Impact Assessment Institute | Acustica

Expert review and reassessment of the cost benefit analysis study on Euro 5 sound level limits of L-category vehicles

IAI-Acustica CBA review-211208

December 8th 2021

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This review has been compiled in a scientific and objective manner, consistent with the principles and practices of the consortium members. Its findings are directed towards informing and contributing to the client's ongoing policy work, by completing the assignments specified by them. We are open at any time, before or after final publication, to feedback, new data and alternative insights. Where possible, we endeavour to respond to contributions and questions.

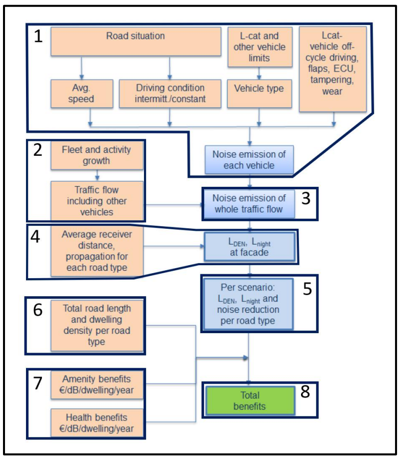
CONTENT

EXECUTIVE SUMMARY

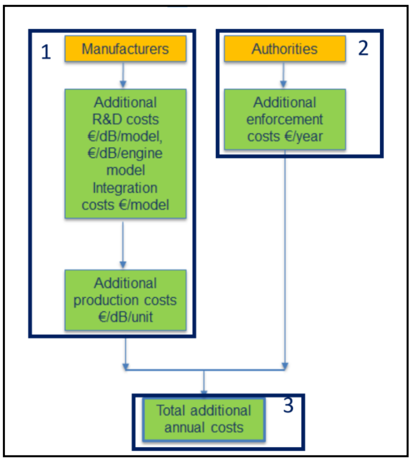
The Impact Assessment Institute and Acustica, commissioned by the European Association of Motorcycle Manufacturers, has carried out an expert review and reassessment of the 2017 cost benefit analysis study on Euro 5 sound level limits of L-category vehicles ("the CBA"). The following contains an outline of the review methodology and the main findings. The main objective was to review the values for costs and benefits of reduction in L-category noise limits.

We followed the logic of the CBA's methodology flowcharts, outlined visually below, which calculates benefits from the average sound pressure level reduction on each road type for day, evening and night. This is a legitimate and rational methodology for assessing the amenity and health benefits, or costs, of changes in noise exposure. We reassessed each element of the methodology, identified potential alternative calculations and their impact on the benefits and costs.

Benefits



Costs



Benefits

Using this methodology, the CBA calculates benefits of 2 dB and 5 dB reductions in the L-category noise limits for Northern and Southern Europe. The following is a summary of the findings of our review for each numbered block in the benefits flowchart. Only the findings having a clear impact are included in this summary.

- **Block 1** - Noise emission of each vehicle:
  a. The values used in the CBA for the increase under acceleration in noise emissions of motorcycles (+5 dB) and mopeds (+3 dB) are overestimated. Values of +3/+1 dB are more plausible, leading to a significant reduction in the benefit of the limit reduction in accelerating sections of roads (a modest reduction overall considering both accelerating and non-accelerating sections).
  b. The CBA did not consider that actual noise emission reductions of vehicles on the road are on average approximately half the level of the limit reduction. This reduces the impact of the limit reduction by approximately half.
  c. The CBA did not appear to consider the noise increase for non L-category vehicles in accelerating traffic, which would result in a modest reduction in the impact of the L-category limit reduction overall.
- **Block 2** - Traffic flow: the figures for traffic flow rates for different vehicle and road categories for day, evening and night, presented in the CBA, are not referenced and

contain some implausible values. We constructed new flow rates from available sources, resulting in significantly lower rates for Southern Europe in particular. In turn these resulted in a significant reduction in the sound pressure level reduction and therefore in the benefits due to lower L-category noise limits.

- **Block 6** - Total road length and dwelling density per road type: the CBA counts the impact only in accelerating traffic. Our calculations indicate that the impact of a limit reduction in non-accelerating traffic is only marginally lower than in accelerating traffic. By including all accelerating and non-accelerating traffic, the total benefits are increased by a factor of approximately five.
- **Block 7** – Amenity and health benefits: the CBA applies a constant value per dB for health and amenity benefits of a reduction in the average sound pressure level. More recent scientific analysis results in dose-response relationships with increased benefits per dB reduction at higher absolute sound pressure levels. These increase the benefits by a factor of 2.5 using the UK dose-response relationship, which we assessed to be the most robust of those available. Further, the dose-response relationship provide cost data per dB increment, with no explicit confirmation what interpretation would be valid is for fractional dB changes. We have calculated assuming impacts of fraction dB changes can be interpolated between the increments. However, an alternative interpretation could be that no discernible impact is present at fractional dB changes.
- **Block 8** – Total benefits: the CBA applies apparently arbitrary time fractions of 20% and 50% to Northern and Southern Europe respectively to the benefit calculations due to the “predominance” of L-category vehicles at certain times. It is more consistent to apply the change in average sound pressure level across all times to estimate the benefits. These fractions are therefore eliminated in the final calculation.

In aggregate the above changes result in benefits of €868m from 2020 to 2040 of a 2 dB reduction in L-category noise limits, using the primary valuation scenario, compared to €667m in the CBA, an increase of 30%. For a 5 dB limit reduction the benefits are calculated to be €1813m compared to €1787, a 1% increase.

Costs for manufacturers

The CBA reports costs incurred by original equipment manufacturers (OEMs) to comply with reductions of 2 dB and 5 dB in L-category noise limits. The figures are derived from data on costs of development and manufacture of the necessary technologies provided by three OEMs. The following are our findings:

- No derivation of the CBA cost figures is provided. There are several substantial inconsistencies in the CBA figures.
- Costs are highly variable according to L-category vehicle model and the assumptions made. Cost figures from one of the three companies are comparable to the CBA figures. The figures from the other companies are significantly higher and lower respectively.
- New data provided to us via ACEM by three OEMs indicate higher costs compared to those reported in the CBA.
- The CBA assumes that total additional costs for compliance with lower noise limits go to zero approximately ten years after introduction of the limits. It is more plausible to assume that compliance costs continue to be incurred indefinitely, to deploy the necessary technology on the vehicles. If a “cost learning factor” of 2 in 2040 is

assumed, total costs from 2020 to 2040 are increased by a factor of 1.65 compared to the CBA.

- Noise source ranking (NSR) tests: The CBA came to the conclusion that the exhaust system is dominant by almost 2-3 dB(A) on accelerated test for most tested vehicles with the consequence that the costs for a 2 dB limit reduction are reasonably moderate because reduction measures for the exhaust system are known and well established. The NSR results of TU Graz on a larger vehicle sample show a different picture. A 2 dB reduction of L_{urban}, would require measures on several sources and the effort is greater for scooters and small to mid-range motorcycles than for high-range motorcycles. Furthermore, a cost calculation is difficult and subject to great uncertainties. For a 5 dB reduction of L_{urban}, the NSR results of TU Graz indicate that a complete redesign of the vehicles would be necessary, with significant doubt whether it would be achievable at all.
- Overall, total costs for manufacturers appear to be higher than reported in the CBA. An estimate of the average cost can be made from the data for the most representative OEM. Using these data, total costs from 2020 to 2040 would be 2.1 times higher than reported in the CBA for a 2 dB reduction. According to the NSR results, a 5 dB reduction may not be feasible for many vehicle models and, if feasible, would incur significantly higher costs per dB reduction due to the many vehicle systems requiring intervention. We therefore make no estimate for a 5 dB reduction.

Single event analysis

The CBA additionally presents a single event analysis as a complementary method to estimate the benefits of noise limit reductions.

- The CBA does not clearly define single events, but does state that their sound level peaks are caused by acceleration well above other traffic noise.
- It does not substantiate its assertion that the impact of larger limit reductions is stronger for single events.
- The calculation for the number of single events per year counts all accelerating events, contradicting the statement that sound level peaks are caused by acceleration well above other traffic noise.
- No derivation or calculations of the figures are presented. The results presented contain significant inconsistencies.

The results are not sufficient to support the CBA's conclusion that *"the benefits are expected to be much higher compared to those from the LDEN analysis"*. In conclusion, due to the shortcomings of the single event analysis, it is consistent to rely only on the assessment of the average sound pressure level changes as described in the previous section.

Conclusion

Due to the many inconsistencies in the figures applied in the CBA and the absence of sources or derivation of many of the input data and results, the results for benefits and costs presented in the CBA are subject to a high level of uncertainty.

By reviewing the assumptions, data and calculations, we generated alternative benefits, costs and therefore benefit/cost (B/C) ratios for a 2 dB reduction in the noise limits of L-category vehicles and 25% illegal exhausts.

Our results rely on the veracity of the following assumptions and simplifications, detailed in the text of this report:

- The impact of fractional dB changes in sound pressure levels can be interpolated between the whole number dB increments in the dose-response relationships.
- The UK dose-response relationship is currently the most robust available.
- The reconstructed flow rates generated from various sources are representative.
- The compliance costs provided by the OEMs with the most representative profile can be used to generalise costs for the whole analysis.

Overall, our reassessment of the benefits and costs leads to a B/C ratio of 0.82 based on the above assumptions, compared to 2.18 in the CBA. Due to the absence of sufficient relevant data in the appropriate form and level of detail, in particular on flow rates and compliance costs, this result is subject to high uncertainty. It is a best estimate that serves as an orientation for assessment of the impacts, subject to the clearly stated assumptions. The B/C ratio is sensitive to those assumptions. Taking into account all the potential scenarios and delta analysis detailed in the benefit and cost chapters 3 and 5, a range of B/C ratios an order of magnitude higher or lower than the primary estimate above could result. This result emphasises the high level of uncertainty inherent in the benefit/cost calculations.

NSR testing results confirm the challenging technical interventions required to meet a 2 dB limit reduction and qualitatively support the substantial R&D and manufacturing costs underlying the cost estimates. Robust and accurate cost estimates are however difficult to achieve because of the many systems requiring intervention and are different for different L-category vehicle types.

Cost data are insufficient to generate equivalent benefit/cost ratios for a 5 dB limit reduction. NSR results indicate that a 5 dB limit reduction would likely be infeasible for smaller motorcycles and very challenging or potentially infeasible for larger motorcycles.

NOMENCLATURE

ACEM: European Association of Motorcycle Manufacturers

ASEP: Additional Sound Emission Provisions

ATV: All-terrain vehicle

BAU: Business as usual scenario

CBA: The 2017 cost-benefit analysis

cc, cm^3: Cubic centimetres

CRS: Cruise (constant speed)

CVT: Continuously variable transmission

DALY: Disability adjusted life year

dB: Decibel

DK: Denmark

EEA: European Environment Agency

END: Environmental Noise Directive

EU: European Union

EV: Electric vehicle

GDP: Gross domestic product

GVA: Gross value added

HGR: High growth scenario

HGV: Heavy goods vehicle

ICE: Internal combustion engine

ITF: International Transport Forum

JRC: European Joint Research Centre

kW: Kilowatt

$L_{aq,16hr}$: Annual equivalent continuous average noise level at the dwelling facade (weighted for day and evening)

LCV: Light commercial vehicle

L_{crs}: Maximum sound level at vehicle pass by test in 7.5 m distance and 1.2 m height at constant speed

L_{DEN}: Annual average noise level at the dwelling facade (weighted for day-evening-night)

L_{night}: Annual average noise level at the dwelling facade (for the night period)

L_{wot}: Maximum sound level at vehicle pass by test in 7.5 m distance and 1.2 m height at full load acceleration

MS: Member State

NACE: Statistical classification of economic activities in the European Community

NSR: Noise Source Ranking

OECD: Organisation for Economic Co-operation and Development

OEM: Original equipment manufacturer

PHEV: Plug-in hybrid electric vehicle

pkm: Passenger-kilometre

PMR: Power to mass ratio

PTW: Powered two-wheeler

R&D: Research and Development

SE: Sweden

STICITE: Sustainable Transport Infrastructure and Charging and Internalisation of Transport Externalities

TU Graz: Graz University of Technology

UK: United Kingdom

VAT: Value added tax

vkm: Vehicle-kilometre

UNECE: United Nations Economic Commission for Europe

VSL: Value of statistical life

WHO: World Health Organisation

WOT: Wide-open throttle

WTP: Willingness-to-pay

1 INTRODUCTION

This study, conducted on behalf of the European Association of Motorcycle Manufacturers (ACEM), scrutinises the 2017 "Study on Euro 5 sound level limits of L-category vehicles" performed by a consortium between Emisia, HSDAC, TNO, and Ricardo for the Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (DG GROW) of the European Commission, and in particular its Chapter 4 "Cost-Benefit Analysis of new sound limits". In this report we refer to the 2017 study as "the CBA".

The CBA includes two main parts:

- A description of the stakeholder survey of sound emissions of L-category vehicles and an assessment of its results.
- The cost-benefit analysis on the reduction of L-category vehicle noise limits, its conclusions and a proposal for the sound limit

The scrutiny of these main parts is introduced in the sections below.

1.1 Stakeholder survey results and analysis

The CBA starts with an assessment of a stakeholder survey conducted in 2016. The conclusions of the survey start on p121. The conduct of such surveys is important to gain insights from all interested affected stakeholders, mostly presenting opinions, whilst also providing additional reports and data. The opinions presented by the survey provide information about the extent of support for certain policy options, amongst those responding to the survey. Survey results are not weighted according to the economic or social relevance of the respondents.

For the above reasons, the results of the survey presented in the CBA are not able to provide sufficient information to reach a concrete conclusion on technical matters such as regulatory options. Its results should be used to gauge the weight of opinion of interested parties, whilst any concrete data and analysis provided can feed into the technical cost-benefit assessment.

On many occasions, statements in this part of the CBA are preceded by the term "is considered", without identifying the party(ies) "considering" the statement. The opinions appear to be written as if generally held, without indicating what proportion of respondents hold that view, or even whether it is a majority, minority or only one stakeholder.

For example, point 4 on page 121 states that test procedures are considered to be recognisable by vehicles, directly concluding "sound measurements at the test site are not representative of the noise produced by the vehicles in-use". This cannot be concluded from the presented information alone and requires specific evidence.

Point 3 on page 123 proposes possible solutions to optimise the acceleration test to correspond better to real use of the vehicle: measuring acceleration noise up to higher speeds on a longer driving distance with more microphones. This option is not explained and it is not clear how in practice this would have the intended effect. On page 126 it states "currently, a lot of money and effort is spent in sound design, hence, there is no indication that designing for lower limits is necessarily more costly". It is not clear if this is an opinion from a stakeholder or of the authors. The conclusion of the statement does not necessarily follow from its opening premise.

Summarising the survey results, it states on p127 *"In any case, and for the needs of the current study, a 2 dB(A) reduction for all L-categories can be considered as a justified proposal to be* *examined by the CBA model (see section 4) as a moderate scenario"*. For the reasons identified above, this is not a conclusion that can robustly be drawn from the responses.

The 2 dB and 5 dB limit reduction options do however appear to be legitimate starting points for investigating the impacts of moderate and more ambitious reductions. However, concluding this from the survey is not consistent with the nature and purpose of the survey. A reasonable alternative would have been 2 dB and 4 dB, reflecting the steps outlined in Regulation (EU) 540/2014 for the heavier vehicle categories.

1.2 The CBA

The Cost-Benefit Analysis (CBA) aimed at:

- exploring the feasibility and relevance, in the medium term up to 2040, of introducing lower sound level limits for L-category vehicles and,
- assessing whether the environmental and health benefits from real world traffic noise reduction would be higher than the associated costs for industry and authorities.

It focuses mainly on mopeds and motorcycles, but also addresses other L-category vehicle types. Calculations of benefits revolved around potential reductions of annual average noise level at the dwelling façade assessed using the weighted day-evening-night indicator (L_{DEN}). They were conducted for several scenarios, characterised by different levels of ambition in noise limit reduction, market growth expectations, enforcement levels, and expected effects on traffic noise levels deriving from other regulations. Different assumptions on L-category vehicle activity were applied to Northern and Southern Europe. Noise level calculations were based on the CNOSSOS-EU model – as detailed by Directive (EU) 2015/996 – with adjustments made to L-category vehicle noise modelling to reflect the study's noise emission tests on a sample of 11 vehicles (presented in section 3 of the study).

An "indicative" single event analysis was also included "to address the particular sound impact caused by sound level peaks due to acceleration well above other traffic sound levels." (p. 15).

CBA results indicated benefit-cost ratios between 1.32 and 2.18 in different scenarios of noise limit reduction over the period 2020-2040, with most of the benefits expected from Southern Europe. Significantly higher ratios resulted from the single event analysis. The study concluded that lowering the sound limits of L-cat vehicles would be technically feasible and economically relevant, especially for a 2 dB reduction. Conclusions on 5 dB reduction are acknowledged to be less robust due to *"higher uncertainty in model parameters (especially costs)"* (p. 191).

The CBA was influenced in its assumptions and orientations by the consultation discussed above - presented in section 2 of the CBA - with industrial stakeholders, national authorities, and social partners, including citizens.

The CBA encompassed, and supported proposals on, three different aspects:

1) reduced limit values for type approval of L-cat vehicles;
2) extended methodology for type approval to better represent real world driving conditions; (e.g. by improved additional sound emission provisions – ASEP)
3) removal of illegal exhausts and other noise increasing modifications from the market (by more effective enforcement measures).

Although all relevant for tackling noise emissions, these aspects pertain to different analytical and regulatory dimensions. A coherent and thorough analysis would require them to be kept clearly separated, whereas in the CBA they were often combined. We have attempted to isolate the effects of limits as the primary object of our own analysis, but in some cases this has not been possible when reviewing the CBA data. This leads to some additional ambiguity in the conclusions.

The CBA partly followed the methodology and data used in previous studies. The methodologies for calculating costs and benefits are summarised in the flowcharts shown in the next section. However, diverging assumptions were in some instances introduced (such as considering accelerating traffic in rural roads), without full explanation and justification.

Overall, transparency concerns can be raised, insofar as numerous references and sources were omitted, and the derivation of most results was not presented or made available. For example, calculations leading to L_{DEN} values and total benefits and costs were not presented or not sufficiently detailed. This makes a comprehensive scrutiny of the study challenging, as some of the steps and conditions taken in the analysis and calculations remain unclear.

1.3 Expert review

This review was organised as follows. Task I scrutinised the CBA methodology, assumptions, quality of supporting evidence, results, and conclusions, highlighting where appropriate the need and relevance of a potential reassessment. The analysis was structured according to the flow diagrams for calculating benefits and costs, as presented in the CBA (figures 23-24, pp. 169, 171 - below). Like the CBA, it also focused mainly on mopeds and motorcycles. It primarily assessed the impact of limit reductions.

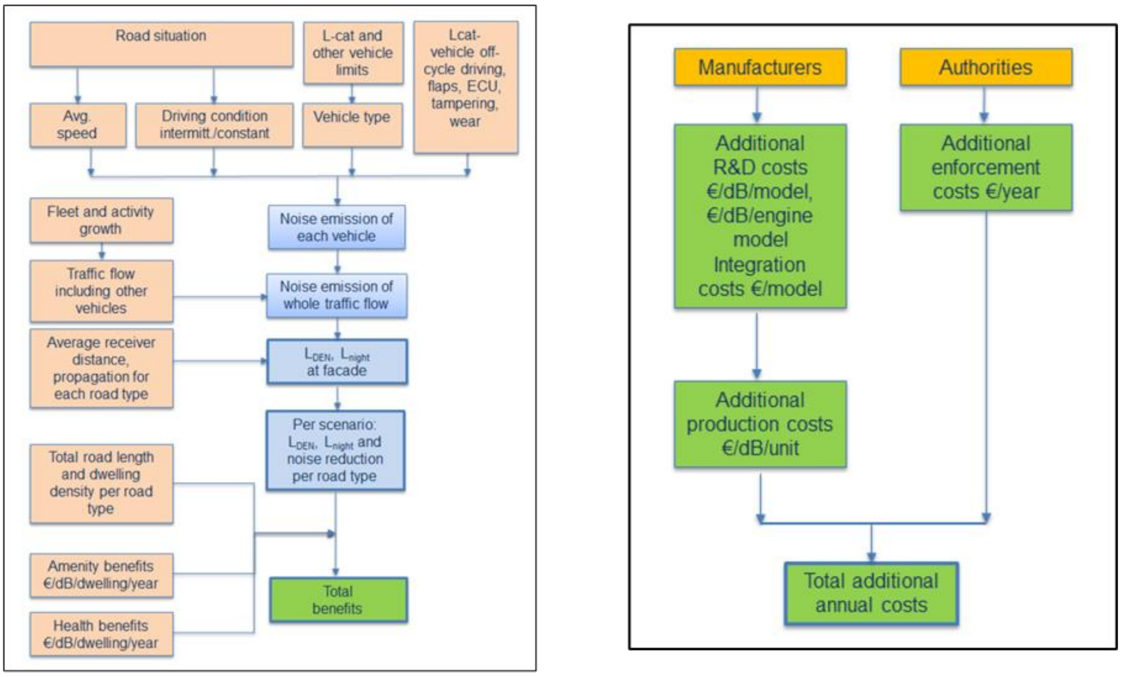


Figure 1: Flowcharts of methodologies for calculating benefits (left) and costs, from CBA (p 169 & 171)

Task II proposed an alternative CBA, building on Task I findings and on additional inputs from stakeholders and experts, including results from Noise Source Ranking (NSR) tests conducted on behalf of ACEM by the Graz University of Technology (TU Graz).

The write-up of Tasks I and II are combined in the subsequent chapters of this report.

1.4 Contact with the CBA authors

On 26th April 2021 we sent a list of questions to the lead author of the CBA study. Answers to these questions would clarify many of the unknowns arising from the absence of calculations and derivations of the numerical results. On 28th June we received a written response to the questions followed by responses to follow up questions (see Annex 1).

The responses provided some useful additional information, in particular on how the final benefits were calculated. This enabled sufficient scrutiny of the CBA results. Additional information, especially the background data and calculations, would have enabled a more sophisticiated review, but was not provided for confidentiality reasons.

2 BENEFITS – REVIEW OF CBA ASSESSMENT

We have grouped the benefits flowchart elements into eight blocks in the chart below. For each block we devote a subsection in this chapter, assessing the CBA results and offering alternative analysis where appropriate.

