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STEER: Strengthening the Effect of quieter tyres on European Roads

Evaluation of strategies enhancing proliferation of quieter tyres and its implications for NRAs

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Table of content

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Executive summary

This deliverable deals with the definition and description of strategies enhancing the proliferation of low noise tyres and the corresponding business cases, what can be expected in terms of costs, benefits (avoided annoyance and health – costs through the mitigation of high exposure situations) and the general reduction in noise exposure for the population.

Literature has shown, that quieter tyres are available in large varieties on the market. It was found, that the consumer is increasingly aware of a tyre labelling system and is able to interpret it for choosing the right tyre. However, when it comes to the consumer importance, the most important parameter for the consumer is besides safety, the price of the tyre. Noise is only of minor importance. Literature however suggests that the price of the tyres is not directly linked to noise levels. The price of a tyre is mainly dependent of its characteristics and whether it has for instance special run flat characteristics.

Another question in this study is to what extent there is a conflict of goals between a further optimization of tyres regarding noise levels and their wet grip or rolling resistance characteristics. In this report, an analysis of current available market tyres in Switzerland has shown that for summer tyres there are many available options for tyres that perform equally well in all three categories (according to their tyre label). The data presented here suggests that a further optimization of tyres regarding exterior noise is still feasible (because in all C1 tyre width categories many products are available that perform well regarding wet grip and rolling resistance). Industry reports and the prototyping undertaken in STEER by Nokian tyres indicate, however, that it remains a challenge to develop quieter tyres without compromising on other key performances.

The tyre market is strongly linked to the current limit values. Within these limit values the consumer has a large span of tyres to choose from. In order to guide the consumer to buy quieter tyres in the future, different possible strategies have been analysed in detail and their influence on the total noise exposure as well as the resulting costs and benefits have been compared. The following scenarios have been investigated:

- ECE Proposal (stricter limit values for tyres)
- Industry agreement (Output oriented requirements regarding average noise label)
- Consumer incentives for purchasing low-noise tyres

Based on simulations with the model TRANECAM, it was shown that all the selected scenarios could help to reduce population exposed to noise levels above an L_{DEN} of 55 dB(A). The scenario calculations show that for several countries the population exposed to harmful/annoying noise levels can be reduced by 15 % thanks to measures enhancing the proliferation of low-noise tyres. The rough calculation provided in this study show that for the investigated scenarios the avoided costs are likely to outperform the implementation costs of the measures in many countries.

Generally, the analysis has shown, that the proliferation of quieter tyres is an efficient and economically viable option for the reduction of the road traffic noise problem.

However current market trends point towards heavier and more powerful vehicles (mainly SUVs) equipped with wider tyres. As wider tyres are generally louder, a slight increase of the total tyre/road noise levels is to be expected. It is estimated that this increase will be probably not more than 1 dB.

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1 Introduction

In the European Union an estimated 113 million people in EU-28 are exposed to road traffic noise levels of at least 55 dB (L_{DEN}) (European Environment Agency, 2020). These long-term exposure to environmental noise is expected to cause 12 000 premature deaths and contribute to 48 000 new cases of ischaemic heart disease per year in the European territory (European Environment Agency, 2020). It is estimated that 22 million people suffer chronic high annoyance, and 6.5 million people suffer chronic high sleep disturbance.

It is however likely that these significant health impacts are underestimated, as the new WHO (World Health Organization) guidelines demonstrate that noise has adverse health effects below the obligatory END (European Noise Directory) reporting thresholds (European Environment Agency, 2020). In addition, the END not comprehensively covers all urban areas, roads, railways and airports across Europe.

Given the population growth in the EU the increasing demand for mobility, the pressure created by road traffic noise is likely to increase in the near future.

Road traffic noise is the most dominant source of environmental noise compared to air and rail traffic. A useful measure to reduce road traffic noise are measures at the source. Measures at the source include low-noise pavements, sound barriers or speed reduction, as well as the use of quiet tyres.

Quieter tyres are a sensible measure, considering that most of the noise emitted by vehicles occurs at the interface between the road surface and the tyre. With increased electromobility in the near future, the importance of tyres is also likely to increase as the emission of the drivetrain is diminishing. A recent study performed in Switzerland (Hammer & Bühlmann, 2018), for example, showed that rolling noise reductions of 2 to 4 dB(A) are achievable depending on the choice of tyre. In this investigation, different tyres available on the market were selected.

The tyre noise label constitutes an effective tool to evaluate and control the noise emissions from tyres. The current tyre noise limits are defined by European Commission and regulated in EC 661/2009[1]. The external tyre noise for labelling has to be measured in accordance to ECE-R117[2].

1.1. Tyre labelling system in the European Commission

In 2009, the European Parliament and the Council adapted the tyre labelling regulation (Regulation (EC) No 1222/2009) to promote sustainable mobility in EU. The aim of this regulation was to harmonize the labelling system for tyres with respect to fuel efficiency and other important parameters. This regulation applies to tyres of categories C1 (passenger cars, vehicles categories categories M_1, N_1, O_1 and O_2), C2 (light commercial vehicles, M2, M3, N, O3 and O4) and C3 (heavy duty) as defined in Regulation (EC) No 661/2009[3]. The tyre labelling system shown in Figure 1-1 has been implemented using a distinct color scheme to rate tyres in terms of fuel efficiency and other important parameters.

[1] https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:200:0001:0024:DE:PDF
[2] https://eur-lex.europa.eu/legal-content/DE/TXT/?uri=CELEX%3A42011X1123%2803%29
[3] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32009R0661

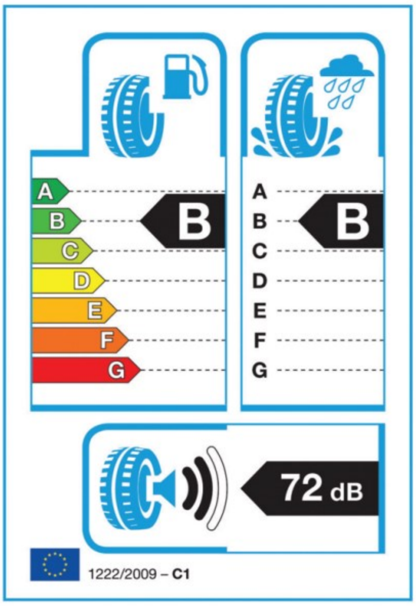


Figure 1-1: Old tyre labelling system (Valid until 30.04.2021). Source of figure: European Commission, EC 1222/2009-C1[4]

This regulation was repealed by 30.04.2021 and replaced with the new regulation (EU) 2020/740[5] from 01.05.2021. Car and van tyres bearing the old label may still be sold until the end of 2021. The main difference regarding the tyre noise is, that the rating with sound waves has been replaced by the A-C classification, where A is the quietest tyre and C is the loudest. Furthermore, optional pictograms have been added to cover snow grip for winter tyres and/or ice grip for Nordic winter tyres.

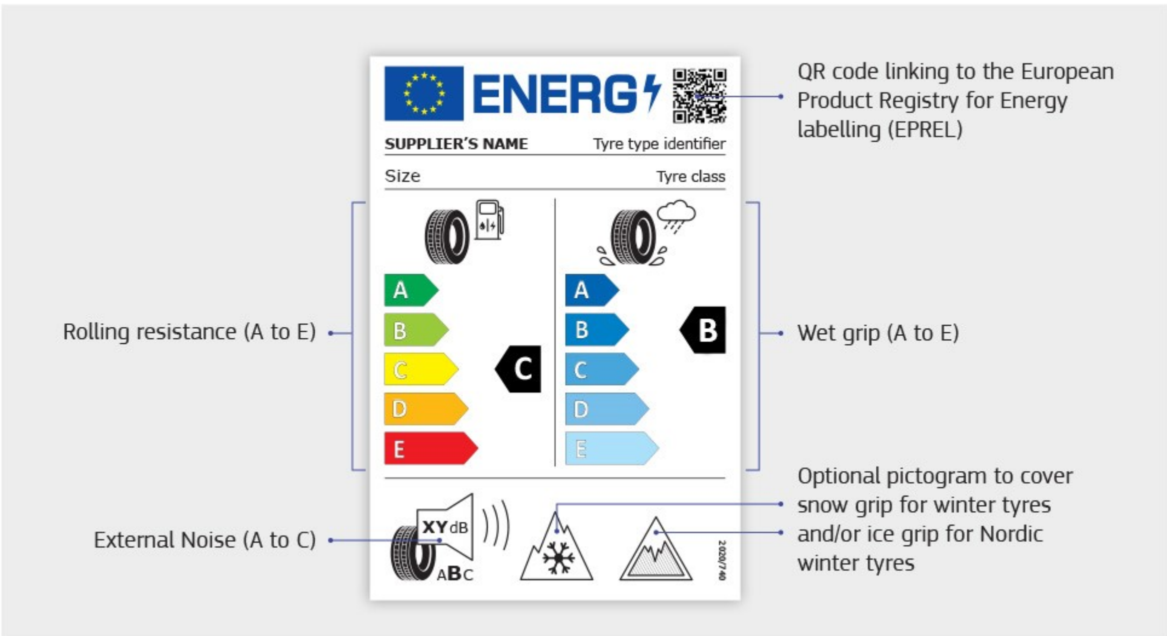
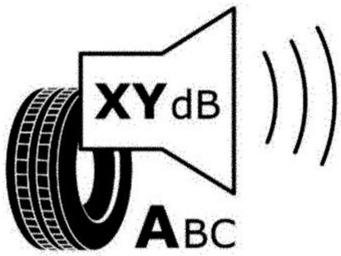
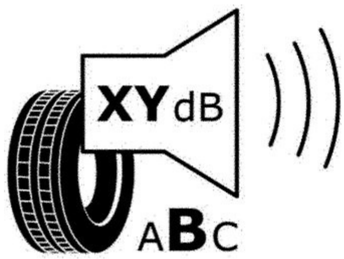
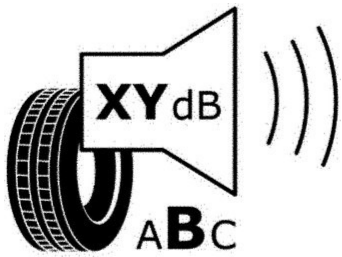


Figure 1-2: New EU rules on the energy labelling of road tyres, valid from 01.05.2021. Source of figure: European Com-mision.[6]

[4] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009R1222&from=EN
[5] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32020R0740&from=EN
[6] https://ec.europa.eu/info/news/new-tyre-labelling-rules-apply-1-may-2021-2021-apr-29_en

The external rolling noise measured value (*N*, in dB(A)) shall be declared in decibels and calculated in accordance with Annex 3 to UNECE Regulation No 117. The external noise class of a tyre should be illustrated as defined in the following Table 1-1.

Table 1-1: External noise classes and their noise label pictogram as defined in REGULATION (EU) 2020/740[7]

$N \leq LV - 3$	$LV - 3 < N \leq LV$	$N > LV$
		

The corresponding limits values are defined in the No 661/2009

Table 1-2: Current noise limit values valid for C1-tyres.

Tyre class	Nominal section width (mm)	Limit values in dB(A)
C1A	≤ 185	70
C1B	> 185 ≤ 215	71
C1C	> 215 ≤ 245	71
C1D	> 245 ≤ 275	72
C1E	> 275	74

For snow tyres, extra load tyres or reinforced tyres, or any combination of these classifications, the above limits shall be increased by 1 dB(A).

[7] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32020R0740&from=EN

2 Strategies Enhancing Proliferation

After initial fitting by the manufacturer, tyres are generally replaced every 2-5 years, depending on their type of use and durability. When it comes to replacement, consumers often rely on the recommendation of their garage owner / tyre dealer and only look at the product itself to a limited extent. Therefore, the garage owner or tyre dealer has a great influence on the consumer's final choice of tyre.

2.1. Influencing factors for consumers choice

According to the literature, various factors that influence consumers' choice of tyres can be identified. These factors are described in more detail in the following subsections.

2.1.1. Tyre price versus noise levels.

In (Maura Killer, Suter, & Ehmann, 2019), a questionnaire among tyre manufacturers regarding the relation of the tyre price versus the noise levels has been performed. It was found that the tyre price is generally not influenced by the noise label itself, but rather when a tyre is from the manufacturer’s premium tyre line or when the tyre has special features, e.g., when it is an original equipment tyre or the tyre has run-flat properties. The same conclusions can be drawn from the study of (De Graaff & Van Blokland, 2007), which examined 141 different pairs of sound levels vs. tyre prices, finding only weak correlations were found between the tyre price and the exterior noise levels. Hence, there seems to be only a very weak (or no) dependency between tyre price and noise. As a result, there currently appears to be no financial incentive for consumers to opt for quieter tyres.

2.1.2. Safety, rolling resistance and noise

The tyre represents the connection between the road surface and the vehicle. Consequently, the tyre must fulfil various aspects, which include safety as well as energy consumption in the form of the rolling resistance coefficient. The noise emission of the tyre is influenced by many factors including the material (rubber hardness), rubber dampening amount in the sidewalls, tyre profile, tyre width, etc. All these characteristics also influence the other components of tyres, as also stated in STEER WP 5.5 (Impediments) and described in this deliverable in section 6, page 52.

However, several studies reveal none to some very weak correlations between tyre noise labels and wet grip or rolling resistance (De Graaff & Van Blokland, 2007; FEHRL, 2006; Grunder, 2019; Haider, Wehr, Conter, Strohmayer, & Hoislbauer, 2011; Kragh & Oddershede, 2013; Milford, Aaseboe, & Strommer, 2014; Sliggers & Graaff Erik, 2017). The literature of the past 20 years does not show a clear picture of the trade-off between noise and safety / rolling resistance. However, several studies reveal no or only very weak correlations between tyre noise labels and wet grip or rolling resistance. (De Graaff & Van Blokland, 2007; FEHRL, 2006; Grunder, 2019; Haider et al., 2011; Kragh & Oddershede, 2013; Milford et al., 2014; Sliggers & Graaff Erik, 2017).

