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TNO report

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Reduction of vehicle noise emission - Technological potential and impacts

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Management summary

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In December 2011 the European Commission published a draft EU Regulation[1] for the sound level of motor vehicles. This draft Regulation introduces a new test method for measurement of the noise emission of road vehicles as part of the type approval procedure, which is intended to be more representative of the actual conditions in normal urban traffic than the old test method. Furthermore, the draft Regulation proposes more stringent limit values for noise emission than the values currently in force. The proposal is largely based on the VENOLIVA study, executed by TNO between November 2009 and March 2011.

At the request of European Federation for Transport and Environment and the Dutch Ministry of Infrastructure and Environment, TNO has performed a new analysis on the impact of the Phase 2/3 vehicle noise limits, as proposed in the draft Regulation[1]. Also the feasibility and impact of a more stringent Phase 4/5 of limit value reductions was assessed. Technical options, appropriate vehicle noise classes with respect to today's vehicle fleet, industry costs and societal and health benefits have been analysed. New available information has been taken into account based on recent publications, industry consultation, comparison of different valuation methods and comments from various stakeholders.

An alternative proposal for lower noise limits including an additional step
A new proposal is made for lower limits, presented in Table 4 of this report. This new proposal adopts the limit values of the Phases 1 and 2/3 of the EC proposal, but recommends a tighter time schedule for implementation. Also the definitions of vehicle sub-categories have been revised, following some of the suggestions from other stakeholders, and two additional Phases, 4 and 5, for further reduction and consolidation of the limit values beyond the EC proposals have been included.

Impact of proposed limit value reductions
Both Phase 2/3 and Phase 4/5 limit values are found to be highly cost effective. For Phase 2/3 limits, the Benefit to Cost Ratio is 39 (previously 11,4) and for Phase 4/5, 32. Benefits of Phase 4/5 are 326 billion Euro over the appraisal period and the costs are 10 billion Euro.

[1] COM(2011) 856 final, 2011/0409 (COD), *Proposal for a regulation of the European parliament and of the council on the sound level of motor vehicles*, European Commission, Brussels, 9.12.2011.

The environmental impact of both phases is substantial. The Phase 2/3 noise limits result on average in 3,1 dB reduction in L_{DEN} traffic noise levels, 25% less highly annoyed people and 15% less highly sleep disturbed people. The Phase 4/5 limits would result on average in 5,2 dB reduction in L_{DEN} levels, 39% less highly annoyed people and 29% less highly sleep disturbed people.

Alternative proposals
Besides the EC proposal, Germany, ACEA and Japan have made proposals on sub-categorisation, limit values and the time frames of the introduction of the various phases of the limit value reduction. The overall conclusion is that the alternatives are generally significantly less ambitious than the EC proposal and are scheduled much later.

Vehicle subcategories
In alternative proposals from ACEA, Germany and Japan modified definitions of vehicle sub-categories were proposed, whilst the EC proposal is based on the same sub-categories as the current limit value system. Therefore the sub-categorisation was reconsidered. As a result modified definitions are now proposed for the vehicle categories M2 (medium size buses), M3 (heavy buses), N1 (vans and light trucks) and N3 (heavy trucks). The suggested introduction of an additional sub-category for passenger cars is not recommended.

Technological potential for noise reduction of trucks
For Phase 2/3 limits for trucks, technology is commercially available for shielding and encapsulation, which is applicable without significant R&D effort. Also the additional reductions in Phase 4/5 are feasible, based on available technical solutions that have already been applied in passenger cars and engine test bench experiments. An additional cost of 250 Euro per dB noise reduction per vehicle is estimated for both Phase 2/3 and Phase 4/5, which is around 0,5 % of the vehicle price. This extra cost is passed on to the customer. For Phase 4/5 limits the additional costs for truck manufacturers are mainly due to additional R&D and tooling effort. As key challenges such as thermal management need to be addressed, the impact on the truck design and production will be larger than for the first limit value reduction.

Further reduction of tyre noise
Additional reduction of rolling noise of tyres for all vehicle types will be necessary to achieve a further overall reduction of vehicle noise emission with 2 dB(A) as proposed in Phase 4/5. In order to maintain the balance between rolling noise and powertrain noise, an estimated reduction of rolling noise by at least 3 dB(A) will be required. Therefore a further improvement of the tyre noise Regulation with lower limit values for rolling noise will be necessary to enable the proposed limit values for Phase 4/5.

Contents

1 Introduction

The permissible sound level of road vehicles is part of the EU vehicle type approval legislation, as laid down in EU Directive 70/157/EEC [1] and in the UN-ECE Regulation No 51 [2] , which also specifies the test method for the noise emission test. Since 1 July 2007 the European Commission has been preparing a revision of Directive 70/157/EEC, aiming at replacing the current noise emission test method (based on ISO 362:1998 [3]) with a new method based on a revised version of ISO 362 from 2007 [4] . This new test method is intended to be more representative of the actual noise emission of road vehicles in normal traffic situations.
Simultaneously with the introduction of the new test method a reduction of the type approval limit values for noise emission was aimed for.

As a first step the UN-ECE published the new test method in 2007 with the purpose to monitor the application of this new method in parallel with the existing test method and to evaluate the qualities of the new method. During a period of three years the new method has been used on a provisional basis for monitoring purposes. The combined monitoring period under UN-ECE Regulation No 51 and Directive 2007/34/EC (amending Dir. 70/157/EEC) lasted from 1 July 2007 until 6 July 2010. During the monitoring period the type approval authorities were obliged to execute the noise emission tests according to both methods and to submit the results of both tests to the European Commission; only the results of the current test were valid for the type approval. By this procedure a database of parallel test results was collected that offered a good opportunity to investigate the qualities of the new method and to quantify the differences between the results of the two methods.

In order to provide a scientific basis for the intended regulatory changes the EC commissioned TNO with a study project, that included:

- Analysis of the data base of type approval test results;
- Investigation of the effectiveness of the new method;
- Development of several alternative options for reduction of type approval limit values;
- Study of the relevance of existing allowances for special vehicle subcategories;
- Assessment of the environmental, social and economical impacts of the proposed regulatory changes;
- Study the necessity and the advisable nature of a set of off-cycle provisions, intended to guarantee the control of in-traffic noise emissions under operating conditions that are not covered by the type approval test conditions.

The results of this study, named VENOLIVA (Vehicle Noise Limit Values), were reported in March 2011 [5]. This report included the recommendation to revise the limit values according to a two step approach, studied as Option 5.
The report also included a completely elaborated table with revised limit values that could replace the current tables in EU Directive 70/157/EEC [1] and in UN-ECE Regulation No 51 [2].

On 9 December 2011 the EC published a proposal for a regulation for the sound emission of motor vehicles [6] that would replace EU Directive 70/157/EEC.

This proposal included a table with revised noise emission limit values that was directly derived from the VENOLIVA report.

The European Federation for Transport and Environment (T&E) considered that the two steps of stringency proposed in the Commission proposal might be insufficient to achieve the necessary real world road noise reductions for the over 200 million EU citizens currently exposed to long-term average noise levels of 55dB(A) L_{den}, which would pose a risk to health. In the view of T&E, further steps of limit value reductions therefore needed to be integrated into the current revision, to ensure a sustainable future development of quieter vehicles with appropriate lead-time demanded by the automotive industry. Past experience had repeatedly shown that updating European and international noise standards was an extremely lengthy process; from the completion of the last update in 1992, to the entry into force of the new standards, it would take well over 20 years. This slow progress was despite the fact that it was already known in the early 1990s that the current standards would be ineffective at reducing real world road traffic noise.

The European Automobile Manufacturers' Association (ACEA), the Japan Automobile Standards Internationalization Center (JASIC) and Germany have raised concerns about the technical feasibility (in particular for Heavy Duty Vehicles), costs and the appropriateness of the proposed vehicle classes.

T&E commissioned TNO to conduct a follow-up study to the VENOLIVA project, taking into account new available information on the above mentioned aspects. The Dutch Ministry of Infrastructure and Environment was co-sponsor for the study.

The objective of the study is "to provide an evidence-based analysis in support of a proposal for a more stringent third step of vehicle noise limit values, including consideration of technical options, industry costs, societal benefits and appropriate vehicle noise classes with respect to today's fleet".

In this report the results of this analysis are presented.

2 Technological outlook

2.1 Motivation

After publication of the VENOLIVA report several drawbacks of and objections against the proposals in this report were brought forward by various stakeholders. Some comments stated that the proposals were too far reaching and would pose very severe problems for the vehicle industry [7] [8] , while other reactions made a strong plea for stricter vehicle noise regulations than proposed [9]. Recently three alternative proposals for revision of the limit values were published by the German Government [10], by ACEA [11] and by JASIC [24] .

In this chapter a review of the technical state of the art is given, taking into account the technical argumentation of these comments. This may be considered as an update of the information presented in the VENOLIVA report, which was based on the situation and available information in 2009 and 2010.

2.2 Reclassification of vehicle sub-categories

One of the questions investigated in the VENOLIVA study was the classification of the vehicle sub-categories. For that purpose all major performance characteristics of vehicles, e.g. mass, engine capacity, maximum engine power, power-to-mass ratio were used in single and multiple regression analyses as explanatory variables. It appeared that all of these characteristics showed poor correlation coefficients (percentage of variance accounted for was always smaller than 25 %). This meant that none of these performance characteristics offered a very useful criterion for subdivision of the sound emission of vehicle categories.

It was decided not to introduce new subcategories, but to keep the subcategories from the current limit value system. That way it would not be necessary for the vehicle industry to adapt to a new system of subcategories at a point in time where they already would have to adapt to a new test method and stricter limit values.
It was envisaged that this decision would increase the acceptance of the proposals. Unfortunately this does not seem to be the case: Germany, ACEA and JASIC have put forward alternative proposals that are based on a different sub-classification than the EC proposal. The topic of sub-classification is reconsidered in this report.

A primary objection to the EC proposal (and the VENOLIVA report, on which it is based) is that the proposed classification of vehicle sub-categories would be no longer representative for the actual composition of the vehicle fleet or for the actual supply of new vehicles on the market. However, the proposed new limit values come into force in two phases (2 and 5 years after publication) and are only applicable to new vehicle types. So, modifications of currently available vehicles will not be necessary, unless these vehicles would still be in production without any changes at the start of the third phase (7 years after publication). This opens the possibility to integrate the objective of noise emission reduction in the total vehicle design, which may offer new possibilities of design and technology. It is therefore not appropriate to judge the limit system and specifically the sub-classification system on the basis of *current* vehicles and their performance characteristics.

The alternative proposals for sub-classification also tend to increase the number of subcategories. This increases the complexity of the limit value system and the chance of application errors and diminishes its effectiveness. Already under the current system many errors are made, which was observed during the study of the data files that filled the data base.

2.2.1 *M1 – Passenger cars*

In Figure 1 the correlation between the power-to-mass ration (PMR) of passenger cars and the sound level tested according to the new method B[2] is shown.
This graph shows that there is a very large spread in the test results of method B between different vehicles of similar PMR. Even if the three highest values are omitted, there is a range of 11 dB(A) in the results. For the petrol engine vehicles there is a slight increase with increasing PMR, but for the Diesel engines there is a drop with increasing PMR. As the distinction between Diesel and petrol engines will not be maintained in the new limit value system, one single limit value for all vehicles with low or average PMR values is clearly the most appropriate. In the current system of limit values there are only two sub-categories for M1 vehicles: normal and high powered cars. In the EC proposals this same subdivision was proposed. However, the three alternative proposals suggest the introduction of an intermediate subcategory for vehicles with medium to high PMR.

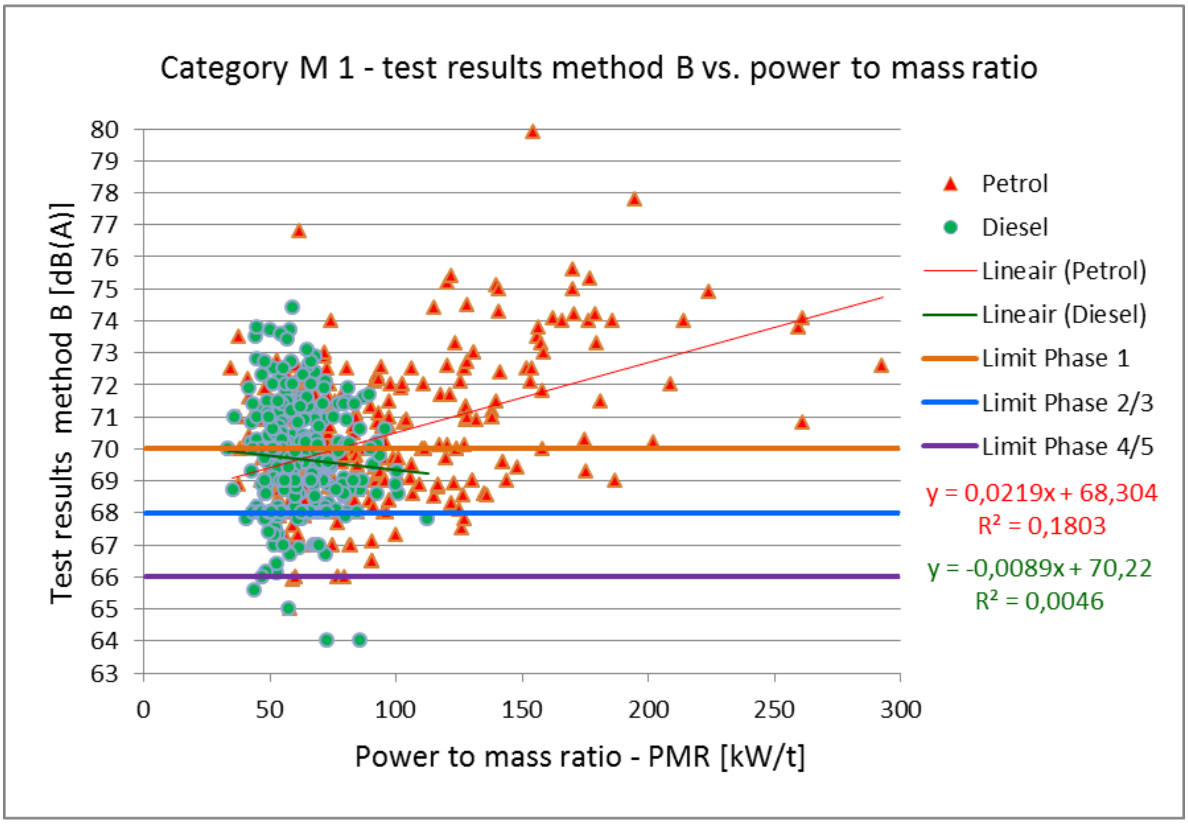

Figure 1 - Correlation between the sound emission according to test method B and the power -to-mass ratio of passenger cars (with indications of the proposed limit values)

[2] The new test method B for light vehicles (proposed in draft EU Regulation 2011/0409 [6]) consists of 2 partial tests (acceleration and constant speed). It is intended to be more representative of actual noise emission in traffic than the current test method A, which only tests at full throttle acceleration.

