526	0.26	0.52
8	2017	33%	22908676.53	67%	32,359,366	29,209,136	8	74.66	0.44	0.759917813	0.34	0.50
9	2018	42%	22908676.53	58%	32,359,366	28,421,579	9	74.54	0.56	0.730690205	0.41	0.48
10	2019	50%	22908676.53	50%	32,359,366	27,634,021	10	74.41	0.69	0.702586736	0.48	0.46
11	2020	58%	22908676.53	42%	32,359,366	26,846,464	11	74.29	0.81	0.675564169	0.55	0.45
12	2021	67%	22908676.53	33%	32,359,366	26,058,906	12	74.16	0.94	0.649580932	0.61	0.43
13	2022	75%	22908676.53	25%	32,359,366	25,271,349	13	74.03	1.07	0.62459705	0.67	0.41
14	2023	83%	22908676.53	17%	32,359,366	24,483,791	14	73.89	1.21	0.600574086	0.73	0.40
15	2024	92%	22908676.53	8%	32,359,366	23,696,234	15	73.75	1.35	0.577475083	0.78	0.38
16	2025	100%	22908676.53	0%	32,359,366	22,908,677	16	73.60	1.50	0.555264503	0.83	0.37
17	2026	100%	22908676.53	0%	32,359,366	22,908,677	17	73.60	1.50	0.533908176	0.80	0.35
18	2027	100%	22908676.53	0%	32,359,366	22,908,677	18	73.60	1.50	0.513373246	0.77	0.34
19	2028	100%	22908676.53	0%	32,359,366	22,908,677	19	73.60	1.50	0.493628121	0.74	0.33
20	2029	100%	22908676.53	0%	32,359,366	22,908,677	20	73.60	1.50	0.474642424	0.71	0.31
21	2030	100%	22908676.53	0%	32,359,366	22,908,677	21	73.60	1.50	0.456386946	0.68	0.30
									16.74	Adjusted=	9.64	9.64

(See notes to Table 1 for description of table content).

1.4 Conclusion Scenario 2.

The arithmetic average of the noise savings over the project horizon is about 0.8 dBA (16.74/21). However, most of the noise savings come towards the end of the project period. If one wants to compare the results of implementing this measure against measures taking effect from day one, it is reasonable to discount future noise and noise savings. The total noise benefit over the project horizon is 9.64 dBA and the integrated vehicle package provides the equivalent benefit over the period from

[1] We arrive at the figure of 1.31 by dividing 19.15 with the annuity factor (over 21 years), that is, 14.59.

2010 to 2030 as a yearly noise reduction of **0.66** dBA (given that the average over vehicle types and road types was only 1.5 dB(A) at full implementation).

2 Cost-effectiveness analyses (deterministic)

We include the results of the cost-effectiveness analyses (CEA) for the project horizon from 2010 to 2030. Windows and noise barriers are assumed to last the whole project period without any remaining value. All annuities are given at the beginning of a year.

Table 3: Summary table of costs and benefits of seven alternative noise abatement solutions.