A recent study on the “*tyre performance of noise versus other performances*” however shows, that “obtaining a low level of rolling sound performance without a compromise regarding other parameters essential for vehicle safety and CO_2 emission reduction could not be proven as feasible by the study” (ACEA UTAC, 2019; Scorianz, 2021). From this study, it can be concluded that in order to achieve a low rolling noise level, certain compromises have to be made on other relevant parameters such safety. However, it is also worth mentioning that among the 16 tyres tested, there were also those that scored well in terms safety, while still providing a low rolling noise level. It is suggested by the authors of the

ACEA – study to extend the analysis done, to check if the outcomes are reproducible for different tyres as well.

2.1.3. Consumer importance of tyre labels

(Maagøe, 2016) investigated the end-users' awareness of the tyre labelling system and to what extent it influences their tyre purchasing behaviour. The survey was conducted with 6000 private car in six EU countries (Italy, Sweden, France, UK, Finland, Germany, 1000 each).

The survey showed that half of the private car owners were aware of a tyre label. As the survey was conducted from 2012 to 2016 and the label was introduced from 2012, the number of end-users might be higher by now, as a positive trend among end-users was observed. The survey also showed that most users understood the labelling system. However the noise labelling system was the least "easy to understand pictogram" among the three labels. With the newly introduced labelling system (compare Figure 1-2), this might change as well.

In Figure 2-1, the importance of the information on the label for the end-users (consumers) is shown. The data is taken from (Maagøe, 2016).

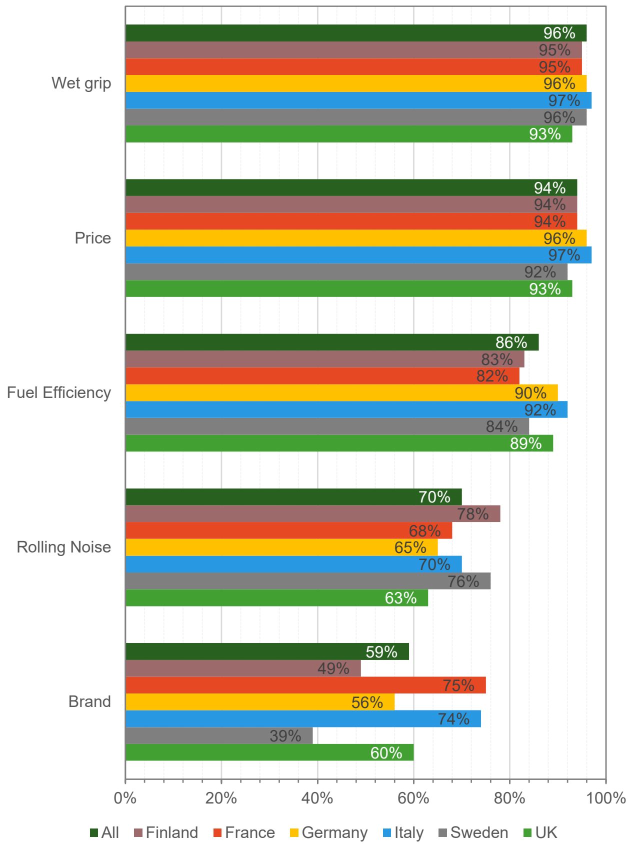


Figure 2-1: Importance of the information on the label for each performance parameter on the label (proportion of consumers who answered *very important* or *important*).
Source of data: (Maagøe, 2016)*, graphic by the authors.*

The figure shows that consumers (end-users) attach the greatest importance to wetness, followed by price. Rolling noise is only rated as *important* or *very important* by 70%. The fact that wet grip is a key performance parameter is also mentionned in other studies (Sandberg, 2008). Hence, it can be concluded, that consumers rather prioritise safety over rolling noise.

2.1.4. Consumer willingness to pay

Different investigations have been made, in order to determine the amount a consumer is willing to pay for low-noise tyres. It was found that "*when consumers have been asked about their interest in various tyre performances, noise has come up as a parameter of interest and where consumers have expressed willingness to purchase low-noise tyres, even if such tyres would cost a little extra*" (Sandberg, 2008).

As mentioned in the previous chapters, the literature has also shown that the price of quiet tyres is not necessarily related to the noise level. Therefore, it can be assumed that, for the time being, the choice of quiet tyres is not necessarily associated with higher financial costs for the consumer. The combination of these aspects leads to the conclusion that the introduction of low-noise tyres (from today's point of view) should not have a major financial impact on the consumer. This means that the consumer should already be able to choose a low-noise product, regardless of the purchase price. The study by (Sandberg, 2008) shows, however, that certain consumers would be willing to pay a higher price for tyres if they could buy a more environmentally friendly (quieter) product. However, the study also showed that about 1/3 of the people would not be willing to pay more for a quiet tyre.

2.2. Strategies for the proliferation of quieter tyres

As indicated in the previous chapter, the legal framework has a major influence on the availability of tyres. The legal framework represents the general framework within which tyres are also found on the market. In the first part of this section, an overview on the current tyre market is given, serving as a starting point for developing scenarios in part two of this section.

2.2.1. Landscape of available tyres on the market

When new tyre noise limits are introduced, the question arises as to which tyres are affected by a change and which tyres are available on the market at all. Since market data on tyres is regarded as business secret by the industry and therefore difficult to obtain, alternative data sources were looked for providing a better picture of the current landscape of market tyres. With permission from the Swiss Federal Office for the Environment FOEN, a product database comprising of all C1 tyre products approved for selling in Switzerland including complete information on their tyre label and performance dimensions was further analyzed for this purpose[8].

A multi-dimensional analysis for C1-tyres was carried out by combining the different categories wet-grip and rolling resistance using a evaluation matrix on the parameters (shown in the top left of Figure 2-2 (summer tyres) and Figure 2-3 (all-season tyres)). The analysis is separately performed for for different **tyre widths** (C1A = narrow tyre & C1E = wide tyre) The evaluation matrix allows to combine the two categories (**rolling resistance** and **wet grip**) using a simple color code (green = favourable values, red = unfavourable values).

Furthermore, the red boxes around the tyre charts show the current tyre noise limits (solid line) and which tyres fulfill these limits. Some tyres are above the limit in each case. These tyres are the so-called extra load tyres, for which an additional decibel to the limit value is granted. With this evaluation, it is now possible to assess the tyres on the tyre market, whether a shift in the noise limits (ban, red dashed lines) will result in changes for the end consumer and whether there may be restrictions on the "best" tyres.

[8] Excerpt from the database: https://www.tcs.ch/de/testberichte-ratgeber/tests/reifentests/

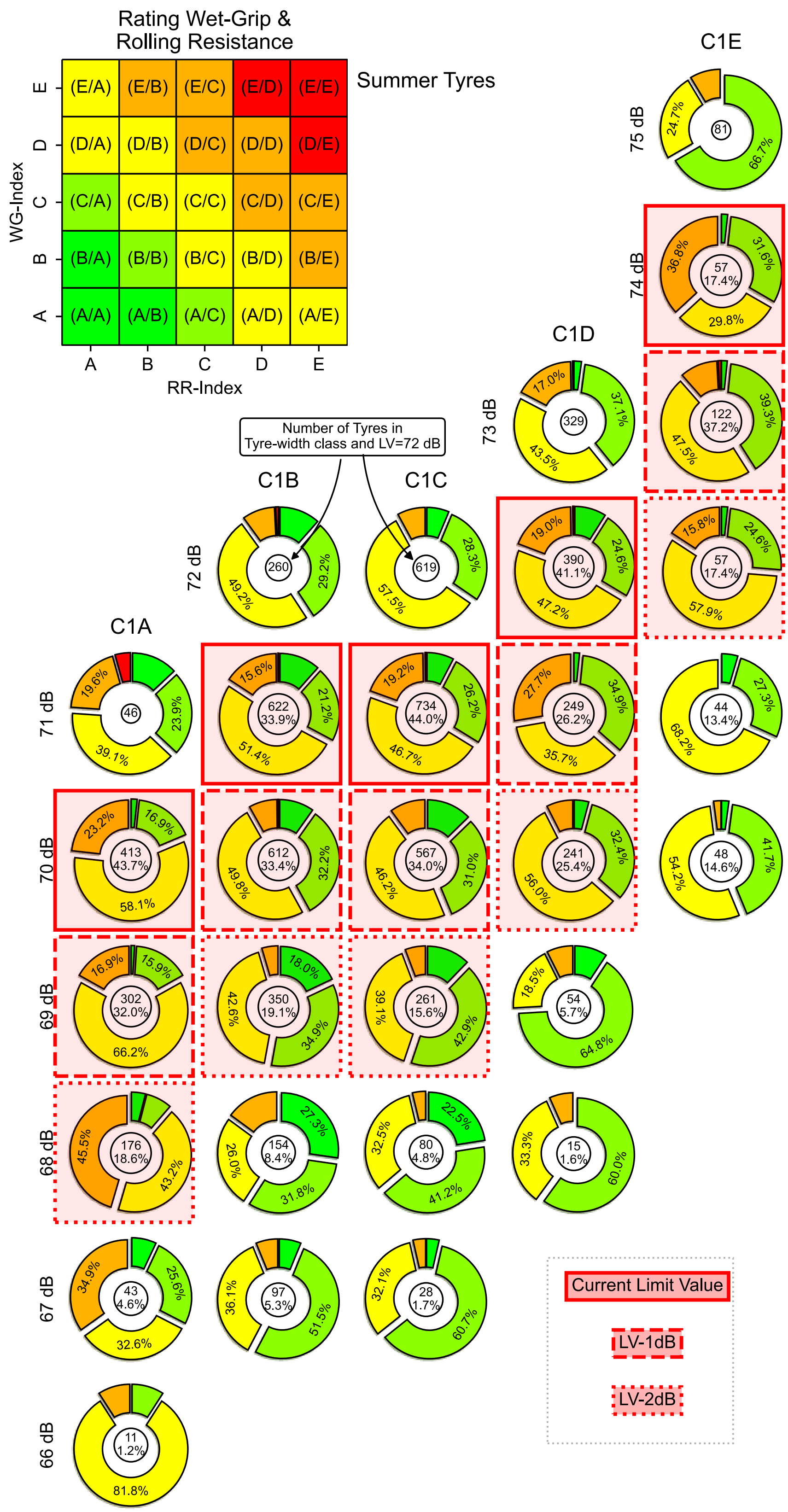


Figure 2-2: Rating of C1 **summer-tyres** (Switzerland 2021) sorted according to their tyre width (hypothetical X-Axis, rated A-E according to EC 661/2009). On the hypothetical Y-Axis the noise limits are depicted. The colours indicate the related Wet-Grip / Rolling Resistance-Index as defined by the matrix. *Source of data: Touring*

Club Switzerland, Illustration and evaluation by the authors, financed by the Swiss Federal Office of the Environment FOEN[9].

Figure 2-2 shows that as the noise limits shift (downwards on the y-axis), fewer tyre types will be available on the market. It can be seen that a large proportion of the available tyres are close to the noise limits. This is shown as a percentage in the figure.

Stricter noise limits will result in less choice for the consumer as some tyres are no longer permitted to mount/use. It remains to be emphasized, however, that especially in the two other categories there is no obvious deterioration in the assessment of wet-grip safety and rolling resistance. Conversely, the tendency is actually the other way round: Although fewer tyres will be avialable, the proportion of the best-rated tyres actually tends to increase. This applies to practically all tyre widths.

When looking at all-season tyres (Figure 2-3), it is noticeable that the ratings tend to shift into the yellow/orange range. Consequently, there are far fewer tyres in the green category (A/A, A/B, B/A) compared to summer tyres. This can be explained by the fact that all-season tyres represent a certain compromise between the performance classes. It is also to be expected that there will be more tyres with a pronounced tread in this tyre segment, which should have an impact on the ratings.