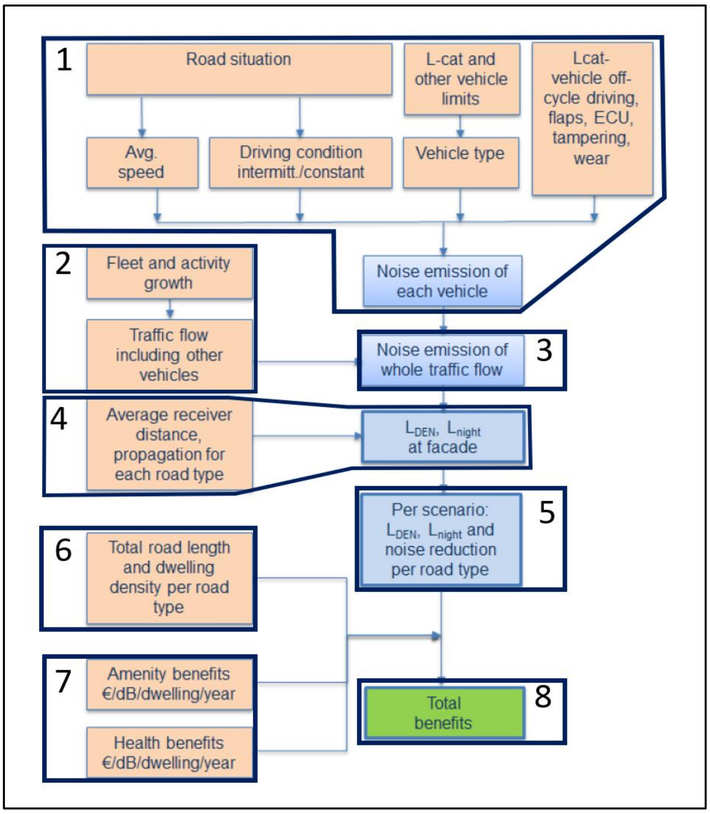
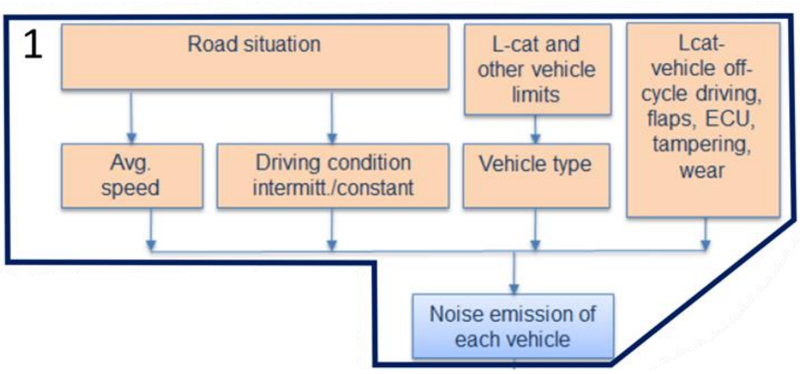


Figure 2: Flowchart split into analysis blocks (benefits)

For each sub-element of each block, we review the assessment presented in the CBA and make a concluding statement on the potential impact of an alternative analysis on the benefit-cost (B/C) ratio, which is fully evaluated in the following sections.

2.1 Block 1 - Calculation of noise emission of each vehicle

The calculation elements of this block are shown below, followed by the assessment of each element in turn, leading to conclusions on the noise emission of each vehicle.



2.1.1 *Road situation*

The road situation element above appears to refer to all the possible situations of road types and traffic flows. For calculation purposes the details are therefore processed by the average speed and driving condition blocks below.

Potential impact on B/C: no direct impact

2.1.2 *Driving condition*

The CBA makes the assumption that only road stretches with accelerating traffic contribute to the noise impacts influenced by L-cat vehicles (33% intermittent of which 50% accelerating = 17% accelerating overall). This relies in turn on the following factors:

i. The validity of the assumption
ii. The increase in vehicle noise under accelerating conditions
iii. The equal treatment of other vehicles in the traffic

These factors are reviewed individually below:

i. The validity of the assumption

The assumption of only calculating noise impacts for accelerating traffic is stated in the CBA without specific reference. The Executive Summary states that considering full lengths of inhabited roads combined with higher valuations of noise impacts would lead to significantly higher benefits. This is not substantiated in the text of the CBA, but is a reasonable conclusion, since exposure of people in significantly more road sections would be included. To determine whether considering only accelerating traffic is a valid assumption, alternative calculations considering all traffic would be necessary. The impact of this is addressed in Section 2.6, where the relevant road lengths are considered.

From preliminary calculations, the reduction in L_{DEN} in steady traffic due to a 2 dB L-category limit reduction is fractionally lower than the reduction in accelerating traffic, assuming accelerating effects for all vehicle categories.

Potential impact on B/C: if including all road sections, a significant increase in benefits, with the magnitude to be addressed in Section 2.6.

ii. The increase in vehicle noise under accelerating conditions

The CBA (p181) estimates the impact of acceleration:

> *"The sound power levels of mopeds and motorcycles are based on the CNOSSOS formulae for source terms, increased* ***by 5 dB for motorcycles and by 3 dB for mopeds****, to account for acceleration effects as illustrated in Figure 25." (p. 181)*

The corrections are based on measurements, detailed in section 3 of the study, and represented in figure 25 below (p. 175), which shows a comparison between CNOSSOS-EU calculated levels and measured levels.

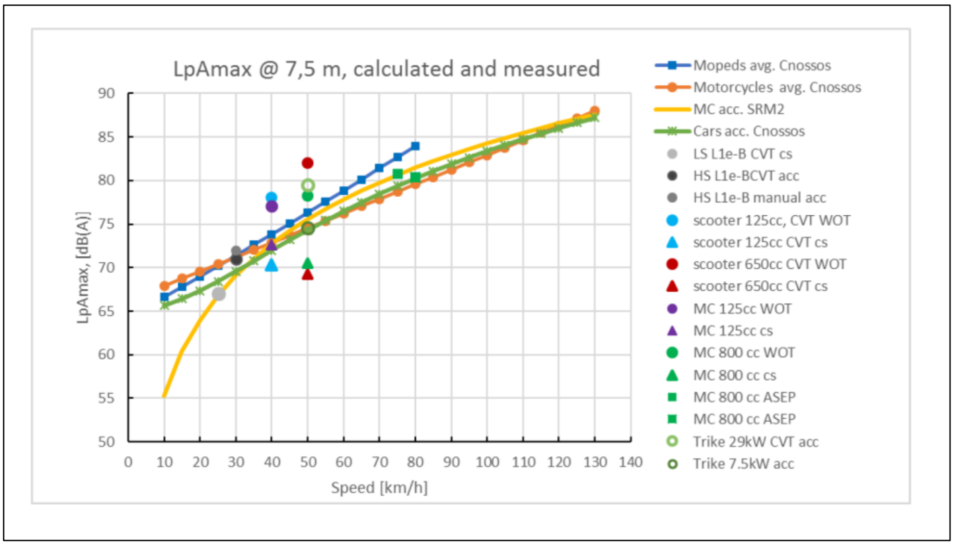


Figure 3: CBA Figure 25, p175

The sample of tested vehicles (section 3 of the CBA) is not large enough to draw reliable results and conclusions with respect to limit values and noise source ranking. An adequate sample should cover variations in technical design of the vehicles, as well as reflect, to a certain extent, market share. The proposed sample (11 vehicles in total: three L1, four L3, two L5, one L6 and one L7) does not meet this condition.

Specifically, three L1 and four L3 vehicles are insufficient to take into account the much higher variety of technical design parameters in the L3 category compared to the L1 category. For reliable results one would need at least 4 vehicles (2 scooters and 2 motorcycles) with pmr <= 50 and at least 8 vehicles (scooter, touring, street, sports, 2 vehicles each) with pmr > 50. For example, in the corresponding study dedicated to the exhaust emissions, Ntziachristos et al. (2017) 31 different vehicles were tested (among them 8 motorcycles). The small sample substantially weakens the robustness of the conclusion.

No justification is provided for applying L_{wot} (wide-open throttle) values to characterise the average L_{wot} values in real traffic. The +5 dB correction applied to motorcycles equals the limit value for L_{wot} in the motorcycle type approval regulation (UNECE R41).

The correction for mopeds (+3dB) is not justified by data presented, as it is acknowledged that "For the L1e vehicles the measured levels are within 1 dB of the calculated levels".

The above factors lead to the conclusion that the +3 dB/+5 dB corrections for mopeds and motorcycles are not justified. Figures of +3 dB for motorcycles and +1 dB for mopeds are values that can more readily be justified, based on the results presented.

Potential impact on B/C: a reduction in the noise increase of accelerating traffic, decreasing significantly the impact in accelerating traffic of reducing the noise emission limits but decreasing the overall impact only modestly when non-accelerating traffic is included.

iii. The equal treatment of other vehicles in the traffic

The CNOSSOS-EU model is used for the calculation of the noise emissions of different vehicle categories (cars and light duty vehicles, medium and heavy trucks, motorcycles and mopeds) in real traffic. It is based on noise emissions for constant speed steady vehicle flows, without considering intermittent and accelerating traffic. A correction factor within 100m for traffic light controlled and roundabout junctions is applied, to take into account the effect of acceleration and deceleration near junctions, with no further acceleration effects modelled. However, this does not apply to mopeds and motorcycles.

CNOSSOS-EU considers the effects of accelerating traffic at crossings with traffic lights and roundabouts by an emission correction which is highest at the crossing and decreasing linearly to 0 up to a distance of 100 m for cars and trucks, but not for motorcycles. Therefore, it is justified to increase the emissions of motorcycles also, but it is not clear that an equivalent increase for the other vehicle categories was considered in the CBA. It is implausible to assume that only L-cat vehicles (and all of them) accelerate in a road section, for all of the time.

Potential impact on B/C: considering an increase in noise emissions of other vehicle categories would decrease modestly the noise reduction attributable to L-category vehicles.

2.1.3 *Average speed*

The CBA study indicates only a range of speeds for each of the road types (table 21). These are the same as in Papadimitriou 2016 (table 4, p. 103), while Venoliva 2011 (table 22, p.59), for residential and main roads, quotes a range but does not indicate a minimum speed.

Typical speeds (km/h) for road categories	Residential Roads	Main Roads	Arterial Roads	Urban Motorways	Rural Motorways	Rural Roads
CBA & Papadimitriou 2016	30-50	30-50	50-70	70-120	80-130	50-100
Venoliva	<50	<50	50-70	70-120	80-130	50-100

Table 1: Quoted speed ranges

Applying an “average speed” to (L-cat) accelerating vehicles to the whole road length can be valid as a first order approximation. However, it does not provide an accurate representation since an accelerating vehicle will not have the same speed at different points A and B on the same road. Further, it not clear which values within the above ranges were used in the L_{DEN} calculation.

Potential impact on B/C: considering a more granular speed range would likely change the impact on overall noise emissions modestly, but calculating the direction and magnitude would require further assumptions and more complicated calculation.

<u>*L-cat and other vehicle limits, vehicle type*</u>

The CBA models the impact of a 2 dB and a 5 dB reduction in the noise limits for both mopeds and motorcycles. It is not clear to what level of actual noise reduction of the vehicles on the road this limit reduction leads.

The CBA page 165 states:

> *“The sound level of other vehicles will go down over the next decade due to lower noise limits as set out in Regulation (EU) No 540/2014, resulting in lower average sound emission levels of the whole fleet by 2040, 4 dB lower for cars and 3 dB lower for medium size and heavy vehicles.” (p. 165).*

It is not clear whether the 4 dB / 3 dB reductions refer to both the limits and the whole fleet or only the limits. The effect on the reduction of noise emission in real traffic is significantly lower than the reduction in the limits. Even within the same category, vehicles have different characteristics, meaning some are already under the prospective limits or require a lower reduction to meet the limits.

The study "Assessment of the impacts of the EU Directive 540/2014 on the traffic noise impact in real traffic" from 2014 forecasts a reduction of 1.6 to 1.8 dB(A), depending on the road category or type, due to a combination of limit reductions for vehicles and tyres. These compare to the 3-4 dB limit reduction, implying that the actual reduction is approximately 50% of the limit reduction.

Further, a limit value reduction does not lead to an equivalent reduction of noise peaks in real traffic nor are all compliant vehicles affected by the limit value reduction.

Potential impact on B/C: assuming the above consideration was not taken into account in the CBA, there would be a reduction of approximately 50% in the impact of reducing the noise limits.

2.1.4 *L-cat vehicle off-cycle driving, flaps, ECU, tampering, wear*

Off-cycle noise emissions require a separate treatment in order to isolate the effect of the limit reduction. One key element is the use of illegal exhausts, which are analysed in the CBA.

A key factor is whether L-category noise limit reduction would also result in an equivalent reduction in the noise emissions of illegal exhausts (e.g. whether a 2 dB limit reduction would result in any reduction of the noise emissions of illegal motorcycle exhausts, whose emissions are increased by 12.5 dB compared to a legal exhaust). Since the point of illegal exhausts is to increase the noise level, it appears unlikely that regulatory limits would have an impact similar to that on illegal exhausts, and most likely would have zero impact.

A brief review of the CBA results provides an indication:

	Northern EU		Southern EU	
Scenario	Δ Lden dB	Δ Lden dB	Δ Lden dB	Δ Lden dB
Year/Lcatlim/%Illegal/Growth	All	Lcat	All	Lcat
2040, -2 dB, 25% IL, BAU	1,77	0,19	1,40	0,39
2040, -2 dB, 0% IL, BAU	2,18	0,27	2,69	0,73

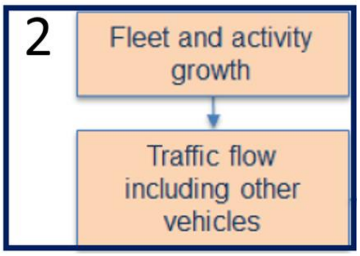
Table 2: Extract from L_{DEN} results from table 24, p182

In the CBA results, for Northern Europe, the impact on the sound pressure level with 25% illegal exhausts (75% legal) is approximately 70% of the impact with 0 illegal exhausts (0.19/0.27). This result is consistent with little or no impact of the limit reduction on the emissions of vehicles with illegal exhausts (as explained above).

For Southern Europe however, the impact with 25% illegal exhausts is approximately 53% of the impact with 0% illegal exhausts. This result indicates that the presence of illegal exhausts decreases the impact of the limits. This could be due to the illegal exhausts dominating the noise level, but no further evidence or explanation is provided. There is also no explanation in the CBA for the inconsistency between Northern and Southern Europe in this case.

Potential impact on B/C: no impact, based on the assumption that the limit reduction does not have an impact on noise levels of illegal exhausts (i.e. the impact is calculated only for vehicles with legal exhausts).

2.2 Fleet, vehicle activity and traffic flow



2.2.1 *Fleet and activity growth*

Values for L-cat fleet composition and activity are presented in the CBA Table 22 p180. Values and assumptions for the rest of the fleet (cars, medium, heavy vehicles) are not presented.

The values appear generally consistent with those presented in Ntziachristos 2017, the principal data source for this section, which mostly used ACEM forecasts, although absolute values for single vehicle categories are not always displayed in the original source.

The total annual mileage for single vehicle categories (column *"Total veh.km/year x10^9"*) present some inconsistencies, as multiplication of the fleet size by the mileage of each vehicle does not give the exact values shown. However, the total of around 156x10^9 vkm is consistent with the value from the 2019 Handbook on the external costs of transport (STICITE) (values derived using table 16 p50).

Values for "active fleet" do not derive from Ntziachristos 2017. If, in Table 22, the stock of vehicles in the active moped fleet for is used instead of the "total fleet" when calculating total annual mileage, it would result in a significant decrease in mopeds' annual mileage, as the active fleet is around half of the total fleet.

The split of activity between urban, rural, and highway roads as shown in Table 22 derives from Ntziachristos 2017, which uses COPERT data. However, the further split of motorcycles and moped activity between urban road types (residential, main, arterial), shown in Table 21, appears to be a new assumption in the CBA.

Table 22 also presents market growth projections under baseline and high growth scenarios. If percentage variations are applied to the total fleet values, resulting figures for baseline and high growth (around 38M and 44M vehicles respectively) are again aligned with Ntziachristos 2017. It is worth mentioning that this study also included a "low growth" scenario, resulting in around 32M vehicles in 2040, i.e. around 16% less than the 2040 baseline scenario. The text mentions the assumed growth for the rest of the fleet (non L-cat) under the baseline and high growth scenarios, +22% and +49% respectively (p. 181), providing no further details. This leads to an expected decrease in the proportion of L-cat vehicles in future flow rates, especially mopeds.

Overall, the values presented in this section appear reasonable and consistent with previous analysis and data, with no major impact on overall calculations expected, since fleet growth does not necessarily correspond to equivalent activity growth on the road. However, scenario-related assumptions might have a material impact if future traffic flow rates were used, and therefore on L_{DEN} values, but a scrutiny is not possible due to lack of details in the study.

Potential impact on B/C: potential reduction in flow rates for mopeds and therefore in the benefits due to limit reductions.

2.2.2 *Flow rates*

Traffic flow rates, an important component for calculating L_{DEN} levels, are presented in table 23, p180 (below).

	Northern Europe: Vehicle flow in no./hour			
Day 12 h	Residential	Main	Arterial	Rural
Cars	30,0	302,6	2030,6	356,9
Medium veh.	4,0	11,1	78,9	16,0
Heavy veh.	0,0	11,4	81,0	17,2
Motorcycles	0,0	15,1	101,5	17,8
Mopeds	1,5	15,1	101,5	0,0
Evening 4 h				
Cars	15,0	154,7	1039,4	183,3
Medium veh.	2,0	2,9	21,9	4,5
Heavy veh.	0,0	4,9	34,0	7,2
Motorcycles	0,0	7,7	52,0	9,2
Mopeds	0,8	7,7	52,0	0,0
Night 8 h				
Cars	10,0	50,4	338,2	58,9
Medium veh.	0,0	2,4	16,3	3,4
Heavy veh.	0,0	3,5	24,6	5,1
Motorcycles	0,0	2,5	16,9	2,9
Mopeds	0,5	2,5	16,9	0,0

	Southern Europe: Vehicle flow in no./hour			
Day 12 h	Residential	Main	Arterial	Rural
Cars	25,0	236,8	842,5	250,0
Medium veh.	4,6	43,4	154,5	45,8
Heavy veh.	1,7	15,8	56,2	16,7
Motorcycles	2,1	19,7	70,2	20,8
Mopeds	8,3	78,9	280,8	83,3
Evening 4 h				
Cars	28,3	268,3	954,8	283,3
Medium veh.	2,5	23,7	84,3	25,0
Heavy veh.	0,4	3,9	14,0	4,2
Motorcycles	2,1	19,7	70,2	20,8
Mopeds	8,3	78,9	280,8	83,3
Night 8 h				
Cars	28,8	272,3	968,9	287,5
Medium veh.	2,1	19,7	70,2	20,8
Heavy veh.	0,4	3,9	14,0	4,2
Motorcycles	2,1	19,7	70,2	20,8
Mopeds	8,3	78,9	280,8	83,3

Table 3: p180 table 23 flow rates

It is not clear from the text of the CBA whether these are average flow rates or apply only to certain sections of road or certain times. Some statements in the text (p165) appear to refer to this point:

> *"Characteristic traffic flow rates are used for roads where the proportion of L-category vehicles is relatively high. (…) Roads with a larger proportion of lorries and trucks are disregarded as these vehicles tend to predominate the equivalent noise level."*

and, with reference to Southern Europe (p.165):

> *"selecting 50% of the roads with lower proportions of heavy vehicles".*

A statement from the author clarified that these are assumed average traffic flow rates based on previous studies and extended for L-cat vehicles. We therefore make the assumption in our assessment that these flows are averages for all roads in each category for the whole year, whilst taking account of the residual uncertainty in the definition.

However, the data do not appear plausible overall. They are quoted as the number of vehicles per hour, i.e. the average number of vehicles passing a single point on each road category. This is the parameter that is fed into CNOSSOS-EU to calculate sound power emission levels. It is however implausible that the vehicle flow in rural roads is higher than main roads (for all vehicle types), as is the case in the table.

The total vehicle kilometres travelled (vkm) on each road type is the flow multiplied by the total length. Performing this calculation with the above flow rates leads in Northern Europe to 65% of vehicle kilometres being driven on rural roads, and in Southern Europe 73%. This result confirms the implausibility of the rural road figures as quoted. The flow rates for non L-category vehicles in residential, main and arterial roads appear to be plausible but this cannot be confirmed.

For Southern Europe in the above table, the percentage of vehicle flow in each road type is identical for each vehicle category, see table below using daytime as an example. This indicates the figures have been generated using a simple multiplier rather than from traffic data.

Day (12h)	**vehicle km (% of total)**			
	Residential	Main	Arterial	Rural
Light duty vehicles	1.8%	17.5%	62.2%	18.5%
Medium vehicles	1.9%	17.5%	62.2%	18.4%
Heavy vehicles	1.9%	17.4%	62.2%	18.5%
Motorcycles	1.9%	17.5%	62.2%	18.4%
Mopeds	1.8%	17.5%	62.2%	18.5%

Table 4: % vehicle km for each road type

Further, the magnitude of the values presented in Table 23 seems implausible for Southern Europe:

- the total number of vehicles in the traffic flow is the same for day, evening, and night;
- precise values for motorcycles and mopeds recur across all time sections;
- the number of cars increases (modestly) from day to evening and night in all road types;
- values for heavy vehicles are the same for evening and night in all road types;
- the daytime flow rates for cars are significantly lower in the South than in the North for all road types.

The CBA states (p. 165):

> *"The proportion of L-category vehicles to other traffic is much higher in Southern European countries".*

It does not quote evidence to justify using values as high as those in table 23. No data on L-cat vehicle stock are available to substantiate the values (Papadimitriou 2016 allocates 55% of total L-cat vehicles in 2013 to Mediterranean countries, p99, using ACEM data).

The proportion of mopeds seems in particular overestimated. According to Table 22, mopeds account for 20% of total km ridden by L-cat fleet (15% if "active fleet" values are used instead of "total fleet"); however, in Table 23 they have a 4 times higher flow rate than motorcycles in all road types in Southern Europe, and as high as motorcycles in main and arterial roads in Northern Europe.

The distribution of L-category vehicles in different road categories does not seem coherent with assumptions on vehicle activity presented in Table 21. For example, mopeds are assumed to ride 40% of their total mileage on main roads and 25% on rural roads. As main roads account for only 7% of the total road length considered (residential, main, arterial, rural) and rural roads account for more than 50%, one would expect a relatively higher number of mopeds in main roads, but reported values are similar (78.9 main; 83.3 rural).

Data are available from the 2010 TRACCS study, which provides total vehicle-kilometres per year in detail for all European countries, allowing differentiation between Northern and Southern Europe. Extracting the data and comparing the percentage of motorcycles and mopeds vehicle-kilometres travelled to the CBA flow rates results in the following:

Northern Europe				Southern Europe			
	CBA	TRACCS			CBA	TRACCS	
Motorcycles	4.2%	1.5%		Motorcycles	5.0%	5.4%	
Mopeds	4.0%	0.6%		Mopeds	20.0%	2.3%	

Table 5: Comparing vehicle-kilometre data between CBA and TRACCS

From the above analysis, it can be concluded that the flow rates proposed in Table 23 do not derive coherently from data and assumptions on L-cat fleet composition and activity. Especially for Southern Europe, they appear to represent extreme traffic situations, rather than normal traffic conditions to be applied to the whole road network considered, potentially leading to a significant overestimate of L-cat contribution to traffic noise levels.

For the case of a 2 dB limit reduction, business as usual growth and 0% illegal exhausts, the total benefits of limit reduction are quoted in the CBA as the following (Table V.1, Annex V):

- Northern Europe €97m
- Southern Europe €1113m

The primary difference in the data between Northern and Southern Europe is the relative vehicle activity, according to Table 23 being significantly higher during the evening and night in Southern Europe. (The additional difference is the assumed 62%/38% split of the roads/population.) The flow rates must therefore explain the majority of the approximately 11-fold difference in the impacts. It would impact the amenity benefits due to the impact on L_{DEN} of the higher L-category vehicle activity during the evening and night. It would also impact the health benefits, due directly to the higher L-category vehicle activity at night.