The large spread of results in each PMR range clearly demonstrates that it is quite possible to realise a low noise emission value, regardless of the PMR value of the vehicle. So there are no technical obstacles related to certain PMR ranges that would hamper the fulfilment of the proposed new limit values.
For PMR values above 140 kW/t no noise emission values lower than 69 dB(A) are present in the data base. This is probably due to the fact that vehicles with these high PMR values have a very sporty character and are supposed to produce a sporty sound to fulfil the customer’s expectations. This does not necessarily mean that there is a technical necessity for these vehicles to produce higher noise emissions. Luxury sedans with high PMR values do not produce higher noise emissions than similar vehicles with lower PMR values. The allowance of 1 dB(A) for vehicles with PMR values above 150 kW/t in the EC proposal is mainly included as a continuation of the current practice.
Accordingly there is no real necessity to introduce an intermediate subcategory for medium to high PMR values with an allowance for a higher noise emission.
Such an allowance would make the system less simple and transparent.

If, however, there is a wish to follow the alternative proposals and to introduce three sub-categories for M1 vehicles it is recommended to restrict the allowance for the intermediate PMR sub-category to 1 dB(A) above the lowest sub-category and for the high PMR sub-category to 2 dB(A) above the lowest sub-category.
In the data base the sub-category of PMR values between 120 and 160 kW/t covers 9 % of the total number of M1 vehicles and the sub-category above 160 kW/t covers 4 % of the total number. If these percentages are representative for their share in the vehicle fleet and if their extra noise emission in traffic is restricted to 1 resp. 2 dB(A) above the normal emission the influence of these vehicles with these allowances would result in an increase of the average overall traffic noise emission by 0,2 dB(A), which is not significant in view of the uncertainties of this estimate.

2.2.2 *M2 – Medium sized buses*

In the EC proposal the sub-categories for M2 vehicles are identical to the current limit value system. No change was introduced because the small number of these vehicles in the data base (28) did not produce any evidence to motivate a change The contribution of this vehicle category to the average noise emission of traffic flows is very small. In view of these facts there are no objections against redefining the sub-categories for M2 vehicles. The three alternative proposals are not in line with each other. The sub-categorisation suggested in the German proposal or in the Japanese proposal may be adopted, on condition that the stringency of the limit values remains similar to the EC proposal.
In section 3.1 the German suggestion is followed for a revised elaboration of the limit value proposal.

2.2.3 *M3 – Heavy buses and N3 – Heavy trucks*

In the EC proposal the two sub-categories of the current limit value system were retained for the M3 and N3 vehicles, with separations between the sub-categories at 150 kW rated engine power. The three alternative proposal suggest three sub-categories for M3 vehicles and two or three for N3 vehicles, in both cases with different separations between the sub-categories than the EC proposal.
In this sub-section two possibilities for reclassification of these two vehicle categories will be discussed, one based on rated engine power and one based on the number of axles of the vehicle.

<u>Subdivision based on rated engine power</u>
In the current UNECE Regulation 51 and EU Directive 70/1157/EEC the categories M3 (heavy busses) and N3 (heavy trucks) are divided in two subcategories, based on rated engine power: below 150 kW and equal to or larger than 150 kW.
As the correlation between the rated engine power and the noise emission test result according to method B is weak (see Figure 2), the subcategories of the current regulation were maintained unchanged in the EC proposal for new limit values.

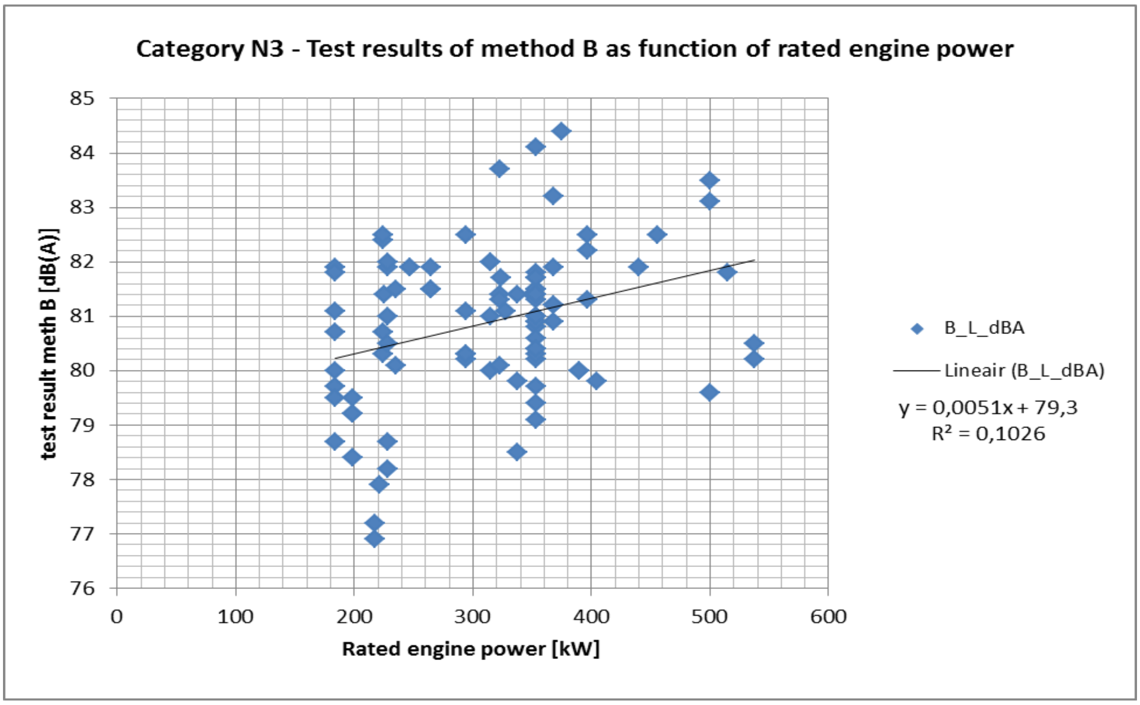

Figure 2 - Correlation between vehicle noise emission according to method B and rated engine power for category N 3 vehicles (heavy trucks).

However, from Figure 2 it can be observed that in the database there are no N3 vehicles with a rated engine power lower than 180 kW. This indicates that for the current and future generations of N3 vehicles the division at 150 kW is no longer relevant.
This observation was confirmed from an analysis of the numbers of registered N3 vehicles in the Netherlands in the years 2005 to 2012, based on data received from RDW, the Dutch type approval and vehicle registration authority; see Appendix A. These data demonstrate that the average percentage of N3 vehicles with a rated engine power between 75 and 150 kW is 0,5 %, between 150 and 250 kW 18.6 % and above 250 kW, 80,9 %. This last percentage has increased from 77,6 % in 2005 to 83,9 % in 2012. This indicates that the subcategory of N3 vehicles with a rated engine power of 250 kW and above is the most important subcategory for the in-traffic noise emission of heavy trucks.

Based on these findings, another subdivision than the one in the EC proposal can be put forward, on condition that the stringency of the EC proposal for the heaviest sub-category be maintained. Following the German proposal, a subdivision for N3 and N3G vehicles based on rated engine power below or equal to 250 kW and

above 250 kW is now proposed. 31 of the N3 and N3G vehicles in the database would fall in the lower sub-category and 108 in the higher (see Table 1).
The average noise emission of N3 and N3G vehicles according to method B would be 80,2 dB(A) for the lower sub-category and 81,5 for the higher sub-category; this difference is statistically significant. Based on these findings a difference in limit values of 1 dB(A) between these 2 sub-categories could be motivated. There is no evidence that the reduction of the limit values would make a larger difference relevant or necessary.

Table 1 - Average noise emission according to method B for subcategories based on rated engine power. Legend of colours: Green: difference is statistically significant; Yellow: difference is not significant due to low number of data.

Vehicle category	Rated engine kW	Noise emission cf. method B: number in data base	Noise emission cf. method B: L_B [dB(A)]
M3 - Buses	< 250	48	76,6
	> 250	26	78,0
Total M3		74	77,1
N3 - Trucks	< 250	30	80,2
	> 250	70	81,2
Total N3		100	80,9
N3G - Off-road trucks	< 250	1	80,0
	> 250	38	82,0
Total N3G		39	82,0
N3 + N3G	< 250	31	80,2
	> 250	108	81,5
Total N3 + N3G		139	81,2

Similarly, the division of the category M3 at a rated engine power of 150 kW, as used in the current regulation, has become less relevant. Only 9 out of 76 M3 vehicles in the data base have a rated engine power below 150 kW. A more balanced division point could be 250 kW, as suggested in all three proposals (with 48 vehicles below or equal and 26 vehicles above – see Table 1).

The German and ACEA suggestions to add a subcategory with rated engine power below or equal to 180 kW are not supported by the data. In view of the steadily increasing engine powers such a subcategory could be irrelevant within a couple of years. Moreover, there is no need for an additional subcategory, that would weaken the overall stringency of the proposed regulation.
In the Japanese proposal an even lower separation at 125 kW is suggested.
Only 8 out of 76 vehicles in the data base would fall in this sub-category.
Consequently this proposal is not supported.

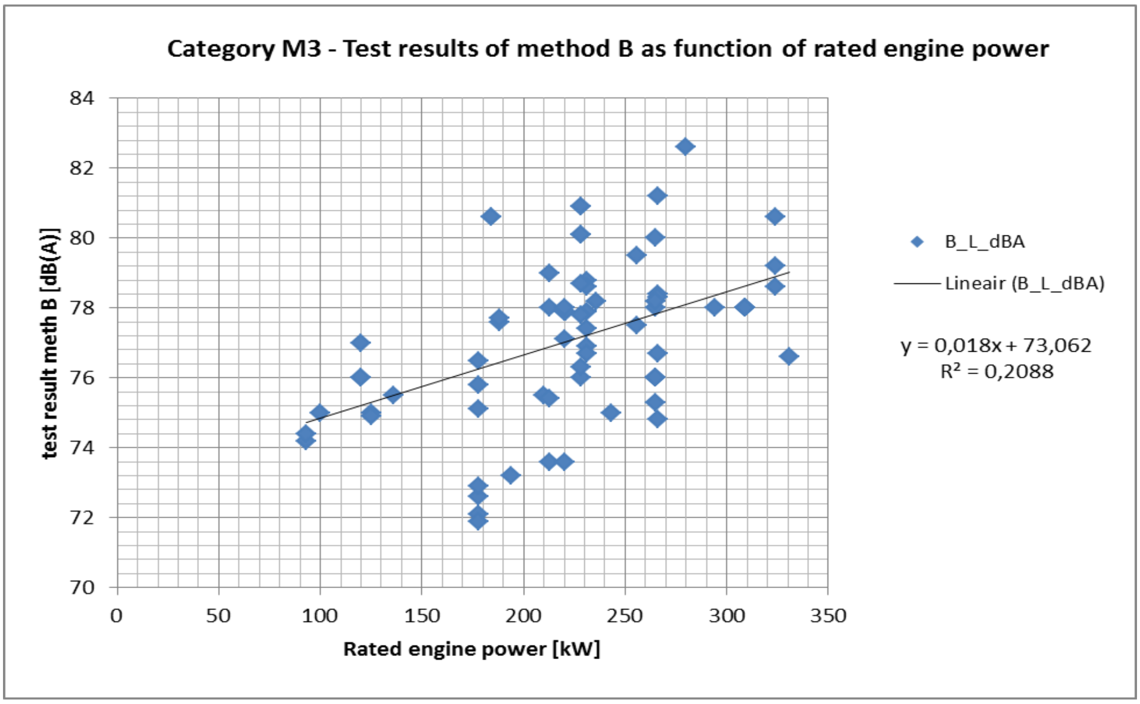

Figure 3 - Correlation between vehicle noise emission according to method B and rated engine power for category M3 vehicles (heavy buses)

<u>Subdivision based on number of axles</u>
Another possibility to make a discrimination between lighter and heavier vehicles within the M3 and N3 vehicle categories would be to introduce subcategories based on the number of axles, and, if relevant, also on the number of drive axles. Therefore the data of the M3, N3 and N3G vehicle categories in the data base were analysed to assess the influence of the number of axles and drive axles on the sound emission measured according to method B. The results are presented in Appendix B.
From the results it may be concluded that the differences in noise emission between sub-categories of M3 and N3 vehicles, based on the number of axles, are significant, but that for N3G vehicles (off-road trucks) the number of axles does not offer a significant distinction. Off-road trucks usually have a larger number of axles and drive axles than on-road trucks. The extra noise emission caused by this larger number of axles is strongly related to their off-road capabilities, which is already accounted for by an extra allowance for off-road vehicles. If a higher limit value would be allowed for a larger number of axles this would overlap with the extra allowance for off-road capabilities. Therefore the number of axles is not a suitable criterion for sub-categorisation of M3, N3 and N3G vehicles.

2.2.4 N1 – Vans
The EC proposal mentions two sub-categories for N1 vehicles with a separation at a maximum mass of 2 tons.
In the German and the ACEA proposals it is suggested to move the criterion for subdivision from a maximum authorised mass of 2 tons to 2,5 tons. The motivation for this shift is that the N1 category can be divided into vehicles that are derived

from passenger cars and vehicles that are developed as vans for goods transport. As the origin of the vehicle design is supposed to be a determining factor for the vehicle technology and, hence, for the noise emission, this distinction could be a good basis for sub-categorisation. An appropriate criterion would then be 2,5 tons.
In the Japanese proposal the maximum mass criterion is supplemented with a PMR criterion. The reason for this is that in the Japanese vehicle market there is a special category of small trucks with low powered engines that may have more difficulties in fulfilling the proposed limit values. As such small trucks are not available on European markets and the vehicles in question are not present in the data base, the proposal cannot be evaluated.
Therefore the German and ACEA proposals are supported in this report, on condition that the stringency of the limit values from the EC proposal be maintained.