[9] https://www.bafu.admin.ch/bafu/en/home.html

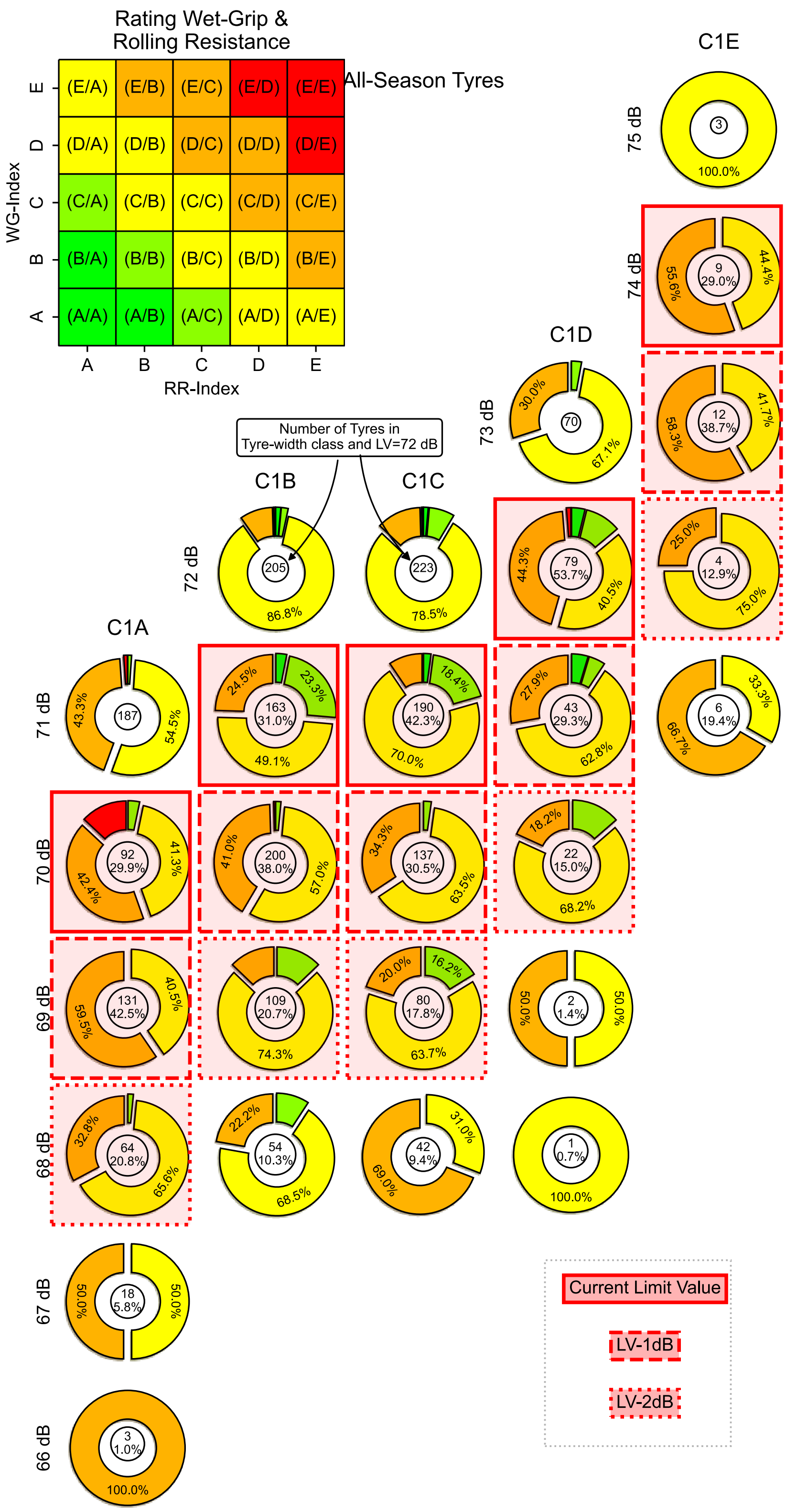


Figure 2-3: Rating of C1 **all-season tyres** (Switzerland 2021) sorted according to their tyre width (hypothetical X-Axis, rated A-E according to EC 661/2009[10]). On the hypothetical Y-Axis the noise limit values are depicted. The colours indicate the related Wet-Grip / Rolling Resistance-Index as defined by the matrix. *Source of data: Touring Club Switzerland, Illustration and evaluation by the authors, financed by the Swiss Federal Office of the Environment FOEN[11].*

[10] https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:200:0001:0024:DE:PDF
[11] https://www.bafu.admin.ch/bafu/en/home.html

It is important to note that this kind of evaluation is limited to the four parameters: noise, wet grip and rolling resistance as well as tyre width. The parameters considered therefore contain all the information that the consumer can find on the old tyre label. On the new tyre label (from 2021), optional pictograms for snow/ice grip will be added.

In addition to the four parameters considered, a tyre must meet other requirements, such as durability, handling on dry roads, etc. Likewise, no conclusion can be drawn from the illustration about the tyre price. This data was not available to the project consortium.

2.2.2. Possible strategies for NRA for the proliferation of quieter tyres

For National Road Administrations (NRA) there are several handling options regarding the proliferation of quieter tyres. However, the NRA's are bound by the current limits. They have only a limited influence on the consumer's final choice. However, there are options for action, which are briefly explained below. It is clear that not all of these options for action are equally realistic or can be equally supported by the different stakeholders. Furthermore, not all of the presented strategies can be directly addressed by the NRA’s. But as we are dealing in a European context, the NRA’s from different member states may have different authorizations and thus, for the elaboration of the different strategies has to the national requirements must be taken into account.

- **Tighter limits (European Commission)**: The current noise limit values will be adapted according to a defined procedure. This leads to a de facto ban on the sale, distribution, and entry into service of tyres of a certain noise class.

- **Promotion of technology**: This strategy targets the development of (new) quieter tyres by the industry. In this context, the development of quieter tyres is to be promoted and financially supported.

- **Industry agreement, output oriented average**: Comparable to the regulation (EU) 2019/631 for CO_2 of passenger cars and light commercial vehicles. Manufacturers have to comply with a defined fleet average regarding CO_2 and will be fined if they do not comply with the assigned fleet average. For noise, a comparable mechanism is imaginable.

- **Voluntary branch agreement:** Tyre dealers and tyre manufacturers sign a voluntary agreement that tyres exceeding a certain noise limit will no longer be produced or sold. This approach follows the solution of other environmental substances. For example, the Montreal Protocol[12] phased out the production and use of ozone-depleting CFCs (halogenated hydrocarbons).

- **Incentives for consumers to buy quieter tyres**: This option envisages that the purchase of quiet tyres will be financially relieved. One possibility could be that the purchase of quiet tyres could be promoted by the exemption of VAT.

- **Information campaign**: The information campaign aims to promote consumer awareness on the issue of noise. One possible aim of an information campaign could be to encourage consumers to choose a low-noise tyre.

[12] https://treaties.un.org/doc/publication/unts/volume%201522/volume-1522-i-26369-english.pdf

- **Recommendations for procurement of low-noise tyres in the public sector**: The road or transport authorities as well as the environmental authorities are very big players in the market. They may recommend or decide that low-noise tyres must be used when procuring tyres or vehicles are to be procured, tyres shall be of low-noise type. This may also be implemented by communal or regional authorities. Since in many cases they have private companies provide various services that have to be approved by an authority (e.g. bus or taxi transport), the authorities can also require such private companies to use only low-noise tyres. This would have a substantial effect on the market.

- **Incentives for garages/tyre sellers in the aftermarket:** Most of the consumers rely on the recommendation of their tyre seller/garagists, when a replacement of the tyre is needed. Accordingly, financial benefits for the sellers/garagists could be implemented, when they successfully advise to sell AAA-tyres in order to increase the proliferation of quieter tyres.

3 Business cases for NRAs

In this task, different variants and business cases for NRAs are examined. The focus was laid on the evaluation of possible benefits regarding noise reduction strategies by the proliferation of quieter tyres in the different EU Member States.

3.1. Calculation procedure

The analysis performed in this is closely linked to the calculations performed in the STEER Task 5.4 (More details are available in the corresponding Task report

3.1.1. Estimation of benefits (environmental benefits)

The estimation of benefits is based on (European Commission, 2019)

Table 3-1:. Environmental costs of traffic noise for the EU28 (€2016/dB/person/year) L_{DEN} (taken from (European Commission, 2019)).

L_{DEN} [dB(A)]	Annoyance [$€_{2016}$/dB/person/year]	Health [$€_{2016}$/dB/person/year]	Total [$€_{2016}$/dB/person/year]
50-54	14	3	17
55-59	28	3	31
60-64	28	6	34
65-69	54	9	63
70-74	54	13	67
≥75	54	18	72

From Table 3-1 it follows, that the total environmental costs comprise of two aspects: The annoyance costs as well as the health costs. Both costs have a different behaviour with increasing sound levels. While annoyance costs increase with a step-function, health costs increase in a squared relationship (Figure 3-1). In order to calculate detailed costs for the reductions, the total environmental costs were parameterized, which are composed of the two functions shown in Figure 3-1.

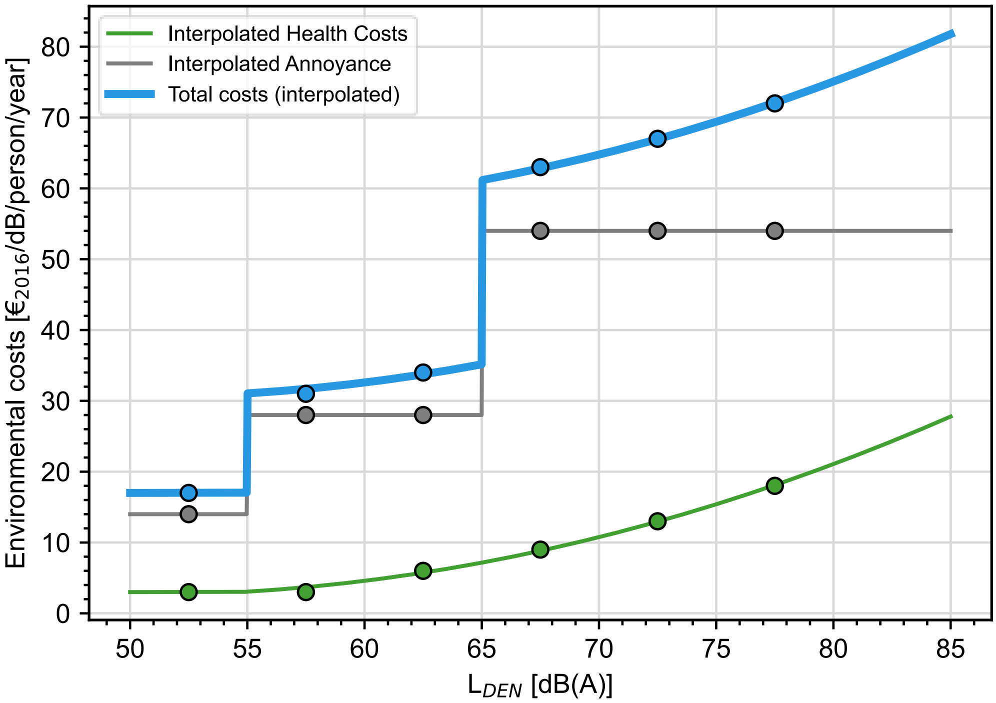


Figure 3-1: Interpolated environmental costs (health & annoyance). The blue line indicates the parameterized total environmental costs.
Source: data from (European Commission, 2019)*, calculation and illustration by the authors.*

In (Salomons et al., 2021), different noise reduction solutions were compared across the European union. In that report, the cost calculations are based on environmental prices, however a second method has been applied, based on the EU project *Heimtsa* (van den Hout et al., 2011). Nevertheless, it was found that "*The costs estimated with method 1 {environmental costs} are considerably higher than the costs estimated with method 2, up to a factor of 4*". This reflects that noise impact assessments are subject to a large uncertainty. In the work presented here, the benefits are only evaluated based on the indicated environmental costs according Table 3-1.

3.1.2. Scenario calculation with TRANECAM

All the scenarios are calculated with the most recent model of the TRANECAM model (Pardo & Steven, 2010). The advantage of the TRANECAM model is that it calculates the effects of the two noise sources, engine noise and rolling noise, separately. Therefore, the different scenarios can be implemented by reducing rolling noise, as the quiet tyres reduce rolling noise generation. All TRANECAM calculations were carried out by Heinz Steven.

3.2. Exposure assessment

The European parliament has decreed with the EU-Directive 2002/49/EC (THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION, 2001) that noise pollution must be collectively recorded and monitored within the European Union as an important environmental variable. The directive 2002/49/EC (Environmental Noise Directive – END) is therefore the main EU instrument for determining noise exposure. Member states have to report every 5 years on the status of noise pollution in the defined agglomerations covered by the Noise Directive. As defined in EU-Directive 2002/49/EC, these are larger municipalities with more than 100’000 inhabitants. Furthermore, the directive requires the member states to report on their action plans and noise maps for:

- agglomerations with more than 100’000 inhabitants
- major roads (more than 3 million vehicles per year)
- major railways (more than 30’000 trains per year)
- major airports (more than 50’000 movements per year, including small aircrafts and helicopters)

The evaluation of reported noise indicators has illustrated that transportation noise, and in particular road noise, has a major impact on the general health of the European population (European Environment Agency, 2020; Reichel, Mortensen, Asquith, & Bogdanovic, 2014).

For the assessment of the different scenarios in this project, the exposure assessment according to END (European Environment Agency, 2020) and the published data[13] were used to estimate the current noise situation in the agglomerations in Europe. The reporting of the END-Data is still lacking and far from complete, as was stated in (European Environment Agency, 2020): “Although some progress has been made on the reporting of noise mapping by countries, more than 30% of data required is still not available after the 2017 END legal reporting deadline. In terms of reporting action plans, significant delays and poor quality suggest that countries may not have taken the necessary steps to address noise pollution. To protect the health of the European population, better implementation of the END is needed.” Furthermore, the total number of people affected is even higher, as the burden is not limited to municipalities with more than 100’000 inhabitants according to the END-Definition. According to END the number of people affected along major roads outside agglomerations are around 45% compared to people in agglomerations. Moreover, the new WHO guidelines indicate that the harmful effects on sleep disturbance and fatigue start far below the 55 dB limit according to the END definition (Basner & McGuire, 2018). However, the reported data are still the best (in terms of availability and comparability) publicly available source, and for this study, the data were taken as published and no further corrections were applied (e.g. gap filling). Figure 3-2 shows the total population[14] for the EU-Countries with a road traffic noise level L_{DEN} > 55 dB for agglomerations. In the figure, the funding countries of the STEER – Project as well as Switzerland are labelled. In this figure, only the agglomerations (population size > 100’000) were taken into account, and thus around 70% of the population in END is covered.