A first order reassessment of these data should be based on more plausible figures when comparing road types. The CBA refers to Venoliva (2011), which contains the following flow rates. The relative values across the various road types appear more plausible, although they were published 10 years ago, are not differentiated by Northern and Southern Europe and no source or reference is provided:

	Residential	Main	Arterial	Urban MW	Rural MW	Rural
Typ.speed	<50	<50	50-70	70-120	80-130	50-100
	Typical traffic intensities N/hour					
DAY 12h	Intmt.+free	Intmt.+free	Free	Free	Free	Free
Pass. Cars	20	500	1000	2000	2000	100
Vans	4	50	100	200	200	10
Lorries	0,2	25	50	100	100	10
Buses	0,1	4	10	10	10	2
HDVs	0,1	15	50	120	130	5
EVE 4h						
Pass. Cars	15	400	1000	1500	1500	50
Vans	2	20	100	150	150	5
Lorries	0,01	4	20	50	50	2
Buses	1	2	10	6	6	2
HDVs	0,01	5	20	90	90	2
NIGHT 8h						
Pass. Cars	2	50	200	500	500	16
Vans	1	5	20	50	50	2
Lorries	0,01	2	17	35	35	1
Buses	0,5	1	5	4	4	1
HDVs	0,01	2	8	50	50	1

Table 6: Traffic intensities from De Roo (2011)

The L-category vehicle flow rates derived from the TRACCS data can be applied to both Northern and Southern Europe to generate flow rates for L-category vehicles. An alternative, more consistent set of flow rates for Southern Europe can be generated with the following characteristics:

- Total daytime traffic as in Table 6 above (Northern and Southern Europe)
- Proportion of motorcycles and mopeds taken from TRACCS for Northern and Southern Europe
- Moped activity set to zero on motorways

Using these guidelines generates the following flow rates for Southern Europe, comparing the CBA (left side) to the new figures (right side):

	CBA figures / hr				Adjusted figures / hr			
	Residential	Main	Arterials	Rural	Residential	Main	Arterials	Rural
Day 12 h								
Cars/Light duty vehicles	25.0	236.8	842.5	250.0	20.0	500.0	1000.0	100.0
Medium vehicles	4.6	43.4	154.5	45.8	4.0	50.0	100.0	10.0
Heavy vehicles	1.7	15.8	56.2	16.7	0.3	29.0	60.0	12.0
Motorcycles	2.1	19.7	70.2	20.8	1.4	32.8	65.7	6.9
Mopeds	8.3	78.9	280.8	83.3	0.6	13.5	27.1	2.8
evening 4 h								
Cars/Light duty vehicles	28.3	268.3	954.8	283.3	15.0	400.0	1000.0	50.0
Medium vehicles	2.5	23.7	84.3	25.0	2.0	20.0	100.0	5.0
Heavy vehicles	0.4	3.9	14.0	4.2	1.0	6.0	30.0	4.0
Motorcycles	2.1	19.7	70.2	20.8	1.0	24.1	64.0	3.3
Mopeds	8.3	78.9	280.8	83.3	0.4	9.9	26.4	1.4
night 8 h								
Cars/Light duty vehicles	28.8	272.3	968.9	287.5	2.0	50.0	200.0	16.0
Medium vehicles	2.1	19.7	70.2	20.8	1.0	5.0	20.0	2.0
Heavy vehicles	0.4	3.9	14.0	4.2	0.5	3.0	22.0	2.0
Motorcycles	2.1	19.7	70.2	20.8	0.2	3.3	13.7	1.1
Mopeds	8.3	78.9	280.8	83.3	0.1	1.4	5.6	0.5

Table 7: Comparing CBA flow rates with adjusted figures for Southern Europe

The above figures exclude the implausibility inherent in the CBA data and are therefore likely to provide more relevant results, to be presented in Section 3. However, high levels of uncertainty remain.

Potential impact on B/C: using the adjusted evening and night-time flow rates in Southern Europe, total amenity and health benefits in 2040 due to limits reductions would be reduced by a significant factor.

2.3 Calculation of noise emission of whole traffic flow

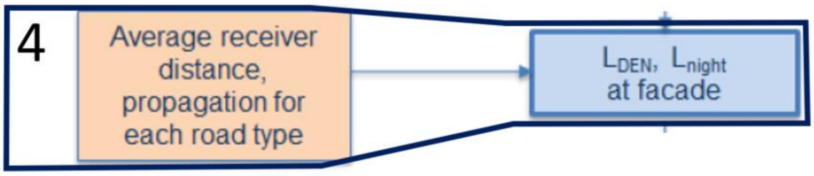
The noise emission of the whole traffic flow is calculated according to the assumptions and values addressed in the above sections. The sound power emission level per metre length of the whole traffic flow was calculated using the CNOSSOS-EU methodology established under EU Directive 2015/996, which was based upon the outputs from the EC funded Harmonise (2001 – 2004) and IMAGINE (2003 – 2006) research projects. The sound emission levels for L-Cat vehicles within CNOSSOS-EU were first introduced within the IMAGINE project and based upon onboard measurements and vehicle pass-bys. The development of the model included a discussion on the effect of illegal replacement silencers, and its prevalence in various countries, and the final model includes 35% illegal exhaust for Category 4 powered two wheelers within the reference conditions.

The sound levels within the CBA are reported using the L_{DEN} and L_{night} noise indicators, which are well-established, deriving from a European Commission position paper from 2000, agreed by consensus among the members of the advisory committee.

We have calculated L_{DEN} and L_{night} using the established method. For the purposes of using the UK's Defra dose-response relationship (Section 2.7 below), we have also calculated L_{eq}(16hr), representing day and evening.

Potential impact on B/C: no direct impact as dependent on data and assumptions above.

2.4 Calculation of L_{DEN} and L_{night} at the façade



The CBA states (p 165):

> *"The equivalent sound pressure level can be determined for a given distance from the road to the dwelling façade, 15 m for residential and main roads, and 50 m for rural roads."*

There is no reference to these distances in the CBA, nor in the Environmental Noise Directive (END).

It further states:

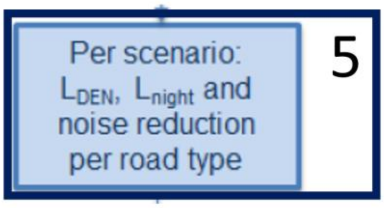
> *"Propagation effects such as ground attenuation and reflections are not included as they may vary significantly per location and are considered to average out."*

For urban situations at 15m distance the assumption appears to be valid. For rural roads, omitting soft ground effects would result in over prediction, and would not "average out". In our calculations, we assume intermediate ground for rural motorways and rural roads. We retain the distances from the road to the façade stated above.

The calculations leading to the L_{DEN} values are not presented in the CBA.

Potential impact on B/C: an increase in noise attenuation attributed to rural roads would decrease the benefit of reducing noise emissions limits for those roads, a modest overall impact.

2.5 Calculation of L_{DEN}, L_{night} and noise reduction per scenario



The values for ΔL_{DEN} in 2040 for the whole traffic flow and for L-category vehicles for both Northern and Southern Europe are presented in pages 173-174 of the CBA for the following 12 scenarios:

- 0% and 25% illegal exhausts
- Business as usual and high growth
- 0, 2 and 5 dB reductions in L-category noise limits

The results are shown in the CBA table 24/26 (below):

	Northern EU		Southern EU	
Scenario	Δ Lden dB	Δ Lden dB	Δ Lden dB	Δ Lden dB
Year/Lcatlim/%Illegal/Growth	All	Lcat	All	Lcat
2020, 0 dB, 25% IL, REF	0,00		0,00	
2020,-2 dB,25% IL, REF	0,14	0,14	0,38	0,38
2020,-5 dB,25% IL, REF	0,26	0,26	0,74	0,74
2040, 0 dB, 25% IL, BAU	1,58		1,00	
2040, -2 dB, 25% IL, BAU	1,77	0,19	1,40	0,39
2040, -5 dB, 25% IL, BAU	1,93	0,35	2,09	1,09
2040, 0 dB, 0% IL, BAU	1,91		1,96	
2040, -2 dB, 0% IL, BAU	2,18	0,27	2,69	0,73
2040, -5 dB, 0% IL, BAU	2,43	0,52	3,42	1,46
2040, 0 dB, 25% IL, HGR	0,73		0,39	
2040, -2 dB, 25% IL, HGR	0,92	0,19	0,83	0,44
2040, -5 dB, 25% IL, HGR	1,08	0,35	1,25	0,86
2040, 0 dB, 0% IL, HGR	1,06		1,12	
2040, -2 dB, 0% IL, HGR	1,33	0,27	1,84	0,72
2040, -5 dB, 0% IL, HGR	1,57	0,52	2,57	1,45

Table 8: ΔL_{DEN} values for all scenarios, Table 24, p182

The meaning of the values for 2020 (top three lines) is not clear.

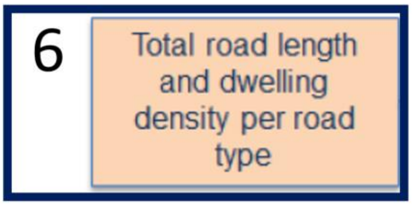
Since the derivation of these results is not available, it is not possible to verify their accuracy. The relative values appear to be consistent with the assumptions stated in previous chapters.

The tabulated values are average ΔL_{DEN} across all roads. They therefore do not have a directly applicable significance. To calculate health impacts, ΔL_{DEN} values for each individual road type are necessary. This information is not presented in the CBA.

A preliminary calculation for the -2 dB, 25% illegal exhausts and BAU growth using our own assumptions leads to a weighted (over all road types) ΔL_{DEN} reduction in 2040 due to L-category limit reduction of 0.015 dB for Northern Europe and 0.067 dB for Southern Europe. This compares to 0.19 dB and 0.39 dB in the above table (indicated row), representing a reduction by a factor of approximately 12 and 6 respectively. A reconciliation of the calculated values is presented in Section 3.2 below.

Potential impact on B/C: from our calculations a reduction in the ΔL_{DEN} values by a significant factor, with a corresponding decrease in the benefits of the limit reduction.

2.6 Total road length and dwelling density per road type



CBA Table 21 (page 180) shows total road lengths across EU28, with values for inhabited sections and exposed people per km, plus calculation of the exposed inhabitants according to intermittent and accelerating road sections, with figures taken from Venoliva (2011). It also shows the distribution of inhabitants between North and South and the proportions of motorcycle and moped activity on each road type.

Table 21: Road types, total and inhabited lengths, lengths with intermittent and accelerating traffic, North/South distribution, population density and numbers exposed, and motorcycle/moped activity for the EU28 as applied. The shaded road types are included in the analysis.

		Residential Roads	Main Roads	Arterial Roads	Urban Motorways	Rural Motorways	Rural Roads	Totals
Typical speeds	km/h	30-50	30-50	50-70	70-120	80-130	50-100	
EU28 totals	Length, km	1660601	251606	100643	5032	95610	2918633	5032125
Inhabited	Length, km	1079391	201285	90578	4026	47805	1459316	2882401
33% intermittent	Length, km	356199	66424	29891	1329	15776	481574	951192
50% accelerating	Length, km	178100	33212	14945	664	7888	240787	475596
62% North EU	Length, km	110422	20591	9266	412	4890	149288	294870
38% South EU	Length, km	67678	12621	5679	252	2997	91499	180727
Exposed/km	People/km	250	500	500	1000	50	20	
Exposed North	People	27605425	10295728	4633065	411860	244523	2985761	46176360
Exposed South	People	16919454	6310285	2839620	252430	149869	1829982	28301640
Motorcycle activity	%	5%	25%	10%	5%	15%	40%	100%
Moped activity	%	20%	40%	15%	0%	0%	25%	100%

Table 9: Table 21 (p180)

On p164 the CBA explains the selection of roads in focus:

> *"For Northern Europe, the main focus is on motorcycles on main road touring routes, for example winding alpine and country roads, in and around towns and villages, which are known to be noise hotspots for high disturbance from motorcycles during the touring season. For mopeds, mainly urban areas are considered, where large numbers of these are present for most of the time. Motorways and arterial roads are considered less relevant for environmental impact due to the small proportion of L-category vehicles compared to others, including trucks and lorries."*

The definition of *"touring routes"* is not explained. From the description above, it may refer both to main roads (*"in and around towns and villages"*) and rural roads.

The source used for touring routes total length (http://www.bestbikingroads.nl) consists of a collection of motorcycles itineraries (see figures below) uploaded and rated by bikers/users. Aggregated figures with the total length for the EU28, or even for single country, are not presented on the website (accessed June 2021). Hence, it is not possible to check how the value presented in the CBA was derived. Furthermore, the itineraries shown on the website does not seem to provide any reliable indication of their popularity and relevance: many of them are rated only by one user, and some areas appear overrepresented (for example, the United Kingdom alone accounts for 1,910 itineraries, approximately equal to the combined total for Italy, France, and Germany).

Comparing the total length of touring routes with the accelerating portion of rural roads, as done in the CBA, is not appropriate, as it implies treating touring routes as 100% with accelerating traffic. If the same assumptions used for rural roads were applied to touring routes (i.e., 50% inhabited of which 33% intermittent of which 50% accelerating), this would result in 22,687 kms (out of 275,000) to be included in the analysis. As a further refinement, the portion of touring routes classifiable as main routes could be treated as 80% inhabited, consistently with CBA assumptions, and deducted from the 33,212 kms of main roads included in the analysis according to table 21 p180, to avoid double counting.

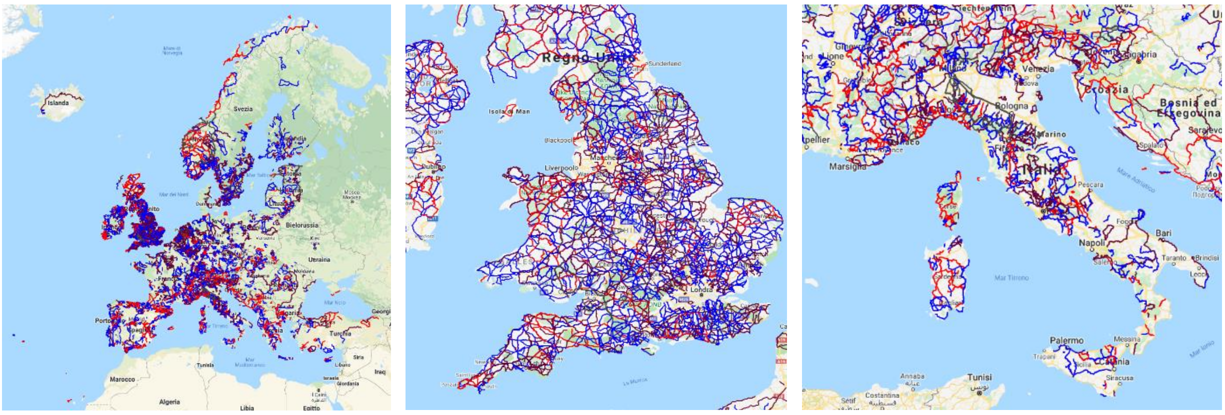


Figure 4: touring routes retrieved on https://www.bestbikingroads.nl/motorroutes/map/europa

It is not clear why touring routes are the "main" focus, as residential and main roads, with their much higher numbers of exposed people, would appear to be at least as important. As the derivation of the impacts is not provided, it is not possible to clarify the meaning of these assumptions.

Further:

> *"For Southern Europe, all roads except motorways are considered, again the inhabited road sections with accelerating traffic, both for mopeds and motorcycles."*

Again, it is not clear what the conclusion and impact of this statement is and how it has been processed in the CBA calculations.

The selection of residential roads, main roads and rural roads does appear on first inspection to be appropriate as an approximation, as these road types have the highest numbers of exposed people and the highest L-category activity, according to the table.

The tabulated values above are reviewed in turn below:

2.6.1 *Total road lengths per road type*

Road lengths are taken from Venoliva (2011), which in turn derives the figures from several sources including Eurostat and national authorities. These therefore appear to be reliable.

Potential impact on B/C: no impact as reliable data.

2.6.2 *Length of inhabited sections*

The percentage of each road type that is inhabited is identical to the values from Venoliva (2011). Venoliva states (p58) they are *"based on various estimates from noise mapping and* *municipal demographic data"*. It does not present further evidence or references. The inhabited percentages are presented in the table extract below.

	residential	main	arterial	urban mot	rural mot	rural roads	totals
EU 28 totals	1,660,601	251,606	100,643	5,032	95,601	2,918,633	5,032,116
inhabited	1,079,391	201,285	90,578	4,026	47,805	1,459,316	2,882,401
percentage of inhabited on total	65.0%	80.0%	90.0%	80.0%	50.0%	50.0%	

Table 10: Extract of total and inhabited road lengths from table 21 (p180) and implied percentages

The higher percentages for main, arterial and urban motorways than for residential roads do not appear fully plausible, since, by definition, residential roads are inhabited. Additional data would be necessary to verify these figures. The 50% figures for rural motorways and roads also appear implausible. However, no further data are available to substantiate these observations. In conclusion, the presented values are subject to high uncertainties.

Potential impact on B/C: high level of uncertainty in the values.

2.6.3 *Excluded sections*

The CBA calculates impacts only for residential, main and rural roads, quoting these as the most relevant road types. A preliminary calculation of ΔL_{DEN} indicates that these are the road types with the highest impact in total. However, a more accurate assessment (notwithstanding the uncertainties inherent in many of the parameters) would include all six road types in the analysis. Calculations indicate that arterial roads have a material impact due to the high level of traffic and therefore high absolute noise levels, despite the relatively low population exposure.

Potential impact on B/C: increase to be determined

2.6.4 *Numbers of exposed persons in inhabited sections*

The question of the validity of only considering the 33% of road sections with intermittent traffic, and only the 50% of those with accelerating traffic (i.e. 17% in total), was addressed in Section 2.1 above. The CBA calculates impacts of noise reduction only in accelerating road sections, but does not provide a full reasoning for this treatment. As indicated in Section 2.1, the reduction in L_{DEN} in steady traffic due to limit reductions is lower by approximately 25% than the reduction in accelerating traffic. Therefore if 1/6 of the traffic is accelerating and 5/6 is steady or decelerating, the total impact on L_{DEN} taking into account all road sections would increase by a factor of approximately 5. This would result in an increase in the benefits of the limit reduction by a similar factor.

The 62%/38% North/South distribution of road lengths is not explained. It was introduced in Papadimitrou (2016) (table 4, p103) but without references. Further, it can be questioned whether the same number of people per km should apply to North and South. As a first order approximation the estimates could be valid, but generate some additional uncertainty.

Potential impact on B/C: an increase in the benefits of a limit reduction by a factor of approximately 5. Additionally, some uncertainty due to the North-South exposed population split.

2.6.5 *Road length fraction*

Through exchange with the authors and verification of the calculations, it is evident that a further parameter, relating to the fraction of relevant road length, was used to calculate the final benefits. This is not mentioned or explained in the CBA, except one reference in the section on single event analysis (p187). The fractions selected, 20% for rural and 10% for urban roads, shown in table 27 (p188), appear to be an arbitrary estimate. They are not consistent with the uninhabited sections referred to above, which include deductions of between 10% and 50% for each road type.

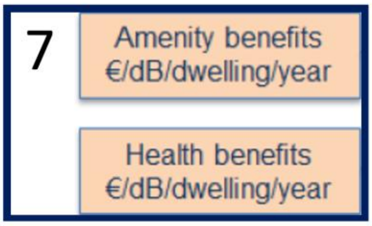
The concept of a road length fraction appears to be reasonable per se. This is not because certain portions of roads, both in urban and rural settings, are uninhabited, as stated in Venoliva, since the average population density over the entire road length remains the same. It would also not arise due to traffic restrictions or very low traffic volume streets (a high percentage of the residential streets), for the same reason.

The main reason is likely to be that, due to the configuration of roads and dwellings, many residents would be facing away from the road, be at a level much higher than the road or otherwise not be exposed. Further, during the day especially and also evenings, many people are present in places of work, education or social interaction, not located at the “façade” of their dwelling.

Determining an accurate magnitude of the impact would require complex data gathering and calculation and therefore an educated guess is the best option available. Whether 20% is representative can be debated but can be used as an orientation.

Potential impact on B/C: highly uncertain due to absence of reliable data for this parameter.

2.7 Monetisation: amenity and health benefits



Costs of noise (and benefit of reduction in noise) is addressed on p170.

2.7.1 *Amenity benefits*

The CBA on p10 states:

> *“For annoyance [=amenity], the 2003 European position paper (EU, 2003) recommends a valuation figure based on willingness to pay (e.g. the value people perceive) or Hedonic pricing (property value change) of €25 per dwelling per annum per dB noise reduction in 2002.”*

It further states *“The real value is often much higher than this, in particular when the traffic noise level affects the sales price of property or even its market attractiveness.”* but does not refer to evidence to support the assertion.

The position paper was arguably based upon the earliest studies of this type, was 14 years old at the time of the CBA’s publication and has been superseded by a number of different approaches within various EU member states. In particular, the constant valuation per dB does not recognise the variable dose-response curve that is acknowledged by many studies.

An inflation rate of 1% is applied to the amenity costs, without explanation (p170). The OECD projects an average EU GDP growth rate of 1.5% from 2020 to 2040. We apply this figure in our assessment.

2.7.2 *Health benefits*

Also on p170:

> *"For sleep disturbance and health effects associated with myocardial heart disease, a valuation figure of €16.75 per dB reduction per household per annum for 2015 is derived from UK figures (IGCB, 2010) adjusted for general application as in Zyl (2012)"*

It is not clear whether "household" and "dwelling" refer to the same thing, as they appear to be used interchangeably in the CBA. From information provided by the CBA author, we understand they are the same.

The above represents the research available at the time of publication of the CBA. Since the publication of the CBA, the official methodology for the assessment of health effects has been published as a revised Annex III of END, in Directive 2020/367, which assess the number of people highly annoyed, highly sleep disturbed, and suffering IHD due to road traffic noise, based on the dose-response curves in WHO (2018). Guidance within RIVM (2019) can be used to assess the impact of long-term noise exposure expressed using the metric of disability adjusted life years (DALY). They do not however place a numerical valuation on the economic impacts.

In the UK, the latest guidance, TAG Unit A3 (2021) on noise impacts establishes a monetary valuation of changes in noise, based on estimation of the number of DALYs lost (or gained) under each impact pathway, and monetisation with a value of £60,000 per DALY. The valuation of noise is based on the recommendations of a 2014 study.

Again, a 1% interest rate is applied. The above arguments apply.

2.7.3 *Dose-response data*

Bristow (2015) and Fryd (2017) both refer to three national studies from 2015 that calculate dose-response relationships dependent on dB level, see below.