Quant	Base?	Measure	Size	Component	C*	~size	Bene.	Q*M*C*B	U annuity	Cost	Effect units	ΣCosts	ΣΣEffect units	CE/Ratio
2000	no	Window insulation	1	Windows	1000	no		2,000,000.00	205.62	411,231,377.43				
2000	no	Window insulation	1	Noise	0.02171	no	2200	95,524.00	8.00		764,192.00	411,231,377.43	764,192.00	**538.13**
												5,999,865,796.70		
177750	no	Thin_layer asphalt CEDR	18	Thin	1000	yes		3,199,500,000.00	0.15	470,964,614.82				
177750	no	Thin_layer asphalt CEDR	18	Noise_thin	0.0135	no	500	1,199,812.50	2.00		2,399,625.00	470,964,614.82	2,399,625.00	**196.27**
												6,871,373,730.22		
2267	no	Noise barrier CEDR	500	NBCNoise	1000	no		2,267,000.00	109.66	248,603,075.37				
2267	no	Noise barrier CEDR	500	Noise	1000	no		2,267,000.00	71.72	162,594,977.00				
2267	no	Noise barrier CEDR	500	Noise_barri	0.0127	no	500	14,395.45	5.00		71,977.25	411,198,052.37	71,977.25	**5,712.89**
												5,999,379,584.08		
40680	no	Porous_single_layer CEDR	25	Porous_sing	1000	yes		1,017,000,000.00	0.21	209,669,320.15				
40680	no	Porous_single_layer CEDR	25	PSLC	1000	yes		1,017,000,000.00	0.21	213,574,614.45				
40680	no	Porous_single_layer CEDR	25	Noise_singl	0.0135	no	1000	549,180.00	2.00		1,098,360.00	423,243,934.60	1,098,360.00	**385.34**
												6,175,129,005.81		
6380	no	Porous_dual_layer CEDR	25	PDLM	1000	yes		159,500,000.00	1.59	253,474,986.25				
6380	no	Porous_dual_layer CEDR	25	PDLC	1000	yes		159,500,000.00	1.03	163,565,566.67				
6380	no	Porous_dual_layer CEDR	25	Noise_dual	0.01295	no	1000	82,621.00	4.00		330,484.00	417,040,552.92	330,484.00	**1,261.91**
												6,084,621,667.10		
1	no	Vehicle_package cedr 3.1	1	Vehicle_pac	1000000	no		1,000,000.00	47.49	47,488,806.95				
1	no	Vehicle_package cedr 3.1	1	Vehicle_pac	1000000	no		1,000,000.00	363.23	363,231,577.88				
1	no	Vehicle_package cedr 3.1	1	Noise IVP	0.0138	no	514000000	7,093,200.00	1.31		9,292,092.00	410,720,384.83	9,292,092.00	**44.20**
												5,992,410,414.67		
1	no	Vehicle_package cedr 1.5	1	Vehicle_pac	1000000	no		1,000,000.00	47.49	47,488,806.95				
1	no	Vehicle_package cedr 1.5	1	Vehicle_pac	1000000	no		1,000,000.00	363.23	363,231,577.88				
1	no	Vehicle_package cedr 1.5	1	Noise	0.0138	no	514000000	7,093,200.00	0.66		4,681,512.00	410,720,384.83	4,681,512.00	**87.73**
												5,992,410,414.67		

Note: "Quant" is the number of units or km implemented of the measure. Measure "size" is a multiplier, such as the width of the road, C* is a multiplier at the component/Effect level. It is used where costs are given per km instead of metre etc.. The multiplier translates a given effect (the noise reduction) into the equivalent EC-wide noise annoyance reduction. "Bene" is the number of people affected by the noise reduction- "QMCB" is simply the product of the multipliers: (Quantity, Measure size, Component multiplier and number of Beneficiaries9. "U ann" is the annuity cost of producing a single unit (1 m^2 road surface, 1 metre barrier, 1 window etc.), of the given noise abatement measure.

The cost and effect columns are the product of the multipliers and the unit annuity values. These are aggregated to produce an aggregated cost figure, and the aggregated noise annoyance reductions (Effect units are here the reduced number of noise annoyed persons in Europe).

3 Sensitivity analysis (simulated CEA)

A sensitivity analysis was carried out, based on simulation of relevant input data. For the road surfaces we assumed cost and effect values to vary ±30% and being distributed according to an underlying (truncated) normal distribution (similar to the approach presented by Klæboe *et al.* 2011 and Veisten and Akthar 2011). Then a series of 10,000 simulations were carried out, and for each simulation the cost effectiveness estimate was retained, yielding a type of histogram where averages (point estimates) and percentiles can be identified directly.