2.2.5 N2 – Medium sized lorries

The EC proposal three sub-categories with separations at 75 kW and 150 kW rated engine power are proposed.
In the German and the ACEA proposals it is suggested to delete the subcategory lorries with a rated engine power of less than 75 kW and to retain the separation at 150 kW. The Japanese proposal also suggests deletion of the lowest sub-category, but proposes a separation at 125 kW. The data base contained only one N2 vehicle with a rated engine power below 75 kW, 32 vehicles between 75 and 125, 8 vehicles between 125 and 150 and 14 vehicles above 150.
For the currently available N2 vehicles a separation at 125 kW might be well balanced, but in view of an expected increase of rated engine powers also for this vehicle category the separation at 150 kW, as used in the EC proposal, should be maintained.

2.3 Comparison of EC limit value proposal and alternative proposals

In Appendix C the EC proposal and the three alternative limit value proposals are presented in a table. The three proposals differ in terms of sub-categorisation, limit values and the time frames of the introduction of the various phases of the limit value reduction. Moreover, the alternatives employ a Stage 1, which expresses merely the effects of the transition from the current test method A to the new test method B. This stage in the alternatives does not introduce a reduction of limit values. In the EC proposal the first phase combines the effects of the transition with a first reduction step of the limit values. This makes the different proposals essentially incomparable, because they are “out of phase” with each other.
In Table 2 an attempt is made to compare the time schedules of the EC Proposal and its alternatives, although the different Phases and Stages are not fully similar.

In addition to the three alternatives discussed above, also the T&E proposal, presented in Section 3.1 of this report, is included.

Table 2 - Comparison of the time schedules of the EC limit value proposal and alternatives.

Phase or Stage	Proposed limit values valid from year				
	EC proposal	ACEA	Germany	Japan	T&E
Stage 1	--	2013	2014	2014	--
Phase 1 ≈ Stage 2	2014	2018	2018/2020	2018/2020	2013
Phase 2 ≈ Stage 3	2017	--	2022/2026	2022/2026	2015
Phase 3 = Phase 2	2019	2020	--	--	2017
Phase 4	--	--	--	--	2020
Phase 5 = Phase 4	--	--	--	--	2022

There are two possible ways to deal with the incomparability of the proposals:

a. By comparing the proposed limit values at corresponding points in time after publication of the regulation. This way of presenting is used in the table in Appendix C. It gives an impression of the stringency of the proposed limit value reductions as a function of time.
b. By comparing the proposed limit values at corresponding phases of the process (see Table 2). This way of comparison shows that the final values of the proposed reductions of the limit values in the various proposals are more or less similar, but the time schedules to reach this final stage are very different.
In Appendix C it can be seen that the Stage 3 limit values of the German and Japanese proposals are approximately equivalent to the Phase 2 and 3 values of the EC proposal. In the EC proposal this stage will be legally required for new types of vehicles 5 years after publication of the regulation. Assuming a penetration period of 12 years the reduction is expected to be fully incorporated in the actual traffic noise emission 17 years after publication of the regulation. In the German and Japanese proposals this stage will not be legally required until 14 years after publication of the regulation. Consequently, the full effect of these adaptations will only be achieved 26 years after the publication.

The presentation of the differences according to variant a. in Appendix C shows clearly that the EC proposal is considerably more stringent over time than the alternatives. In Table 3 the average and the range of the differences are summarised per vehicle category and per phase and / or stage of the process.

Table 3 - Overview of differences between the limit values of the EC proposal and alternatives (per vehicle category and per phase or stage of the process.

	Phase 1 - Stage 1			Phase 2 - Stage 2			Phase 2/3 – Stage 3	
Vehicle category	**German vs. EC**	**ACEA vs. EC**	**Japanese vs. EC**	**German vs. EC**	**ACEA vs. EC**	**Japanese vs. EC**	**German vs. EC**	**Japanese vs. EC**
M1	+ 2 / +4	+2 / +4	+2 / +4	+2 / +5	+2 / +5	+2 / +4	0 / +4	0 / +2
M2	-1 / +1	0 / +2	-1 / +2	-1 / +1	0 / +3	-1 / +2	-3 / 0	-3 / 0
M3	+1 / +3	+1 / +3	+1 / +3	+1 / +3	+2 / +4	+1 / +3	0 / +1	-1 / +1
N1	+1 / +2	+1 / +2	+1 / +3	+1 / +2	+1 / +2	+1 / +3	-1 / +1	-1 / +1
N2	+1 / +3	+1 / +3	+2 / +4	+2 / +3	+2 / +4	+2 / +4	-1 / 0	0 / +2
N3	+1 / +4	+1 / +2	0 / +3	+1 / +4	+2 / +3	0 / +3	-1 / +2	-2 / +1
Average	**+1,7**	**+1,8**	**+1,9**	**+2,0**	**+2,5**	**+2,0**	**+ 0,2**	**0,0**

During the first 2 phases and / or stages the EC proposal is on average approximately 2 dB(A) more stringent than the alternatives.
Phase 3 of the EC proposal serves to consolidate the limit value reduction by making it obligatory for sale and entry into service of all new vehicles, regardless of their time of design. The German and Japanese proposals comprise a third stage of reduction. Only in this third stage the proposed values become comparable to the Phase 2 / 3 values of the EC proposal.
Assessing the proposal only by their average differences may be misleading, as not all vehicle categories contribute equally to the in-traffic noise emission reduction.
In this respect the dominant vehicle categories are passenger cars and heavy trucks, while in urban traffic also vans may be relevant. Specifically for these dominant vehicle categories the alternative proposals show larger differences than for the less important categories.
For heavy trucks the Japanese proposal suggest Stage 3 values that are more stringent than the Phase 2/ 3 values of the EC proposal

The overall conclusion is that the alternatives are generally significantly less ambitious than the EC proposal and are phased to be introduced later.

2.4 Technological potential for noise reduction of trucks

As was recently found, a major European truck manufacturer offers an optional package for exterior noise reduction beyond the current noise limit value of 80 dB(A) for N3 category trucks. The availability of such a package at one OEM demonstrates that OEMs already have technological capabilities to achieve further noise reduction beyond the level of the current limit values

Industry consultation
An industry consultation was undertaken to make an inventory of the specifications, cost and availability of similar packages at other OEMs. In particular, the current and future potential for exterior noise reduction of trucks was of interest. Contact was sought with staff involved in homologation at Dutch import organizations for five major truck manufacturers (OEMs) through the Dutch Automotive Industry Association (RAI). These persons were interviewed about the availability and specifications of noise reduction options in the product range of their companies. Several of them indicated that they were well informed about the technological state-of-the-art in their companies.
In addition, an interview was conducted with technical and commercial staff of a supplier company of vehicle noise control components and engine encapsulation products.

Optional noise reduction packages
In the interview with one large truck manufacturer, it was verified that an optional package for noise reduction below the current EC noise limit value of 80 dB is offered. The specifications of this package are however not published and the Dutch import organization could not make this information available.

None of the other truck manufacturers currently offer optional noise reduction packages that reduce the exterior noise below the present European limit value.

Some of the companies interviewed do indicate that exterior noise reduction is included in their R&D programme.

It should be noted that national regulations may require the noise emitted by trucks in specific situations to comply with more strict noise limits. An example is the Dutch ‘PIEK’ programme which restricts peak noise levels during goods distribution in urban areas. Most OEMs however do not offer packages for trucks to comply with national regulations as the market for such products is considered to be too small for a positive business case. Specific noise mitigating measures are often post fitted by dedicated companies.

Technical options for noise reduction
Engine noise is one of the dominant sources in vehicle exterior noise. Reduction of engine noise at the source is not simple due to a number of technical constraints. Changing the combustion characteristics has a serious impact on fuel consumption and exhaust gas emission. Changing the stiffness properties of the engine structure can have high impact on durability and tooling costs. Therefore changes to the engine are normally only done in a complete redesign of the engine with a lead time of around 10 years.

Reduction of engine noise by encapsulation or shielding may be a viable alternative with a shorter lead time (1 a 2 years) and lower tooling and development costs. However costs per vehicle are normally higher, and the impact on cooling has to be taken into account.

The engine encapsulation supplier Autoneum was interviewed as market leader in the industry. The head of the acoustics laboratory for trucks and the head of the experimental technologies department indicated that the company has supplied large numbers of engine encapsulations to the Truck OEMs in the early 1990’s. At that time the truck industry faced a challenge to reduce truck noise emission in the short term. In 1989 the European noise limit was reduced from 88 to 84 dB(A). Soon after this the Austrian night time truck ban “Nachtfahrverbot” was announced. This truck ban could be avoided by complying with an 80 dB(A) noise limit. Effectively the noise emission of trucks was reduced by 8 dB(A) in 2 or 3 years. An EU noise limit value of 80 dB(A) was introduced in 1996.

This led to massive use of engine encapsulation and shielding in the 1990’s. When more silent truck engines using common rail and multi jet injection technology were introduced in the following years, the company saw their turnover in noise shields decline as trucks met the noise limit value of 80 dB(A) with less additional shielding. In the 1990s, encapsulation measures for a heavy truck typically consisted of a full tunnel encapsulation of engine and gearbox (shielding of both sides of the power train as well as the bottom and top). Modern trucks have much less encapsulation, typically a partial shield on the left and right side of the engine to cover the aperture between cabin and chassis, combined with an engine shield on the top rear end of the engine to cover the aperture between cabin and trailer.

Recently, the company has tested a truck equipped with commercial-off-the-shelf (COTS) engine encapsulation for exterior noise. The shields absorb and isolate the noise generated by the engine and have an additional mass of 15 – 20 kg. The shielding was equipped with closeable apertures for thermal management.

This tunnel encapsulation covered both engine and gearbox and effectively represented the amount of encapsulation which was found on vehicles in the early 1990's.

The noise emission of the Euro V truck equipped with and without this encapsulation was measured according to the new method B. The head of the acoustics laboratory stated that the noise emission was measured at 81 dB(A) without and 77 dB(A) with the extra encapsulation. No changes were made to the exhaust, intake, tires and other noise generating parts. This indicates that it is possible to comply with phase 2/3 of the proposed noise limit value reduction scheme with COTS technology.

It should be noted that thermal management of encapsulated Euro VI compliant engines may prove to be a challenge. The Euro VI regulation requires the application of both adblue and exhaust gas recirculation (EGR) technologies, whereas the application of one of the aforementioned currently suffices.
Truck manufacturers who have not applied EGR before will face an increased heat production inside the encapsulation. The implication of complying with both Euro VI and a more strict noise limit value may include a re-design of the cooling system in order to separate the air flows to the engine and the intercooler and to increase the cooling capacity. Examples of such split cooling units already exist in buses.

Furthermore the actual noise emission reduction for people exposed to traffic noise will depend on the willingness of transport companies to have the encapsulation re-installed after engine maintenance. When re-installation is a labour-intensive or time consuming process, it is likely that this task will be omitted in order to reduce costs and save time for a share of the fleet. At least some of the engine encapsulations currently available are designed with maintenance time taken into consideration.

No off-the-shelf solutions are available to achieve an additional 2 dB noise reduction to comply with the noise limit value of 76 dB(A) that will be proposed in phase 4/5 (see sub-section 3.1). Experiments with close engine shielding, where sound insulating and absorbing parts are mounted directly on the noise radiating sources do however show promising results in test bench configurations.
These results, and the experience with similar solutions in passenger car applications [25] are a basis for the expectation that a limit value of 76 dB(A) for heavy trucks is technologically feasible.

Thermal management, by splitting cold and hot airflow through the engine bay will be a key challenge in the design of the additional noise reducing measures, as will the effort to realize a maintenance friendly design. The application of these technologies is currently not widespread for trucks, but the company indicated to have significant experience with these technologies in passenger cars. By the time of the introduction of the phase 4 noise limit value reduction, 8 years after the publication of this proposal, this technology is assumed to have matured enough to be applied in trucks without an insurmountable research and development effort for truck manufacturers.

Other recent innovations in truck engines can lead to noise emission reduction in some situations, but not for the full operational range of truck use. For example hybrid trucks can be relatively quiet when driven electrically at low speeds, but will produce similar noise as regular trucks when they are operated at higher speeds.

Cost of truck noise emission reduction for industry / consumers
As only one major truck manufacturer currently offers add-on noise reduction packages, and the specifications for noise reduction were not available at the time this report was written it is hard to quantify costs for the technological options discussed in the previous section.

It is however estimated that the cost of applying COTS engine and gearbox encapsulation in order to comply with the phase 2 noise limit value reduction to 78 dB(A) will be between 1000 – 2000 Euro per truck. If this cost increase is directly passed to the consumer, the price of a truck will increase by around 1 %.

The additional R&D and tooling effort for truck manufacturers will drive the cost of measures to comply with the noise limit value reduction to 76 dB(A) proposed in phase 4. As key challenges such as thermal management need to be addressed, the impact on the truck design and production will be larger than for the first limit value reduction. It is estimated that the cost of future measures will be twice as large, i.e. between 2000 – 4000 Euro per truck.

Passing the increase of cost to consumers will lead to an additional increase of the price of circa 1 %, or an increase of around 2 % with respect to the current price level.

The above costs are based on add-on components for existing vehicles, and can be summarized by a cost of around 500 Euro per dB reduction. If however this type of solution is introduced into mass production and better integrated into the design, a cost of 250 Euro per dB reduction is considered achievable.

In a publication from 1991 [27] it is shown that an engine noise reduction from 90 to 84 dB(A) would cost around 3% of the retail price, so around 0,5% per dB reduction. This would support the estimate of 250 Euro per dB reduction for encapsulation.

2.5 Contribution of tyre-road noise to noise emission of heavy vehicles

2.5.1 Influence of tyre-road noise during the noise emission test

Under the current test specifications for trucks according to test method A the use of various types of tyres for the test is not very strictly regulated. As a consequence of this in most cases the tests are conducted with tyres with relatively low rolling noise emission on all axles. In those cases during the tests, the drive axles are not equipped with traction tyres, as is the case in normal traffic.
In order to avoid this non-representative use of tyres, in the description of method B it was specified that:
“The tyres to be used for the test shall be representative for the axle”
and:
“Snow tyres and special tyres (…) shall be excluded during type-approval- and COP-measurements on request of the manufacturer”.

The test for trucks according to method B during the monitoring period were conducted in general with traction tyres on the driven axles. The observed increase by 1,2 and 0,6 dB(A) for the N3 and N3G test results of method B relative to method A can be attributed, at least partially, to the use of more noisy tyres on the driven axles.