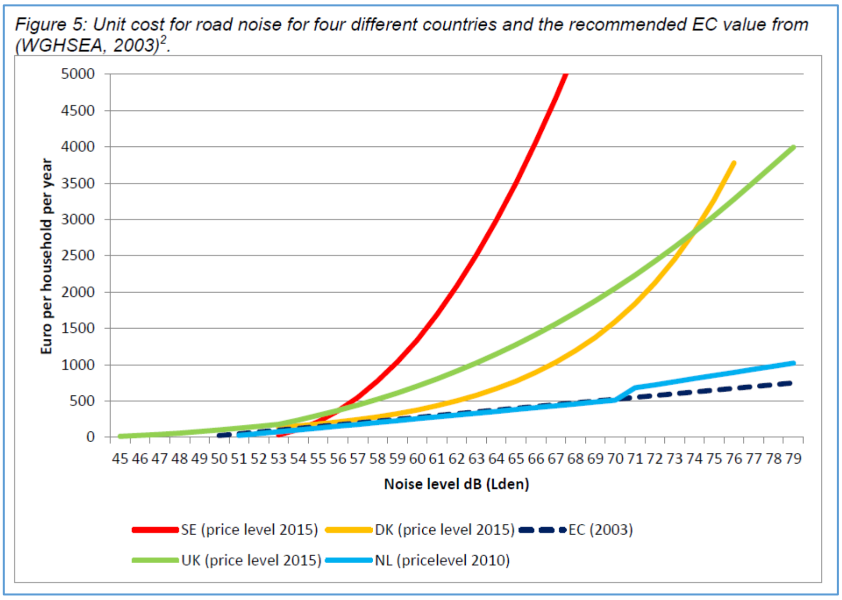


Figure 5: Unit costs curves for noise annoyance from Fryd (2017) p14

The unit cost curves in the chart sum both amenity and health benefits, which are reported separately in the raw data. The correct comparison to the data used in the CBA would therefore be to the sum of amenity and health benefits (the blue dashed line with its slope increased by about 60%).

It would be appropriate to consider the assessment using the UK, SE and DK cost curves as they are the most recent and recognise the non-linear dose-response relationship. This depends on a robust calculation of L_{DEN} (or $L_{Aeq,\ 16hr}$ and L_{night} for UK) at the building façade on the included road sections (Section 2.4 above) to provide accurate absolute L_{DEN} for using the above curves. The following table summarises the background conditions of the three valuation schemes to enable a comparison.

	UK	SWEDEN	DENMARK
Noise level indicator	$L_{Aeq,\ 16hr}$	$L_{Aeq,24h}$	L_{Aeq}
Allocation	Household	Person (2.8/household)	Person
Step	dB change	dB change	dB change
Type of effects (only one row)	Amenity (high sleep disturbance, high annoyance); Health (Direct AMI, Strokes, Dementia)	Disturbance, health	Contains only explanation of annoyance
Involved research parties	Defra (Interdepartmental Group on Costs and Benefits Noise Subject Group).	Swedish National Road and Transport Research Institute (VTI)	Danish Road Directorate (contractor: COWI)
Investigative method	Dose-response functions for proportion of highly sleep disturbed and highly annoyed. Disability weighting.	Based on a Swedish hedonic price study - and international literature. **Health**: use of Impact Pathway Approach (HEATCO 2006).	First, use of EU value (EUR 25/household/year), converted into EUR 32/person for Denmark, weighted by a Danish “noise

	Odds ratio (relationship between noise and probability) for strokes and dementia. AMI: use of dose-response relationship (Babisch 2006). Use of DALYs. Periodic review.	Acknowledges great uncertainty in calculation of dose-response. Values for <70dB are extrapolated. **Disturbance**: marginal effect on the property price based on one municipality and adjusted nationally for income differences. Cost split 50%-50% between outdoors and indoors	exposure factor" according to dwelling situation. Then, use of official Danish exponential relationship, with a weight for each dB reduction in the 55 dB-75 dB range. Discount rate applied: 3.5%. Based on dose response from 1989 originally from 1970s data.

Table 11: Comparison of UK, Sweden and Denmark noise impact evaluation schemes

The UK valuation scheme is divided into bands of 3 dB intervals. It was originally intended for the evaluation of large projects in specific geographical areas that could be expected to have sounds level impacts of that magnitude. The accompanying documentation does however acknowledge the possibility of 1 dB increments, in which case the cost/benefit values can be interpolated within the 3 dB bands.

The Swedish and Danish schemes have 1 dB increments. For none of the three schemes is there an acknowledgement of their validity for evaluating the impact of fractional dB changes over wide areas and continent-wide populations, as is relevant to the object of the CBA. (Our assessment results in sound pressure level changes down to 0.015 dB due to the reduction in L-category noise limits.) None of the valuation schemes were specifically designed for the purpose of calculating impacts of such low dB increments. However, there is also no text that excludes their use for this purpose. It would therefore appear to be legitimate to use the three valuation schemes to generate estimates for benefits of the fractional dB decreases in sound pressure level experienced by the EU population due to reductions in L-category vehicle noise limits. Results should be accompanied by clear statements acknowledging the above caveats. It should also be acknowledged that a possible interpretation of the fraction dB changes is that these result in negligible impact.

The main characteristics of the three schemes can be characterised as follows:

- UK: bottom-up assessment with valuation based on a cost figure for disability adjusted life years and subject to period review as the evidence base has evolved.
- SE: bottom-up assessment using data from one municipality with acknowledged high uncertainties, extrapolation below 70 dB and split indoors/outdoors evaluation.
- DK: starting with EU valuation multiplied by a factor of 2 applying a Danish exponential relationship, based on a dose-response relationship from 1970s data.

The UK methodology appears to be the most well-documented and aligned to the conditions of the CBA analysis. The Swedish methodology is subject to three significant caveats (above). The Danish methodology is well documented but appears to rely on data collected in the 1970s. Due to its apparent robustness and its values lying between the SE and DK ones, it would appear to be legitimate to use the UK scheme as the primary estimate. The SE and DK schemes can be presented as delta versions, clearly stating the relevant parameters of each when presenting results.

An additional consideration is the applicability of valuations derived from these three countries to the entire EU, especially considering the North/South split applied in the CBA. For example, applying a UK or SE evaluation to countries such as Bulgaria or Greece, with significantly lower GDP per capita, would exclude a standard principle of performing international economic assessment, namely adjusting for GDP per capita when comparing countries with different income levels.

For example, Marseille (2015) and Robinson (2017) refer to cost-effectiveness for disability affected life years expressed in comparison to GDP per capita for different countries. Marseille also addresses the shortcomings of this approach. For health effects, therefore, the literature indicates that adjusting for GDP per capita may be a legitimate methodology, with significant caveats. For annoyance, based on willingness to pay, it can also be expected that GDP per capita is a relevant factor to compare economic costs/benefits between different countries.

In order to acknowledge the difference between countries with differing income levels, we will present the benefits both with and without adjusting for GDP for Northern and Southern Europe, clearly stating the limitations of each approach.

Potential impact on B/C: applying the UK dose-response relationship results in a significant increase in the benefits of a noise limit reduction, with the alternative Swedish relationship significantly higher again and the Danish somewhat lower. If adjusting for GDP, benefits for Southern Europe are reduced significantly compared to our initial assessment.

2.8 Impact of time fraction

The CBA counts the *"most relevant situations where annoyances from L-category vehicles may occur"* (p165), referring to road types and vehicle categories. It also introduces the concept of time fraction (p180), which determines the proportion of the year during which the respective vehicle categories are active. The two concepts appear to overlap and are therefore somewhat ambiguous. No sources or references are given to support the values.

On page 165 (most relevant situation):

> *"**Northern EU**:*
>
> *Accelerating traffic on*
>
> - *Touring routes, other traffic and motorcycles (on popular touring dates [).*
> - *Residential roads, other traffic and mopeds (all year).*
> - *Main roads, other traffic including heavy vehicles, mopeds and motorcycles (all year).*
>
> *Other traffic includes cars, vans, lorries, buses and trucks.*
>
> ***Southern EU**:*
>
> *All accelerating traffic including motorcycles and mopeds, all of the year, but selecting 50% of the roads with lower proportions of heavy vehicles."*

No reference is provided to identify which roads have lower proportions of heavy vehicles. As indicated in Section 2.6 above, no reference or definition of "touring routes" is provided.

On page 183 (time fraction):

"The valuation rates are adjusted for the time fraction that L-category vehicles are predominant, set at 20% of the year for the Northern EU for motorcycles on touring routes, and for mopeds in urban areas. For the Southern EU, the time fraction is chosen at 50% for both mopeds and motorcycles."

These are summarised in the following table:

Region	**Route**	**p165**	**p183**	**Comment**
Northern EU	Touring routes	*On popular touring dates*	20% time fraction for motorcycles	Assume 20% = proportion of popular touring dates
	Residential	All year	20% time fraction for mopeds	Assume 20% for mopeds and 100% for motorcycles
	Main roads	All year		
Southern EU	Touring routes	*50% of* roads with lower proportions of heavy vehicles	50% time fraction	Unclear if 50% figures refer to the same proportion in both references. Unclear if all roads are equally treated
	Residential			
	Main roads			

Table 12: Comparison of data presented on relevant conditions and time fraction

The statements appear not to be fully consistent. Additional information from the authors indicated that a 20% time fraction has been used for all three included roads types, and for both motorcycles and mopeds for Northern Europe. A reconciliation of the CBA results confirms this calculation. For Southern Europe, the same check generates an inconclusive result. The 50% time fraction may have been applied across all three road types.

The basic concept of applying time fractions is flawed, as the "predominance" of certain vehicle categories is not absolute. The relative contribution of each vehicle category will fluctuate throughout the year. It is likely to be above average during the high activity seasons recognised by the time fractions. Use of time fractions therefore excludes the remaining percentage of the year during which L-category vehicle activity may be below the average. There is however still a relevant contribution, which can best be represented by applying the average flow across the whole year.

This leads to the conclusion that instead of 20% / 50% of the time being relevant in Northern and Southern Europe respectively, 100% is relevant. This, in isolation, can be expected to increase the benefits of the reduction in L-category noise levels by a factor of 5 in Northern Europe and up to 2 in Southern Europe.

Potential impact on B/C: increase by factor of 5 (North) and up to 2 (South).

2.9 Calculation of total benefits

The calculations leading to total benefits (and costs) values (table 26 p. 185) are not presented in the CBA.

For better visibility, the following is an extract of table 26 with the values for 2 dB noise limit reduction for the BAU/HGR growth scenarios and the 0%/25% illegal exhaust scenarios, showing only L_{DEN} reductions and the corresponding accumulated benefits:

	Northern EU		Southern EU		Accumulated benefits Meuro		
Scenario	Δ Lden dB	Δ Lden dB	Δ Lden dB	Δ Lden dB	NE	SE	Total
Year/Lcatlim/%Illegal/Growth	All	Lcat	All	Lcat	Only Lcat	Only Lcat	Only Lcat
2040, -2 dB, 25% IL, BAU	1,77	0,19	1,40	0,39	66	601	668
2040, -2 dB, 0% IL, BAU	2,18	0,27	2,69	0,73	97	1107	1204
2040, -2 dB, 25% IL, HGR	0,92	0,19	0,83	0,44	66	676	742
2040, -2 dB, 0% IL, HGR	1,33	0,27	1,84	0,72	97	1101	1198

Table 13: Extract from Table 26, p183, summary of benefits and costs

According to the text accompanying Table 24 (identical to the left hand side of table 26), the ΔL_{DEN} values derive only from the changes in the vehicle noise limits. However, it is not clear whether the benefits of going to 0% illegal exhausts, due to the enforcement measures, are accounted for the accumulated benefits.

Potential impact on B/C: calculation dependent on previous data and assumptions – overall impact to be presented in Chapter 6 below. Likely different results for mopeds and motorcycles.

2.9.1 Electrically powered L-category vehicles

As an additional consideration, the expected penetration of electrically powered L-category vehicles (EVs) would influence the calculations measurably. For L-category vehicles, engine and exhaust noise dominate, with tyre noise making a very small contribution. An electrically powered vehicle eliminates the engine and exhaust noise, with the powertrain noise of the vehicle being negligible.

If a projected penetration rate of L-category EVs is taken into account, the emission of the whole traffic flow will be reduced. This will be assessed as a scenario in Chapter 3 below.

Potential impact on B/C: L-category EVs contribute only negligibly to traffic noise, thereby reducing the benefits of the noise limit reductions depending on their penetration rate in the fleet.

2.9.2 Timeframe of the analysis

The CBA calculates total costs and benefits over the 20 year period from 2020 to 2040. As the costs and benefits will continue to be incurred/realised indefinitely (N.B. this point is not acknowledged by the CBA in the case of costs), any cut-off date is by its nature arbitrary. However, a 20 year period appears to be a reasonable timeframe for long-term analysis and we retain it for our calculations.

However, since our review has been carried out in 2021, the original timeframe is no longer relevant. Shifting to 2025 to 2045 would maintain similar relative timing, with our publication 4 years later than the CBA. It is unlikely that new legislation would be in place by 2025 due to requirements of political negotiations and industry lead-time. However, 2025 to 2045 can be selected to serve as an illustration. Constraints on lead time will be addressed where relevant (for example Section 5.1.4 on new cost data).

Potential impact on B/C: no direct impact on the B/C calculation.

3 BENEFITS – REASSESSMENT OF DATA

Having reviewed and evaluated each of the blocks in the CBA's assessment, in this chapter we apply the findings and our further analysis to generate alternative results. We summarise below the impacts of the alternative assessment in each analysis block as reviewed in Chapter 2. We then apply all the findings in our own calculations. The calculations are generated by our own spreadsheets using the functions of CNOSSOS-EU. The spreadsheets are available for stakeholders to review.

Block 1		
Treatment in CBA	**Our assessment**	**Further analysis**
Only accelerating traffic contributes	All traffic contributes	Fed into calculations below
Sound power levels increase under acceleration: • Motorcycles 5 dB • Mopeds 3 dB	Sound power levels increase under acceleration: • Motorcycles 3 dB • Mopeds 1 dB	Fed into calculations below
No increase in sound power levels of other accelerating vehicles	Increase in sound power levels of other accelerating vehicles	Fed into calculations below
Limit reduction leads to equal noise reduction on the road	On-road noise reduction approximately ½ limit reduction	Fed into calculations below
Block 2		
Treatment in CBA	**Our assessment**	**Further analysis**
Southern Europe evening and night time flow rates equal to day time	Evening and night time should be lower, set same ratio of total day/evening/night in South to same as North, maintain ratio between vehicle categories as in South	Fed into calculations below
Block 3		
Treatment in CBA	**Our assessment**	**Further analysis**
Calculation of L_{DEN} of the whole traffic flow based on standard day-evening-night weighting	No change	Results of calculation shown below for each scenario (based on above input)
Blocks 4 & 5		
Treatment in CBA	**Our assessment**	**Further analysis**
Calculation of L_{DEN} at the façade assuming dissipation over 15m for urban and 50m for rural roads	Same assumptions except *soft surface* dissipation for rural roads	Results of calculation shown below for each scenario (based on above input)
Block 6		
Treatment in CBA	**Our assessment**	**Further analysis**
Only residential, main and rural roads included	All roads included (plus arterial, urban and rural motorways)	Fed in calculations below

20% road length fraction applied	20% fraction is a best guess but cannot be validated	See discussion
Block 7		
Treatment in CBA	**Our assessment**	**Further analysis**
Constant amenity and cost curves	Dose-response curves from country analyses (UK, SE, DK)	Fed into calculations below
Block 8		
Treatment in CBA	**Our assessment**	**Further analysis**
Time fraction of year for certain roads	No time fraction	Fed into calculations below

Table 14: Comparison of CBA to our analysis for each block

The numerical impact of the above analysis is addressed below

3.1 Scenarios

We assessed all combinations of the following scenarios:

Parameter	**Scenarios**		
Decrease in noise level	1 dB	2 dB	4 dB
Dose-response valuation source	United Kingdom (UK)	Sweden (SE)	Denmark (DK)
Region	Southern Europe	Northern Europe	
Sound power level increase under acceleration for L-cat vehicles	MC +3 dB Mop +1 dB		
Sound power level increase under acceleration for non L-cat vehicles	Yes		
Road categories	All 6		
Illegal exhausts	25%		

Table 15: Overview of scenario parameters

The 25% illegal exhausts scenario is selected in order to differentiate the impacts of enforcement and limit reduction.

The following chart shows the total benefits according to our calculation from 2025 to 2045 for Northern and Southern Europe for the three dB reduction scenarios, with a bar showing the range of values due to the three dose-response relationships applied.

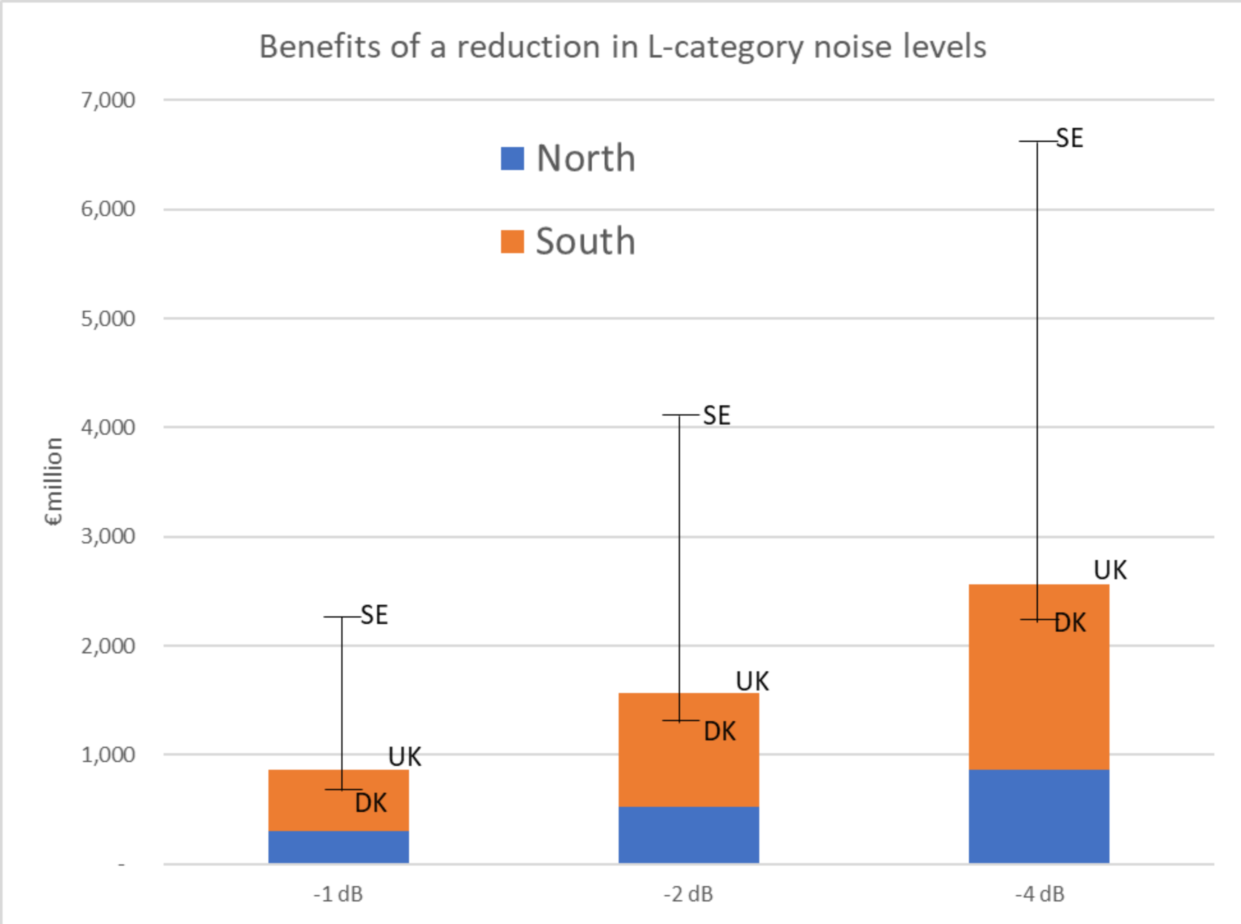


Figure 6: Total benefits for three noise reduction scenarios

The progression of values with increasing noise emission reduction is as expected.

The following chart compares the total benefits for Northern and Southern Europe between our calculations and the CBA. In this case the CBA -2 dB scenario is compared to our -1dB scenario, due to the effects highlighted in Section 2.3.

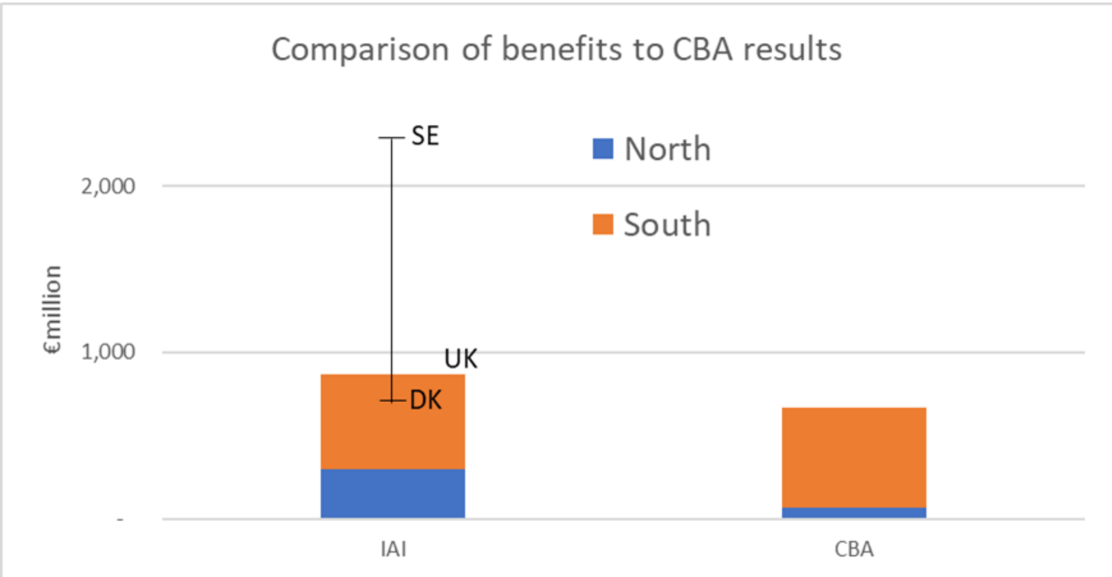


Figure 7: Comparison of benefits according to our calculation compared to CBA for the 2 dB limit reduction

Our assessment results in total benefits of €867m using the UK dose-response relationship, 30% higher than the CBA estimate. The sources of the difference between our results and the CBA are addressed in the Section 3.2 below.

3.2 Reconciliation to CBA calculations

To review the CBA calculations and compare them to our own, comparison of the 25% illegal exhaust scenario is necessary, i.e. excluding the effects of enforcement. The CBA presents detailed data only for the 0% illegal exhaust scenario. Therefore, some reverse engineering of the CBA results is necessary to generate the detailed figures for 25% illegal exhausts. We refer to Table V.1 from Annex V, showing the annual benefits and costs for the 0% illegal exhaust scenario.