[13] Link to the data: https://www.eea.europa.eu/data-and-maps/data/data-on-noise-exposure-7/noise-exposure-information-under-the/end_df4_df8_results_2017.xls, (Last visit: 23.09.2021)

[14] According to END-definition

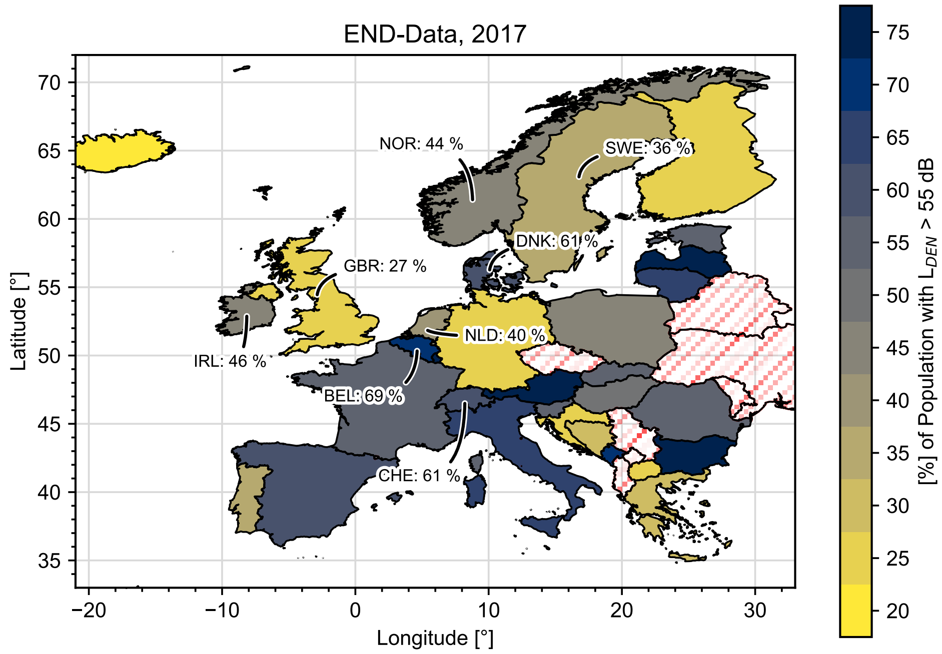


Figure 3-2: Percentage of population[14] exposed to road traffic noise levels L_{DEN} > 55 dB for agglomerations. Non-reported data are hatched and marked in red. (population size > 100'000) Source of data: (European Environment Agency, 2020), Graphics by the authors.[15]

The data shows, that in some countries a high percentage of the population in the agglomerations is exposed to high road noise levels. It is also clearly visible, that between different countries there is a high variability.

3.2.1. Extrapolation and refinement of END-Data

The noise bands reported in the ranges specified in the European Noise Directive (END) are divided into 5 dB bands, with the lowest band between 55 dB and 60 dB. These ranges are too large and too coarse to extract fine differences from the scenarios. Accordingly, the END-Data were refined according to the approach described in (van den Hout et al., 2011).

The lowest bands are extrapolated using the following approach:

$$P_{45-50} = 1/3 * P_{rem}$$

$$P_{50-55} = 2/3 * P_{rem}$$

With:

$$P_{rem} = 1 - (P_{55-60} + P_{60_65} + P_{65-70} + P_{70-75} + P_{>75})$$

The total number of inhabitants was furthermore used to calculate P_i with i representing the noise classes.

With the extended noise classes (for the low emission classes), the distribution was parameterised using a kernel density estimator. Using this density estimator, the original bin width of the END-Data of 5 dB was reduced to a bin width of 0.05 dB. The following Figure 3-3 shows the resulting (interpolated and refined) distribution of the noise population with a bin- width of 0.05 dB. The summation of all values thus results in the total amount of the population.

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[15] Link to the data: https://www.eea.europa.eu/data-and-maps/data/data-on-noise-exposure-7/noise-exposure-information-under-the/end_df4_df8_results_2017.xls, (Last visit: 23.09.2021)

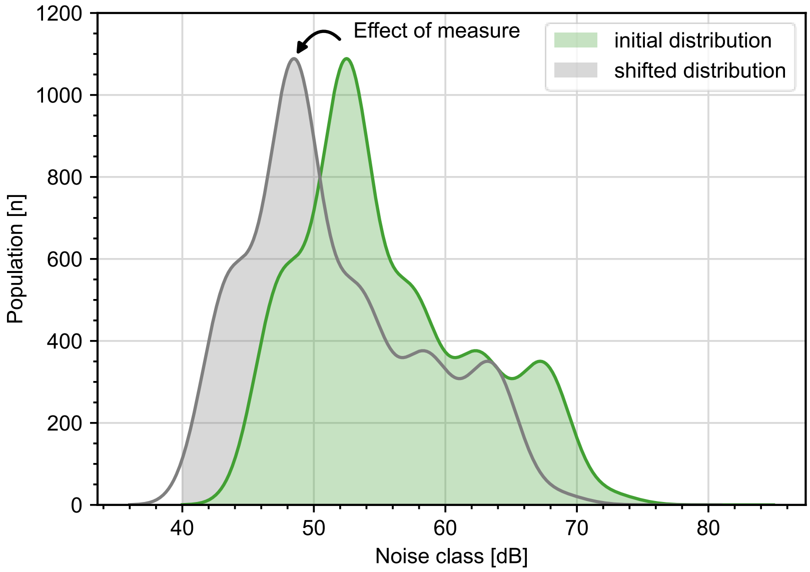

Figure 3-3: Illustration of interpolated and refined END-Data and the effect of a potential measure resulting in a different distribution (gray).

In Annex A, the selected cumulative distributions of noise population densities and their relationship to the original END data can be found.

In Figure 3-3, the basic methodology of calculating the effect of a scenario (noise abatement measure) is depicted. A change in the total noise level leads to a shift in the distribution. Thus, with lower exposure a higher number of the population is exposed to lower noise levels. It has to be stated that the simple shift of the exposure distribution is an assumption and that the shape of the exposure distribution may change in reality as the effects of the noise measures are not equally distributed over the whole noise level range.

This methodology was applied to all the END-Agglomerations reported in 2017. In total, this results in 528 different noise-population densities for the European Union. (Compare selected distribution curves given in Annex A, page 73)

Based on a questionnaire submitted to the CEDR[16] (organization of European national road administrations), different business scenarios have been designed and their effect on the total noise reduction potential has been assessed. The scenarios are described in the following paragraph.

[16] https://cedr.eu/

3.3. Scenario description

In the following Table 3-2, the different evaluated scenarios are listed. For all the scenarios, the reference scenario (status quo) is always included and thus, the enforcement of the directive 2009/661/EC is taken into account in all the scenarios calculated. This also makes it possible to compare the individual scenarios directly with each other and the consequences of the implementations can be studied while everything being equal.

Table 3-2: Scenarios for calculating the impact of tyres

Scenario Name	Short description
Reference (Status quo)	Defined in 2009/661/EC, status quo, nothing happens (already calculated)
Scenario 1, Baseline ECE-Proposal	ECE-Proposal 2022
Scenario 2, Industry agreement	Output-oriented noise levels average for tyres
Scenario 3, Subsidies for tyre manufacturers	Subsidies for tyre manufacturers to produce tyres with LV-3
Scenario 4, Consumer incentives	Potential incentives to consumers buying cat. 1 tyre (LV-3 tyre)

3.3.1. Reference (status quo)

The reference scenario comprises of the so-called *status quo*. This *status quo* serves as the basis for all other scenarios and includes the EU regulation 540/2014[17] on the sound level of motor vehicles and of replacement silencing systems and, of course, EU regulation 661/2009[18]. Especially the regulation 540/2014 prescribes a tightening of the vehicle noise limit in the type-approval in three stages for the years 2022 (stage 2) and 2024-2026 for stage 3.

3.3.2. Scenario 1, Baseline ECE-Proposal

The *scenario 1, ECE-Proposal* comprises of the proposal of the Netherlands[19].

The *ECE-Proposal* foresees a reduction of all three different types of tyres C1-C3 as specified in Table 3-3.

Table 3-3: Reduction of noise limits according the ECE-Proposal.

Year	Tyre-type C1	Tyre-type C2	Tyre-type C3
2022	1 dB	1 dB	-
2024	-	-	2 dB
2032	3 dB	2 dB	
2034	-	-	4 dB

3.3.3. Scenario 2, Industry agreement

[17]Regulation (EU) No 540/2014: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32014R0540
[18]Regulation (EC) No 661/2009 https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A32009R0661
[19] Informal document GRB-62-11-Rev.1, 64th GRB, 5-7 September 2016, agenda item 7

The scenario, *Industry Agreement* requires tyre manufacturers and tyre dealers to sign a letter of intent. The basic idea is that quiet tyres are already available on the market and only consumer buying behaviour needs to change. This is to be achieved with an industry agreement so that the sum of all tyres sold does not exceed a certain threshold level of noise (compare annex B, page 77). This measure is comparable to other areas. For example, EU regulation 2019/63 sets the maximum CO_2 emissions for passenger cars and light commercial vehicles in Europe.[20]

Put simply, the system works in such a way that vehicle manufacturers have to comply with a certain limit value for CO_2 emissions (weighted according to vehicle weight). In case of non-compliance, the manufacturer is fined for exceeding the limit. With regard to noise limits, a similar system would be conceivable.

3.3.4. Scenario 3, Subsidies for tyre manufacturers

This scenario originally envisaged that the design of quiet tyres should be supported. With subsidies, the development of quiet tyres by tyre manufacturers would be boosted. However, this scenario is problematic with regard to European legislation. For example, no subsidies to private manufacturers are possible. Similarly, subsidising European tyres would have a significant impact on the global market economy. For this reason, it was decided within the STEER consortium not to pursue this scenario any further.

However, the principle that technological progress can lead to the development of quieter tyres cannot be completely abandoned. But this would have to be solved on a European level in a way other than subsidies.

3.3.5. Scenario 4, Consumer incentives

This scenario involves a shift in consumer behaviour. The objective of this scenario is to encourage the consumer to buy a Cat. 1 (noise) tyre. The purchase of these tyres is to be financially exempt from VAT.

[20]Regulation (EU) 631/2019: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32019R0631&from=DE

3.4. Resulting exposure reductions

In Figure 3-4, the resulting total reduction in comparison to the baseline scenario (*status quo*) is shown for the different scenarios and the years 2030 and 2040. It is apparent, that the reduction will increase in the year 2040 for all scenarios, as they all include the final stage of the EU 540/2014[21] with the reduction of engine noise. As the engine noise will be further reduced as defined in the regulation, the even already dominant influence of the tyre noise will become even more important.

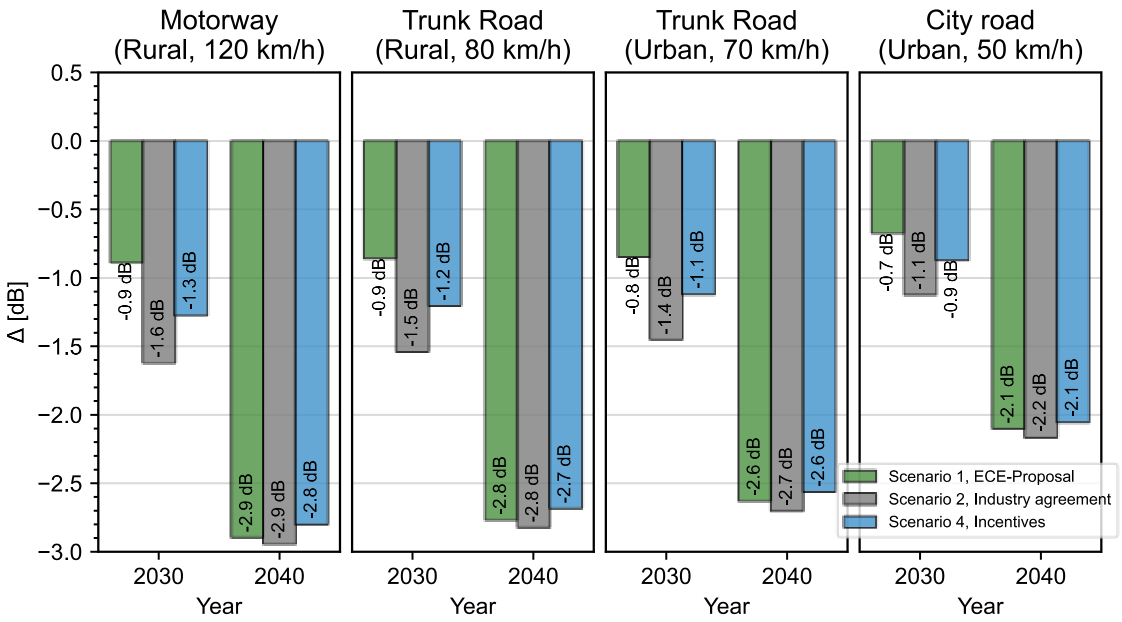

Figure 3-4: Result of scenario modelling, free-flowing traffic for different road categories and the two years 2030 and 2040. The results indicate the total noise reduction of road noise in comparison to the reference scenario.