3.1 Overview

The uncertainty (simulation) analysis shows that there is a clear demarcation between the integrated vehicle packages and the various silent noise surfaces.

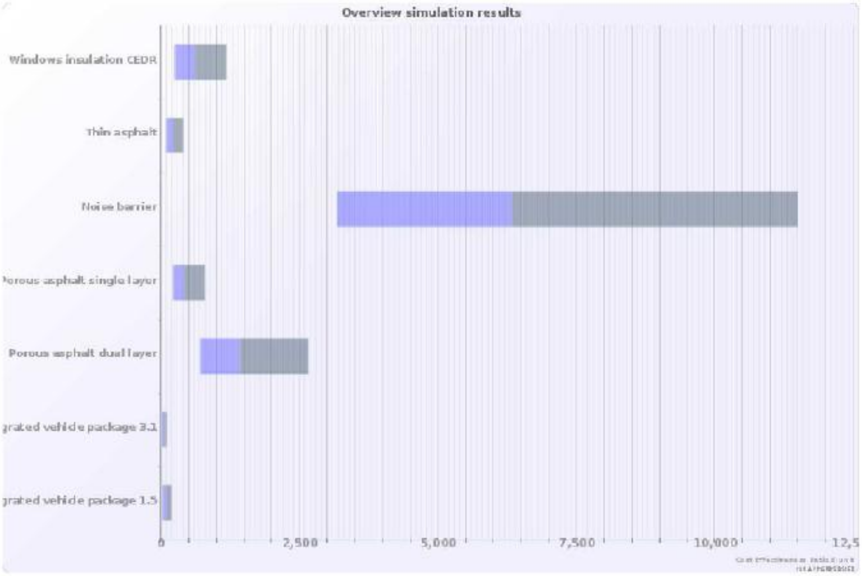


Figure 1. The abscissa axis shows the simulated cost effectiveness results (costs of reducing annoyance by one) and the uncertainty (lilac to the left and grey to the right of the simulated point estimate); which are comparable to 90% confidence intervals (5% to either side). The measures are given at the ordinate axis

We conclude that the integrated vehicle packages –assuming 3.1dBA (and even if only 1.5 dBA) noise reductions are almost certain to perform better in terms of cost-effectiveness of obtaining noise reduction, than the competing alternatives – given that actual costs and effects lie within the specified uncertainties. With a noise reduction of 1.5 dBA instead of 3.1, the integrated vehicle packages, there is a very slight chance that thin layer asphalt could perform economically better than the integrated vehicle package.

3.2 Detailed simulation results

To provide a closer visual impression of the impact of the various uncertainties on the resulting cost effectiveness ratios of the most interesting alternatives, we provide the following charts. The horizontal scale is here fixed to 700€/noise annoyed person. The distributions are thus comparable. Whereas the vertical axis is fixed, indicating the number of observations, the meaning of the height depends on the width of the bars – and the absolute height can therefore vary from chart to chart. However, the shape and location of the distributions are comparable.

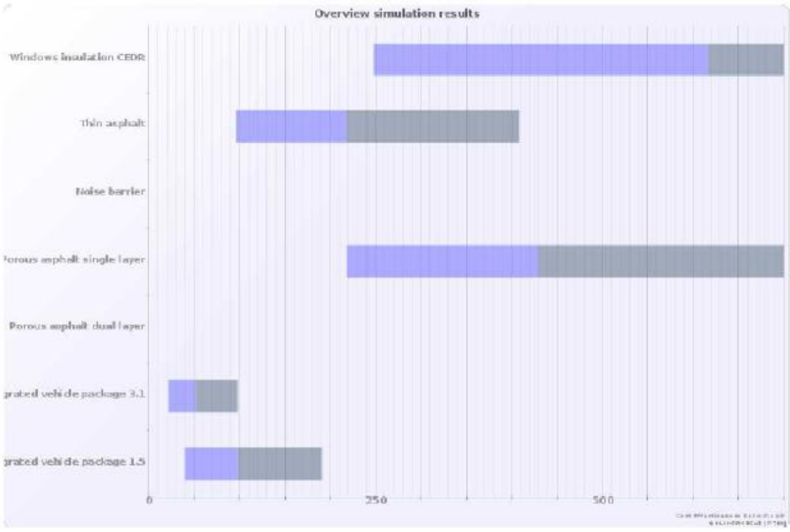
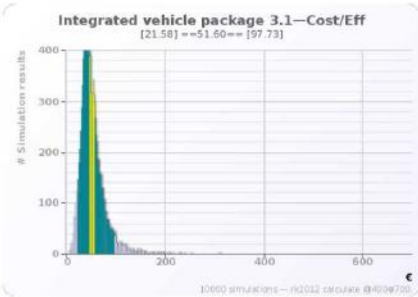