	Northern Europe		Benefits including discounting MEuro				Southern Europe		Benefits including discounting MEuro				EU28 Stakeholder costs Costs including discounting (Meuro)					
Year	dB reduction	Exposed people	Amenity	Health	Total Benefits	Acc. Benefits	dB reduction	Exposed people	Amenity	Health	Total Benefits	Acc. Benefits	R&D	Production	Enforcement	Total Costs	Acc. Costs	NPV
2020	0,000	41295782	0,0	0,0	0,0	0,0	0,000	28178335	0,0	0,0	0,0	0,0	4,2	44,0	51,0	99,2	99,2	-99
2021	0,021	41708740	0,4	0,2	0,7	0,7	0,056	28460118	4,8	2,8	7,7	7,7	4,0	42,3	49,0	95,4	194,5	-186
2022	0,042	42125827	0,8	0,5	1,3	2,0	0,112	28744719	9,5	5,6	15,1	22,7	3,7	39,1	45,3	88,2	282,7	-258
2023	0,062	42547086	1,2	0,7	1,9	3,9	0,168	29032166	14,0	8,2	22,2	44,9	3,3	34,8	40,3	78,4	361,0	-312
2024	0,083	42972557	1,6	0,9	2,5	6,4	0,225	29322488	18,2	10,7	29,0	73,9	2,8	29,7	34,5	67,0	428,0	-348
2025	0,104	43402282	1,9	1,1	3,1	9,5	0,281	29615713	22,4	13,2	35,5	109,5	2,3	24,4	28,3	55,1	483,1	-364
2026	0,125	43836305	2,3	1,3	3,6	13,1	0,337	29911870	26,3	15,5	41,8	151,3	1,8	19,3	22,4	43,5	526,6	-362
2027	0,145	44274668	2,6	1,5	4,2	17,3	0,393	30210989	30,1	17,7	47,9	199,2	1,4	14,7	17,0	33,1	559,7	-343
2028	0,166	44717415	2,9	1,7	4,7	21,9	0,449	30513099	33,8	19,9	53,7	252,9	1,0	10,7	12,4	24,2	583,9	-309
2029	0,187	45164589	3,2	1,9	5,1	27,1	0,505	30818230	37,3	21,9	59,2	312,1	0,7	7,5	8,7	17,0	600,8	-262
2030	0,208	45616235	3,5	2,1	5,6	32,7	0,562	31126412	40,6	23,9	64,5	376,6	0,5	5,1	5,9	11,5	612,3	-203
2031	0,228	46072397	3,8	2,2	6,0	38,7	0,618	31437676	43,8	25,8	69,6	446,3	0,3	3,3	3,8	7,5	619,7	-135
2032	0,249	46533121	4,1	2,4	6,5	45,2	0,674	31752053	46,9	27,6	74,5	520,8	0,2	2,1	2,4	4,7	624,4	-58
2033	0,270	46998452	4,3	2,5	6,9	52,0	0,730	32069573	49,8	29,3	79,2	600,0	0,1	1,2	1,4	2,8	627,2	25
2034	0,270	47468437	4,2	2,5	6,7	58,8	0,730	32390269	48,9	28,8	77,7	677,7	0,1	0,7	0,8	1,6	628,8	108
2035	0,270	47943121	4,2	2,4	6,6	65,4	0,730	32714172	48,0	28,2	76,2	753,8	0,0	0,4	0,5	0,9	629,7	190
2036	0,270	48422552	4,1	2,4	6,5	71,9	0,730	33041313	47,0	27,7	74,7	828,6	0,0	0,2	0,2	0,5	630,2	270
2037	0,270	48906778	4,0	2,4	6,4	78,2	0,730	33371727	46,1	27,2	73,3	901,9	0,0	0,1	0,1	0,2	630,4	350
2038	0,270	49395846	3,9	2,3	6,2	84,5	0,730	33705444	45,3	26,6	71,9	973,8	0,0	0,1	0,1	0,1	630,5	428
2039	0,270	49889804	3,8	2,3	6,1	90,6	0,730	34042498	44,4	26,1	70,5	1044,3	0,0	0,0	0,0	0,1	630,6	504
2040	0,270	50388702	3,8	2,2	6,0	96,6	0,730	34382923	43,5	25,6	69,2	1113,5	0,0	0,0	0,0	0,0	630,6	579

Table 16: Table V.1, Annex V, p226, annual benefits and costs (2 dB limit reduction)

Highlighted is the discounted 2040 benefit for Northern Europe. The same calculation can be performed for the 25% illegal exhaust scenario:

Illegal exhausts	Year	dB reduction	Exposed people	Amenity (€m)	Health (€m)	Total benefits (€m)	Acc. benefits (€m)
0% (above table)	2040	0.270	50,388,702	3.8	2.2	6.0	96.6
25% (calculated)	2040	0.190	50,388,702	2.65	1.55	4.2	67.9

Table 17: 2040 benefits calculation for 25% illegal exhausts

The accumulated benefits for 25% illegal exhausts are calculated assuming the same progression of benefits over the 20 year period as for 0%. The total of €67.9 is very close to the €66m reported in the CBA (Table 26, 185), confirming the consistency of the above approach. A similar calculation for Southern Europe results in accumulated benefits of €595m, again close to the CBA reported figure of €601 (Table 26, 185).

These calculations allow the following reconciliations to be performed.

3.2.1 *Northern Europe*

The following is the benefits calculation methodology as performed in the CBA, on the example of Northern Europe, for the year 2040 only (highlighted in above tables):

Benefit	=	L_{DEN} change	x	exposed households	x	valuation	x	time fraction	x	road length fraction	x	Discount factor (4%)		
Amenity benefit	=	0.19	x	50.388m/2.4	x	€36.5	x	20%	x	20%	x	0.456	=	€2.65m
Health benefit	=	0.19	x	50.388m/2.4	x	€21.5	x	20%	x	20%	x	0.456	=	€1.55m
Total benefit	**=**	**0.19**	**x**	**50.388m/2.4**	**x**	**€59.0**	**x**	**20%**	**x**	**20%**	**x**	**0.456**	**=**	**€4.2m**

To compare, our calculation for the same scenario using the following parameters is derived from the effects listed in Table 14 above. For illustration it applies the UK valuation scheme:

Daytime benefit	=	0.013*	x	280m/2.4	x	€90.2*	x	100%	x	20%	x	0.456	=	€12.7m
Night-time benefit	=	0.016*	x	280m/2.4	x	€39.4*	x	100%	x	20%	x	0.456	=	€6.6m
Total benefit	**=**	**0.015**	**x**	**280m/2.4**	**x**	**€129.6**	**x**	**100%**	**x**	**20%**	**x**	**0.456**	**=**	**€19.3m**

*$L_{eq,16hr}$ and L_{night} weighted average values across all road types

The above is an illustration using Northern Europe to show how the calculation was generated for a single year. For the whole 20 year timeframe, equivalent calculations were done for each year in the period and summed to reach the aggregate total. It should be noted that for Southern Europe, an equivalent comparison leads to a similar final value as in the CBA.

The difference in the sound levels at the façade is significant, with the reconciliation between our values and the CBA summarized in the following table for both Northern and Southern Europe. ΔL_{DEN} is used for consistency.

ΔL_{DEN}	Northern Europe (dB)		Southern Europe (dB)		Comment
CBA values	0.19		0.39		
Our calculation, CBA conditions	0.19		0.37		Small discrepancy
Noise increase for accelerating non-L-category vehicles	0.17		0.35		Small impact
Average over accelerating and non-accelerating traffic	0.12		0.29		Reduces average (over a larger population)
+3 dB / +1 dB noise increase for	0.11		0.28		Reduces impact in accelerating traffic

motorcycles/mopeds (instead of +5/+3)					
2 dB limit results in 1 dB reduction per vehicle	0.062		0.15		Reduced impact by approximately 50%
Altered flow rates ➔ final value	0.015		0.067		Significant reduction due to lower flow rates

Table 18: Reconciliation of ΔL_{DEN} between CBA and our calculations

The above reconciliation is valid for the assumptions explained in previous sections, summarised in the above table. It represents one scenario, with a high level of uncertainty, partly due to unconfirmed assumptions about the CBA calculations.

The following reconciliation lists all the parameters that generate the difference between the results, using Northern Europe as an illustration. An exact comparison is not possible due to the variable nature of the valuations for different road types but an approximate calculation is shown. In this case $\Delta L_{eq,16hr}$ is shown as it was used for the benefits calculation using the UK Defra dose-response relationship.

	CBA total	IAI total	Ratio	Comment
Sound level reduction $\Delta L_{eq,16hr}$ (dB)	0.19	0.015 (weighted average)	0.074	See Table 18
Exposed households	50.388m/2.4	280m/2.4	5.2	Includes non-accelerating sections & all 6 road types
Valuation (€)	59.0	129.6	2.2	Higher variable evaluation
Time fraction	20%	100%	5.0	Time fraction invalid
Road length fraction	20%	20%	1.0	First order orientation
Discount factor	0.456	0.456	1.0	Standard factor
Total	**4.2m**	**19.3m**	**4.6**	

Table 19: Reconciliation of CBA figures to our calculations – Northern Europe

Despite the lower sound level reduction compared to the CBA, there is a significant increase in the benefits of the noise reduction (for Northern Europe) due to the following three factors:

1. Including non-accelerating traffic into the evaluation, as stated in Section 2.6, increases the benefits by a factor of about 5.
2. The valuation of benefits due to using the UK dose-response curve is higher by a factor of about 3.5 compared to the CBA.
3. Eliminating the time fraction increases the benefits by a factor of 5.

Partially countering these is the lower sound level reduction by a factor of about 12, reconciled above.

3.2.2 *Southern Europe*

In the case of Southern Europe, the benefits in year 2040 according to our calculation, using the UK dose-response relationship, are similar to those presented in the CBA (in contrast to Northern Europe, for which our assessment was higher than the CBA). We do not have access to the same detail as above for the Southern Europe calculations, but the difference can be partly explained by the following:

- The significantly lower flow rates, especially at night, as detailed in Section 2.2.
- Eliminating the 50% time fraction reduces the difference by a factor 2, compared to a factor of 5 (20%) for the North.
- An unexplained additional factor of more than 2 in the CBA calculation.

The benefits in the South are still higher than in the North, as would be expected, but the differential, also taking into account the lower population, is significantly lower than in the CBA.

3.3 Additional scenarios and delta analysis

3.3.1 Adjusting amenity and health valuations for GDP

As indicated in Section 2.7, adjusting valuations of amenity and health benefits for the GDP per capita of the country or region in question can be a legitimate consideration for adapting dose-response relationships developed by one country. Since the dose-response relationships derive from three countries (UK, SE, DK) from Northern Europe, the largest impact of the adjustment will be on Southern Europe as its average GDP per capita is significantly lower.

To illustrate, the impact of the adjustment on the case of a 2 dB limit reduction (1 dB actual reduction) using the UK dose-response relationship is presented in the following table:

Total benefits of 2 dB limit reduction	**Without GDP adjustment**	**With GDP adjustment**
Northern Europe	€294.3m	€294.2m
Southern Europe	€ 573.5m	€ 338.2m
Total	**€ 867.8m**	**€ 632.4m** (-27%)

Table 20: Impact of GDP adjustment on total benefits for –2 dB limit change and UK dose-response relationship

A similar reduction (27%) results for the higher limit reduction scenarios.

The equivalent Swedish and Danish valuations are lower by 43% and 50% respectively when adjusting for GDP, due to their higher GDP per capita.

3.3.2 Scenario analysis with EV penetration

As indicated in Section 2.9 above, the impact of EV penetration in the L-category market on the calculation of the benefits can be assessed by making two assumptions:

- L-category EVs have negligible contribution to traffic noise emissions.
- A scenario for the penetration rate in the new vehicle market, assuming the total market develops as projected. We assume 100% EV penetration of the market in 2045 with the penetration rate increasing until then by a constant percentage each year.

These assumptions lead to an approximately 48% reduction in the benefits of a limit reduction over the 2025-2045 period, compared to the case with no EV penetration. Penetration of the on-road fleet lags sales penetration, and the 2020-2040 assessment includes years during which penetration is still low.

If the 100% sales penetration were realised in 2035, as is currently being considered for some larger vehicle categories, the total benefits would be reduced by 70%. A slower EV rollout with 50% penetration in 2045 would result in a 25% reduction in total benefits.

The impact on costs is addressed in Chapter 5.

3.4 Analysis

The reasons behind these large differences in the results between the CBA and our calculations can be attributed to a few main factors, discussed below. Potential additional reasons for the discrepancy should also be considered.

3.4.1 *Including non-accelerating traffic (1)*

Our calculations have shown that the impact of lower L-category noise levels in non-accelerating traffic is reduced by approximately 25% on average compared to accelerating traffic. Taking into account non-accelerating road sections in addition to accelerating sections, leads to a benefit approximately 5 times higher than only considering accelerating traffic.

3.4.2 *Valuation of benefits (2)*

The primary calculation above was performed using the UK's Transport Analysis Guidance (TAG) dose-response function, resulting in a valuation per dB change (or fraction thereof) in sound pressure level significantly higher than the European Commission Working Group 2003 value. This represents state of the art based on recent analysis and the relative increase in impact can be considered robust.

The results obtained using the Swedish and Danish dose-response relationships, being significantly higher and marginally lower respectively, are illustrations of possible alternative valuations but due to certain caveats discussed above are not used as the primary evaluation method.

3.4.3 *Time fraction (3)*

The time fraction was determined in the CBA by assuming that only parts of the year or the week are relevant for certain traffic. As stated in Section 2.8 above, in reality the modulation of the traffic and noise level throughout the year or week is likely to vary about the mean. Assuming that the traffic flow rates are calculated as averages from vehicle activity rates (this is not confirmed in the CBA), above-average times (e.g. summer on "touring routes") will compensate for below average times. This compensation is unlikely to be accurate but can serve as a valid first order approximation. Therefore, eliminating the time fraction appears to be an appropriate action.

3.4.4 *Road length fraction (unchanged)*

As stated in Section 2.6 above, applying a road length fraction appears to be relevant in principle, but its valuation is subject to high uncertainty. We have maintained the 20% figure as an orientation, but it could be significantly lower or higher. Further in-depth investigation would be necessary and this factor is the primary uncertainty in the overall evaluation.

3.4.5 *Overall evaluation*

Our estimate for the benefits of the 2 dB limit reduction (1 dB actual reduction) scenario is higher than the CBA estimate of €667m. There are many factors involved each with their own assumptions and uncertainties.

This level of benefit represents between €2 and €5 per person or between €5 and €12 per household over a 20 year period – i.e. about 10-25¢ per person per year.

This is a low figure but in aggregate very high due to the large population involved.

4 NOISE SOURCE RANKING TESTS

ACEM commissioned Technische Universität Graz (TU Graz) to perform noise source ranking (NSR) tests on a selection of L-category vehicles, to assess the sources of noise and their respective magnitude. This section assesses those results, providing valuable information relevant to costs, and is therefore placed before the chapter on costs to provide input to the analysis of that chapter.

4.1 Review of NSR results in the CBA

In the 2017 CBA report the NSR method is described as follows (see chapter 3.3.6):

To assess the potential for noise reduction of the different sub-systems of the L-category vehicles, a Noise Source Ranking (NSR) by suppression has been carried out on the most representative vehicles:

- *Scooter 125cc CVT with 25 < PMR ≤ 50.*
- *Motorcycle 800cc with PMR > 50.*
- *ATV 250cc CVT 12kW vehicle.*

The principle is based on the vehicle sound level being considered as the joined contribution of the following four different sub-systems:

- *Exhaust*
- *Intake*
- *Powertrain/engine*
- *Driveline/transmission*

The above sub-systems are covered with heavy and effective acoustic material or muffled with additional "over-sized" infinite mufflers (for intake and exhaust). These mufflers are not production representative but, purposely, reduce the exhaust orifice sound emission (see note below).

Each configuration is measured separately on pass-by measurement set up on both accelerated and cruise (constant speed) conditions. The comparison of all the various runs shows the influence of the corresponding non-covered subsystems.

Note: Such a suppression is voluntarily extreme and is not designed to be representative of the quantitative potential for realistic noise reduction solutions. Nevertheless, the results obtained in that way can be considered as indicative of the potential for noise reduction.

The closeness of the different sources also helps understanding the overlap of the various sub-systems contribution, and how many sub-systems would need design actions in a quantified sound level limit reduction proposal (with an indication of the influence on the cost).

The successive tested configurations are:

Scooter 125cc CVT with 25 < PMR ≤ 50:

1- Original configuration
2- CVT suppressed
3- CVT and engine suppressed

4- CVT, engine and intake supressed
5- CVT, engine, intake and exhaust suppressed

Motorcycle 800cc with PMR > 50 & ATV 250cc CVT 12kW:

1- Original configuration
2- Drive suppressed
3- Drive and engine suppressed
4- Drive, engine and intake supressed
5- Drive, engine, intake and exhaust suppressed

The interpretation (reading) principle of the tests

- *dB power subtractions of the various configurations show the comparison of individual contributions to the global noise source on pass-by conditions (test in motion, both accelerated and constant speed) from the four main subsystems.*
- *Comparison of the contributions to the total noise show the dominant and secondary sources in the area of maximum pass-by sound pressure dB levels.*

Note: According to UN R41-04 methodology for the L3e category, calculation of L_{urban} is as follows:

L_{urban} *[dB(a)] =* $L_{wot} – kp * (L_{wot} - L_{constant})$

with $kp = 1 – (a_{urban} / a_{wot,ref})$ *(or* $kp = 1 – (a_{urban} / a_{wot}$ *with single speed test) [/]*

L_{wot} *= maximum sound level measured on either side during test in motion accelerated [dB(A)]*

$L_{constant}$ *= maximum sound level measured on either side during constant speed test [dB(a)]*

This means that both the sub-systems contributions (accelerated and constant speed) and side-to-side comparative results must be taken into account to assess sound level reduction possibilities (as limits are expressed on L_{urban}*).*

The method described above has the advantage that the measurements can be performed with reasonable effort and costs in a reasonable time period and works well, if the differences in the measurement results are higher than the uncertainty for measurement repetitions (about +/- 0.5 dB(A)). However, this condition was not always fulfilled. A disadvantage is the fact that the source contributions can only be suppressed but not fully eliminated. That means that the sound emission in the fully covered version can still be influenced by the engine and the drivetrain. In addition to that, the suppression measures increase the mass of the vehicle and thus influence the acceleration performance of the vehicle.

In principle the same approach was used by TU Graz, but the rank order of the suppression of the sources was different:

1. Original configuration,

2. Exhaust suppressed,
3. Exhaust suppressed and engine covered,
4. Exhaust and intake suppressed, vehicle fully covered.

In order to reduce the influence of increasing mass with increasing sound suppression measures the L_{urban} values for the TU Graz measurements for the different configurations were always calculated on the basis of the vehicle speeds and accelerations achieved for the original vehicle.

The NSR results in the 2017 CBA report are presented as follows:

Scooter 125 cm³ CVT with 25 < PMR ≤ 50:

On left side:

- *Accelerated test results show that engine and intake are the highest (equivalent) contributors, and exhaust is a secondary contributor (ca.2 dB(A) below).*
- *Constant speed test exhaust contribution is higher than other subsystems by ca. 5 dB(A).*

On right side:

- *Both accelerated and constant test results are dominated by driveline (CVT) subsystem. Driveline contribution is higher than other subsystems by more than 5 dB(A) on accelerated test, and ca. 2 dB(A) on constant speed test.*

The figures in the following table are taken from figure 18 in the CBA report:

Scooter 125 CVT, pmr <= 50						
	left side, wot			**right side, wot**		
	78.0			76.2		
		62494500.4			41580182.3	
engine	73	19952623.1	31.9%	75	31622776.6	76.1%
intake	73	19952623.1	31.9%	66	3981071.71	9.6%
exhaust	71	12589254.1	20.1%	66	3981071.71	9.6%
driveline	70	10000000	16.0%	63	1995262.31	4.8%
			100.0%			100.0%
	left side, crs			**right side, crs**		
	71.2			69.0		
		13182277.7			8010345.13	
engine	65	3162277.66	24.0%	60	1000000	12.5%
intake	40	10000	0.1%	45	31622.7766	0.4%
exhaust	70	10000000	75.9%	64	2511886.43	31.4%
driveline	40	10000	0.1%	66.5	4466835.92	55.8%
			100.0%			100.0%

Table 21: NSR results from figure 18 in the 2017 EU-Comm report

The wot results are dominated by engine and intake, the crs results by exhaust and driveline. wot means maximum power acceleration test, crs means constant speed test. Normally one would expect that the wot result is dominated by the exhaust and the crs result by the engine and the driveline. The differences between left and right side for the crs results with respect to the source contributions are surprisingly high, but there are no further explanations in the report.

Motorcycle 800 cm³ with PMR > 50:

On accelerated test:

- *Exhaust is the dominant subsystem, both driveline and engine are secondary contributors at wot*
- *On left side, both driveline and engine are secondary contributors*

On constant speed test:

- *Engine and driveline are dominant subsystems, in similar measure.*

Reduction of exhaust contribution is a priority to achieve noise reduction of L_{urban}. But sound reduction of engine and driveline will also be necessary to reduce the sound level $L_{constant}$ due to the calculation of L_{urban} methodology in UN R41-04.

The figures in the following table are taken from figure 19 in the CBA report:

Motorcycle 800 cm³, pmr > 50, 3rd gear wot						
	left side, wot			**right side, wot**		
	75.5			75.8		
		35757699.2			37995595.6	
engine	69	7943282.35	22.2%	68	6309573.44	16.6%
intake	45	31622.7766	0.1%	45	31622.7766	0.1%
exhaust	72.5	17782794.1	49.7%	75	31622776.6	83.2%
driveline	70	10000000	28.0%	45	31622.7766	0.1%
			100.0%			100.0%
	left side, crs			**right side, crs**		
		66.5			66.2	
		4456069.86			4201409.16	
engine	62	1584893.19	35.6%	60	1000000	23.8%
intake	55	316227.766	7.1%	45	31622.7766	0.8%
exhaust	55	316227.766	7.1%	62	1584893.19	37.7%
driveline	63.5	2238721.14	50.2%	62	1584893.19	37.7%
			100.0%			100.0%

Table 22: NSR results from figure 19 in the 2017 EU-Comm report

The 2017 CBA report reaches the following conclusions:

Reduction of exhaust contribution is a priority to achieve noise reduction of L_{urban}. But sound reduction of engine and driveline will also be necessary to reduce the sound level $L_{constant}$ due to the calculation of L_{urban} methodology in UN R41-04.

4.2 Analysis of NSR results TU Graz

TU Graz tested 8 vehicles according to the NSR method.

no	manufacturer	model	engine capacity in cm³	no cylinders	rated power in kW	rated speed in min-1	max torque in Nm	at engine speed in min-1	Transmission	vehicle mass in kg	power to mass ratio in kW/1000 kg	L_{urban} in dB(A)	L_{wot_ref} in dB(A)	L_{crs_ref} in dB(A)
1	Honda	Forza 125	124.9	1	10.7	8750	12.3	6500	CVT	162	45.1	74.5	77.8	68.7
2	Piaggio	Vespa 300	278	1	15.5	8250	26	5250	CVT	183	60.1	74.8	80.3	70.8
3	KTM	390 Duke	373	1	32	9500	35		6speed	162	135.0	74.7	77.1	71.5
4	Yamaha	T-Max	562	2	35	7500	55.7	5250	CVT	218	119.5	74.9	81.0	71.4
5	Kawasaki	Vulcan S	649	2	44.7	7500	62.4	6600	6speed	229	147.0	74.4	78.1	68.1
6	Triumph	Street Triple	765	3	86.8	11750	79	9350	6speed	187	331.3	76.7	80.4	73.3
7	BMW	R 1250 GS	1254	2	100	7750	143	6250	6speed	249	308.6	74.2	78.5	69.7
8	Harley Davidson	Street Bob	1745	2	64	5020	155	3250	6speed	297	172.0	74.8	79.3	70.2

Table 23: Technical data and annex 3 test results of the vehicles tested by TU Graz according to the NSR method. The test results in the table are for the original version.