[21] Regulation (EU) No 540/2014: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32014R0540

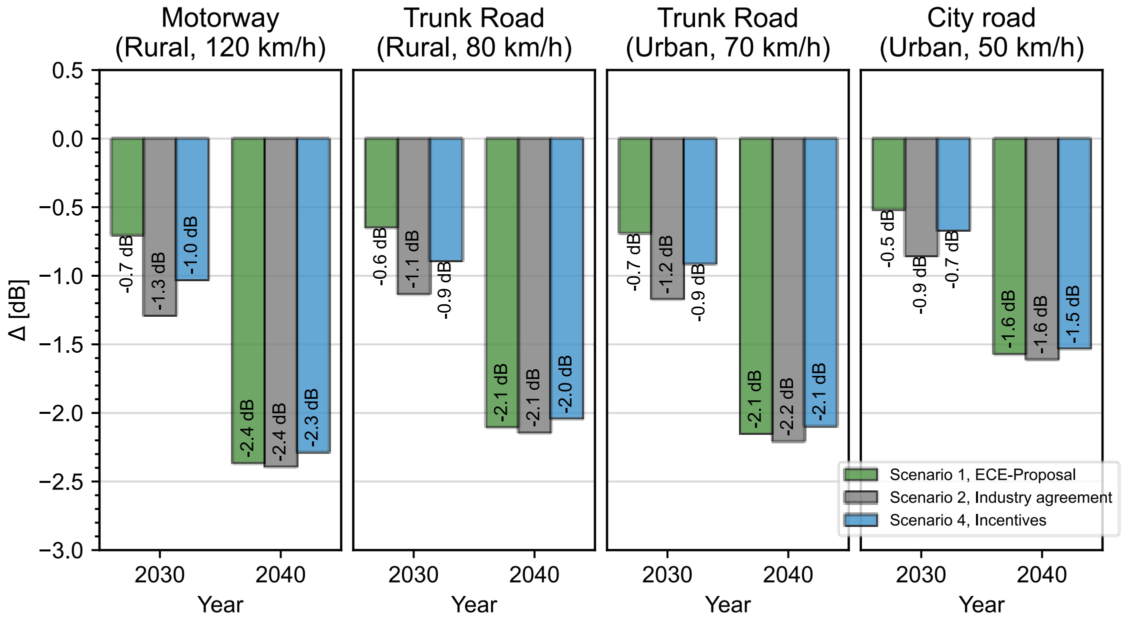

Figure 3-5: Result of scenario modelling, congested traffic (stop and go) for different road categories and the two years 2030 and 2040. The results indicate the total noise reduction of road noise in comparison to the reference scenario.

3.5. Exposure results on a national level

Figure 3-6 depicts the overall result from the scenario modelling. The scenarios have been evaluated on a national level for the STEER-funding countries as well as for Switzerland. In the figure, the percentage of the population (within the definition of the END) with a L_{DEN} of >55 dB is depicted.

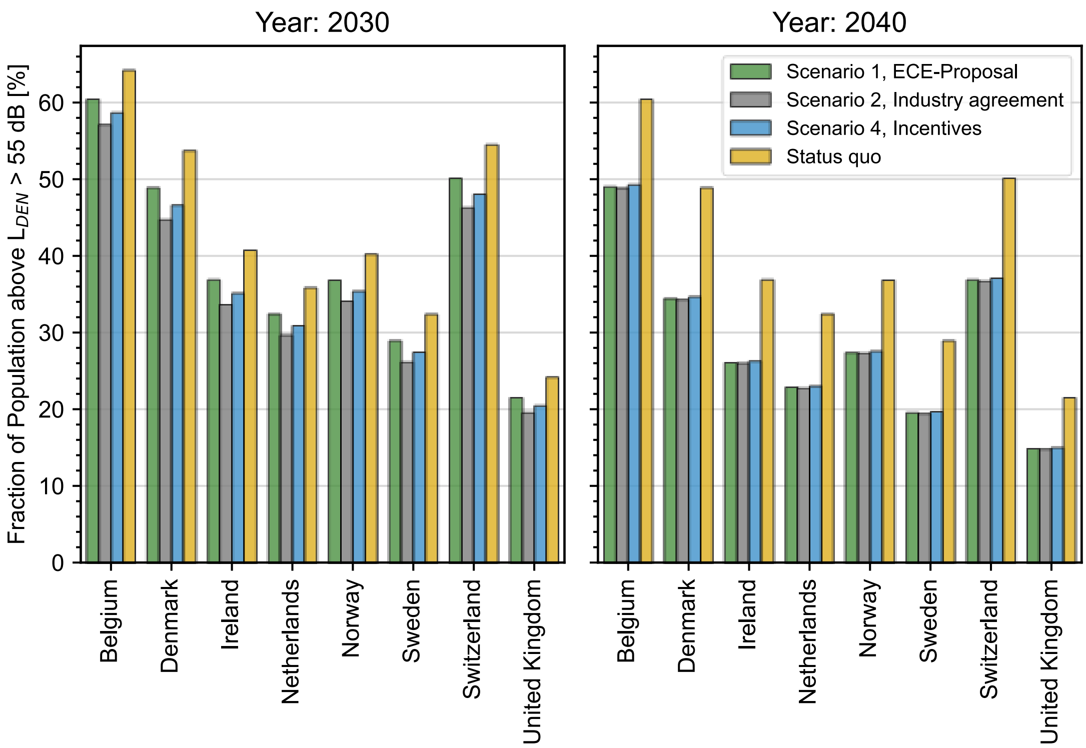

Figure 3-6: Fraction of END-Population exceeding the threshold value of 55 dB for the years 2030 and 2040

It is obvious that the scenarios 1-4 result in a lower percentage of people exposed to high road noise levels in all countries. It is also worth mentioning that the effects of the regulation the EU 540/2014[22] have an impact on the resulting noise levels, such that even in the *status quo* a reduction in noise level and thus a reduced percentage of population with L_{DEN} > 55 dB can be observed.

[22] Regulation (EU) No 540/2014: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32014R0540

3.5.1. National Distribution, Year 2030, EU- wide distribution

In the following Figure 3-7 to Figure 3-10, the fraction of the population (According the END-Agglomeration) definition is shown, exposed on noise levels $L_{DEN} > 55\ dB$ for the different scenarios as given in section 3.3 for the reference year 2030.

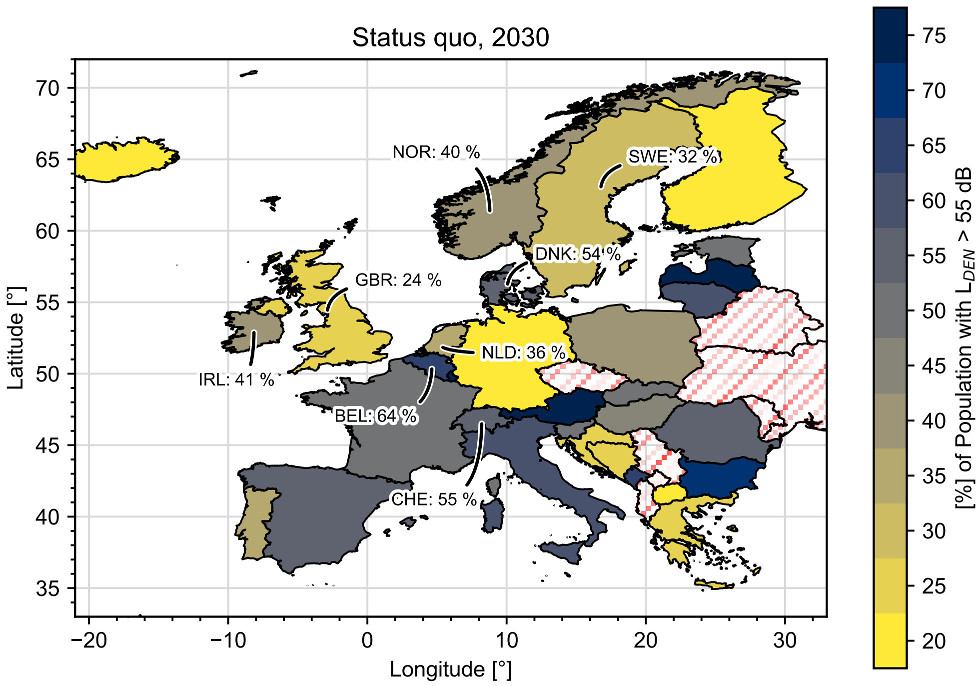

Figure 3-7: Fraction of population (according to END-Agglomeration) in Europe with L_{DEN} > 55 dB for scenario *status quo*, and the year 2030.

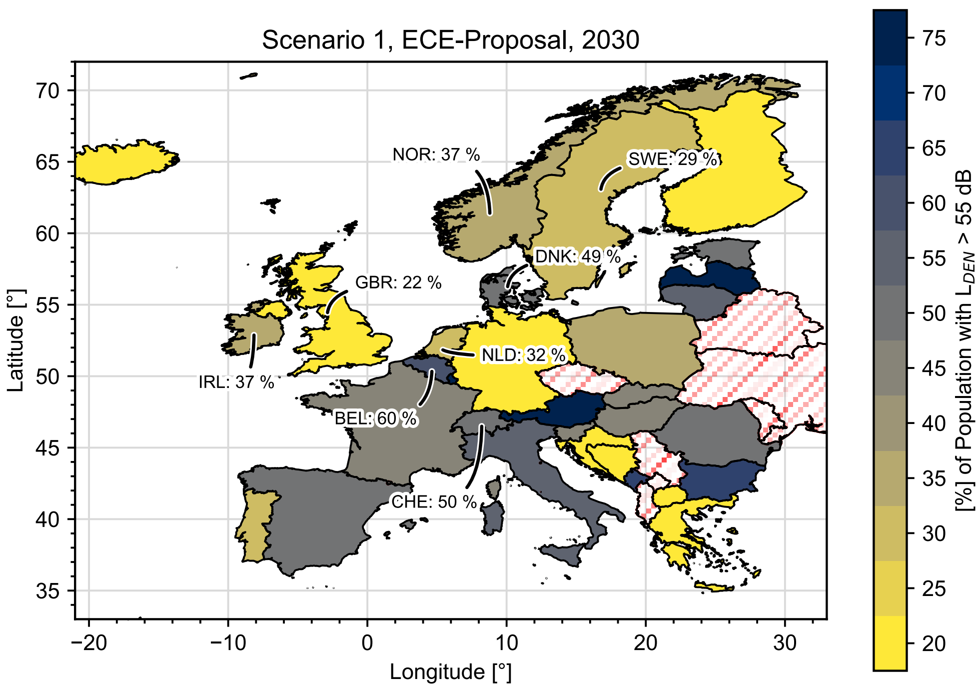

Figure 3-8: Fraction of population (according to END-Agglomeration) in Europe with L_{DEN} > 55 dB for scenario 1 *ECE-Proposal*, and the year 2030.

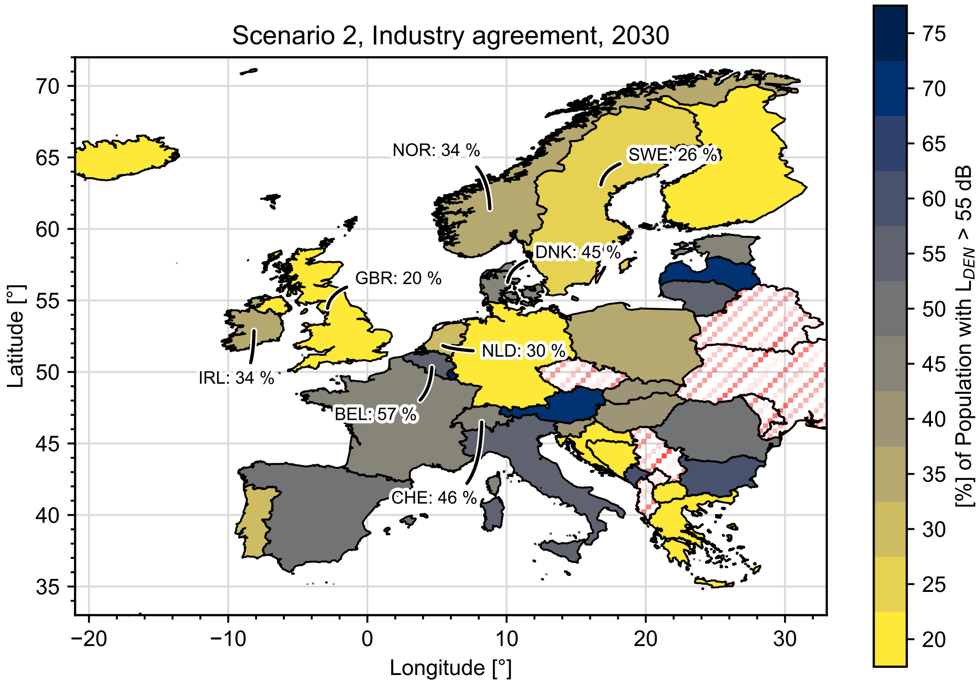

Figure 3-9: Fraction of population (according to END-Agglomeration) in Europe with L_{DEN} > 55 dB for scenario 2 *Industry agreement*, and the year 2030.

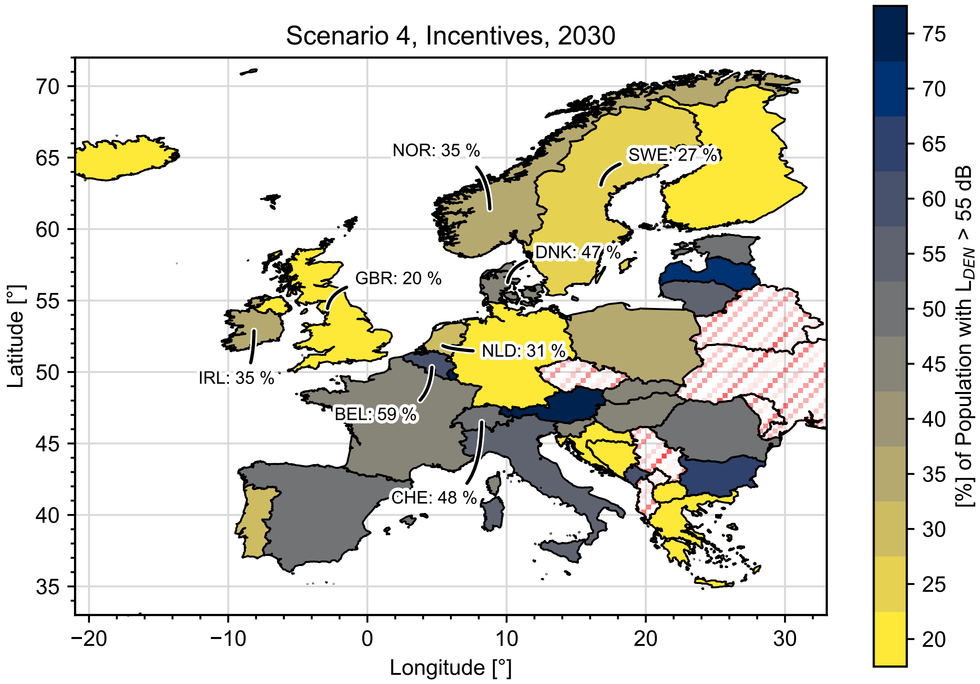

Figure 3-10: Fraction of population (according to END-Agglomeration) in Europe with L_{DEN} > 55 dB for scenario 4 *Consumer incentives* and the year 2030.