Furthermore a more specific result is available, because one truck manufacturer carried out a specific series of tests, in which each tested truck or bus was measured two or three times with different tyres mounted on the drive axles. These tyre types were: a steering tyre, a traction tyre of the same brand as the steering tyre and a traction tyre of a different brand. This data set contained 17 N3 trucks, 8 N3G off-road trucks and 1 M3 heavy bus. The differences between the test results with traction tyres and with steering tyres ranged between -0,1 and +1,6 dB(A). The average difference was 0,6 dB(A) between traction and steering tyres of the same brand and 1,0 dB(A) between traction and steering tyres of different brands (see section 8.7 of [5]). This result is well in line with the general difference between method A and B test results.

In article 3.2.2 of Annex II of the draft regulation on the sound level of motor vehicles [6] the wording of the instructions for the use of tyres in test method B was changed as follows:
"The tyres to be used for the test shall be representative for the vehicle"
and:
"Traction tyres, snow tyres and special use tyres (…) shall be excluded during type-approval- and COP-measurements on request of the manufacturer".

A consequence of this change will be that the noise emission tests of trucks will be performed with the type of truck tyres that produce the lowest rolling noise emission. Usually these will be steering tyre types.
This change in the test method will produce test results that are on average 0,6 to 1,0 dB(A) lower than the values in the data base acquired during the monitoring period, which were the basis for development of the proposal for limit value reduction.
Consequently the proposed limit values for heavy trucks must be lowered by 1 dB(A) to take account of the change of the instructions for the use of tyres.

An alternative solution for this inconsistency would be to re-introduce the original wording, stating that "The tyres to be used for the test shall be representative for the axle"

2.5.2 Influence of tyre-road noise on in-traffic noise emission of trucks

The main focus of the different topics discussed in this report is on the noise emission during the type approval tests. An important question, in particular for heavy vehicles, is how the behaviour during the test relates to the in-traffic noise emission under normal conditions of use.
The conditions during the type approval test of trucks are representative of urban traffic conditions at speeds around 50 km/h. It may be expected that the influence of tyre-road noise during the noise emission test will be similar to the influence during normal traffic in urban areas. This implies that the proposed limit values (with the lowering of 1 dB(A) according to 2.5.1) will be adequate to regulate the noise emission of trucks in urban traffic.
The relative contribution of tyre-road noise increases with speed. At motorway speeds (80 - 100 km/h) tyre-road noise will be dominating the in-traffic noise emission of heavy vehicles. For such conditions the vehicle type-approval test is less relevant. For these cases the rolling noise emission test for truck tyres (at 70 km/h – according to [12]) will give relevant results.

It may be expected that the noise emission of heavy vehicles in various traffic conditions can be regulated effectively by the combined application of the vehicle noise emission test and the rolling noise emission test for truck tyres.

2.6 Characteristics of the noise emission test track

The vehicle noise emission test are influenced in a significant way by tyre-road noise. Therefore the acoustical characteristics of the test track on which the tests are performed are of major importance for the noise test results.
In Annex VII of the draft regulation on the sound level of motor vehicles [6] the specifications of the test track are based on ISO 10844:1994. In 2011 this ISO standard was revised to improve the uniformity of the characteristics of the test tracks.
Therefore the specifications of the test track in Annex VII of the draft regulation [6] should be modified to be in line with and refer to ISO 10844:2011.

2.7 Synergies of noise reduction with other design criteria

Vehicle noise reduction in future years will have several potential synergies with other design criteria. Fuel economy is an major issue which is linked with noise reduction in the following aspects:

- Further covering of the underside of all types vehicles to reduce aerodynamic resistance and thereby fuel consumption, will also have the benefit of shielding engine noise.
- Limitation or control of engine speeds as applied in some low noise vehicles (Dutch PIEK programme) benefits both noise and fuel consumption.
- Improved engine cooling concepts and energy management may both reduce fuel consumption and facilitate better engine encapsulation.
- If the use of electric drives increases both in hybrid and electric vehicles, this will benefit both exhaust emissions and noise levels.

3 Limit value reduction beyond EC proposal

3.1 Elaboration of an alternative proposal for limit value reduction including an additional step

In Section 2.2 it was recommended to redefine several subcategories. Therefore a revised table of proposed limit values is provided to incorporate this reclassification; see Table 4. This Table also recommends shorter time delays for the implementation of the Phases 1 and 2/3 than the EC proposes, based on demonstrated technical feasibility.
Moreover, from various sides it was suggested to include an additional phase of limit value reductions in the proposal, that would be more challenging with respect to technological feasibility than the second phase of the EC proposal.

For passenger cars the large spread of results below the current limit values gives a useful indication of the potential for further noise reduction, based on currently available technology, but for several other vehicle categories the spread of the results of the monitoring test data does not reach as low as the future limit values; see Section 3.2. However, the data base covers vehicles tested between 2007 and 2010. This means that the development of those vehicles took place in the years before the monitoring period. Therefore the design was not aimed at achieving a low noise emission. Especially for commercial vehicles the cost effectiveness is an important design target, so no unnecessary measures are included in the design.
In Section 3.2 to feasibility of an additional phase of limit value reductions will be discussed further.

In the past (until 1996) the limit values were revised on a regular basis with reduction steps of approximately 2 dB(A). By analogy with this long standing practice an additional phase with a limit value reduction of 2 dB(A) for all vehicle categories is now proposed in Table 4. This Phase 4 should become valid for type approval of new vehicle types 8 years after publication of the EU regulation.
These same limit values should be consolidated in Phase 5, which should widen the field of application to registration, sale and entry into service of all new vehicles 10 years after publication of the regulation.

Table 4 - Alternative proposal for reduction of noise emission limit values, incorporating recommendations for reclassification of vehicle categories and a third reduction step.

Vehicle category	Description of vehicle sub-category	Limit values expressed in dB(A) [decibels(A)]					
		Limit values for Type approval of new vehicle types		Limit values for Type approval of new vehicle types *)		Limit values for Type approval of new vehicle types *)	
		Phase 1 valid from [1 year after publication]		Phase 2 / 3 *) valid from [3 resp. 5 years after publication]		Phase 4 / 5 *) valid from [8 resp. 10 years after publication]	
		General	Off-road **)	General	Off-road **)	General	Off-road **)
M	**Vehicles used for the carriage of passengers**						
M1	no of seats ≤ 9; power-to-mass ratio ≤ 150 kW/ton	70	71***)	68	69***)	66	67***)
	no of seats ≤ 9; power-to-mass ratio > 150 kW/ton	71	71	69	69	67	67
M2	no of seats > 9; maximum mass ≤ 2,5 tons	72	73	70	71	68	69
	no of seats > 9; 2,5 tons < max. mass ≤ 3,5 tons	73	74	71	72	69	70
	no of seats > 9; 3,5 tons < max. mass ≤ 5 tons;	74	75	72	73	70	71
M3	no of seats > 9; maximum mass > 5 tons; rated engine power ≤ 250 kW	75	76	73	74	71	72
	no of seats > 9; maximum mass > 5 tons; rated engine power > 250 kW	77	79	75	77	73	75
N	**Vehicles used for the carriage of goods**						
N1	Maximum mass ≤ 2,5 tons	71	72***)	69	70***)	67	68***)
	2,5 tons < max. mass ≤ 3,5 tons	72	73	70	71	68	69
N2	3,5 tons < max. mass ≤ 12 tons; rated engine power ≤ 150 kW	75	76	73	74	71	72
	3,5 tons < max. mass ≤ 12 tons; rated engine power > 150 kW	77	79	75	77	73	75
N3****)	maximum mass > 12 tons; rated engine power ≤ 250 kW	77	78	75	76	73	74
	maximum mass > 12 tons; rated engine power > 250 kW	79	81	77	79	75	77

*) Phases 3 and 5 consolidate the limit values introduced in Phases 2 and 4 for type approval of new vehicle types by widening the field of application to registration, sale and entry into service of all new vehicles.

**) Increased limit values are only valid if the vehicle complies with the relevant definition for off-road vehicles according to article A.4 of Annex II of EU Directive 2006/46/EC

***) For M1 and N1 vehicles the increased limit values for off-road vehicles are only valid if the maximum authorised mass > 2 tons

******)** All limit values for N3 vehicles have been lowered by 1 dB(A) to take account of the change of the instructions for the use of tyres in test method B.

Yellow marking The definition of the sub-categories has been modified compared to the EC proposal (see Section 2.2)

Orange marking The limit values have been modified compared to the EC proposal (see Sub-section 2.5.1)

3.2 Technological potential for meeting the limit value reduction requirements

A considerable percentage of the vehicles that were tested during the monitoring period (1 July 2007 until 6 July 2010) will fulfil some of the future limit values proposed in Table 4. These percentages are listed in Table 5 for the various vehicle subcategories. The percentages given for the categories M2, N1 and N2 are an average over the subcategories, as the assignment of the vehicles to subcategories was in many cases unclear.

Table 5 - Percentage of vehicles tested during the monitoring period (2007 – 2010) per vehicle sub-category that comply with future limit values; for the yellow marked cases none of the tested vehicles between 2007 – 2010 did already comply with the future limit values.

Vehicle category	Sub-category	Phase 1		Phase 2		Phase 4	
		Limit value	Percentage compliant	Limit value	Percentage compliant	Limit value	Percentage compliant
M1	P ≤ 150 kW	70	63 %	68	22 %	66	3 %
M2	All	72 – 74	> 43 %	70 – 72	> 7 %	68 – 70	0 %
M3	P ≤ 250 kW	75	31 %	73	10 %	71	0 %
	P > 250 kW	77	31 %	75	8 %	73	0 %
N1	All	71 – 72	> 31 %	69 – 70	> 12 %	67 – 68	0 %
N2	All	75 – 77	53 %	73 – 75	31 %	71 – 73	> 7 %
N3	P ≤ 250 kW	78	17 %	76	0 %	74	0 %
	P > 250 kW	80	27 %	78	0 %	76	0 %

For all cases where at least a small percentage of the existing vehicles complies with a proposed limit value, it is obvious that the current technology makes it possible to fulfil this requirement. This also implies that it must be feasible for other manufacturers to comply as well, which means that there are no technological obstacles to implement such limit values.

For Phase 2 there were no tested, existing N3 vehicles that did already comply, while for Phase 4 most of the tested, existing vehicles did not comply with the proposed limit values. Only 3 % of the passenger cars (N1) and at least 7 % of the medium size lorries (N2) would comply. This does not mean that the proposed limit values are not technologically feasible. Especially commercial vehicles are designed to fulfil the current requirements at minimal cost. If these vehicles would already now fulfil the future limit one could conclude that the proposed limit values would not be sufficiently challenging.
The proposed limit values will not be valid for existing vehicles, but in the first years only for new vehicle types, for which lower noise emission should be an integrated design target.
A basic assumption in the VENOLIVA study was that after a (relatively short) period of adaptation the vehicle designers will integrate the new noise requirements in an early stage of the design and a new distribution of noise test values will emerge that will have a similar shape as before the revision of the limit values, but will be shifted towards lower values. The shift of the distribution will be approximately the same as the lowering of the applicable limit values. This assumption is based on the

experience that vehicle design is a continuous process of improvements and adaptations, in which many simultaneous design objectives are integrated. Vehicle technology is a dynamically evolving field.

In section 2.4 the technological potential for noise reduction of trucks has been discussed. This showed that the current off the shelve engine encapsulation technology is sufficient for N3 vehicles (heavy trucks) to achieve the Phase 2 / 3 limit values. Furthermore it was substantiated that the technology of close engine shielding, which has already been applied in luxury passenger cars, will enable a further 2 dB(A) reduction, sufficient to achieve the Phase 4 / 5 limit values. Another example from a different field of application, sc. the low noise design of Diesel driven power generators, corroborates this conclusion:
From the NOMEVAL study [26] it is known that a full encapsulation of a Diesel engine driven outdoor power generator will yield a reduction of the noise emission by 10 dB(A) and more. As some of these engines are quite comparable to heavy truck Diesel engines, a similar noise reduction may be expected for the application of a well designed encapsulation of a truck engine. Based an a current average noise emission of 81 dB(A) (see Table 1), a limit value of 76 dB(A) for heavy trucks in 2020 is fully within reach with available technology.

The argumentation given above applies primarily to the power train noise of vehicles. However, also the tyre-road noise will have to be addressed in view of further reductions of the limit values.

For the elaboration of the limit values proposed for the Phases 1 and 2 in the VENOLIVA study it was estimated that the rolling noise of tyres will decrease as a result of the implementation of the new tyre noise Regulation [12], that will come into force from 1 November 2012. The estimated average reductions in the final stage would be 3,8 dB(A) for car tyres and 3,3 dB(A) for truck tyres.
These rolling noise reductions will not be sufficient to enable the further overall vehicle noise reductions required to fulfil the limit values proposed in Phase 4 / 5. In order to enable an overall vehicle noise reduction with a further 2 dB(A) for most vehicle categories it will be necessary to reduce both the rolling noise and the power train noise in a balanced way. The required rolling noise reductions are estimated at 3 dB(A) at least. Therefore a further improvement of the tyre noise Regulation with lower limit values for rolling noise, will be necessary to enable the proposed limit values for the sound level of motor vehicles according to Phase 4 /5.

4 Impact assessment

4.1 Introduction

Since the completion of the Venoliva Study in 2010 [5], several new reports, documents and comments have appeared providing further basis for updating the impact assessment. These include the ACEA study [13], the Expert response letter to the ACEA study [9] , the WHO report on burden of disease [14], UK guidance on noise valuation [15], the Noise and Health report by IGCB [16], the EEA Good Practice Guide on noise exposure and health effects [17] and others.
Where appropriate, the Venoliva impact assessment for option 5 shown in Table 2 (Phases 1,2,3) is updated in this study, taking these documents into account. Also, the impact of a potential third step for noise limits is assessed here (Phase 4 in 2020 in table 2).

In the Venoliva study the average noise exposure of the population in the EU27 was assessed, based on characteristic road types, population distributions, traffic flows and driving conditions. Although it is also feasible to use EEA noise mapping data and to extrapolate the findings to the entire EU population this has large uncertainties and limited scope (agglomerations and major roads) in available mapping data.