The NSR test results are summarised in the tables in Annex 2.

Scooters and mid-range motorcycles (vehicles 1 to 5)

The results for the scooters (vehicles 1, 2 and 4) are more uniform than for the corresponding vehicle in the 2017 CBA report: Such extreme differences between left and right side as for the corresponding vehicle in the 2017 CBA report were not found here.

The by far highest contribution to the overall sound emission comes from the driveline and/or other sources (about 58% to 79% for wot, 45% to 83% for crs) followed by the engine (about 13% to 38% for wot, 0 to 31% for crs), in most cases exhaust and intake play a subordinate role. wot means maximum power acceleration test, crs means constant speed test.

That means an OEM has to work on several sources and thus it is not an easy task to reduce the sound emission of these vehicles.

Similar results are found for the standard mid-range motorcycle (vehicle 3) and the mid-range cruiser (vehicle 5). Also for these vehicles an OEM would need to work on several different sources in order to achieve a reduction of 2 dB for the L_{urban} values.

That it is not an easy task to reduce the sound emission of these vehicles is also apparent if one compares the sound emission values for the original vehicle with the fully covered version. The differences for the vehicles mentioned above (vehicles 1 to 5) are between 1.7 dB(A) to 2.8 dB(A) for wot conditions and 1.8 dB(A) to 3.5 dB(A) for crs conditions (see corresponding values in the tables in Annex 2).

Therefore, it is difficult to forecast the costs for reduction measures. But it can be forecasted that a 2 dB(A) reduction of the L_{urban} values will require laborious measures and correspondingly high costs. A 5 dB reduction appears to be out of the range of feasibility without extensive intervention into the vehicle and engine design.

High-range motorcycles (vehicles 6 to 8)

The results for the sports motorcycle (vehicle 6), the big bike (vehicle 7) and the softail motorcycle (vehicle 8) are different. They are less uniform than for the smaller motorcycles and the exhaust has a much higher contribution to the overall sound emission.

At wot conditions the exhaust accounts for 50% to 67% of the overall sound emission for the softail and the big bike, followed by drive train and others (16% to 37%) and the engine (10% to 20%). The difference between the sound emission values for the original vehicle and the fully covered version at wot condition (L_{wot}) is 4.7 dB(A) for the softail and 7.8 dB(A) for the big bike. The lower value is 1.9 dB(A) higher than the highest value of the scooters and mid-range motorcycles group.

At constant speed (crs) the main source for the big bike and the softail is drivetrain and others (47% to 65%) followed by engine (11% to 42%); the exhaust plays a subordinate role. The differences between the sound emission values for the original vehicle and the fully covered version are 1.9 dB(A) and 1.8 dB(A) which is at the lower end of the range for the scooters and mid-range motorcycles group.

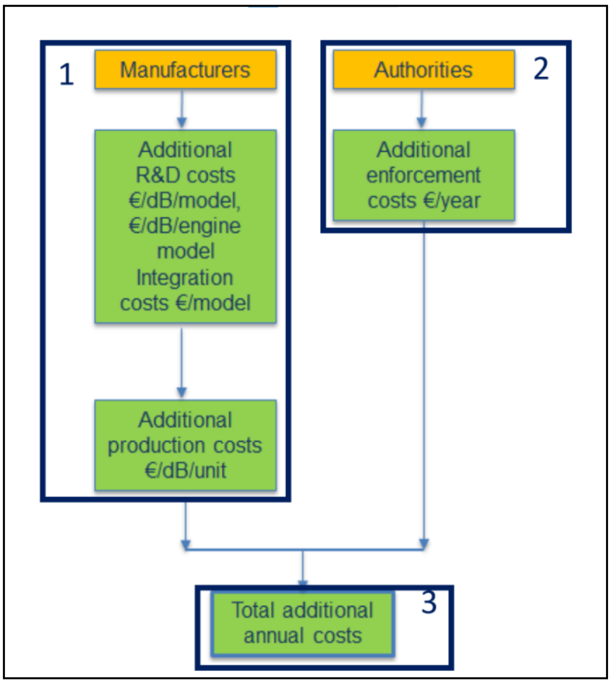
The sports motorcycle shows somewhat different results. The two main and almost equivalent sources are exhaust and drivetrain and others, followed by the engine; in fact, for wot and crs conditions. The engine plays a slightly bigger role for crs conditions, the intake for wot conditions, but the influence of the latter on the overall sound emission is marginal.

The differences in the sound emission values for the original vehicle and the fully covered version are significantly higher than for the scooters and mid-range motorcycles group. The L_{wot} difference is 4.1 dB(A) which is 1.3 dB(A) higher than the highest value for the scooters and mid-range motorcycles group. But the L_{crs} difference is 4.6 dB(A) and thus even higher than the L_{wot} difference and 1.1 dB(A) higher than the highest value for the scooters and mid-range motorcycles group (see corresponding values in the tables in Annex 2).

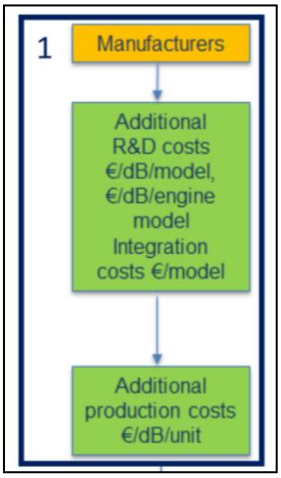
But even for these high range motorcycles, an OEM would need to work on several sources in order to achieve a 2 dB(A) reduction of L_{urban}. A 5 dB(A) reduction of L_{urban} would certainly require a redesign of the vehicle at high cost, if achievable at all. Also, for these vehicles it is difficult to forecast the costs for reduction measures.

5 COSTS

As in the chapter on benefits, we have grouped the cost flowchart elements (p. 171) into three blocks shown in the chart below. The logic of the cost flowchart appears to be consistent and we use it as the basis for our further analysis. For each block we devote a subsection in this chapter, assessing the CBA results and offering alternative analysis where appropriate.



5.1 Costs for manufacturers



The CBA states (p170) that the cost data have been derived by taking into consideration data from Ntziachristos (2017) and from the manufacturers' association ACEM, for which tables of figures are presented on p177. Ntziachristos provides the general figures for the vehicle fleet, presented in Table 25 of the CBA (p184). The CBA quotes costs for manufacturers to reduce vehicle noise levels, composed of costs for research & development (R&D: exhaust and intake, engine, integration) and costs for additional production (materials and manufacturing) (pp 171 & 172). It does not explain how these figures have been derived from the source. There is not a clear connection to the industry figures.

To review the CBA's cost results and generate our own estimate, we have followed the CBA's analytical logic, adapting the figures according to our own findings. The assumptions underlying the CBA analysis and calculations also underly our results unless explicitly altered by our assessment below.

5.1.1 *R&D costs*

The table below compares some of the R&D costs for motorcycles, derived from the figures in Table 25, p 184 (CBA) and Tables 18-20, p 177 (industry), for a 2 dB reduction.

The definition of "model", as used in the CBA, requires some analysis. Company A provides data for two low volume models. No subdivision of models is indicated. Company B includes 16 engine models and 25 vehicle models. We take the number of vehicle models as the appropriate parameter for comparing to table 25. Company C does not indicate vehicle models but does indicate 11 engine models in total. For this company we take the number of engine models as the appropriate parameter. This is not a fully consistent treatment but appears to be the only method that can provide a relevant approximation.

The results are as follows:

Source	**Model**	**Average R&D (engine, exhaust, vehicle integration) costs per model**
CBA (Table 25)	All	€ 400,000
Company 1 (Table 18)	A	0
	B	€ 2,275,212
Company 2 (Table 19)	L3e-A2 & A3	€ 392,000
	L3e-A2E / A3E	€ 458,000
Company 3 (Table 20)	100-250cc single	€ 4,500,000
	251cc single twin tri four	€ 5,600,000

Table 24: Comparison of CBA and industry cost figures for 2 dB noise reduction for motorcycles

There is clearly a wide range of industry values, ranging from comparable to the CBA value to higher by a large factor. The highest R&D cost figures provided are for the low volume (and presumably high value) model B for Company 1, approximately five times higher than the CBA. It is also informative to note that the R&D costs are estimated to be higher than the sum of the manufacturing and testing costs, in contrast to the approximately 1:10 ratio in the CBA (Table 25). The R&D costs per unit for a 2 dB reduction are approximately 300 times higher than the CBA average estimate. This model is unlikely to be representative for the industry, although is informative for that category of vehicles (L5e). Model B contrasts with its sister model A, for which zero R&D costs are reported.

The values for Company 2 are of a very similar order to the CBA estimate and could be considered as a partial validation of those figures. However, when converting to cost per unit, as shown in Table 19, Company 2's average R&D costs for a 2 dB reduction are €30, compared to €3 per unit in table 25, i.e. a 10-fold difference. This also implies a discrepancy in the definition of model in the CBA.

Table 20 for Company 3 presents a very high value for the yearly production of the 100-250cc vehicle (first row - 4,800,000). On further investigation, Company 3's volumes are understood to represent global production (for both models). Using these volumes to calculate the costs cannot therefore be used to generate consistent results for compliance with EU-only regulations. There also appears to be a particular inconsistency in the definition of "model" in this case. For a 2 dB reduction, development costs of €22.5m are spread over only 5 engine models but nearly 5 million units. There is clearly a discrepancy in how the concept of model can be applied to this case compared to the other companies and the CBA. Using these figures, the R&D costs per model are over 10 times as high as the CBA estimate.

Papadimitriou (2016) included among the costs also the sales loss of replacement exhaust retailers (valued at €43M/year for mopeds and motorcycle market). We have not included this cost, as it represents a loss of a business whose products are in contradiction to the objectives of EU policy (i.e. noise reduction). However, ACEM (2004) highlights other compromises required when applying measures required to reduce noise levels, including safety, exhaust emissions, cost, productivity, durability, and rideability. These could be considered additional costs, but their evaluation is not possible with available data.

The CBA assumes that manufacturers incur different R&D costs for mopeds and motorcycles. While the text presents this assumption only for engine-related costs (p.171), table 25 applies it to all R&D cost categories (exhaust and intake, engine, integration), resulting in costs for motorcycles being double those for mopeds across all cost categories, according to table 25. It should be noted that, according to ACEM, moped technology is similar to that of small motorcycles (L3-A1), i.e. single cylinder and often a CVT transmission, resulting in similar expected cost for these 2 vehicle categories. Since the noise limits for mopeds are already at a lower level compared to motorcycles, costs of additional noise reductions can be expected to be comparatively higher for mopeds compared to L3-A1 motorcycles. The comparison to larger motorcycles is unclear. Furthermore, noise-emission related modifications in moped design can be expected to have a relatively higher impact on performance, already affected by the prescribed limitation in top speed (45km/h).

Regarding development costs for new engines, the CBA assumes (p171) they are only relevant for reductions over 2 dB. However, statements provided by the L-category vehicle manufacturers' association ACEM assert that this is an incorrect assumption.

The CBA states (p. 171):

> *"No additional costs for type approval testing are foreseen, as changing the sound limits does not affect the test method or the test facilities for the sound type test".*

However, as the CBA analysis suggests on a number of occasions, a revision of the type approval test methodology would include additional measurement procedures, implying additional testing costs. This was done in Papadimitriou 2016 (p97), which included testing costs for both manufacturers and testing agencies. Testing costs are expected to be low compared to other cost categories, as also stated in the CBA (p183).

Potential impact on B/C: there are significant variation and uncertainty in the R&D costs according to the data from the manufacturers, preventing a clear conclusion. Figures indicate that R&D costs could in some cases be 10 times higher than reported in the CBA, in other cases are zero.

5.1.2 *Materials and manufacturing (production) costs*

Additional unit production costs are expressed in the CBA in terms of €/dB/unit and occur for each of the 6 years of the assumed average lifetime of a vehicle model (the only exception being 4 years for ATVs - table 25, p184). For each vehicle category, the table quotes a single figure for costs per dB reduction, implying that incremental costs are independent of the reduction already achieved.

As assessed from the NSR test results, this is implausible. The NSR results show that even for a 2 dB reduction the OEM has to improve the sound contributions of several sources (including the drivetrain), especially for smaller motorcycles. That would lead to a progressive increase of costs per dB with increasing sound reduction. A 5 dB reduction for smaller motorcycles is outside the range of the reduction in the NSR testing, therefore requiring extensive intervention into the engine as well as the exhaust and intake systems. The costs for such interventions can be expected to be significantly higher per dB than at the 2 dB reduction level. For larger motorcycles, a 5 dB reduction is within the range of the reductions in the NSR testing, but would require intervention into multiple systems. Again, higher costs per dB reduction can be expected at those levels. For these reasons and due to the absence of sufficient data, we make no estimate for the cost of 5 dB reductions.

The cost differential between mopeds and motorcycles shown in the table (€ 10/dB per moped and € 20/dB per motorcycle) could be justified on average. Compared to smaller motorcycles, the analysis in the previous subsection identified that costs for mopeds would be higher. However, compared to larger motorcycles, whose unit prices are between 3-4 times those of mopeds on average, costs for motorcycles could be expected to be higher.

In summary, compared to the CBA's estimates (Table 25), production costs per unit for motorcycles reported by manufacturers are higher by a factor of 8 (Company A), higher by 40% (Company B) lower by 75% or lower by 99% (Company 3).

Potential impact on B/C: see next section.

5.1.3 *Total unit costs*

The table below compares the total additional costs per unit (€/unit/year) related to several limit value reductions for different motorcycles models, as derived from the figures in Table 25, p 184 (CBA) and Tables 18-20, p 177 (industry).

The CBA states (p. 178):

> *"Tooling costs are not included as these are considered part of the overall production costs, and sound reduction can often be integrated into existing components such as exhaust, and intake."*
>
> *"It could also be argued here that the costs of testing facilities and molding are not additional costs as these are not a consequence of tighter limits."*

The CBA (p176) expressed doubt as to whether the tooling and testing costs are actually additional costs for compliance with lower limits. There is no explicit information in the CBA regarding the validity of tooling and testing as additional costs for reducing noise levels, or whether these costs would anyway be incurred. We assume for our primary estimate that all OEM-reported costs are additional, as OEMs were requested to provide only additional costs. As a delta analysis to test the possible boundaries, we also do the assessment excluding tooling and testing (figures in brackets below).

Source	Model	Limit value reduction		
		1 dB	2 dB	5 dB
CBA	Motorcycles	/	€ 43	€ 111
Company 1	Model A	€ 0	€ 0	€ 2,290
	Model B	€ 571 (€ 353)	€ 916 (€ 698)	€ 2,470 (€2,252)
Company 2	L3e-A2 and A3	€ 43 (€ 20)	€ 78 (€ 39)	/
	L3e-A2E/A3E (Enduro)	€ 99 (€ 76)	€ 151 (€ 114)	/
Company 3	100-250cc single	€ 0.5 (€ 0.3)	€ 1.2 (€ 0.8)	/
	251cc single twin tri four	€ 29 (€ 22)	€ 34 (€ 26)	/

Table 25: Comparison of CBA and industry total cost figures for 1, 2, 5 dB noise reductions for motorcycles (figures in brackets exclude tooling and testing)

For a 2 dB reduction (including tooling and testing):

- Company 1's unit costs (model B) are 21 times the CBA estimate (zero for Model A).
- Company 2's unit costs are between 1.8 and 3.5 times the CBA estimate (weighted average 2.1).
- Company 3's unit costs are 20% or 97% lower than the CBA respectively.

Company 2's profile appears to be the most representative of the market as a whole and it provides the most detail on the costs. The 2.1 times weighted average cost multiplier compared to the CBA is therefore a relevant orientation. Excluding tooling and testing costs, for the delta analysis, results in weighted average cost 1.3 times the CBA estimate. According the these figures, therefore, the question of whether tooling and testing costs are valid on-top costs is a key factor.

Company 1 represents a niche segment and is therefore unlikely to be representative of the market but indicates that for some (high level, low volume) models the costs could be considerably higher than the CBA. Company 1 also provides evidence that for some models the costs can be zero. The very low cost values for Company 3's models were derived from global production volumes and are therefore inconsistent with the CBA's methodology. The 1.8 and 3.5 times cost multipliers for Company 2 represent relevant evidence for a different cost estimate. These figures can be used as an orientation, but are not robust enough to enable a concrete conclusion.

It should also be noted that industry-provided cost categories do not match with those in the CBA (development, production). Company 1 reports testing costs, company 2 tooling costs, company 3 mould manufacturing and testing costs.

Total production costs reconcile well between the figures in the CBA Table 25, the line graphs in Figures 27 and V.1 and the totals in Tables 26 and V.1. However, there appears to be a discrepancy in the total R&D costs reported in the CBA. For a 2 dB noise reduction for motorcycles, Table 25 quotes R&D costs per model of €200,000 for exhaust and intake design, zero for engine design and €200,000 for integration - €400,000 in total. If it is assumed that the additional R&D costs apply once to each model and are zero for successor models (see R&D Section above), this figure is applied to 350 models. Total R&D costs, using CBA R&D cost estimates, would therefore be €140m. The R&D line in Figure 27 indicates a total over all years of less than €30m. These calculations partially explain and validate the higher end of the range of expected costs explained above.

The figures in Table 25 (p184) indicate that R&D costs per vehicle are approximately 10% compared to unit costs. This is consistent with the line graphs in figures V5.1 (p227) and V5.2 (p229) in the annex. However, the industry data in tables 18 and 19 show R&D costs between about 30% and 190% of unit costs. Without additional background data and a derivation of the CBA figures, it is not possibly to scrutinise fully the reason for this discrepancy. It does however introduce an additional level of uncertainty in the robustness of the estimates.

Potential impact on B/C: the data provided by industry for the 2017 CBA indicate that, depending on assumptions, weighted average total costs for development and production could be on average 2.1 times higher than reported in the CBA.

5.1.4 New OEM cost data

During the course of the compilation of this review, three members of ACEM, manufacturers of L-category vehicles, provided additional data on costs of compliance with lower limits. Two of these were the same OEMs that provided data for the CBA (Company 1 and Company 2).

The new cost data correspond to a different concept to the data in CBA. The new data relate to the cost of a 2 or 4 dB reduction in the sound level of the exhaust and the engine each independently. These data cannot therefore be compared directly to the CBA cost data, which are quoted for a 2 dB reduction of the vehicle overall. A 2 dB reduction from the engine and a 2 dB reduction from the exhaust would combine to result in less than 2 dB reduction overall. The magnitude of the total reduction depends on the proportion of the total emissions represented by the engine and exhaust. This implies that the costs for a 2 dB reduction overall would be higher than the quoted figures from the new data, but there is insufficient information available to estimate the extent of the difference.

The following table shows the additional cost per unit reported by the OEMs for meeting a 2 dB lower limit, comparing to the raw OEM figures presented in the CBA:

Cost data from CBA (2 dB reduction overall)		New cost data from 2 dB reduction for both engine and exhaust	
CBA designation	**Average cost /unit CBA**	**Designation of new data**	**Average cost/unit new data**
Company 1 (Tricycle manufacturer)	€916	OEM3	€916
Company 2 (small, medium and high performance MC)	€ 86.11	OEM2	€ 244.69
Company 3 (small, medium and high performance MC)	€ 2.74	n/a	n/a
Company 4 (new) (medium and high performance MC)	n/a	OEM1	€ 85.33

Table 26: New cost data from OEMs compared to CBA data for a 2 dB reduction

Company 1: The costs provided by company 1 are identical to those reported in the CBA for a 2 dB reduction for "Model B", with no individual data on the engine and exhaust. No new data for "Model B" were provided, for which in the CBA zero costs were reported for the 2 dB reduction.

Company 2: The new data for company 2 result in a three-fold increase compared to the CBA, which can be attributed mainly to an €82m estimate for R&D costs covering five engine and five vehicle models. As indicated above, the costs for an overall 2 dB reduction would be higher than the quoted figure (€245).

Company 3: No new data for company 3 were provided.

Company 4: It is understood from conversation with ACEM that the costs provided for the new Company 4 above represent worst case scenarios, in which OEMs would be required to reengineer their vehicles for lower limits with very short lead time (2-3 years). This implies that if sufficient lead time were allowed, for example by delaying implementation until 2030, lower cost estimates could be appropriate. In that case, to maintain the 20 year timeframe for the assessment, an assessment period of, for example, 2030 to 2050 would be required. The given figures remain applicable to the 2025-2045 analysis.

The new cost data from companies 2 and 4 can be further assessed for application to the benefit/cost analysis. The portfolio of Company 2 appears to be the most representative to the overall L-category market, encompassing small, medium and large motorcycles. However, its new estimate is both three times the original one and three times the estimate from Company 4, whose portfolio covers only medium and large motorcycles. In addition, the estimate from company 4 is quoted as a worst case with short lead-times, whereas company 2's estimate did not include this qualification.

Due to the factors identified above, there is a significant inconsistency in the available costs figures, pointing to a high level of uncertainty. Due to this uncertainty, the data are insufficient to result in a new estimate for the costs of a 2 dB reduction. We continue to use the €86/unit from Company 2 in the CBA data as the primary estimate of costs. This corresponds approximately to the €85/unit estimate for company 4 from the new data (for which some additional costs to reach a 2 dB reduction overall would be expected).

Using the new estimate from Company 2 would however increase cost by an additional factor of more than 3. This can be considered a delta scenario.

It should additionally be noted that with these new estimates, the proportion of tooling and testing costs is significantly lower than in the figures provided in the CBA. For Company 3 (OEM1), tooling and testing costs represent 21% of the total costs, compared to 39% in the estimates in the CBA. For company 2 (OEM2) they represent a very small proportion.

Potential impact on B/C: the new data do not result in a significant change to the primary cost assessment, except when tooling and testing costs are excluded. Comparing directly new data from one of the companies however results in a factor of 3 higher costs.

5.1.5 Costs when accounting for electric vehicle share

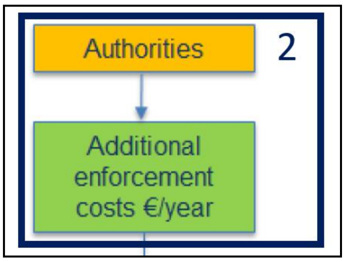
In Section 3.3 above we calculated the impact on the benefits of an L-category noise limit reduction assuming a 100% penetration of electrically chargeable vehicles (EVs) by 2045. The EV penetration will additionally have an impact on the total cost of compliance with lower limits, since market volumes of non-EVs would be lower. In this assessment, we assume that L-category EVs would make negligible contribution to road traffic noise due to the near elimination of engine and exhaust noise. Fixed costs (R&D etc) for noise reduction of non-EV L-category vehicles is assumed to remain the same.

For the OEM cost data used for the primary estimate above, fixed costs represent approximately 75% of the unit costs. Making the assumption that these fixed costs are incurred regardless of volume, the impact of the central scenario of 100% penetration of EVs by 2045 would be a 13% reduction in total compliance costs for a 2 dB limit reduction from 2025 to 2045.

Whether the conditions underlying this assumption would be remain valid until 2045, or whether such a high penetration of EVs would result in a significantly different overall market profile, thereby rendering such estimates invalid, in an unknown parameter in this assessment.

Potential impact on B/C: modest impact on total costs in the case of 100% EV penetration by 2045.