3.5.2. National Distribution, Year 2040

In the following Figure 3-11 to Figure 3-14, the fraction of the population (According the END-Agglomeration) definition is shown, exposed on noise levels $L_{DEN} > 55\ dB$ for the different scenarios as given in section 3.3 for the reference year 2030.

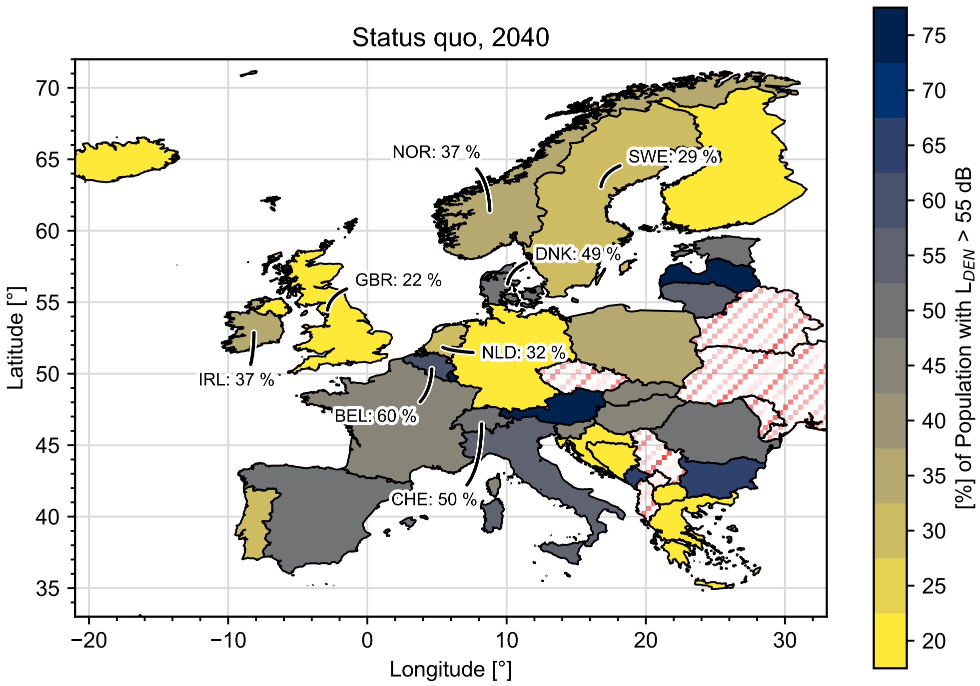

Figure 3-11: Fraction of population (according to END-Agglomeration) in Europe with L_{DEN} > 55 dB for scenario *status quo*, and the year 2040.

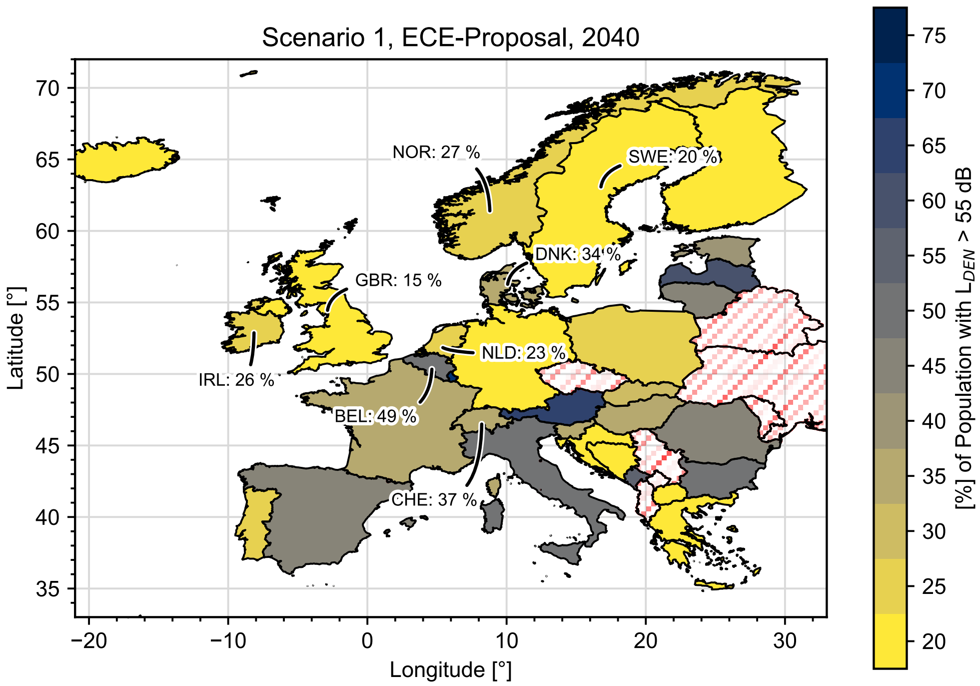

Figure 3-12: Fraction of population (according to END-Agglomeration) in Europe with L_{DEN} > 55 dB for scenario *ECE-Proposal*, and the year 2040.

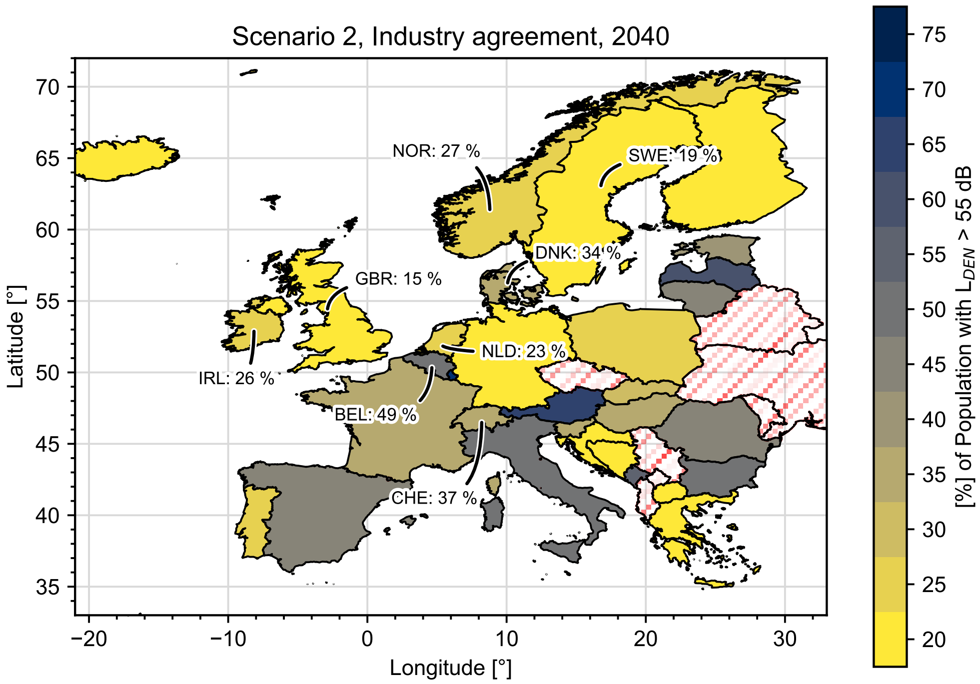

Figure 3-13: Fraction of population (according to END-Agglomeration) in Europe with L_{DEN} > 55 dB for scenario 2 *Industry agreement*, and the year 2040.

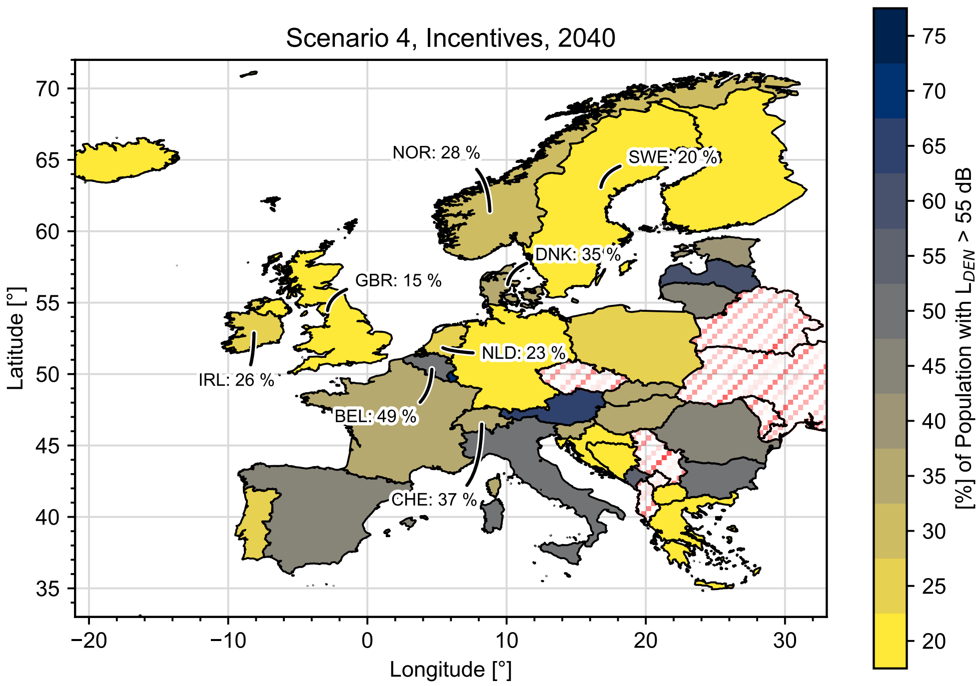

Figure 3-14: Fraction of population (according to END-Agglomeration) in Europe with L_{DEN} > 55 dB for scenario 4 *Consumer incentives* and the year 2040.

3.6. Benefits on a national level

In the following Figure 3-15, the annual benefits from the avoided external costs according to Table 3-1 are shown for the STEER funding countries. The benefits are depicted as annual benefits in euros per person per year. Accordingly, the results are comparable between the different countries.

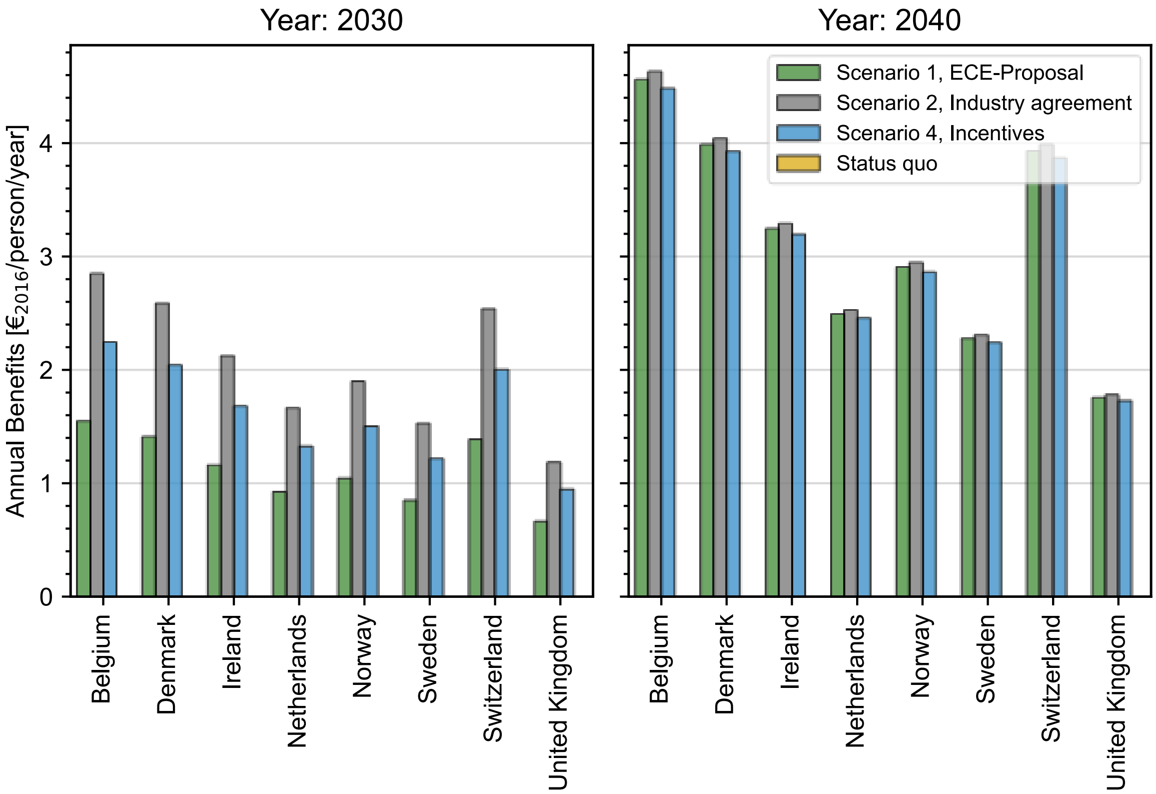

Figure 3-15: Resulting benefits from avoided external costs (health and annoyance) for the different scenarios relative to the *status quo* of the respective year. Basis for the calculation are the environmental costs as specified in (European Commission, 2019) and depicted in Table 3-1.