Figure 2. The abscissa axis shows the simulated cost effectiveness results (costs of reducing annoyance by one) and the uncertainty (lilac to the left and grey to the right of the simulated point estimate); which are comparable to 90% confidence intervals (5% to either side). The measures are given at the ordinate axis. (The confidence band for noise barriers, and double layer porous asphalt are here, given a cut off of 700€ per dBA, off the chart to the right).

The following figures show the cost effectiveness distributions more in detail, for the vehicle noise limit (main assumption of 3.1 dB reduction and pessimistic assumption of 1.5 dB reduction), for single-layer porous asphalt and for thin asphalt



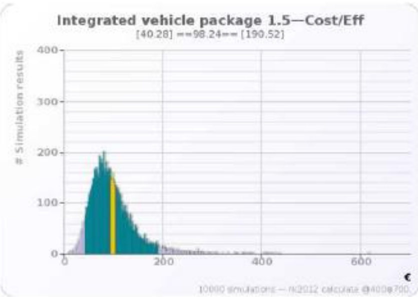
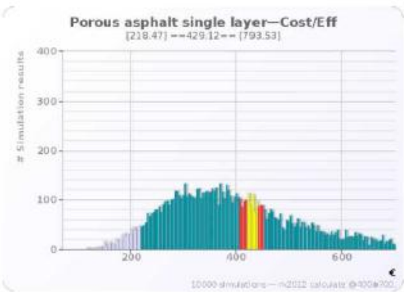


Figure 3a. Simulated cost effectiveness, vehicle noise limit 3.1

Figure 3b. Simulated cost effectiveness, vehicle noise limit 1.5



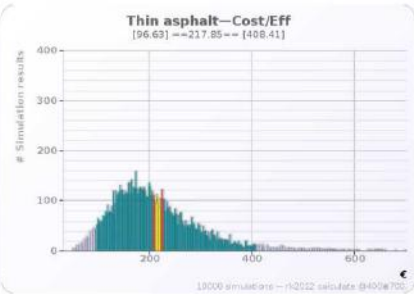


Figure 3c. Simulated cost effectiveness, single layer porous asphalt

Figure 3d. Simulated cost effectiveness, thin asphalt

As Figures 3a-3d have common scales, they are comparable, and it is indicated that the mass of cost-effectiveness for the integrated vehicle package is clearly further to the left (lower cost for goal attainment). Given the assumptions of the measure effects and costs (de Roo *et al.* 2011, Milford *et al.* 2012), and that these lie within the specified uncertainties, the integrated vehicle package represent the measure with best cost-effectiveness and lowest uncertainty.

4 Literature

de Roo, F., Dittrich, M.G., van Beek, P.J.G., Bosschart, C., Derksen, G.B. & de Kievit, M. 2011. VENOLIVA - Vehicle Noise Limit Values - Comparison of two noise emission test methods – Final Report. TNO report MON-RPT-2010-02103, TNO Science and Industry, Mobility, Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek (TNO), Delft.