5.2 Costs for authorities



Enforcement costs are relevant for the "0% IL" scenarios (p. 173). It can be argued that costs incurred by authorities for additional enforcement should be out of the scope of the CBA analysis, as they are not directly related to type approval. At least, they (and the related benefits) should be considered separately from vehicle costs in order to isolate the impacts of each. Since they are not separated in the CBA, the result cannot easily be interpreted.

The daily costs assumed for enforcement staff, set at € 2,400/day for each "roadside testing team" composed of 3 persons working 8 hours/day, appear overestimated, due to an hourly rate set at € 100 per person (p. 172). On the other hand, the deduction from the daily costs of each testing team of the fines imposed, assumed at € 1,000/day, leading to lowering the net cost for each team to € 1,400/day, can be questioned. The deduction implies that fines are accounted as a benefit, but it can be argued they should be treated instead as a cost incurred by riders or, as an alternative, kept out of the analysis.

Achieving 0% illegal exhausts would likely be extremely difficult, if not impossible, even with enforcement resources directed towards it. Costs would probably increase exponentially as the proportion approaches zero. There would likely be a crossover point where the benefit-cost ratio for enforcement is equal to 1. In addition, for any dB reduction in noise limits, there would be an optimum (from an economic point of view) percentage of illegal exhausts, where the marginal benefit-cost ratio for enforcement is equal to the marginal benefit-cost ratio for lower limits.

The above observations emphasise the need for separating the impacts and costs of enforcement and limit reduction, to isolate the benefit-cost ratios for each and determine the optimum combination.

Potential impact on B/C: as a first approximation, the impact of enforcement should be excluded in order to consider only the impacts of noise limit reductions.

5.3 Total additional annual costs

The CBA calculations leading to total costs, displayed in table 26 p.185 and Annex V, are not presented. Data shown in table 25 (p.184) allows only for a partial estimate of the calculations conducted for manufacturers' costs. This estimate can be done for additional production costs, correcting the displayed number of produced vehicles/year to take into account the proportion of vehicles already compliant with proposed lower type approval limits (bottom of table 25) and multiplying that figure by the cost/dB/unit. A similar estimate can be done for R&D costs, if it is assumed that the proportion of vehicle models/year and engine models/year already compliant is equal to the proportion of compliant vehicles. This is unlikely to be an accurate assumption but can be used as an estimate. Since R&D costs are projected to drop to zero from about 2028 (according to Tables 27 and 28), it appears also to be assumed that R&D costs are assumed to be incurred once only for each vehicle and engine model. It appears to assume that a follow-on model requires no R&D costs to maintain the sound level baseline of the compliant predecessor. No evidence is presented to support whether this assumption is correct.

Making the above assumptions and using the CBA cost figures in Table 25, the resulting total manufacturing costs appear to be consistently calculated. However, the discrepancy between the CBA costs and the costs provided by manufacturers, identified in Section 5.1 above, indicates a weighted average factor 2.1 higher costs.

The charts in Figures 27 and 28 (p186) project that production costs start dropping from 2021 onwards and approach zero around 2034. This implies that additional costs are no longer incurred in complying with lower noise limits. This does not appear to be plausible, since a vehicle manufactured in 2035 complying with 2 dB lower emission limits would have to incorporate the technology necessary to meet that limit, which the same vehicle with the original emission level would not require. It would be more consistent to assume that additional production costs are still incurred out to 2040, but also that the long-term cost per unit is reduced by a certain factor due to learning effects. As a first approximation, a learning factor of 2 to 2040 can be projected and the impacts calculated:

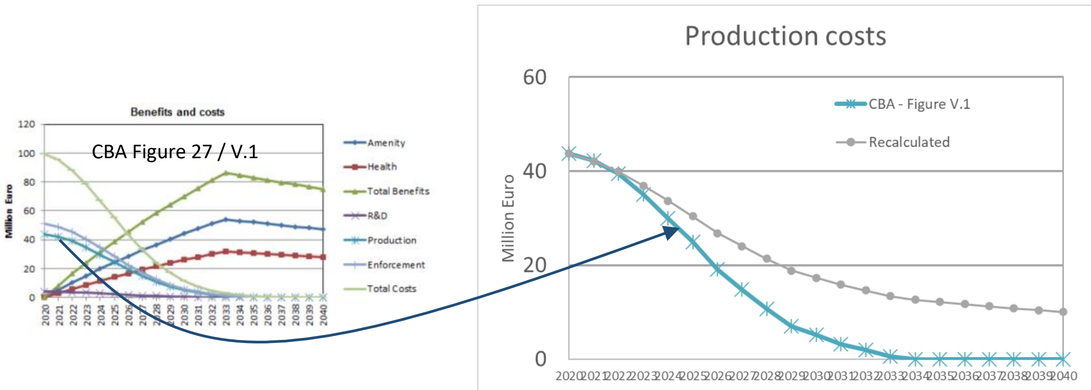


Figure 8: Production costs assuming additional costs are incurred to 2040

If this is the case, the total production costs over the 20-year period in question, taking into account discounting effects, would be increased by a factor of 1.65 compared to the CBA estimate. This would be on top of the 2.1 (1.3) weighted average factor indicated in the previous Section.

It also does not appear to be appropriate that enforcement costs drop to zero before 2040. In fact, the need for enforcement should be assumed to remain over time. If a learning factor of 2, similar to that applied above to production costs, can similarly be applied to enforcement costs, a similar 1.65 multiple would result over the period 2020 to 2040 (for our analysis 2025-2045). This effect could be compounded if (as also mentioned in the CBA, pp12, 21, 195) lower type approval values lead to an increase in the attractiveness of after-market noise enhancing devices.

It appears from the text and Table 25 that the CBA takes into account that some models are already below the limit and therefore does not apply a blanket reduction equal to the limit reduction. This represents a consistent treatment, but is potentially in contrast to the treatment of the calculation of noise reduction in Section 2.1 above.

Potential impact on B/C: using industry reported costs and accounting for costs continuing out to 2045, total costs could be 2 to 3.5 times the figure reported in the CBA. Assuming that noise limit compliance costs for vehicles out to 2045 increases the enforcement costs by a factor of 1.65, for the scenario with zero illegal exhausts.

5.4 Presentation of total accumulated costs

The following is an extract from Table 26, p185, showing scenarios for the 0 and 2 dB limit reductions for 25% and 0% illegal exhausts.

	Northern EU		Southern EU		Accumulated benefits Meuro			Acc. Costs	B/C ratio
Scenario	Δ Lden dB	Δ Lden dB	Δ Lden dB	Δ Lden dB	NE	SE	Total	Meuro	
Year/Lcatlim/%Illegal/Growth	All	Lcat	All	Lcat	Only Lcat	Only Lcat	Only Lcat		Only Lcat
2040, 0 dB, 25% IL, BAU	1,58		1,00		0	0	0	0	n.a.
2040, -2 dB, 25% IL, BAU	1,77	0,19	1,40	0,39	66	601	668	306	2,18
2040, 0 dB, 0% IL, BAU	1,91		1,96		0	0	0	324	n.a.
2040, -2 dB, 0% IL, BAU	2,18	0,27	2,69	0,73	97	1107	1204	631	1,91

Table 27: Extract from Table 26, p183, summary of benefits and costs

It is clear from the right hand side of the table that the enforcement costs are included (€324m for no limit change and 0% illegal exhausts). A robust presentation would separate the enforcement from the vehicle costs for all scenarios, in order to isolate the impacts of limit reduction and reduction in illegal exhausts.

From the assumptions and analysis in the preceding sections above, the following estimates can be made for the total costs, derived only from the figures provided in the CBA. To simplify, we focus on the BAU growth scenario:

		CBA estimate (€m)			Our assessment (€m)		
Limit reduction	Illegal exhausts	Unit costs	Enforcement costs (implied)	Total	Unit costs	Enforcement costs	Total
-2 dB	25%	306	0	306	1061	0	1061
	0%	306	325	631	1061	536	1597
-5 dB	25%	962	0	962	n/a	0	n/a
	0%	962	326	1286	n/a	538	n/a

Table 28: Total costs compared to CBA estimates

As indicated in the previous Section, we have not estimated costs for a 5 dB reduction. The above results for a 2 dB reduction are shown graphically below:

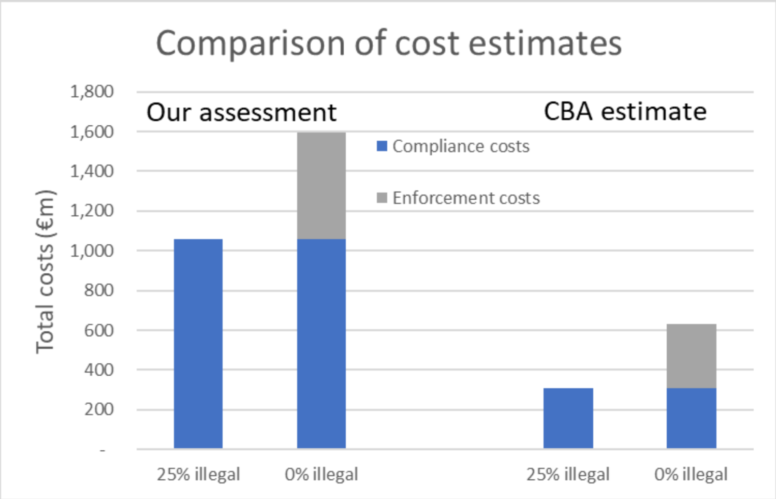


Figure 9: Comparison of costs estimates between this assessment and the CBA

5.4.1 Uncertainties

In the above sections of this chapter, many scenarios, ranges of values and delta-analyses have been addressed. The overall impact of these effects is to demonstrate a very high level of uncertainty in the costs of a 2 dB or other reduction in the noise level of L-category vehicles. The cost estimate tabulated and visualised above represents one value for the costs under stated assumptions. Significantly higher and lower estimates can be generated with different assumptions or simply using different available data.

It is therefore to be emphasised that the results of this review are to be understood in the context of the uncertainties, in particular those in the cost figures.

6 SINGLE EVENT ANALYSIS

Chapter 4.5 of the CBA presents an analysis of single noise events as an alternative approach. It is not clear whether this would replace the L_{DEN} analysis or be a complement to it. In principle both average noise levels and single events are relevant at the same time on the same stretches of road. The CBA does not explicitly define single events, but the introduction refers to it by stating *"much of the impact from L-category vehicles is caused by sound level peaks due to acceleration well above other traffic noise" (p187)*.

It further states *"The impact of larger limit reductions is stronger for single events."* It does not explain or substantiate this assertion. It also does not appear to take into account the increase in noise emissions from other (non L-category) vehicles in the accelerating sections of traffic.

The CBA then calculates the number of single events using the following formula for the length of each road type over which single events occur:

$N_{km,veh,y}$ *= annual vehicle mileage x activity rate x road portion*

In turn it calculates road portion:

road portion = % inhabited x % intermittent x % accelerating

It then calculates the number of single events as:

 # single events = $N_{km,veh,y}$ *x active fleet size x households per km x portion affected*

It calculates the number of events using the above formulae for residential, main and rural roads, with the results shown in table 27 (p188), below.

		Resid.int	Main Int.	Rural Int.
EU28 totals	km	1660601	251606	2918633
Inhabited	km	1079391	201285	1459316
Inhabited	%	65%	80%	50%
Intermittent	km	356199	66424	481574
Intermittent	%	33%	33%	33%
Accelerating	km	178100	33212	240787
Accelerating	%	50%	50%	50%
Activity	%	5%	25%	40%
km/year	5100	255	1275	2040
Road portion		10,73%	13,20%	8,25%
km events/veh/year		27,35	168,30	168,30
Active fleet size	20000000			
km events/year		546975095	3366000000	3365999423
Households/km		104,2	208,3	8,3
Affected part of 1 km		10%	10%	20%
Total single events/year		5697657240	70125000000	5609999039
	Euro			
Valuation/event/dB/hh	0,001			

Table 29: Single event calculations (Table 27, p188)

The following are the results for the number of single events per year (experienced by households):

- Residential roads: 5.7bn
- Main roads: 70.1bn
- Rural roads: 5.6bn

The formulae are in contradiction to the initial assertion that sound level peaks are caused by acceleration well above other traffic noise. They calculate the number of accelerating events, without identifying whether those are at noise levels above other traffic.

Most of the inputs listed in the above table are consistent with figures used for other calculations in the CBA. However, no reference is provided for the "portion affected", quoted as 10% for residential and main roads and 20% for rural. These appear to be best guesses but without substantiation cannot be considered reliable.

To determine the impact of the events, the CBA estimates their average noise level, correcting the calculated noise level for the limit reduction, accelerating condition (ΔL_{acc}), and, off cycle conditions (ΔL_{OC}), illegal exhausts (ΔL_{IL}) and driving behaviour (ΔL_{rpm}). It then states *"If a limit change does not affect the terms ΔL_{acc}, ΔL_{OC}, ΔL_{IL} and ΔL_{rpm} …, the average reduction of single events is equal to the limit reduction times the portion of compliant vehicles."* As indicated in Section 2.1 above, the average reduction of noise from vehicles on the road under normal conditions can be estimated as approximately half the limit reduction. The assumption that a limit change does not affect the above terms appears to be a reasonable approximation (see Section 2.1).

It then assumes values for the noise increase due to illegal exhausts (10 dB), off-cycle conditions (5 dB) and driving behaviour (5 dB). No references are provided for these values. For the monetary valuation, it "proposes" an indicative value of €0.001/dB/household/year, asserting that it is "low in comparison" to established values for L_{DEN} level reduction. Again, no reference or derivation is provided.

The CBA presents a table of reductions in single event noise levels due to noise limit reductions and the corresponding benefits for four scenarios. These results are included in the table below, alongside the corresponding results for benefit-cost ratio.

Scenario	**Average single event reduction**	**Benefit-cost ratio**
-2 dB, 25% illegal	1.1 dB	2.8
-5 dB, 25% illegal	2.75 dB	5.5
-2 dB, 0% illegal	5.85 dB	37.8
-5 dB, 0% illegal	7.5 dB	30.5

Table 30: Results of single event analysis from Table 28, p190 and benefit-cost ratio from Table 30, p191

No derivation or calculations of the figures are presented. The table combines the impact of limit reductions and elimination of illegal exhausts. As stated previously, it would be necessary to separate these two impacts to analyse each independently. Further detail on benefits and costs per year is provided in Tables V.3 to V.6 in the Annex, but sources and derivation of the values are not provided.

In particular, it is not clear how the benefit-cost ratio for the -2 dB scenario increases by a factor of 13.5 going from 25% to 0% illegal exhausts (2.8 to 37.5), when the average single event reduction increases only by a factor of 5.3 (1.1 dB to 5.85 dB), which would also be associated with higher enforcement costs. Further, the very high B/C ratios for the 0% illegal exhaust scenario indicate that the effects of limit reduction and enforcement against illegal exhausts have been combined. This is also evidenced by the fact that the quoted value for average single event reduction is higher than the limit reduction, for the 0% illegal scenario.

The above observations indicate that the methodology and calculations are unreliable for reaching valid conclusions on the impact of noise limit reductions on single events. Specifically, it is not sufficient to support conclusion point C (p191), that *"the benefits are expected to be much higher compared to those from the L_{DEN} analysis"*. Similarly, the statement in the 5th bullet of conclusion point F (p192) is not substantiated:

"As single events are not averaged out as done when the L_{DEN} approach is used, it follows that reductions of single event sound levels would be comparable to the limit reduction for new compliant vehicles."

As indicated in Section 2.1, a, for example, 2 dB limit reduction lead to an approximately 1 dB noise reduction for all compliant vehicles.

Potential impact on B/C: the lack of consistent and reliable data and methodology casts doubt on the viability of the benefit-cost results for single events.

7 BENEFIT-COST RATIOS AND CONCLUSION

The CBA's benefit-cost (B/C) ratios are presented in Table 26, p185, reproduced below:

	Northern EU		Southern EU		Accumulated benefits Meuro			Acc. Costs	B/C ratio
Scenario	Δ Lden dB	Δ Lden dB	Δ Lden dB	Δ Lden dB	NE	SE	Total	Meuro	
Year/Lcatlim/%Illegal/Growth	All	Lcat	All	Lcat	Only Lcat	Only Lcat	Only Lcat		Only Lcat
2020, 0 dB, 25% IL, REF	0,00		0,00		0	0	0	0	n.a.
2020,-2 dB,25% IL, REF	0,14	0,14	0,38	0,38	50	582	632	274	2,31
2020,-5 dB,25% IL, REF	0,26	0,26	0,74	0,74	93	1123	1216	859	1,42
2040, 0 dB, 25% IL, BAU	1,58		1,00		0	0	0	0	n.a.
2040, -2 dB, 25% IL, BAU	1,77	0,19	1,40	0,39	66	601	668	306	2,18
2040, -5 dB, 25% IL, BAU	1,93	0,35	2,09	1,09	125	1661	1787	962	1,86
2040, 0 dB, 0% IL, BAU	1,91		1,96		0	0	0	324	n.a.
2040, -2 dB, 0% IL, BAU	2,18	0,27	2,69	0,73	97	1107	1204	631	1,91
2040, -5 dB, 0% IL, BAU	2,43	0,52	3,42	1,46	186	2227	2412	1286	1,88
2040, 0 dB, 25% IL, HGR	0,73		0,39		0	0	0	0	n.a.
2040, -2 dB, 25% IL, HGR	0,92	0,19	0,83	0,44	66	676	742	347	2,14
2040, -5 dB, 25% IL, HGR	1,08	0,35	1,25	0,86	126	1312	1438	1086	1,32
2040, 0 dB, 0% IL, HGR	1,06		1,12		0	0	0	324	n.a.
2040, -2 dB, 0% IL, HGR	1,33	0,27	1,84	0,72	97	1101	1198	671	1,78
2040, -5 dB, 0% IL, HGR	1,57	0,52	2,57	1,45	185	2213	2398	1410	1,70

Table 31: Table 26, p183, summary of benefits and costs

As stated in Section 2.9 above, it is not clear whether the benefits of going to 0% illegal exhausts through enforcement measures are accounted for in the accumulated benefits. As stated in Section 5.4 above, both enforcement costs and vehicle costs are included in the accumulated cost figures. The benefit-cost (B/C) ratios in the table therefore do not compare equivalent conditions for the 0% illegal exhaust cases. The robustness of the cost benefit ratios for these cases cannot therefore be verified with the available information.

The CBA calculates the present value of total costs and benefits from the annual values using a discount rate of 4%, referring to the recommended social discount rate in the European Commission's Better Regulation Toolbox (2015). The Toolbox was updated in 2017, with the recommendation for discount rate unchanged.

It is appropriate to use a social discount rate when considering social impacts such as amenity and health effects of noise emissions. The selection of a discount rate has an arbitrary element and the 4% was defined by the European Commission. The rate is well-established but its provenance is not clear. The total value of costs and benefits is sensitive to discount rates, especially when, as in the case of the CBA, the timing of the costs and benefits are different (ref Figure V5.1, p227). For example, a lower discount rate increases the relative present value of the benefits (longer term) compared to the cost (nearer term). We reach no further conclusion regarding discount rates, except to acknowledge the inherent uncertainties. In our assessment we use the same 4% discount rate.

The assessment presented in this report applies different data and assumptions than the CBA, leading to different results for costs, benefits and the B/C ratio. The table below summarises the calculation of the B/C ratio, derived from the calculations in Section 5.1 above using the UK dose-response relationship. We compare only the result for the following scenario:

- BAU growth, due to the marginal difference to the HGR scenario
- -2 dB reduction, due to absence of robust cost estimates for 5 dB
- 25% illegal exhausts, in order to exclude the effect of enforcement costs, addressed separately

-2 dB limit reduction 25% illegal exhausts BAU growth	**Costs (€m)**	**Benefits (€m)**	**B/C ratio (€m)**
Cost estimate (includes tooling and testing)	1061	867	0.82
CBA estimate	306	668	2.18

Table 32: Benefit/cost ratio results

This calculation leads to a B/C ratio of 0.82 under the assumptions presented, for a 2 dB limit reduction, compared to 2.18 in the CBA. This is our primary estimate for the B/C ratio, as the underlying assumptions are the most consistent and representative.

Our estimate of the costs is significantly higher than the CBA, derived from the available cost data, as well as the assumption that additional manufacturing costs will continue to be incurred over a longer period than accounted for in the CBA. The higher estimate for benefits compared to the CBA is defined by a significantly lower change in sound pressure level, more than outweighed by the elimination of the time fraction, the extension from accelerating traffic only to all traffic, and the dose-response relationships.

The following scenarios and delta analyses provide information on the impact of alternative assumptions, each assessed independently:

- Excluding tooling and testing costs from total costs increases the B/C ratio to 1.32. It is therefore important to determine whether these costs represent true on-top costs for compliance with noise limits. Further evidence is required to reach a robust conclusion.
- Using the new cost data from OEMs results in an almost identical B/C ratio of 0.81, but in this case excluding the tooling and testing costs results in a B/C ratio of 1.04.
- Using the Swedish dose-response relationship increases the benefits by a factor of 2.6 (B/C 2.1), whereas the Danish relationship decreases by them by about 12% (B/C 0.72).
- Adjusting for GDP per capita reduces the benefits and the B/C ratio by 27% for the UK dose-response relationship (0.60), 43% for Swedish (1.53) and 50% for Danish (0.53).
- Accounting for an accelerated penetration of EVs to 100% of L-category sales in 2045 leads to a reduction in the benefit/cost ratio by 40% to 0.49.

The available figures and calculations can be used to determine a “breakeven point” for the costs to comply with a 2 dB limit reduction. Based on the primary estimate for the benefits (€867m), an average cost per unit of approximately €65 would lead to a B/C ratio of 1.0 and a net present value of zero.

For a 5 dB reduction, insufficient data on costs are available to generate a reliable B/C ratio. However, the NSR test results indicate that approaching a 5 dB reduction would require extremely intensive and potentially unfeasible measures for small motorcycles and for some large motorcycles. For some other large motorcycles, significant measures on multiple systems would be necessary. These costs of these measures would likely decrease the B/C ratio significantly for a 5 dB reduction compared to our estimate above for 2 dB of 0.82. Again this value would be significantly lower than the B/C ratio reported in the CBA (1.86 for the same conditions as above), which itself is only marginally lower than the value reported in the CBA for the 2 dB reduction.

As final consideration of the B/C ratio, Section 2.7.3 acknowledges the absence of a scientific confirmation that any dose-response relationship remains valid at fractional changes in dB sound pressure levels, generating additional uncertainty on the valuation of the benefits.

7.1 Conclusion

The primary estimate for the B/C ratio for a 2 dB L-category noise limit reduction indicates benefits 18% lower than costs, based on the stated assumptions. However, both the benefit and cost calculations are characterised by high uncertainty and are sensitive to the many assumptions, with B/C ratios both well below and well above 1.0 depending on specific assumptions. These factors prevent a unique robust conclusion based on the B/C ratio.

In this context it should be emphasises that underlying our result were impacts significantly increasing the B/C ratio (including elimination of time fraction, counting all accelerating traffic) alongside other significant decreasing it (significantly lower sound pressure level changes). These factors point to a high level of uncertainty in the calculations. Further, one possible interpretation of the dose response relationships is that no discernible impact can be implied at the fractional dB changes in average sound pressure level. This is an additional indication of the high level of uncertainty.