4.2 Cost assessment

In the Venoliva study, costs for industry were estimated to fulfil the limits, based on additional production and R&D costs. In view of the findings of the technology review in section 2.4 and the database analysis in section 3.2, it is concluded that costs for R&D to achieve step 2 limits will be smaller than previously estimated. For cars this is the case because a substantial percentage already complies to the lower limits. For trucks it is the case because off-the-shelf noise reduction packages are available to fulfil the limits. A margin of 4 dB should be available for application of existing technology to fulfil the second step limits.

For third step limits which will be for vehicles of new design, more R&D effort is required as only a small percentage of cars in the database currently fulfil those limits, and for trucks more R&D work on the engine and cooling system will be required. Additional manufacturing costs may be less as the production process can take required modifications into account at an early stage.

The assumptions on costs for the tyre industry are significantly lower than assumed in the Venoliva study for step 2 limits. Whereas previously only a general figure of 2 billion Euros per annum was assumed, a new estimate is made based on the development required to fulfil current limits and potential further limits.
The Tyre industry annual turnover is estimated at 28 billion Euros, of which around 4% is spent on R&D. If 15% of this is spent annually on noise R&D, the annual R&D expenditure for the whole industry is 168 million Euros per annum, which runs from 2010 through until the first year of new tyre noise limits, estimated at 2017.
Tooling costs are not considered, as production machinery will be replaced anyway over that time period.

In the ACEA study, the additional costs for industry are multiplied by a factor for the consumer of 1,7. This is based on the cost of up front investment (interest rate), the time between manufacture and sale, sale costs, profit margin and taxes.
In the Venoliva study, only the direct additional (marginal) costs to industry were considered. If at all such a multiplier is used it should only include costs of investment between product development and sale of the product.
Over a development period of 5 years at an interest rate of 4%, the multiplier would be a factor of 1,2. It is not probable that profit margins, sales costs and taxes can simply be added to the additional costs. In [23], a factor of 1,16 is applied for additional costs. So it is proposed to apply this figure of 1,16 in the updated cost estimate..

From the industry consultation and cost change data from the 1980s and 1990s it is estimated that add-on noise reduction kits for trucks will cost around € 1500,- for second step limits and around € 3000,- for third step limits. This results in 500 Euros per dB reduction, but should be adjusted by around 50% for mass production and integration into the production process. So for trucks, lorries and buses, with an increase of 250 Euro per dB noise reduction is used.

Once noise reduction is integrated in the development process of new models after a whole product cycle, both the development and production costs should be far lower than in the initial years.

The updated costs for development and production are set out in tables 5, 6 and 7 below (compare Venoliva report Section 7.7.2). The accumulated industry costs of 7 billion Euros for Phase 2/3 (4 dB reduction) over the appraisal period is far lower than the ACEA estimate of 22 billion Euros. For Phase 4/5 the difference is even much larger, 10 billion Euros versus the ACEA figure of 112 billion Euros.

Table 6 - Estimated annual additional development costs for Phases 2/3 and 4/5, as function of number of new models n_j per vehicle type j per annum, base annual development cost C_{dj} for first dB reduction, reduction margin NR_{0j} and required reductions NR_j for vehicle type j.A multiplier of 1,16 is applied for cost of investment.

Vehicle group j	n_j	Base annual devt. cost for first dB C_{dj} (€)	$NR_{0,j}$ dB	NR_j for Phase 2/3 dB	Additional annual devt. cost Phase 2/3 $C_{dev,j}$ (M€)	NR_j for Phase 4/5 dB	Additional annual devt. cost Phase 4/5 $C_{dev,j}$ (M€)
Cars	225	150.000	4	4,6	25,3	6,5	93,5
Vans	8	150.000	4	4,4	0,8	6,3	2,9
Buses	10	150.000	4	4,0	0,8	6,0	3,0
Lorries	10	150.000	4	3,0	0,4	5,0	1,5
HGVs	15	150.000	4	3,0	0,6	5,0	2,3
Total/year (M€)					27,8		103,1
Incl. investment multiplier 1,16					32,2		119,6

Table 7 - Annual additional production costs as a function of required noise reduction for Phases 2/3 and 4/5, number of vehicles produced per annum m_j and average additional production cost per dB of noise reduction C_{pj}.

Vehicle group j	Number of vehicles of type j produced annually m_j	Additional annual production cost per vehicle / dB C_{pj} (€)	NR Phase 2/3 (dB)	Additional annual production cost $C_{prod,j}$ (M€)	NR Phase 4/5 (dB)	Additional annual production cost $C_{prod,j}$ (M€)
Cars	14500000	20	4,6	916	6,5	1330
Vans	2200000	20	4,4	139	6,3	192
Buses	30000	250	4,0	23	6,0	30
Lorries	100000	250	3,0	50	5,0	75
HGVs	100000	250	3,0	50	5,0	75
Total(M€)				1177		1702

Table 8 - Additional development and production costs for Phases 2/3 and 4/5 over the appraisal period and including a 4% discount rate.

M€	Phase 2/3				Phase 4/5			
Year	Development	Production	Total	incl. discount 4%	Development	Production	Total	incl. discount 4%
2010	200,2	0	200,2	200,2	287,6	0	287,6	287,6
2011	200,2	0	200,2	192,5	287,6	0	287,6	276,5
2012	200,2	0	200,2	185,1	287,6	0	287,6	265,9
2013	200,2	1702	1902,1	1690,9	287,6	2446,8	2734,4	2430,8
2014	200,2	1459	1659,0	1418,1	287,6	2097,2	2384,8	2038,6
2015	200,2	1216	1415,8	1163,7	287,6	1747,7	2035,3	1672,9
2016	200,2	972	1172,7	926,8	287,6	1398,2	1685,8	1332,3
2017	168,0	729	897,4	681,9	287,6	1048,6	1336,2	1015,4
2018	0	486	486,2	355,3	119,6	699,1	818,7	598,2
2019	0	243	243,1	170,8	119,6	349,5	469,1	329,6
2020	0	0	0	0	0	0	0	0
2021	0	0	0	0	0	0	0	0
2022	0	0	0	0	0	0	0	0
2023	0	0	0	0	0	0	0	0
2024	0	0	0	0	0	0	0	0
2025	0	0	0	0	0	0	0	0
2026	0	0	0	0	0	0	0	0
2027	0	0	0	0	0	0	0	0
2028	0	0	0	0	0	0	0	0
2029	0	0	0	0	0	0	0	0
2030	0	0	0	0	0	0	0	0
Total M€	1570	6807	8377	6985	2540	9787	12327	10248

4.3 Benefit assessment

For assessing the benefits, the same general approach is taken as in the Venoliva project, with some modifications. The benefits still consist of valuation of change in property prices, savings on health costs and savings on noise abatement.

But in particular, level-dependent noise valuation for property pricing and health costs is taken into account based on more recent UK methodology.

Environmental impact
The estimated average traffic noise levels in terms of L_{DEN} and L_{night} and reductions due to Phase 2/3 and Phase 4/5 limits are shown in table 8 below for the different road types defined in the Venoliva study. These are residential roads, main roads, both with either free flowing or intermittent traffic, arterial roads, urban motorways, rural motorways and rural roads. These reductions are only fully achieved when all vehicles are replaced, after the average life time of vehicles of around 12 years.

Table 9 - Estimated average noise level and future traffic noise reductions in L_{DEN} and L_{night} for Phase 2/3 and Phase 4/5 limits for the different road types. The reductions take a vehicle lifetime to fully take effect.

LDEN	Resid.int.	Resid.free	Main int.	Main free	Arterial	Urban MW	Rural MW	Rural	Avg.
Current	54,4	52,3	67,3	65,3	74,1	71,5	73,6	55,0	
Phase 2/3	50,4	49,4	63,2	62,7	71,4	68,9	70,9	52,3	
Phase 4/5	48,5	47,1	61,3	60,4	69,1	66,6	68,6	50,1	
LNIGHT									
Current	45,7	43,1	57,0	54,8	65,0	63,4	65,3	46,3	
Phase 2/3	41,9	40,1	52,9	52,1	62,4	60,7	62,6	43,5	
Phase 4/5	40,0	37,9	51,0	49,8	60,1	58,4	60,3	41,3	
dLDEN									
Phase 2/3	4,0	2,9	4,2	2,6	2,7	2,7	2,7	2,7	3,1
Phase 4/5	6,0	5,1	6,0	5,0	5,0	5,0	5,0	5,0	5,2
dLNIGHT									
Phase 2/3	3,8	3,1	4,0	2,7	2,7	2,7	2,7	2,7	3,0
Phase 4/5	5,7	5,2	5,9	5,0	5,0	5,0	5,0	5,0	5,2

The average noise reductions for L_{DEN} in the right hand column are used as input for the cost benefit calculations.

The numbers of Highly Annoyed (HA), Annoyed (A), Highly Sleep Disturbed(HSD) and Sleep Disturbed (SD) people are derived using dose-response relationships given in the European Position paper from 2002 [29], and set out in table 9 below for the current situation, Phase 2/3 and Phase 4/5 limits. Percentages highly annoyed and highly sleep disturbed can be derived from the average L_{DEN} levels for each road type in table 8 above; the actual numbers of highly annoyed and highly sleep disturbed are then obtained from these percentages and the numbers of exposed people per road type.

The reduction of highly annoyed people is 25% for Phase 2/3 and 39% for Phase 4/5. The reduction of highly sleep disturbed people is 19% for Phase 2/3 and 29% for Phase 4/5.

Table 10 - Estimated numbers of (highly) annoyed and (highly) sleep disturbed people (millions) for the current situation and future endpoints for step 2 limits and step 3 limits.

	MHAnnoyed	Reduction	%Reduction	MAnnoyed	Reduction	%Reduction
Current	55			119		
Phase 2/3	41	13,5	25%	95	23,6	20%
Phase 4/5	33	21,6	39%	81	38,3	32%
	MHSD			MSD		
Current	27			60		
Phase 2/3	22	5,0	19%	49	10,3	17%
Phase 4/5	19	7,8	29%	43	16,7	28%

It should be noted that any time delay in introducing the Phase 2/3 or Phase 4/5 limits will also significantly delay the effect of all the benefits, both in terms of environmental noise levels, numbers of severely annoyed and sleep disturbed people and the associated social-economic and health effects.

Hedonic pricing or property valuation for traffic noise reduction
For the valuation of the effect of traffic noise reduction on property prices, a fixed valuation of noise reduction was applied in the Venoliva study, in accordance with recommendations from the 2003 EU position paper on noise valuation [18] and adjusted for inflation.

In the UK a variable valuation is applied, according to table 2 in the ‘Transport Analysis Guidance Unit 3.3.2’ [15]. The health valuation per household starts at exposure levels of 45 dB L_{eq18hr} and increases progressively with the exposure level in 1 dB steps. The L_{eq18h} quantity can be converted to L_{DEN} for motorways and non-motorway roads according to [28]. The noise valuation is tabulated in Appendix E, and has been converted from GBP to Euros and from $L_{eq,18h}$ to L_{DEN} exposure levels. Whereas the valuation used in Venoliva was fixed at € 27 per household per dB in 2010, the UK figures for 2010 vary from around € 10 at 46 dB L_{DEN} upto € 187 at 79 dB $L_{DEN.}$

In the ACEA report only a fixed valuation of € 25 per dB per household was applied, not corrected for inflation over the appraisal period. Health effects were not estimated separately.

Health benefits
Health effects of environmental noise are well known but not all simple to quantify, especially in terms of valuation. These include cardiovascular disease, hypertension (high blood pressure), stress, sleep disturbance, mental illness, cognitive affects on children, annoyance and their associated effects. This is still an ongoing area of research including the field of night time noise (see [21]). In a recent UK study also the effects of noise (all sorts including environmental noise) on productivity related to sleep disturbance have been investigated and quantified in monetary terms [30] .

Several approaches are feasible to estimate the health benefits. When considering health benefits and property valuation benefits, overlap may occur depending which health benefits are included. These can be based on annoyance and/or sleep disturbance, but to avoid overlap, it can be argued to only include heart disease as done the UK. This approach is applied here. Other approaches are explained in Appendix D.

In the UK approach, health costs due to environmental noise have been estimated based on statistical data on acute heart disease, in particular that for Acute Myocardial Infarction (AMI) in combination with the odds associated with a given environmental noise level, derived from a curve proposed by Babisch [19].
A variable valuation is given depending on the environmental noise level. No valuation is made for hypertension or other health effects due to lack of reliable data.

The UK valuation figures based on reduced AMI are given in the second IGCB report "Noise & Health – Valuing the Human Health Impacts of Environmental Noise Exposure" of July 2010 [16], which are tabulated in Appendix E. Valuation figures are derived corresponding to the average L_{DEN} noise levels for each road type given in tables E2 and E3 in Appendix E. Roads with low noise levels tend to have little or no benefits in valuation terms, whereas busier roads with high noise levels have a much higher valuation for noise reduction.

The annual health benefit valuation B_{health} per household and per dB noise reduction can be calculated from

$$B_{health} = V_{AMI} * N_H * NR$$

where V_{AMI} = health benefit per household per dB noise reduction, related only to Acute Myocardial Infarction,
N_H = number of households
NR = dB noise reduction

Over the whole appraisal period 2010-2030, the total accumulated health benefits for Phase 2/3 are estimated at around 79 billion Euros, assuming 55 million people seriously annoyed at around 66 dB L_{DEN} in 2010. For Phase 4/5 the total accumulated health benefits over the same period are 89 billion Euros, which continue to grow beyond 2030.
Abatement benefits
Abatement benefits consist of savings on noise barriers, dwelling insulation and quiet road surfaces, the three common noise abatement measures for road traffic. The approach taken is to estimate total expenditure in the EU27 for each of these measures, and to reduce it in proportion to the ratio between noise reduction due to noise limit changes and the average noise reduction from each measure. The input data for these estimates is based on data from the Venoliva report, The Netherlands [31] and more recent information from CEDR [32] and the Norwegian Road Authority [33].

In the EU27 an estimated 290 km of noise barriers are built or replaced annually (Venoliva estimate). Besides barriers, also tunnels and embankments are built, which are not quantified here due to lack of data. The average noise reduction for noise barriers is taken at 10 dB, at a cost of 2,4 million Euro per kilometre, with an average height of 4m. The 5 dB reduction of Phase 4/5 noise limits would already halve the amount of barriers required in the long term. For the estimated 25000 dwellings insulated each year in the EU27, the Phase 4/5 limits reduce the amount of insulation by a quarter, assuming an average noise reduction of 20 dB for dwellings. For quiet road surfaces, the reduction could be 100% or more, due to the smaller effects of quiet surfaces, around 4 dB noise reduction. In terms of savings on abatement, clearly the savings on noise barriers will be largest. The combined savings for all abatement measures are estimated at 240 million Euro per annum for Phase 2/3 limits and 403 million Euros per annum for Phase 4/5 limits.