For the year 2030, all scenarios result in annual benefits of 0.5 €/person/year to up to 2.8 €/person/year. Interestingly, scenario 1 with the *ECE-Proposal* leads to the lowest annual benefits for the year 2030. However, with the adapted limits for stage 4 of the proposal applicable in 2032 (see scenario definitions in chapter 3.3 on page 27, and Annex B, page 77), the scenarios result in comparable annual benefits.

The benefits rise significantly in the year 2040 in comparison to 2030. However, the country specific distribution shows large differences. For instance, Belgium seems to profit more than the United Kingdom. These differences reflect the underlying data from the European Noise Directive (END). The UK already has a rather low percentage of its population with L_{DEN} > 55 dB(A) in the reported 2017 data.

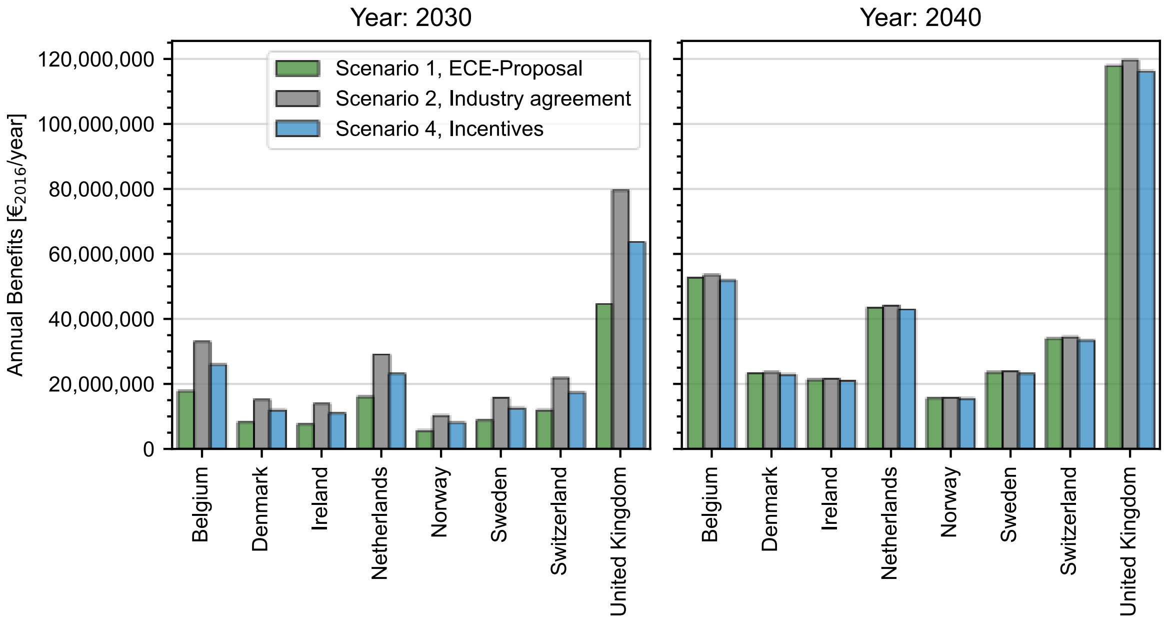

Figure 3-16: Resulting absolute benefit from avoided external costs (health and annoyance) for the different scenarios compared to the *status quo* of the respective year. Basis for the calculation are the environmental costs as specified in (European Commission, 2019) and depicted in Table 3-1, and Multiplication of relative benefits from Figure 3-16 by the total number of inhabitants.

The total amount in terms of environmental benefits for the scenarios are depicted in the Figure 3-16.

3.6.1. EU-Wide distribution, Year 2030

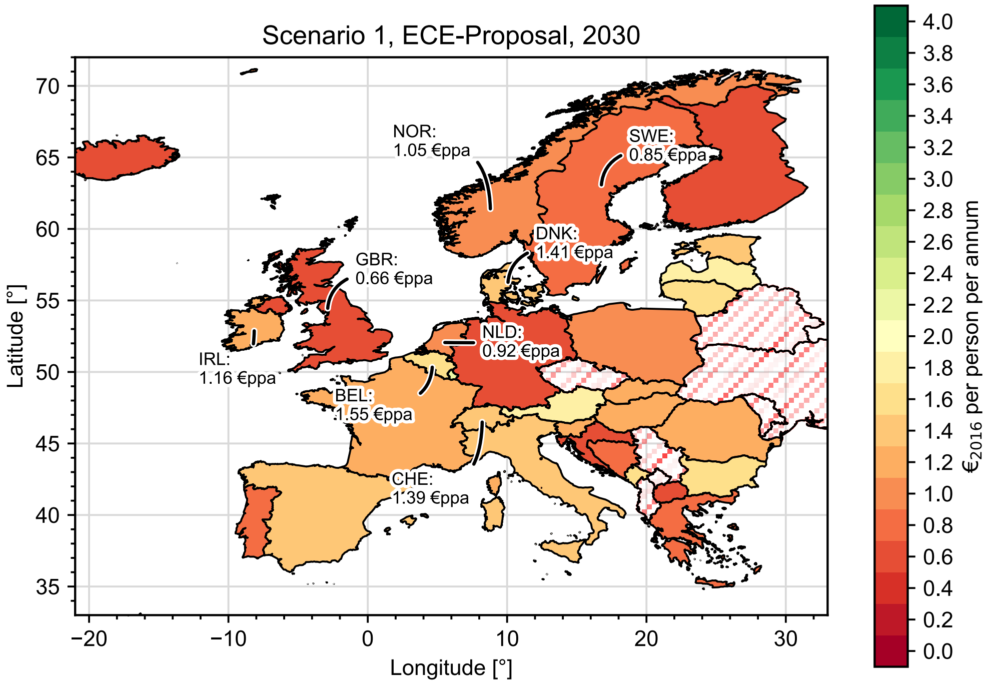

Figure 3-17: Avoided environmental costs (annoyance and health) for population (according to END-Agglomeration) in Europe expressed as the annual benefit in [€/person/year] for scenario 1 *ECE Proposal* in comparison to the status quo of the respective year (2030).

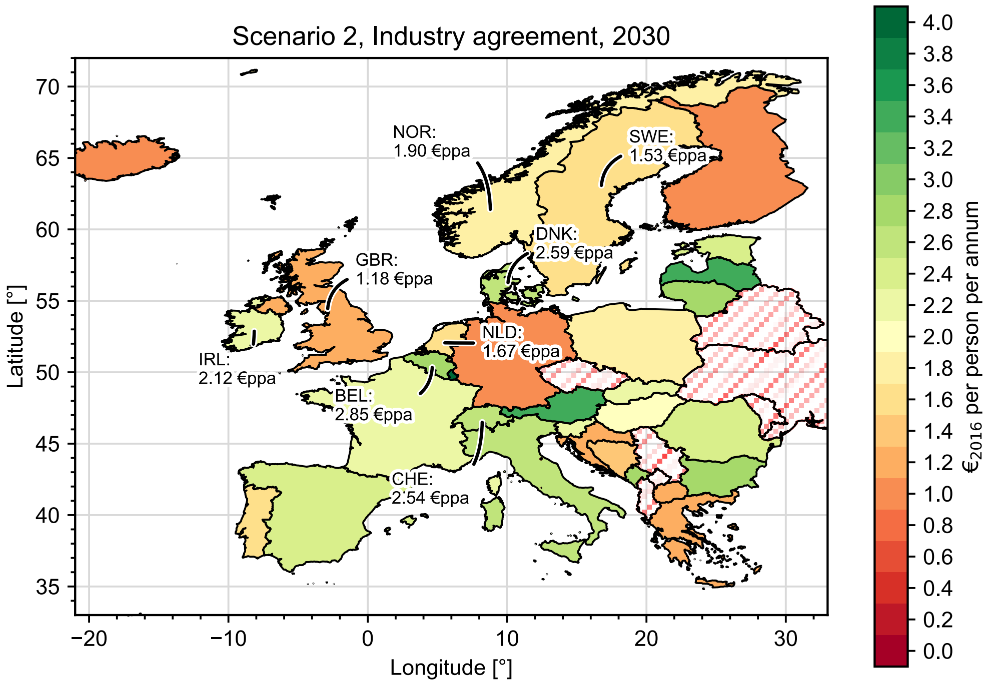

Figure 3-18: Avoided environmental costs (annoyance and health) for population (according to END-Agglomeration) in Europe expressed as the annual benefit in [€/person/year] for scenario 2 *Industry agreement* in comparison to the status quo of the respective year (2030).

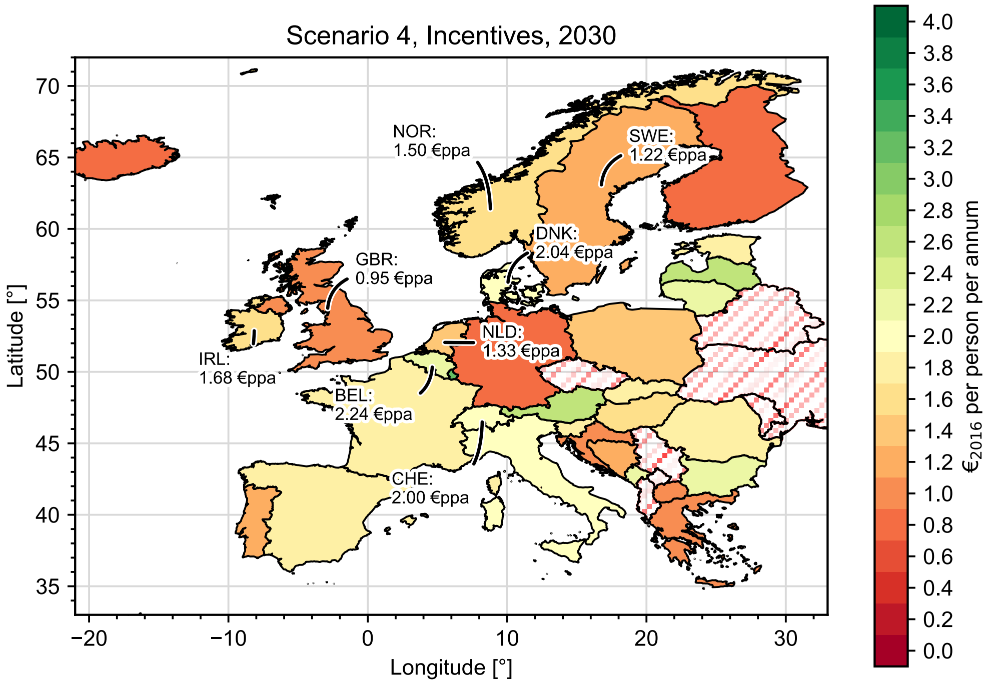

Figure 3-19: Avoided environmental costs (annoyance and health) for population (according to END-Agglomeration) in Europe expressed as the annual benefit in [€/person/year] for scenario 4 *Consumer incentives* in comparison to the status quo of the respective year (2030).

3.6.2. EU-Wide distribution, Year 2040

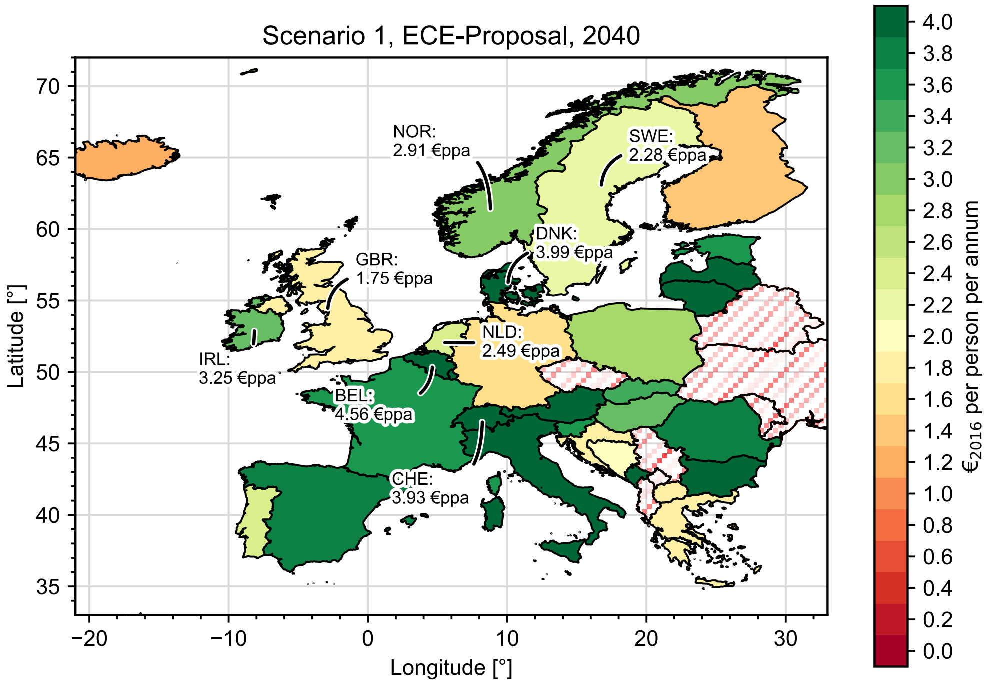

Figure 3-20: Avoided environmental costs (annoyance and health) for population (according to END-Agglomeration) in Europe expressed as the annual benefit in [€/person/year] for scenario 1 *ECE Proposal* in comparison to the status quo of the respective year (2040).