Klæboe, R., Veisten, K., Amundsen, A.H. & Akhtar, J. 2011. "Selecting road-noise abatement measures: economic analysis of different policy objectives." *Open Transportation Journal*, 5: 1-8.

Milford, I., Aasebø, S.J. & Strømmer, K. 2012. "Value for money in road traffic noise abatement." *Procedia – Social and Behavioral Sciences*, forthcoming.

Veisten, K. & Akthar, J. 2011. "Cost-benefit analysis of low-noise pavements: dust into the calculations." *International Journal of Pavement Engineering*, 12(1): 75-86.

Annex G Examples of arguments from industry on the European Commission regulation proposal on the sounds level of motor vehicles

The «arguments» and the «reality» is put together by Transport and Environment[5]

Argument from industry	Reality
"Enough lead time will be needed. If time steps are too short manufacturer will not be able to implement properly integrated solutions. Only inefficient short term solutions are possible."[6]	The ENVI proposal delays the Commissions proposed introduction of the regulation by a couple of years. Furthermore, in the early 1990s manufacturers were able to achieve a larger reduction in vehicle noise levels within just 5 years after Austria introduced a night time driving ban for noisy trucks and this limit became the de-facto lorry noise emission limit throughout Europe.[7]
Noise reduction requirements will lead to CO_2 emissions increase.	There are clear synergies between improving fuel efficiency and reducing noise from cars and vans using current market technologies. Technologies to make cars quieter such as: downsizing the engine and using a turbocharger; introducing advanced engines; using stop-start and hybrid technology all make cars quieter too.[8]
The legislation will 'will only hurt European automotive industry by reducing its ability to compete and might even lead to its destruction.'	The Commission Impact Assessment estimates around EUR 20 per dB reduction per car, and approximately EUR 250 per dB reduction for each truck/bus.[9] A study by TNO estimates even these modest costs are probably too high.[10]
The industry is over-burdened with regulation.	EU and national noise policies and strategies recognise that achieving safe road noise levels requires a reduction of at least 10 dB on today's road noise levels.[11] Noise emissions limits have not changed since 1995. The last revision of the noise standards proved to be ineffective in reducing overall road noise levels.[12] The amount of vehicle regulation is totally in proportion to the widespread effects of vehicles on health and environment.
This legislation has many drawbacks: increased with, reduced safety not sufficiently validated product stability and reduced performance.[13]	Recent research proves that cutting traffic noise from vehicles would enable national governments, local authorities and society at large to enjoy benefits which would outweigh costs by a factor of more than thirty to one.[14]

[5] Transport and Environment is an international non-profit organization which represents, and is supported by about 50 organisations across Europe.
[6] ACEA, March 2012, Agenda item: Noise presentation
[7] Quiet incentives in Germany and Austria
[8] TNO (2012) Road Vehicle Noise versus fuel consumption and pollutants emissions.
[9] TNO (2011) VENOLIVA, Final report, and European Commission (December 2011) Impact Assessment
[10] TNO (2012) Reduction of vehicle noise emission – Technological potential and impacts
[11] Including EU 6th Environmental Action Plan, Noise Green Paper (1996), CALM network, ERTRAC, national policies in Sweden and Germany (Nationales Lärmschutzpaket, 2009) and organisations including I-INCE and CAETS.
[12] European Commission, Enterprise and Industry – Automotive, Noise emissions of motor vehicles.
[13] ACEA, March 2012, Agenda item: Noise presentation
[14] TNO (2012) Road Vehicle Noise versus fuel consumption and pollutants emissions.