Although the traffic noise reduction due to the above abatement measures does not occur straight away after introduction of new vehicle noise limits, benefits are assumed to do so due to the planning process which takes upto 9 or 10 years.
In other words, less abatement measures will be projected and built if new effective noise limits are scheduled.

Table 11 – Estimated costs and savings on noise abatement measures for Phase 2/3 and Phase 4/5 limits.

EU27 - Measure quantity per year	Cost/km	Cost/year	Avg. effect	dB reduction	Phase 2/3	dB reduction	Phase 4/5
Barriers km construction per year	€	M€	dB	3,1	Savings M€	5,2	Savings M€
290	2379000	690	10	31%	213,9	52%	358,8
Insulated dwellings per year	Cost/dwelling						
25000	5000	125	20	16%	19,4	26%	32,5
New quiet road surfaces km/y @15m	Cost/m2						
300	2	9	4	78%	7,0	130%	11,7
Total					**240,2**		**403,0**

4.4 Cost benefit analysis of Phase 2/3 and Phase 4/5

The cost-benefit analysis is performed in a similar way to the Venoliva study, but now taking modifications into account, including the UK valuation method for amenity and health, new estimates for abatement savings and industry costs, and comparing the Phase 2/3 and Phase 4/5 noise limits for the whole appraisal period of 2010-2030. The overall accumulated costs and benefits, the benefit to cost ratios (BCR) and the net present value (NPV) are given in table 11 below.

Table 12 – Overall accumulated benefits and costs in millions of Euros, BCR and net present value for the introduction of Phase 2/3 and Phase 4/5 limits.

	Amenity benefits	Health benefits	Abatement benefits	Total Benefits	Cost Industry	BCR	NPV
	M€	M€	M€	M€	M€	-	M€
Phase 2/3	191395	79341	4763	275498	6985	39	268513
Phase 4/5	228612	88963	7989	325564	10248	32	315316

For Phase 2/3, the BCR is 39 (previously 11,4) and for Phase 4/5, 32. This implies that with the updated input data, for Phase 2/3, the benefits at 275 billion Euro still far outweigh the costs of 7 billion Euro. Phase 4/5 is also shown to be very cost effective, with a BCR of 32, benefits 326 billion Euro over the appraisal period and costs of 10 billion Euro. The costs and benefits per annum for Phase 2/3 and 4/5 are set out graphically in figures 4 and 5. The accumulated costs and benefits are set out in figure 6. The tabulated values are listed in Appendix F.

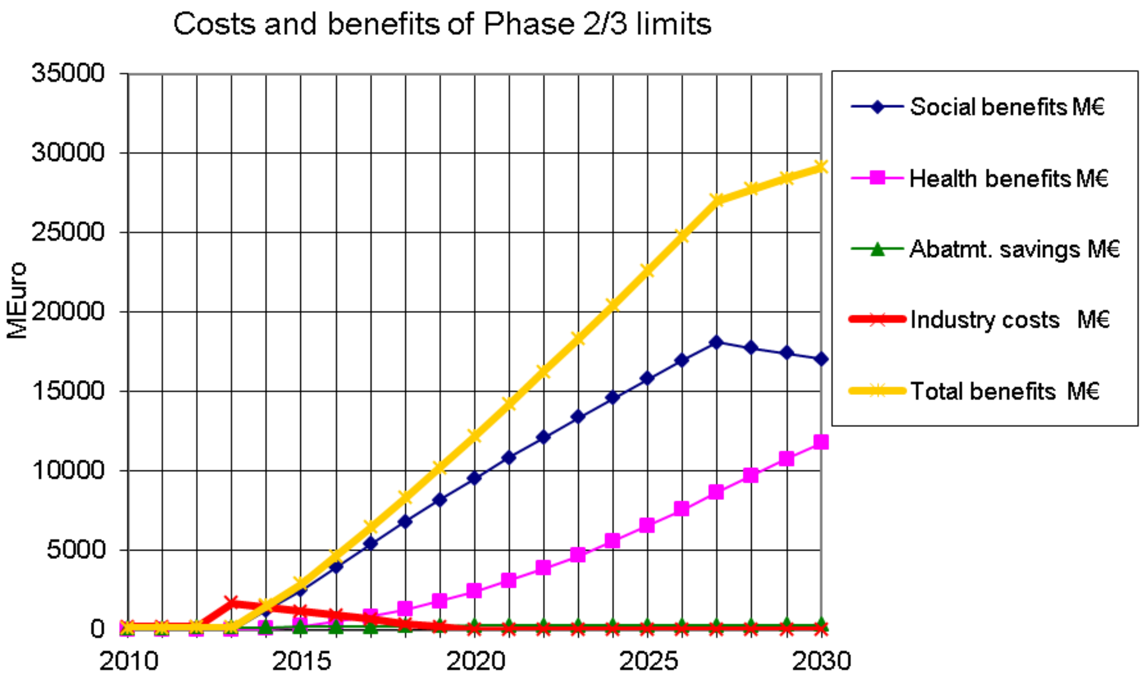

Figure 4 – Costs and benefits of Phase 2/3 limits.

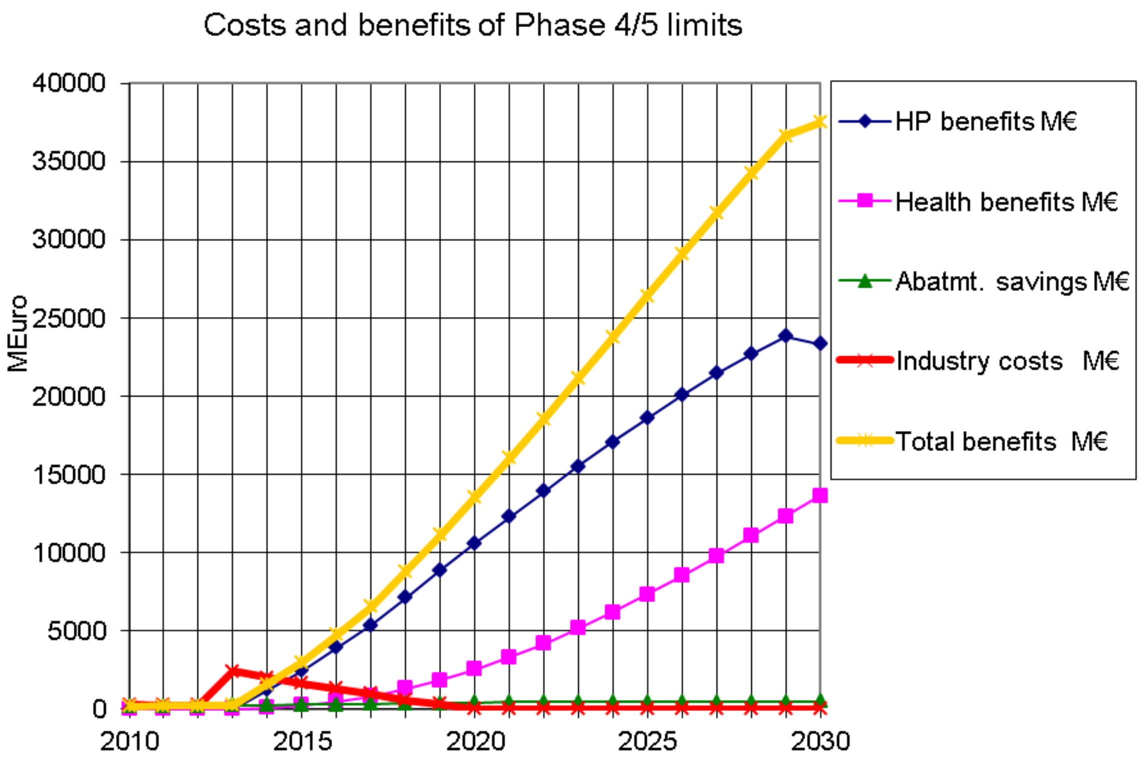

Figure 5 – Costs and benefits of Phase 4/5 limits.

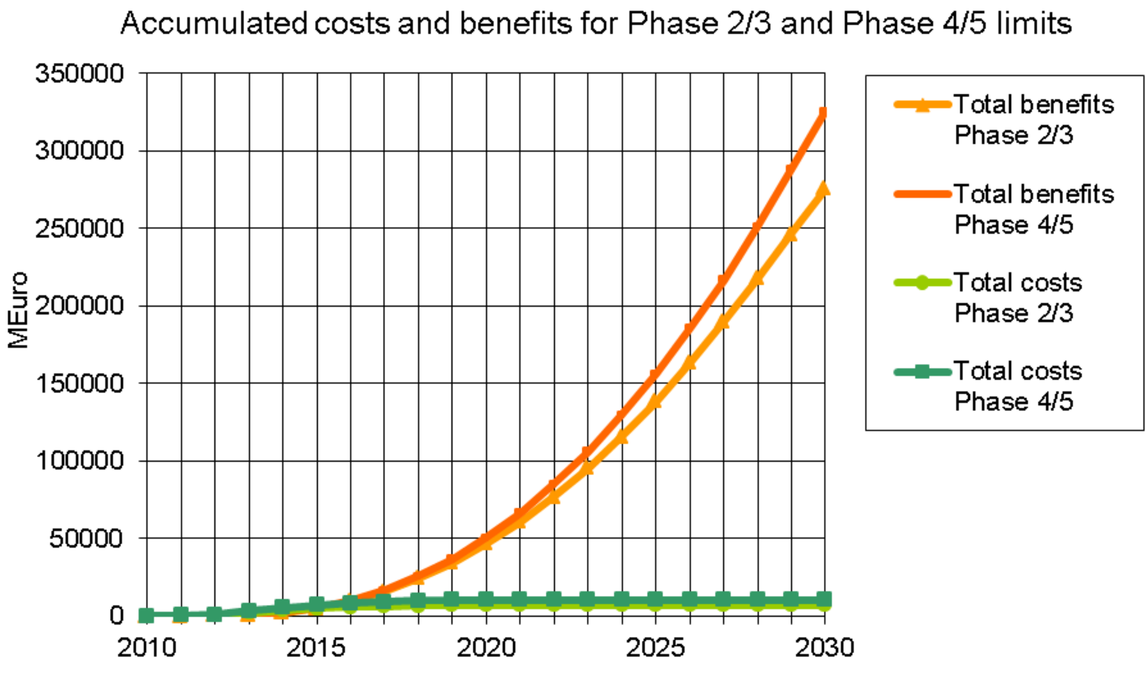

Figure 6 – Accumulated costs and benefits of Phase 2/3 and 4/5 limits.

5 Summary of findings and recommendations

As a follow-up to the VENOLIVA study, an new analysis has been performed on the impact of the Phase 2/3 of the EC proposal for reduction of the vehicle noise limit values and on the feasibility and impact of a more stringent Phase 4/5 for vehicle noise limit values, including consideration of technical options, industry costs, societal benefits and appropriate vehicle noise classes with respect to today's and tomorrow's fleet. New available information has been taken into account based on recent publications, industry consultation, comparison of different valuation methods and comments from various stakeholders.

Vehicle subcategories
In alternative proposals from ACEA, Germany and Japan (JASIC) for reduction of limit values modified definitions of vehicle subcategories were proposed, whilst the EC proposal is based on the same subcategories as the current limit value system. Therefore the subcategorisation was reconsidered. As a result modified definitions are now proposed for the vehicle categories M2 (medium size buses), M3 (heavy buses), N1 (vans and light trucks) and N3 (heavy trucks).

Alternative limit proposals
The proposals from the EC, Germany, ACEA and Japan differ in terms of sub-categorisation, limit values and the time frames of the introduction of the various phases of the limit value reduction. The EC proposal is considerably stricter than the alternative proposals if the comparison is based on corresponding points in time after publication of the regulation. On average, the alternatives are 1,7 to 2,5 dB less stringent than the EC proposal. If corresponding phases or stages of the proposals are taken as a basis for comparison, it appears that the German and Japanese proposals reach an equivalent level of reduction in the final stage, but that the full effect of these limit value reductions will be delayed by 9 years compared to the EC proposal.

Technological potential for noise reduction of trucks
It was found that that a major European truck manufacturer offers an optional package for exterior noise reduction beyond the current noise limit value of 80 dB(A) for N3 category trucks. The availability of such a package at one OEM demonstrates that some OEMs already have the capability to achieve further noise reduction. After fairly widespread application of engine encapsulation in the 1990s, engines were made intrinsically quieter and much of the engine encapsulation was no longer needed. It is still commercially available as an add-on to existing engines resulting in upto 4 dB reduction or more. This reduction will be sufficient to fulfil the proposed limit values of Phase 2/3 of the EC proposal. Further reductions will be feasible by using close engine shielding, a technology that has already been applied in luxury passenger cars. Results of test bench experiments with truck engines show that a further 2 dB(A) reduction of the limit values in Phase 4/5 for heavy trucks is technologically feasible.

The cost of applying commercial off-the-shelf engine and gearbox encapsulation in order to comply with the Phase 2/3 noise limit at 78 dB(A) will be around 2% increase in vehicle price, and 3% increase for Phase 4/5 limits. It is however estimated that mass production and integration in the long term design process will halve this cost to 1% for Phase 2/3 limits and to 1,5% for Phase 4/5 limits. The extra cost is passed on to the customer. For Phase 4/5 limits the additional costs for truck manufacturers are mainly due to additional R&D and tooling effort. As challenges such as thermal management need to be addressed, the impact on the truck design and production will be larger than for the first limit value reduction.

Influence of tyre-road noise on the noise emission of trucks
The change of the instructions for the use of tyres during the noise emission test according to method B as published in the draft EU regulation for the sound level of motor vehicles [6] requires a lowering of the proposed limit values for heavy trucks by 1 dB(A), because less noisy tyres will be used during the truck noise tests.

It may be expected that the noise emission of heavy vehicles in various traffic conditions can be regulated effectively by the combined application of the vehicle noise emission test and the rolling noise emission test for truck tyres.

The specifications of the test track in Annex VII of the draft regulation [6] should be modified to be in line with and refer to ISO 10844:2011 instead of the 1994 version of this standard.