Additional information is provided by the NSR results. According to these results a 2 dB reduction of L_{urban} would require measures on several sources for all motorcycle categories tested. The effort would be greater for scooters and small to mid-range motorcycles than for high-range motorcycles. Laborious measures and high costs can be expected, whereby a specific cost calculation is difficult and subject to great uncertainties.

The CBA (p199) concluded "*Even a 3 dB(A) reduction may be feasible depending on the performance impacts and additional costs; in this case, other vehicle components, apart from the exhaust, need to be tackled (intake, engine, driveline).*" The NSR results indicate that this conclusion is unlikely to be the case for scooters and small motorcycles, which would require additionally intrusive measures and redesign. For some large motorcycles, 3 dB may be feasible at high cost due to intervention on many systems and possible full redesign of the vehicles.

The CBA differentiates its conclusions for mopeds, stating that a 1 dB limit reduction can be recommended. The CBA is correct to state (p199) that there is "*less margin for reductions*" and "*Limit reduction is technically less feasible … due to due to technological and size limitations of mopeds*". No explicit cost information is available to conduct a robust analysis. The evidence is therefore insufficient to support the CBA's stated conclusion.

For a 5 dB reduction of L_{urban}, the NSR results indicate that a complete redesign of the vehicles would be necessary, if achievable at all. This is a stronger conclusion than in the CBA (p196), which points to *"higher uncertainty"* making it *"difficult to reach robust conclusions"*.

The single event analysis reported in the CBA contains significant inconsistencies and is not sufficient to lead to credible conclusions. This conclusion applies to the B/C ratios reported in the CBA for single event analysis (25% illegal exhausts), of 2.8 for 2 dB reduction and 5.5 for 5 dB reduction. The B/C ratios of 37.8 and 30.5 for the case of 0% illegal exhausts are based on fully inconsistent assumptions, mixing the impacts of limit reductions and enforcement measures.

Regulation 540/2014/EU on noise emissions of M and N category vehicles foresees a four-year lead-time. Specific evidence was not presented in the CBA to support the conclusion (p203) that a two to three-year period is “considered sufficient” for the industry to adapt to a 2 dB limit reduction. A four-year lead time is consistent with the available evidence.

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ANNEX 1: RESPONSES FROM THE CBA AUTHOR

- Can you provide the background data and calculations for the main figures (if possible full spreadsheets), in particular tables 21, 22, 23, 24, 26, V.1 and V.2?

  We cannot provide the spreadsheets, but here are some answers on how the data was obtained.

  Table 21: The road lengths, traffic intermittency, inhabited road length and inhabitant densities are similar to those used in the Venoliva study from 2011. 50% accelerating is for the portion of intermittent traffic acceleration, as opposed to deceleration. Exposed North/South is based on population distributions in the countries grouped as North and South. Motorcycle and moped activity is based on figures from a previous study on L-category exhaust emissions 'Effect study of the environmental step Euro 5 for L-category vehicles' (2017)

  Table 22: Also based on the 2017 study.

  Table 23: These are assumed average traffic flow rates based on previous studies and extended for L-cat vehicles.

  Table 24: These are the calculated effects in L_{DEN} for different reduction scenarios, with and without the foreseen reductions for other vehicle types

  Table 26: Same but with accumulated benefits and costs

- Can you clarify the definition of touring routes and the relationship between touring routes and rural roads?

  Touring routes are generally on rural roads, but only part of these. If the length of touring routes (as given by touring a website) is compared to the total length of rural roads, taking 33% for intermittent traffic and 50% of that for accelerating traffic, a similar figure is obtained. These are simply two ways of obtaining a relevant length estimate which happen to give a similar value.

- Is dwelling the same as household?

  Yes we used this in the same sense, although strictly a dwelling could also refer to a multiple household building.

- P180 table 21: what do the vehicle activity levels represent and how are they used in calculating noise levels (how do they fit into the flow chart figure 23).

  These just show on which road types the motorcycles and mopeds can have the strongest contribution, but do not feed back into the calculation

- P180 table 21: A range of typical speeds for different road categories is shown. What speed values were actually used for calculations?

See below:

	Resid.int.	Resid.free	Main int.	Main free	Arterial	Urban MW	Rural MW	Rural
Speed	30-50	30-50	<50	<50	60-80	100/80	120/80	50-100
distance	15	15	15	15	15	50	50	50
speed LV	30	45	35	50	75	80	-	60
speed MV	30	40	45	50	70	80	-	60
speed HV	30	35	40	45	70	80	-	50
speed MC	40	50	45	50	80	80	-	70
speed MP	40	40	40	40	45	45	-	45

- P180 table 21: why are accelerating and intermittent traffic percentages applied to the number of inhabitants, whereas in Figure 23 they are in the vehicle noise part of the calculation?

  The vehicle conditions are applied to the road sections intermittent and free flowing in the calculation. Fig 23 is just a visualisation of the principles.

- P183, time fraction: is it correct that the valuation rates are simply multiplied by the indicated percentages for the respective road types?

  Yes, so a valuation figure for a whole year is multiplied by the fraction of total time when L-cat vehicles are frequent

- P180 table 22: where were the "active fleet x million" values derived from, and were they taken into account for calculations of kms driven and flow rates (esp. mopeds)?

  Also from the 2017 report. Only used indirectly to assess consistency.

- P180 table 23: Why are arterials listed although it is stated in table 21 that only residential, main and rural roads are included in the analysis?

  For completeness, as previous studies have used the same road types.
  Also to show the activity percentages per road type.

- P180 table 23: can you provide the source of the data. Evening and night-time traffic in Southern Europe is equal to or greater than daytime. This looks implausible, is there an explanation?

  There may have been some incorrect figures for SE inserted here, however this has no effect on the end result in terms of noise reduction or the CBA.

- P180 table 23: are these same flow rates also used for future year projections or are the growth rates indicate on page 182 incorporated? If so, how are they applied?

Yes, but the growth figures are added to the L_{DEN} levels as would be done to correct traffic flow rates.

- P182 table 24: what do the Delta-L_{DEN} figures for 2020 represent – what is the baseline and assumptions?

  All parameters stay the same except for the propulsion noise levels of Lcat vehicles, which are reduced by the limit changes, as if taking effect immediately

- P182 table 24: were separate L_{DEN} values calculated for each road type? If so, are they and their derivation available?

  Yes, using adapted CNOSSOS-EU source levels and a simple propagation model. See fig 26.

- P226 & 228: multiplying the dB reduction by the exposed people (assume 2.4/dwelling) by the amenity and health benefits does not result in the same total benefits. Presumably this is because the calculations were done for each road type separately. In that case, was there a reason for presenting the data in this way?

  Correct. To avoid too much detail, as more extensive tables would probably not help.

ANNEX 2: DATA FROM NSR RESULTS

Scooter 125 cm³, pmr = 45.1 (vehicle 1)

		Vehicle 1 annex 3 with a_wot and kp from naked			Vehicle 1, Annex 3 result	
		Lurban	Lwot	Lcrs	left	right
	vAA' in km/h				34.8	
	vPP' in km/h				40.3	
	vBB' in km/h				46.5	
	aAA'_BB' in m/s²				1.67	
	aPP'_BB' in m/s²	Lurban	Lwot	Lcrs	1.89	
Lmax wot in dB(A)	naked	74.5	77.8	68.7	76.7	78.8
	exhaust covered	74.2	77.5	68.3	76.2	78.5
	exhaust + engine covered	72.6	75.7	67.1	75.1	76.7
	fully covered	72.5	75.4	67.3	74.9	76.4
		2.0	2.4	1.4	**1.8**	2.4
source contribution to overall sound emission	exhaust	10.5%	6.7%	16.8%	10.9%	6.7%
	engine	27.4%	**31.7%**	20.1%	19.9%	**31.7%**
	intake	1.7%	4.1%	0.0%	3.1%	4.1%
	rest	**60.5%**	**57.5%**	**63.1%**	66.1%	**57.5%**
	sum	100.0%	100.0%	100.0%	100.0%	100.0%
	vAA' in km/h				40.3	
	vPP' in km/h				40.1	
	vBB' in km/h				40.1	
	aAA'_BB' in m/s²				-0.02	
	aPP'_BB' in m/s²				-0.01	
Lmax crs in dB(A)	naked				69.1	70.1
	exhaust covered				68.3	69.3
	exhaust + engine covered				68.1	67.6
	fully covered				68.3	68.1
					0.8	2.0
source contribution to overall sound emission	exhaust				16.8%	16.8%
	engine				0.0%	20.1%
	intake				0.0%	0.0%
	rest				**83.2%**	63.1%
	sum				100.0%	100.0%

Table 33: NSR results for vehicle 1 of the TU Graz measurements

Scooter 278 cm³, pmr = 60.1 (vehicle 2)

		Vehicle 2, annex 3, from max values, v and a from naked		Vehicle 2, annex 3, with a_wot and kp from naked			Vehicle 2, ASEP, v_bb = 80km/h WOT		Vehicle 2, ASEP, v_aa = 10 km/h WOT	
		left	right	Lurban	Lwot	Lcrs	left	right	left	right
	vAA' in km/h	43.0					78.2		12.3	
	vPP' in km/h	49.9					79.5		36.0	
	vBB' in km/h	57.5					80.6		45.0	
	aAA'_BB' in m/s²	2.56					0.65		3.29	
	aPP'_BB' in m/s²	2.86		Lurban	Lwot	Lcrs	0.62		2.57	
Lmax wot in dB(A)	naked	81.3	80.4	74.8	80.3	70.8	80.58	80.63	81.00	79.81
	exhaust covered	81.5	79.8	76.0	80.5	72.8	80.40	78.92	80.60	78.22
	exhaust + engine covered	80	78.6	73.7	79	70	79.02	78.46	79.54	77.02
	fully covered	78.1	78.6	71.6	77.6	67.3	78.31	78.88	78.88	77.86
		3.2	**1.8**	3.2	**2.7**	3.5	2.3	1.8	2.1	2.0
source contribution to overall sound emission	exhaust	0.0%	12.9%	0.0%	0.0%	0.0%	3.9%	32.5%	8.7%	30.7%
	engine	25.9%	21.0%	20.7%	25.9%	16.8%	26.3%	6.9%	19.8%	16.6%
	intake	26.3%	0.0%	31.1%	20.4%	38.5%	10.4%	0.0%	10.0%	0.0%
	rest	47.9%	66.1%	48.2%	53.7%	44.7%	59.4%	60.7%	61.4%	52.7%
	sum	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	vAA' in km/h	49.5								
	vPP' in km/h	50.1								
	vBB' in km/h	50.9								
	aAA'_BB' in m/s²	0.25								
	aPP'_BB' in m/s²	0.24								
Lmax crs in dB(A)	naked	71.8	69.3							
	exhaust covered	73.8	71.1							
	exhaust + engine covered	71	69.5							
	fully covered	68.3	68.3							
		3.5	1.0							
source contribution to overall sound emission	exhaust	0.0%	0.0%							
	engine	16.8%	30.8%							
	intake	38.5%	16.7%							
	rest	44.7%	52.5%							
	sum	100.0%	100.0%							

Table 34: NSR results for vehicle 2 of the TU Graz measurements

Standard mid-range motorcycle 373 cm³, pmr = 135 (vehicle 3)

		Vehicle 3, annex 3, 3. gear		Vehicle 3, annex 3 is 3. gear result, kp and acc from naked		
		left	right	Lurban	Lwot	Lcrs
	vAA' in km/h	42.9				
	vPP' in km/h	49.9				
	vBB' in km/h	57.6				
	aAA'_BB' in m/s²	2.59				
	aPP'_BB' in m/s²	2.89		Lurban	Lwot	Lcrs
Lmax wot in dB(A)	naked	77.5	78.1	74.7	77.1	71.5
	exhaust covered	76.6	77.9	74.5	76.9	71.2
	exhaust + engine covered	75.3	76.9	73.0	75.9	69.0
	fully covered	75.1	76.4	72.9	75.4	69.5
		2.4	**1.7**	1.8	**1.7**	2.0
source contribution to overall sound emission	exhaust	18.7%	4.5%	5.5%	4.5%	6.7%
	engine	**21.0%**	19.6%	28.6%	**19.6%**	37.1%
	intake	2.7%	8.2%	0.5%	8.2%	**0.0%**
	rest	**57.5%**	67.6%	65.4%	**67.6%**	**56.2%**
	sum	100.0%	100.0%	100.0%	100.0%	100.0%
	vAA' in km/h	49.7				
	vPP' in km/h	50.2				
	vBB' in km/h	50.4				
	aAA'_BB' in m/s²	0.11				
	aPP'_BB' in m/s²	0.05				
Lmax crs in dB(A)	naked	72.5	72.1			
	exhaust covered	72.2	72			
	exhaust + engine covered	69.6	70			
	fully covered	69.8	70.5			
		2.7	1.6			
source contribution to overall sound emission	exhaust	6.7%	2.3%			
	engine	39.6%	28.5%			
	intake	**0.0%**	0.0%			
	rest	**53.7%**	69.2%			
	sum	100.0%	100.0%			

Table 35: NSR results for vehicle 3 of the TU Graz measurements

Maxi-Scooter 562 cm^3, pmr = 119.5 (vehicle 4)

		Vehicle 4, from max values, v and a from naked		Vehicle 4, annex 3, with a_wot and kp from naked			Vehicle 4, ASEP, 10 km/h at AA WOT		Vehicle 4, ASEP, 80 km/h at BB WOT	
		left	right	Lurban	Lwot	Lcrs	left	right	left	right
	vAA' in km/h	36.3					10.8		68.0	
	vPP' in km/h	50.0					37.7		73.3	
	vBB' in km/h	61.4					52.1		78.8	
	aAA'_BB' in m/s^2	4.30					4.56		2.80	
	aPP'_BB' in m/s^2	4.45		Lurban	Lwot	Lcrs	4.53		2.94	
Lmax wot in dB(A)	naked	80.2	82	74.9	81	71.4	80.29	80.64	81.35	81.85
	exhaust covered	80	81.6	74.0	80.6	70.3	80.39	81.04	81.30	81.69
	exhaust + engine covered	78.9	79.5	72.7	78.5	69.5	78.34	78.52	79.53	79.87
	fully covered	79.2	79.2	72.2	78.2	68.8	78.29	79.31	79.34	79.57
		1.0	2.8	2.7	2.8	2.6	2.0	1.3	2.0	2.3
source contribution to overall sound emission	exhaust	4.5%	8.8%	17.7%	8.8%	**22.4%**	0.0%	0.0%	1.2%	3.5%
	engine	**16.1%**	**35.0%**	20.8%	**35.0%**	**13.1%**	**36.2%**	**38.6%**	**33.0%**	**33.1%**
	intake	0.0%	3.8%	7.4%	3.8%	9.6%	0.8%	0.0%	2.8%	4.2%
	rest	**79.4%**	**52.5%**	54.1%	**52.5%**	**55.0%**	**63.0%**	**61.4%**	**62.9%**	**59.1%**
	sum	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	vAA' in km/h	49.9								
	vPP' in km/h	50.0								
	vBB' in km/h	50.1								
	aAA'_BB' in m/s^2	0.03								
	aPP'_BB' in m/s^2	0.04								
Lmax crs in dB(A)	naked	71.3	72.4							
	exhaust covered	70.4	71.3							
	exhaust + engine covered	70.5	70.3							
	fully covered	69.5	69.8							
		1.8	2.6							
source contribution to overall sound emission	exhaust	**18.7%**	**22.4%**							
	engine	0.0%	**16.0%**							
	intake	**15.2%**	6.7%							
	rest	**66.1%**	**55.0%**							
	sum	100.0%	100.0%							

Table 36: NSR results for vehicle 4 of the TU Graz measurements

Mid-range cruiser 649 cm³, pmr = 147 (vehicle 5)

		Vehicle 5, annex 3, from max values, v and a from naked		Vehicle 5, annex 3, with a_wot and kp from naked		
		left	right	Lurban	Lwot	Lcrs
	vAA' in km/h	43.9				
	vPP' in km/h	50.3				
	vBB' in km/h	58.2				
	aAA'_BB' in m/s²	2.56				
	aPP'_BB' in m/s²	3.01		Lurban	Lwot	Lcrs
Lmax wot in dB(A)	naked	79	79.1	74.4	78.1	68.1
	exhaust covered	78.7	78.1	73.9	77.7	67.3
	exhaust + engine covered	77.4	77	73.6	76.4	66
	fully covered	77.2	76.9	73.1	76.2	65.6
		1.8	**2.2**	1.3	**1.9**	2.5
source contribution to overall sound emission	exhaust	6.7%	20.6%	8.5%	8.8%	16.8%
	engine	24.1%	17.8%	6.4%	23.6%	21.5%
	intake	3.1%	1.4%	8.1%	3.0%	5.4%
	rest	66.1%	60.3%	77.0%	64.6%	56.2%
	sum	100.0%	100.0%	100.0%	100.0%	100.0%
	vAA' in km/h	49.8				
	vPP' in km/h	50.1				
	vBB' in km/h	50.7				
	aAA'_BB' in m/s²	0.16				
	aPP'_BB' in m/s²	0.19				
Lmax crs in dB(A)	naked	68.5	69.1			
	exhaust covered	68	68.3			
	exhaust + engine covered	67	66.7			
	fully covered	66.6	66			
		1.9	3.1			
source contribution to overall sound emission	exhaust	10.9%	16.8%			
	engine	18.3%	25.6%			
	intake	6.2%	8.6%			
	rest	64.6%	49.0%			
	sum	100.0%	100.0%			

Table 37: NSR results for vehicle 5 of the TU Graz measurements

Sports bike 765 cm³, pmr = 331 (vehicle 6)

		Vehicle 6, 3. gear		Vehicle 6, annex 3, a_wot and kp from naked		
		left	right	Lurban	Lwot	Lcrs
	vAA' in km/h	38.8				
	vPP' in km/h	50.4				
	vBB' in km/h	61.6				
	aAA'_BB' in m/s²	4.01				
	aPP'_BB' in m/s²	4.41		Lurban	Lwot	Lcrs
Lmax wot in dB(A)	naked	81.5	81.3	76.7	80.4	73.3
	exhaust covered	79.5	78.7	74.8	78.5	71.3
	exhaust + engine covered	77.7	78.4	73.1	77.4	69.1
	fully covered	77.4	77.4	72.5	76.4	68.7
		4.1	3.9	4.3	4.0	4.6
	exhaust	**36.9%**	**45.0%**	36.9%	**36.9%**	**36.9%**
	engine	**21.4%**	**3.7%**	20.1%	**14.1%**	**25.1%**
	intake	2.8%	10.5%	6.3%	10.1%	3.3%
	rest	**38.9%**	**40.7%**	36.7%	**38.9%**	**34.7%**
	sum	100.0%	100.0%	100.0%	100.0%	100.0%
	vAA' in km/h	50.2				
	vPP' in km/h	50.5				
	vBB' in km/h	50.3				
	aAA'_BB' in m/s²	0.03				
	aPP'_BB' in m/s²	-0.04				
Lmax crs in dB(A)	naked	74.3	72.7			
	exhaust covered	72.3	71.4			
	exhaust + engine covered	69.6	70.1			
	fully covered	69.5	69.7			
		4.8	3.0			
	exhaust	**36.9%**	**25.9%**			
	engine	**29.2%**	**19.2%**			
	intake	0.8%	4.8%			
	rest	**33.1%**	**50.1%**			
	sum	100.0%	100.0%			

Table 38: NSR results annex 3 of ECE Regulation 41, vehicle 6 of the TU Graz measurements

Big bike 1254 cm³, pmr = 308.6 (vehicle 7)

		Vehicle 7, annex 3, from max values, v and a from naked		Vehicle 7, annex 3, with a_wot and kp from naked		
		left	right	Lurban	Lwot	Lcrs
	vAA' in km/h	39.8				
	vPP' in km/h	50.2				
	vBB' in km/h	61.8				
	aAA'_BB' in m/s²	3.92				
	aPP'_BB' in m/s²	4.56		Lurban	Lwot	Lcrs
Lmax wot in dB(A)	naked	78.6	79.5	74.2	78.5	69.7
	exhaust covered	75.4	74.6	72.0	74.4	69.5
	exhaust + engine covered	72.9	72.4	70.2	71.9	68.5
	fully covered	71.7	71.6	69.3	70.7	67.8
		6.9	**7.9**	4.9	**7.8**	1.9
source contribution to overall sound emission	exhaust	52.1%	67.6%	39.6%	61.1%	4.5%
	engine	20.9%	12.9%	20.2%	17.0%	19.6%
	intake	6.5%	3.3%	7.9%	5.3%	11.3%
	rest	20.4%	16.2%	32.3%	16.6%	64.6%
	sum	100.0%	100.0%	100.0%	100.0%	100.0%
	vAA' in km/h	50.2				
	vPP' in km/h	50.5				
	vBB' in km/h	50.8				
	aAA'_BB' in m/s²	0.10				
	aPP'_BB' in m/s²	0.10				
Lmax crs in dB(A)	naked	70.7	70.4			
	exhaust covered	70.5	70.1			
	exhaust + engine covered	69.5	68.5			
	fully covered	68.8	68.7			
		1.9	1.7			
source contribution to overall sound emission	exhaust	4.5%	6.7%			
	engine	19.6%	28.8%			
	intake	11.3%	0.0%			
	rest	64.6%	64.6%			
	sum	100.0%	100.0%			

Table 39: NSR results for vehicle 7 of the TU Graz measurements

Softail 1868 cm³, pmr = 172 (vehicle 8)

		Vehicle 8, annex 3, 3. gear, v and a are for naked		Vehicle 8, annex 3, 4. gear, v and a are from naked	
		left	right	left	right
	vAA' in km/h	39.5		42.7	
	vPP' in km/h	49.9		50.1	
	vBB' in km/h	61.6		59.2	
	aAA'_BB' in m/s²	3.92		2.95	
	aPP'_BB' in m/s²	4.58		3.49	
Lmax wot in dB(A)	naked	80.5	82	78.7	79.3
	exhaust covered	77.6	78.2	74.2	74.4
	exhaust + engine covered	77	75.6	74.5	73.9
	fully covered	76.2	74.5	74.1	73.3
		4.3	7.5	**4.6**	6.0
source contribution to overall sound emission	exhaust	**48.7%**	**58.3%**	**62.0%**	**67.6%**
	engine	**6.6%**	**18.8%**	**0.0%**	**3.5%**
	intake	7.5%	5.1%	3.3%	3.7%
	rest	**37.2%**	**17.8%**	**34.7%**	**25.1%**
	sum	100.0%	100.0%	100.0%	100.0%
	vAA' in km/h	50.2		50.1	
	vPP' in km/h	50.1		50.0	
	vBB' in km/h	50.2		50.0	
	aAA'_BB' in m/s²	0.00		-0.02	
	aPP'_BB' in m/s²	0.02		0.01	
Lmax crs in dB(A)	naked	72.1	70.8	70.6	69.8
	exhaust covered	72	71	69.6	68.7
	exhaust + engine covered	70.6	68.6	70.1	67.3
	fully covered	69.7	67.7	68.4	66.4
		2.4	3.1	2.2	3.4
source contribution to overall sound emission	exhaust	2.3%	**0.0%**	0.0%	**22.4%**
	engine	**26.9%**	42.5%	**10.9%**	21.4%
	intake	13.3%	10.8%	28.9%	10.5%
	rest	**57.5%**	**46.8%**	**60.3%**	**45.7%**
	sum	100.0%	100.0%	100.0%	100.0%