Annex H Summary from presentation in Brussels 18 December 2012

Vehicle Noise Regulation: A Sound Investment?
Brussels 18th December 2012
Workshop Summary

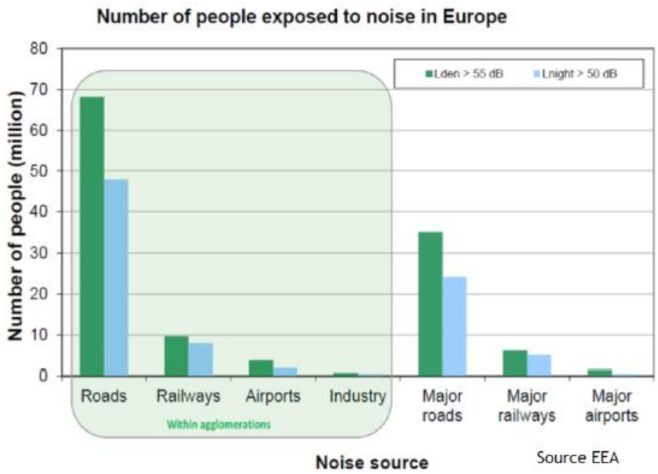
The workshop was hosted by the Cyprus EU Presidency for the technical harmonization of noise working group and other officials of member states working on the vehicle noise regulations. The purpose of the event was to update participants in new evidence concerning the impacts, sources and solutions and costs of abating vehicle noise.

Presentations were made by:

1. Dr. Mette Sørensen, Senior Researcher at the Danish Cancer Society
2. Mr. Hans Kaltwasser, European Blind Union
3. Ms. Ingunn Milford, Conference of European Directors of Roads Project Group Noise
4. Mr. Henk Wolfert, chair of EUROCITIES Noise working group
5. Mr. Colin Nugent, European Environmental Agency
6. Mr. Maurizio Mantovani, Autoneum Management AG

The main messages from the presentations were:

1. **There is currently limited compliance with the Environmental Noise Directive leading to large numbers of EU citizens being exposed to noise and therefore a higher risk to health**. Mr Colin Nugent presented data from the European Environment Agency illustrating show that a high number of EU citizens are exposed to noise levels which are above WHO's interim target.



Mr Henk Wolfert reinforced this message showing that 220 million people (45% of EU population) were exposed to harmful levels of noise during the day. He advocated the need for a shared responsibility for reducing noise through:

- Stricter EU emission values for noise sources
- The car industry reducing their "aversion against quieter vehicles"
- Cities devising and implementing noise ACTION Plans
- Citizens behaving more quietly.

2. **There is significantly higher risk of stroke, heart attacks and diabetes for citizens experiencing high levels of road noise**. Dr Mette Sørensen commented that:
    - Per 10 dB increase in road traffic noise, stroke increase by 14%, heart attack by 12% and diabetes 11%
    - For stroke indications of threshold limit is around 60 dB, whereas for heart attacks and diabetes there is no threshold limit

3. **Reducing vehicle noise at source is significantly more cost-effective to reduce the numbers of annoyed people that introducing noise barriers and quiet noise surfaces**. Ms. Ingunn Milford showed:
    - The cost of reducing noise annoyance varies from €16 for vehicles to €4200 for barriers per person per year
    - A sensitivity analysis showed reducing vehicle noise was the most cost-effective solution in all cases
    - A 3dB reduction in vehicle noise would result in a reduction in 19,7 mil people annoyed at a cost of 18euro / person. A bigger abatement of 5 bB would achieve in greater reductions at lower cost per person (16 euro / person).

4. **That reducing vehicle noise is entirely consistent with improving vehicle CO2 emissions** (dispelling a commonly held myth). Mr Maurizio Mantovani's highlighted the benefits of engine encapsulation for reducing noise and cold running (that increases pollutant emissions and CO2). He also showed the additional mass of the encapsulation materials was very small (4-6kg) leading to an increase of just 0.3g/km in CO2 emissions

5. **That it is a human right for blind people to travel independently and that silent vehicles compromise this**. Mr Hans Kaltwasser highlighted the need for the AVAS system to be mandatorily installed in all low sound vehicles and of sound to be produced automatically at speeds up to 40 km/h.