An alternative proposal for limit value reduction including an additional phase
A revised table of proposed limit values is provided in Table 2 to incorporate several redefined subcategories. A Phase 4/5 of limit value reductions is proposed, that is more challenging with respect to technological feasibility than the Phase 2/3 of the EC proposal. The fourth phase should become valid for type approval of new vehicle types 8 years after publication of the EU regulation. It is recommended to consolidate this step in a fifth phase, in which the same limit values should become valid for registration, sale and entry into service of all new vehicles 10 years after publication of the EU Regulation.

Technological potential to meet the reduced limit values
For passenger cars, the large spread of results below the current limit values in each range of power-to-mass ratios demonstrates that the current technology enables a considerably lower noise emission than the current requirements. This makes both the Phase 2/3 and Phase 4/5 limit values feasible. This is less clear for other vehicle types, but it seems that these are designed to just fulfil the limit values at minimal cost. Reduction of the noise levels in order to fulfil the Phase 2/3 limits can at least in the short term be achieved by applying off-the-shelf solutions such as shielding and encapsulation. The Phase 4/5 limit values are achievable by applying available technical solutions such as close engine shielding, already implemented in passenger cars.

For the elaboration of the limit values proposed for the Phases 1, 2 and 3, one of the basic assumptions was that the rolling noise of tyres will decrease as a result of the new tyre noise Regulation that will come into force from 1 November 2012. The estimated average reductions in the final stage are 3,8 dB(A) for car tyres and 3,3 dB(A) for truck tyres. These rolling noise reductions are insufficient to fulfil the limit values proposed in Phase 4/5. For most vehicle categories, an overall vehicle noise reduction by a further 2 dB(A) will require lowering both the rolling noise and the powertrain noise in a balanced way. The required rolling noise reductions are estimated at 3 dB(A) at least. Therefore a further improvement of the tyre noise

Regulation with lower limit values for rolling noise will be necessary to enable the proposed limit values for the sound level of motor vehicles according to Phase 4/5.

Environmental impact

The Phase 2/3 noise limits result on average in 3,1 dB reduction in L_{DEN} levels, 25% less highly annoyed people and 15% less highly sleep disturbed people. The Phase 4/5 limits would result on average in 5,2 dB reduction in L_{DEN} levels, 39% less highly annoyed people and 29% less highly sleep disturbed people.

Cost-benefit analysis

For the cost-benefit analysis both the calculation of benefits and costs was updated taking into consideration

- the available technology, percentage of compliant cars and noise reduction packages for trucks;
- cost of R&D investment;
- new estimates for R&D costs for quieter tyres; Phase 4/5 limits will require new R&D but sufficient time is available to fully integrate this into the total design process;
- the UK approach for estimating valuation of property and health impacts related to heart disease, using noise level dependent figures and cut-off points at lower exposure levels.

Both Phase 2/3 and Phase 4/5 limits are highly cost effective. For Phase 2/3 limits, the Benefit to Cost Ratio is 39 (previously 11,4) and for Phase 4/5, 32.
This demonstrates that with the new input data, the benefits at 275 billion Euro still far outweigh the costs of 7 billion Euro. Phase 4/5 limits are also shown to be very cost effective, despite the additional R&D costs. Benefits of Phase 4/5 are 326 billion Euro over the appraisal period and the costs are 10 billion Euro.

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7 Signature

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A Distribution of N3 vehicles (heavy trucks) in subcategories of rated engine power per year of registration (2005 – 2012)

Rated engine power	N3 vehicles - Registered numbers per year of registration																	
	2005		2006		2007		2008		2009		2010		2011		2012		Total	
[kW]	number	%	number	%	number	%	number	%	number	%	number	%	number	%	number	%	number	%
≥75 < 150	96	1,1%	92	0,6%	45	0,4%	31	0,2%	23	0,2%	45	0,5%	67	0,6%	7	0,4%	406	0,5%
≥150 < 250	1844	21,3%	2473	17,4%	2139	17,6%	2765	18,0%	2340	22,2%	1788	19,6%	1836	16,4%	302	15,7%	15487	18,6%
≥250	6713	77,6%	11635	81,9%	9976	82,0%	12553	81,8%	8194	77,6%	7283	79,9%	9293	83,0%	1611	83,9%	67258	80,9%
Total	8653	100%	14200	100%	12160	100%	15349	100%	10557	100%	9116	100%	11196	100%	1920	100%	83151	100%
Percentage	10,4%		17,1%		14,6%		18,5%		12,7%		11,0%		13,5%		2,3%		100,0%	

B Influence of the number of axles and drive axles on the noise emission of M3, N3 and N3G vehicles

Table B.1 - Influence of the number of axles and of drive axles on the noise emission of heavy vehicles (categories M3, N3 and N3G), measured according to method B.Legend of colors: Green: difference is statistically significant; Orange: difference is statistically not significant; Yellow: difference is on the edge of significance.

Vehicle category	Number of axles	Number of driving axles									
		1		2		3		4		all	
		n	L_B [dB(A)]	n	L_B [dB(A)]	n	L_B [dB(A)]	n	L_B [dB(A)]	n	L_B [dB(A)]
M3 - Buses	**2**	61	76,9							61	76,9
	3	14	77,9							14	77,9
Total M3		75	77,1							75	77,1
N3 - Trucks	**2**	69	80,6	2	81,2					71	80,6
	3	18	81,6	4	80,8					22	81,4
	4	3	82,1	4	82,7					7	82,4
Total N3		90	80,8	10	81,6					100	80,9
N3G - Off-road trucks	**2**	2	80,0	29	82,3					31	82,2
	3			3	80,7	3	81,2			6	80,9
	4							2	82,4	2	82,4
Total N3G		2	80,0	32	82,2	3	81,2	2	82,4	39	82,0
N3 + N3G	**2**	71	80,5	31	82,2	0		0		102	81,1
	3	18	81,6	7	80,7	3	81,2	0		28	81,3
	4	3	82,1	4	82,7	0		2	82,4	9	82,4
Total N3 + N3G		92	80,8	42	82,0	3	81,2	2	82,4	139	81,2

From the data in Table B.1 the following conclusions may be drawn:

- For vehicle category M3 (heavy buses) there is a clear influence of the number of axles, resulting in a significant 1 dB(A) difference between buses with 2 and 3 axles. No influence of the number of drive axles can be detected, as all buses had only 1 drive axle;
- For vehicle category N3 (heavy trucks) there is a clear influence of the number of axles, resulting in a significant 0,8 difference between trucks with 2 and 3 axles and a 1 dB(A) difference between trucks with 3 and 4 axles;
- The number of N3 trucks with 2 drive axles is small compared with the number with 1 drive axle (11%). Therefore the difference between trucks with 1 and 2 drive axles is not significant;
- Most (74%) of the N3G vehicles (off-road trucks) have 2 axles, which are also drive axles. The number of vehicles in the other sub-categories is small and the influence of the number of axles or drive axles is not obvious. As a result the differences between trucks with different numbers of (drive) axles are not significant, except for the difference between trucks with 1 and 2 drive axles. However, as only two N3G vehicles with 1 drive axle are included in the data base, this last fact is of little importance;
- If the N3 and N3G categories are merged, the lack of significance of the number of axles for the N3G vehicles reduces the significance of the number of axles for the N3 vehicles, so, for the combined truck categories the influence of the number of axles is less obvious than for the N3 trucks alone.

From these points it may be inferred that under the conditions of the noise emission tests for heavy vehicles the engine noise dominates, which obscures the presumably existing influence of the number of (driven) axles on the noise emission. This influence is probably also shaded by stochastic variations of the test results, specifically for subcategories that are represented by only a few specimens.

C Comparison between the EC limit value proposal and two alternatives: the German proposal [10] and the ACEA proposal [11]

	Vehicle classes				LIMIT VALUES Phase 1 / Stage 1							LIMIT VALUES Phase 2 / Stage 2									LIMIT VALUES Phase 3 / Stage 3							
	EC proposal COM(2011)856	German proposal GRB	ACEA proposal STOA workshop nov2011	Japanese (JASIC) proposal - GRB	EC proposal COM(2011)856	German proposal GRB		ACEA proposal STOA workshop nov2011		Japanese (JASIC) proposal - GRB		EC proposal COM(2011)856	German proposal GRB			ACEA proposal STOA workshop nov2011		Japanese (JASIC) proposal - GRB			EC proposal COM(2011)856	German proposal GRB			ACEA proposal STOA workshop nov2011	Japanese (JASIC) proposal - GRB		
					Tye approval new vehicles							Tye approval new vehicles										Type approval new vehicles				Type approval new vehicles		
					2 years after publication	2 years after publ	Diff. vs. EC proposal	1 year after publ	Diff. vs. EC proposal	2 years after publication	Diff. vs. EC proposal	5 years after publ	6 years* after publ	8 years* after publ	Diff. vs. EC proposal	6 years after publ	Diff. vs. EC proposal	6 years* after publ	8 years* after publ	Diff. vs. EC proposal	7 years after publ	10 years* after publ	14 years* after publ	Diff. vs. EC Phase 2	8 years after publ	10 years* after publ	14 years* after publ	Diff. vs. EC Phase 2
M1 Seats ≤ 9	Seats < 9	PMR ≤ 120 kW/ton	PMR ≤ 125 kW/ton	PMR ≤ 120 kW/ton	70	72	2	72	2	72	2	68	70		2	70	2	70		2	Registration, sale and entry into service of new vehicles (same limits as phase 2)	68		0	Registration, sale and entry into service of new vehicles (same limits as phase 2)	68		0
		120 < PMR ≤ 160 kW/t	125 < PMR ≤ 150 kW/t	120 < PMR ≤ 160 kW/t		73	3	73	3	73	3			71	3	71	3	71		3		70 (12 years after publ)		2		69		1
	Seats < 9 > 150 kW/ton	PMR > 160 kW/ton	PMR > 150 kW/ton	PMR > 160 kW/ton	71	75	4	75	4	75	4	69	74		5	74	5	73		4		73		4		71		2
M2 Seats > 9	mass ≤ 2 ton	mass ≤ 2,5 t	mass ≤ 2,5 t	mass ≤ 3,5 t	72	72	0	72	0	74	2	70	70		0	70	0	72		2		69		-1		70		0
	2 t < mass ≤ 3,5 t	2,5 t < mass ≤ 3,5 t	2,5 t < mass ≤ 3,5 t		73	74	1	74	1		1	71	72		1	72	1			1		71		0				-1
	3,5 t < mass ≤ 5 t P<150 kW	mass > 3.5 t	3,5 t < mass ≤ 5 t P<150 kW	mass > 3,5 t	74	75	1	76	2	75	1	72		73	1	75	3		73	1			71	-1			71	-1
	3,5 t < mass ≤ 5 t P ≥ 150 kW		3,5 t < mass ≤ 5 t P ≥ 150 kW		76		-1	77	1		-1	74			-1	76	2			-1				-3				-3
M3 seats > 9	mass > 5 t P < 150 kW	P ≤ 180 kW	mass > 5 t P ≤ 180 kW	P ≤ 125 kW	75	76	1	76	1	76	1	73		74	1	75	2		74	1			73	0			72	-1
	mass > 5 t P ≥ 150 kW	180 < P ≤ 250 kW	mass > 5 t 180 < P ≤ 250 kW	125 < P ≤ 250 kW	77	78	1	79	2	79	2	75		78	3	78	3		78	3			76	1			76	1
		P > 250 kW	mass > 5 t P > 250 kW	P > 250 kW		80	3	80	3	80	3			78	3	79	4		78	3			76	1			76	1
N1	mass ≤ 2 ton	mass ≤ 2,5 t	mass ≤ 2,5 t	mass ≤ 2,5 t PMR ≤ 35 kW/t	71	72	1	72	1	74	3	69	70		1	70	1		72	3		68		-1			70	1
				mass ≤ 2,5 t PMR > 35 kW/t						72	1							70		1						68		-1
	2 t < mass ≤ 3,5 t	2,5 t < mass ≤ 3,5 t	2,5 t < mass ≤ 3,5 t	2,5 t < mass ≤ 3,5 t	72	74	2	74	2	74	2	70	72		2	72	2	72		2		71		1		70		0
N2	3,5 t < mass ≤ 12 t P < 75 kW	P ≤ 150 kW	3,5 t < mass ≤ 12 t P< 150 kW	P ≤ 125 kW	74	77	3	77	3	78	4	72		75	3	76	4		76	4			72	0			74	2
	3,5 t < mass ≤ 12 t 75 ≤ P < 150 kW				75		2		2		3	73			2		3			3				-1				1
	3,5 t < mass ≤ 12 t P ≥ 150 kW	P > 150 kW	3,5 t < mass ≤ 12 t P ≥ 150 kW	P > 125 kW	77	78	1	78	1	79	2	75		77	2	77	2		77	2			75	0			75	0
N3	mass > 12 t 75 ≤ P < 150 kW	P ≤ 250 kW	mass > 12 t P ≤ 180 kW	P < 250 kW	77	81	4	79	2	80	3	75		79	4	78	3		78	3			77	2			76	1
	mass > 12 t P ≥ 150 kW		mass > 12 t 180 < P ≤ 250 kW		80		1	81	1		0	78			1	80	2			0				-1				-2
		P > 250 kW	mass > 12 t P > 250 kW	P > 250 kW		82	2	82	2	81	1			81	3	81	3		79	1			79	1			77	-1
	Average of differences						**1,7**		**1,8**		**1,9**				**2,0**		**2,5**			**2**				**0,22**				**0**

D Other approaches for health benefit estimation

Health valuation based on heart disease and hypertension
In the Venoliva study, costs due to heart disease and hypertension were included in health benefits, assumed to be separate from property valuation as they are not part of property value assessment. These health effects can be related to annoyance. They were derived from Swiss figures on Life years lost (LYL) and prevalence (PR) for ischemic heart disease and for high blood pressure (hypertension) and the cost of hospital treatment, converted to values for the EU 27 in Euros using population scaling. The annual health benefit B_{health} can be calculated from:

$$B_{health} = (NR * PR)\sum_i VLYL_i + COI_i$$

NR = noise reduction in dB,
PR = per dB prevalence (occurrence) reduction factor = 0,02.
$VLYL_i$ = Value of Life Years Lost for illness i, =VOLY*LYL_i
for ischemic heart disease (IHD) or high blood pressure related disease (HBP),
COI_i = Cost Of Illness I, for IHD or HBP.

A VOLY value of € 63 250 was used in the Venoliva study (see page 80 of the report). This resulted in a health benefit for Phase 2/3 limits for the EU27 of 84,5 million Euros/dB/year and an accumulated health benefit of **1,4 billion Euros** over the whole appraisal period, including discounting of 4%.

Health valuation based on annoyance and DALYs
Another approach is to apply the Value of a healthy life year to the estimated number of DALYs (Disability Adjusted Life Years) associated with annoyance. This approach was not used here due to the large uncertainty in the severity s (or DALY weight) of health effects associated with annoyance, from 0,01 to 0,12 (see RIVM report [20]). In addition there is a potential overlap with property valuation.

The annual value of healthy years associated with reduced number of highly annoyed people is

B_{health} = VOLY*$DALY_{HA}$, with $DALY_{HA}$ = N_{HA}*s*N_y (N_y=1)

If the average severity of 0,06 is used, the VOLY is valued at € 63 250 and the number of highly annoyed is reduced by 13,5 million people for Phase 2/3, the total accumulated benefit is **275 billion Euros** for the whole appraisal period including discounting of 4%.

Health valuation based on sleep disturbance
In the Expert letter [9] an estimate of health savings is made based on high sleep disturbance, for which the severity of health effects is more accurately known, s=0,07 according to the Night Noise Guidelines [21]. Also an alternative value for the VOLY was quoted from the NEEDS project [22] of € 40 000 with an uncertainty range of € 25 000 upto € 100 000.

The valuation can be calculated from

B_{health} = VOLY*$DALY_{HSD}$, with $DALY_{HSD}$ = N_{HSD}*s*N_y (N_y=1)

For a reduction in numbers of highly sleep disturbed of N_{HSD} = 5 million people after Phase 2/3 limits have taken effect (after 12 years) the health benefits are estimated at **321 billion Euros** over the whole appraisal period for a VOLY value of € 63 250 and including discounting of 4%.

The 3 above methods and the UK method for assessing health benefits are compared in the tables below for both Phase 2/3 and Phase 4/5. The methods based on DALYs give the largest estimates which are rather sensitive to the choice of severity factor s.

Table D1: Comparison between health valuation methods for Phase 2/3 limits. HP+HBP=Heart disease and hypertension costs based on Swiss data and used in Venoliva; DALYHA= based on DALYS for highly annoyed people; DALYHSD = based on DALYS for highly sleep disturbed people; UK: UK health valuation based on Acute Myocardial Infarction (AMI).All values in Millions of Euros, including 4% discount.

	Phase 2/3	HD+HBP	DALYHA	DALYHSD	UK
Year	dB red.	M€	M€	M€	M€
2010	0,0	0	0	0	0
2011	0,0	0	0	0	0
2012	0,0	0	0	0	0
2013	0,0	0	0	0	0
2014	0,1	10	1916	2236	82
2015	0,3	19	3745	4369	244
2016	0,5	30	5907	6892	500
2017	0,6	41	7992	9324	848
2018	0,8	51	10005	11673	1284
2019	1,0	61	11956	13948	1806
2020	1,2	71	13850	16159	2410
2021	1,5	80	15697	18313	3093
2022	1,7	89	17504	20422	3852
2023	1,9	99	19281	22495	4683
2024	2,2	108	21038	24544	5582
2025	2,5	116	22784	26582	6545
2026	2,8	125	24534	28623	7568
2027	3,1	134	26301	30685	8646
2028	3,1	129	25290	29505	9702
2029	3,1	124	24317	28370	10739
2030	3,1	120	23382	27279	11755
Total		1409	275501	321418	79341

Table D2: Comparison between health valuation methods for Phase 4/5 limits. HP+HBP=Heart disease and hypertension costs based on Swiss data and used in Venoliva; DALYHA= based on DALYS for highly annoyed people; DALYHSD = based on DALYS for highly sleep disturbed people; UK: UK health valuation based on Acute Myocardial Infarction (AMI). All values in Millions of Euros, including 4% discount.

	Phase 4/5	HD+HBP	DALYHA	DALYHSD	UK
Year	dB red.	M€	M€	M€	M€
2010	0,0	0	0	0	0
2011	0,0	0	0	0	0
2012	0,0	0	0	0	0
2013	0,0	0	0	0	0
2014	0,1	10	1916	2236	82
2015	0,3	19	3745	4369	244
2016	0,5	30	5907	6892	500
2017	0,6	41	7992	9324	848
2018	0,9	54	10606	12374	1309
2019	1,1	67	13174	15370	1878
2020	1,4	80	15708	18326	2552
2021	1,7	93	18223	21261	3327
2022	2,0	106	20737	24193	4198
2023	2,3	119	23269	27148	5159
2024	2,7	132	25844	30152	6205
2025	3,1	146	28492	33241	7328
2026	3,5	160	31250	36459	8519
2027	4,0	175	34169	39864	9766
2028	4,6	191	37316	43536	11052
2029	5,2	209	40790	47588	12357
2030	5,2	201	39221	45758	13637
Total		1832	358362	418089	88963

E IGCB amenity and health valuation tables

Table E1 - UK valuation tables for property (amenity) and health valuation, converted from GB pounds per household per dB noise reduction to Euros, and from $L_{eq,18h}$ to L_{DEN} for motorways and non-motorway roads.

Non-motorway		Motorway							1 GBP=1,18 Euro	
0,9241Leq18h+4,1982		0,8963Leq18h+9,6917				ICGB table 2			Growth=1%	
LDEN		LDEN		LAeq, 18hr dB(A)		£ per household per dB(2002)			Euro	Euro
Low	High	Low	High	Low	High	**Amenity**	**Health**	**Both**	2002	2010
					<45 0.0	0	0	0	0,00	0,00
46	47	50,0	50,9	45	46	8,4	0	8,4	9,91	10,73
47	48	50,9	51,8	46	47	11,1	0	11,1	13,10	14,18
48	49	51,8	52,7	47	48	13,7	0	13,7	16,17	17,51
49	49	52,7	53,6	48	49	16,3	0	16,3	19,23	20,83
49	50	53,6	54,5	49	50	19	0	19	22,42	24,28
50	51	54,5	55,4	50	51	21,6	0	21,6	25,49	27,60
51	52	55,4	56,3	51	52	24,2	0	24,2	28,56	30,92
52	53	56,3	57,2	52	53	26,9	0	26,9	31,74	34,37
53	54	57,2	58,1	53	54	29,5	0	29,5	34,81	37,69
54	55	58,1	59,0	54	55	32,1	0	32,1	37,88	41,02
55	56	59,0	59,9	55	56	**34,8**	**0**	34,8	41,06	44,47
56	57	59,9	60,8	56	57	37,4	0,48	37,88	44,70	48,40
57	58	60,8	61,7	57	58	40	2,7	42,7	50,39	54,56
58	59	61,7	62,6	58	59	42,7	4,16	46,86	55,29	59,88
59	60	62,6	63,5	59	60	45,3	5,67	50,97	60,14	65,13
60	61	63,5	64,4	60	61	48	7,22	55,22	65,16	70,56
61	61	64,4	65,3	61	62	50,6	8,82	59,42	70,12	75,93
61	62	65,3	66,2	62	63	53,2	10,47	63,67	75,13	81,36
62	63	66,2	67,1	63	64	55,9	12,17	68,07	80,32	86,98
63	64	67,1	68,0	64	65	58,5	13,92	72,42	85,46	92,54
64	65	68,0	68,8	65	66	61,1	15,71	76,81	90,64	98,15
65	66	68,8	69,7	66	67	63,8	17,56	81,36	96,00	103,96
66	67	69,7	70,6	67	68	66,4	19,45	85,85	101,30	109,70
67	68	70,6	71,5	68	69	69	21,39	90,39	106,66	115,50
68	69	71,5	72,4	69	70	71,7	23,37	95,07	112,18	121,48
69	70	72,4	73,3	70	71	74,3	25,41	99,71	117,66	127,41
70	71	73,3	74,2	71	72	76,9	27,49	104,39	123,18	133,39
71	72	74,2	75,1	72	73	79,6	29,62	109,22	128,88	139,56
72	73	75,1	76,0	73	74	82,2	31,81	114,01	134,53	145,68
73	74	76,0	76,9	74	75	84,9	34,03	118,93	140,34	151,97
74	74	76,9	77,8	75	76	87,5	36,31	123,81	146,10	158,20
74	75	77,8	78,7	76	77	90,1	38,64	128,74	151,91	164,50
75	76	78,7	79,6	77	78	92,8	41,01	133,81	157,90	170,98
76	77	79,6	80,5	78	79	95,4	43,43	138,83	163,82	177,39
77	78	80,5	81,4	79	80	98	45,9	143,9	169,80	183,87
78	79	81,4	82,3	80	81	98	48,42	146,42	172,78	187,09

Table E2 - Derived valuation for amenity and health per road type for Phase 2/3 limits based on UK approach.

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	intermittent	free flow	intermittent	free flow	free flow	free flow	free flow	free flow		Exp. with health risk
Exp.inhab.	89049742	180797961	33212025	67430475	45289125	4025700	2390259,4	29186325	451381613	152347584
Avg. level	54,4	52,3	67,3	65,3	74,1	71,5	73,6	55,0		
upperval	€ 37,69	€ 30,92	€ 115,50	€ 103,96	€ 158,20	€ 115,50	€ 133,39	€ 41,02	**€ 64,11**	Wgtd. Avg.
Red. Level	50,4	49,4	63,2	62,7	71,4	68,9	70,9	52,3		
lowerval	€ 27,60	€ 20,83	€ 86,98	€ 86,98	€ 139,56	€ 103,96	€ 115,50	€ 30,92	**€ 50,72**	Wgtd. Avg.

Table E3 - Derived valuation for amenity and health per road type for Phase 4/5 limits based on UK approach.

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	intermittent	free flow	intermittent	free flow	free flow	free flow	free flow	free flow		Exp. with health risk
Exp.inhab.	89049742	180797961	33212025	67430475	45289125	4025700	2390259,4	29186325	451381613	152347584
Avg. level	54,4	52,3	67,3	65,3	74,1	71,5	73,6	55,0		
upperval	€ 37,69	€ 30,92	€ 88,17	€ 81,52	€ 111,80	€ 88,17	€ 98,26	€ 41,02	**€ 53,66**	Wgtd.Avg.
Red. Level	48,5	47,1	61,3	60,4	69,1	66,6	68,6	50,1		
lowerval	€ 17,51	€ 14,18	€ 64,66	€ 61,33	€ 94,94	€ 71,43	€ 78,07	€ 24,28	**€ 35,20**	Wgtd.Avg.

F Cost-Benefit tables

Table F1 – Benefits and costs for Phase 2/3 limits including cumulative values and discounting.

Phase 2/3		incl disc. 4%	incl disc. 4%				incl disc. 4%		
Year	**Traffic noise reduction dB**	**Social benefits M€**	**Health benefits M€**	**Abatmt. savings M€**	**Total benefits M€**	**Acc.total ben. M€**	**Industry costs M€**	**Acc.total costs M€**	**Net benefit M€**
2010	0,0	0,0	0	108	108	108	200	200	-92
2011	0,0	0,0	0	121	121	229	193	393	-163
2012	0,0	0,0	0	135	135	364	185	578	-214
2013	0,0	0,0	0	149	149	513	1691	2269	-1756
2014	0,1	1255,4	82	162	1500	2013	1418	3687	-1674
2015	0,3	2480,0	244	177	2901	4914	1164	4851	63
2016	0,5	3945,1	500	191	4637	9550	927	5777	3773
2017	0,6	5379,1	848	206	6433	15984	682	6459	9524
2018	0,8	6782,6	1284	221	8288	24272	355	6815	17457
2019	1,0	8156,3	1806	236	10199	34471	171	6985	27485
2020	1,2	9500,8	2410	252	12163	46634	0	6985	39648
2021	1,5	10816,4	3093	268	14178	60811	0	6985	53826
2022	1,7	12103,3	3852	271	16226	77037	0	6985	70051
2023	1,9	13361,2	4683	273	18317	95354	0	6985	88369
2024	2,2	14589,7	5582	276	20448	115802	0	6985	108817
2025	2,5	15787,6	6545	279	22612	138414	0	6985	131428
2026	2,8	16953,2	7568	282	24803	163217	0	6985	156232
2027	3,1	18083,5	8646	284	27014	190231	0	6985	183245
2028	3,1	17737,4	9702	287	27727	217958	0	6985	210972
2029	3,1	17398,0	10739	290	28427	246385	0	6985	239399
2030	3,1	17065,1	11755	293	29114	275498	0	6985	268513

Table F2 – Benefits and costs for Phase 4/5 limits including cumulative values and discounting.

Phase 4/5		incl disc. 4%	incl disc. 4%				incl disc. 4%		
Year	**Traffic noise reduction dB**	**HP benefits M€**	**Health benefits M€**	**Abatmt. savings M€**	**Total benefits M€**	**Acc.total ben. M€**	**Industry costs M€**	**Acc.total costs M€**	**Net benefit M€**
2010	0,0	0,0	0	181	181	181	288	288	-106
2011	0,0	0,0	0	203	203	385	277	564	-179
2012	0,0	0,0	0	226	226	611	266	830	-219
2013	0,0	0,0	0	249	249	860	2431	3261	-2401
2014	0,1	1254,9	82	273	1610	2470	2039	5299	-2830
2015	0,3	2478,1	244	296	3019	5488	1673	6972	-1484
2016	0,5	3940,1	500	321	4761	10250	1332	8305	1945
2017	0,6	5369,3	848	346	6563	16813	1015	9320	7493
2018	0,9	7147,9	1309	371	8828	25641	598	9918	15722
2019	1,1	8893,7	1878	397	11168	36809	330	10248	26561
2020	1,4	10606,7	2552	423	13582	50391	0	10248	40143
2021	1,7	12286,4	3327	450	16063	66454	0	10248	56206
2022	2,0	13931,1	4198	454	18583	85037	0	10248	74789
2023	2,3	15538,2	5159	459	21156	106194	0	10248	95946
2024	2,7	17103,3	6205	463	23772	129965	0	10248	119717
2025	3,1	18619,1	7328	468	26415	156380	0	10248	146132
2026	3,5	20074,2	8519	472	29066	185446	0	10248	175198
2027	4,0	21450,5	9766	477	31693	217139	0	10248	206891
2028	4,6	22718,3	11052	482	34253	251392	0	10248	241144
2029	5,2	23828,1	12357	487	36672	288064	0	10248	277816
2030	5,2	23372,2	13637	492	37500	325564	0	10248	315316