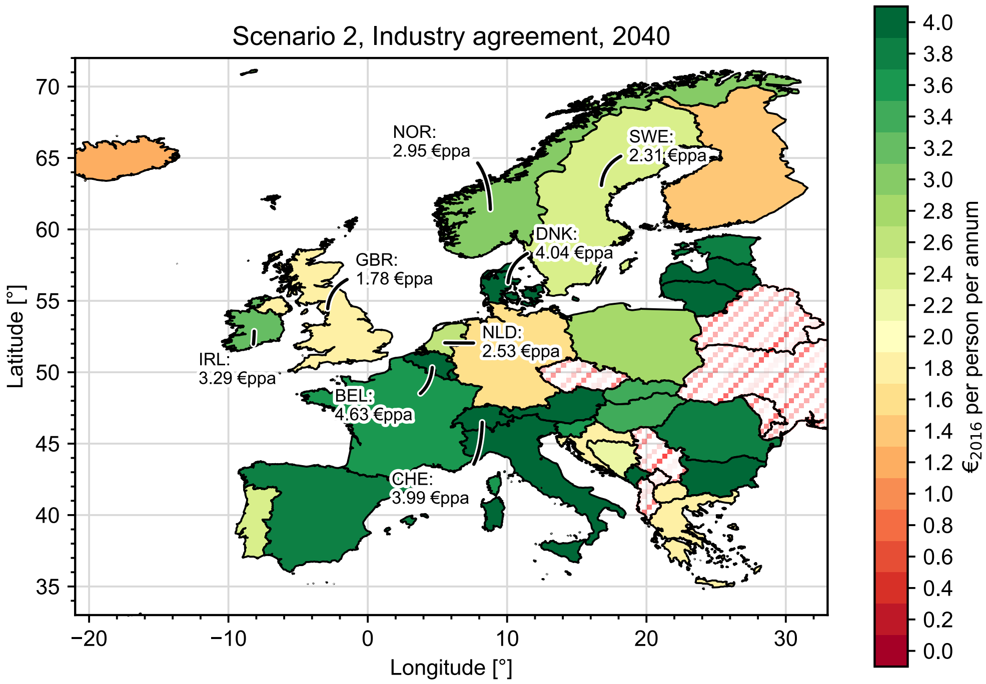

Figure 3-21: Avoided environmental costs (annoyance and health) for population (according to END-Agglomeration) in Europe expressed as the annual benefit in [€/person/year] for scenario 2 *Industry agreement* in comparison to the status quo of the respective year (2040).

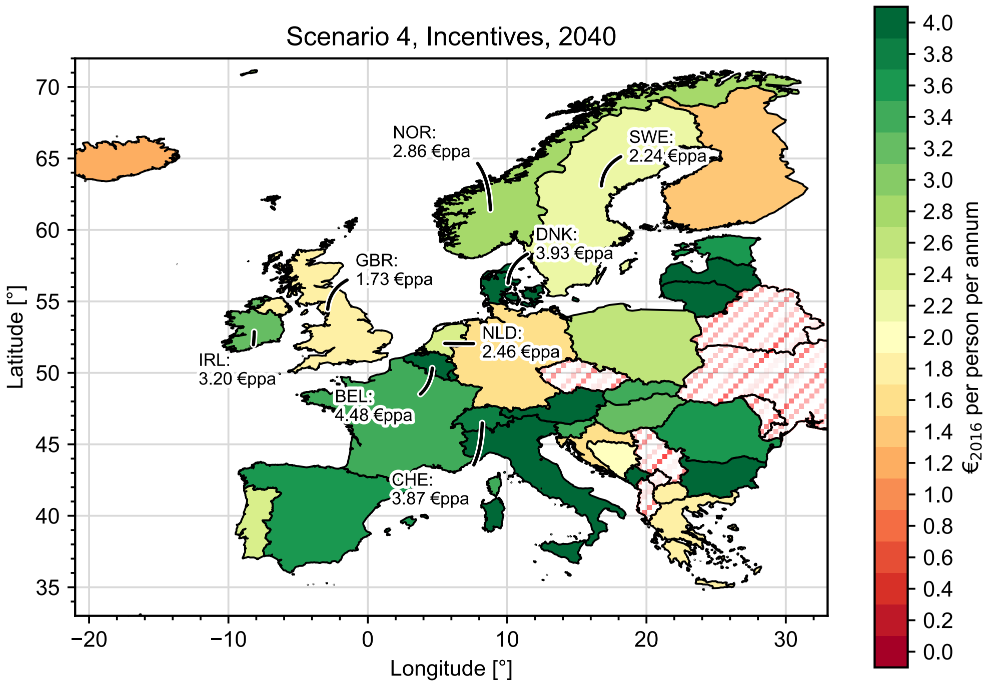

Figure 3-22: Avoided environmental costs (annoyance and health) for population (according to END-Agglomeration) in Europe expressed as the annual benefit in [€/person/year] for scenario 4 *Consumer incentives* in comparison to the status quo of the respective year (2040).

3.7. Estimate of costs and benefits for scenarios

In order to assess the different costs of the scenarios, the implementation costs for the individual scenarios are estimated. The implementation costs are, depending on the scenario and the measure, distributed amongst different stakeholders. For example, no implementation costs are estimated for the *status quo*. However, all other scenarios are accompanied by certain costs. For instance, scenario 1 with the *ECE-Proposal*, which foresees a tightening of the limit values, is assumed to cause external costs that have to be financed by the tyre industry (as some tyres may no longer be sold). Therefore, the tyre industry "loses" a product which they can sell and thus R&D is needed to develop new products.

In the following Table 3-4, possible costs and the corresponding stakeholders are estimated. The range of the costs is estimated only qualitatively (-- for highest expected costs, ++ for highest expected benefits, and 0 indicates a neutral option, compared to the *status quo*).

Table 3-4: Qualitative illustration of costs and benefits for different scenarios and stakeholders.

Stake-holder	Measure	Status quo]	Scenario 1, ECE-Proposal	Scenario 2, Industry agreement	Scenario 4, Consumer incentives
Public authority	Costs for enforcement	0	(nearly 0) changing of technical documents, update enforcement procedure	- (New enforcement, checking for contractual requirements regarding fleet average)	- (National enforcement)
	Funding	0	0	0	- (Reduced VAT revenue)
Tyre industry	R&D Investment & Testing	0	- (Product replacement, costs for the or development of new products)	+- (Some manufacturers will profit, some will have to pay fines or develop new products)	0
Consumer	Additional tyre cost	0	0	0	+ (Consumers can opt to buy VAT exempted tyres)

In almost all scenarios, the public sector must finance enforcement. This mainly includes the additional enforcement effort required by the introduction and review. The only scenario in which the public sector might need annual funding would be scenario 4 in which the consumer is exempt from VAT when buying a category 1 tyre (A-rated tyre according the definition in Table 1-1). However, the consumer might profit a little bit from this option.

3.8. Conclusions

For a national road administration, there are a set of different options to promote the proliferation of quieter tyres. However, for the spread of quiet tyres, the legal framework has a high influence on which tyres are available on the market. Therefore, one can conclude that *what is allowed is produced,* and the market (and the consumer) regulates the supply.

The final decision on which tyres are to be mounted to fit on a car is ultimately made by the consumer. Research on the importance of the tyre for consumers has shown that consumers' main focus is primarily on the safety and price of the tyre and less on the noise. Noise labelling is therefore of little importance.

Nevertheless, it has also been shown that consumers are aware of tyre labelling and attach some importance to it. Road authorities therefore have limited options besides advice and information when it comes to choosing strategies for the dissemination of quieter tyres, as consumers ultimately decide what best suits their needs.

The latest evaluation of tyres available for Switzerland, however, has shown that there are options that represent a good compromise between rolling resistance, wet grip and noise characteristics. This assessment, though, was carried out without reference to the tyre price. The assessment also showed that it is generally possible to buy a tyre with…

a.) low noise levels
b.) good wet grip characteristics
c.) low rolling resistances

This evaluation has shown that it is possible to select a tyre with good overall performance, especially for summer tyres. The analysis could also indicate that the trade-off between low-noise tyres and other properties such as wet grip or rolling resistance is not an obvious problem, at least in this simplified consideration. This conclusion could be drawn because the proportion of good tyres overall actually increased as the noise rating value is decreasing.

The picture is not all that different for all-season tyres. However, the proportion of tyres with good overall performance is lower. The same applies to winter tyres. The evaluation, however, only investigated four different characteristics (including the tyre width). A tyre, however, has to fulfil many more functions than only the noted characteristics, that are also visible on the label. For example, the issue of durability, which also has a major impact on the environment, is not yet considered.

This general conclusion is in line with the findings from the literature, which examined possible targets of conflicts between different tyre characteristics. In the literature, there are partly contradictory results on the topic of the goal of conflicts.

It can be concluded that overall there are good tyres on the market that are quiet, have good wet grip properties and low rolling resistance.

The question remains, however, how consumers can be persuaded to equip their vehicles with low-noise tyres.

Within this report, different strategies have been elaborated and a (non-conclusive) list is shown here:

- **Tighter limits**: The current noise limits will be adapted according to a defined staged procedure. This results in a de facto ban on the sale, distribution, and entry into service of tyres in a certain noise class.

- **Information campaign**: The information campaign aims to promote consumer awareness on the issue of noise. One possible goal of an information campaign could be to encourage consumers to buy low-noise tyres. With regard to the possibility that these tyres exist on the market, further information for the consumer might be needed by NRA.

- **Promotion of technology**: This strategy targets the development of (new) quieter tyres by the industry. In this context, the development of quieter tyres is to be promoted and financially supported.

- **Industry agreement, output oriented average**: This strategy is ccomparable to EU regulation 2019/631 for CO_2 of passenger cars and light commercial vehicles. Manufacturers have to comply to a defined fleet average regarding CO_2 and will be fined if they do not comply with the assigned fleet average. For noise, a comparable mechanism is imaginable.

- **Voluntary branch agreement:** Tyre dealers and tyre manufacturers sign a voluntary agreement that tyres exceeding a certain limit will no longer be produced or sold. This approach follows the solution of other environmental substances. For example, the Montreal Protocol[23] phased out the production and use of ozone-depleting CFCs (halogenated hydrocarbons).

- **Incentives for consumers to buy quieter tyres**: Financial incentives should encourage consumers to buy quiet tyres. One possibility would be to exempt tyres classified as "A" tyres, i.e. 3 dB below the limit value, from VAT.

- **Recommendations for procurement of low-noise tyres in the public sector**: The road or transport authorities as well as the environmental authorities are very big players in the market. They may recommend or decide that low-noise tyres must be used when procuring tyres or vehicles are to be procured, tyres shall be of low- noise type.. This may also be implemented by communal or regional authorities. Since they in many cases let private companies provide various services that must be accepted by some authority (for example bus or taxi transportation), the authorities can require also such private companies to use only low-noise tyres. This will have a substantial effect on the market.

- **Incentives for garages/tyre sellers in the aftermarket:** Most of the consumers rely on the recommendation of their tyre seller/garagists, when a replacement of the tyre is needed. Accordingly, financial benefits for the sellers/garagists could be implemented, when they successfully advise to sell AAA-tyres in order to increase the proliferation of quieter tyres.

As the proliferation involves different stakeholders, detailed proliferation scenarios need to be elaborated.

As part of this task, the impact of certain scenarios was assessed in terms of their effectiveness at national and international (European) level. The basis for this calculation was the reported noise level (distribution of road noise in agglomerations among the population in the agglomeration) according to the European Noise Directive (European Environment Agency, 2020). With the help of the TRANECAM model, three scenarios were calculated for the reference years 2030 and 2040.

Concerning the exposure assessment, all scenarios have shown a high reduction potential in the percentage of the population exposed to high noise levels (L_{DEN} > 55 dB(A)). Compared to the respective *status quo,* which includes tightening limits according regulation EU 540/2014 of vehicle noise, the scenarios could reduce the percentage of people with L_{DEN} above 55 dB(A) by about 10%.

The proliferation of quiet tyres has benefits in terms of avoided external costs (health and annoyance) compared to the *status quo*. Estimating the avoided health and annoyance costs of a noise abatement measure is subject to great uncertainty, and most costs are also not directly attributable, as they are external and are also likely to occur with a time lag; i.e. medical expenses, rent losses,…

However, as outlined in this report, all measures have significant benefits in terms of avoided external health and nuisance costs. The benefits range in the selected STEER-funding countries from 0.5 €/per person/year in the year 2030 to up to 2.8 €/per person/year.

[23] https://treaties.un.org/doc/publication/unts/volume%201522/volume-1522-i-26369-english.pdf

Of course, these benefits must be weighed against the costs that each scenario entails. The overall benefit of the scenarios will be different for each country, as it depends to a large extent on how much and to what extent the population is exposed to which noise level and to what extent exposure is reduced. However, the range of benefits will most likely exceed the estimated costs, as also shown by a similar result presented in the *Phenomena project*[24] (Salomons et al., 2021), where different noise abatement solutions were investigated and compared against each other. One of these solutions was to investigate the influence of low-noise tyres. The benefit-cost ratio (BCR) amounted, depending on the method of calculation to was 30.3 or 5.5 for the period from 2017 to 2035, depending on the calculation method. The scenario included the total noise reduction of 2 to 4 dB. This reduction is a little bit higher than in the scenarios examined in this deliverable. In general, tyre noise reduction can be considered a viable measure to reduce road noise at source.

3.9. Recommendations

It is known, that with increasing speed, the importance of the tyre road noise is increasing. Especially on high-speed roads, the share of the rolling sound is clearly dominating. With increasing share of EV in the future, the focus will be laid even more on the rolling sound, as engine noise will most likely decrease.

The analysis and the scenarios have shown that the consumer is aware of a tyre label. But the most important factor for the decision which tyre is equipped on a vehicle is still safety, and the price. Noise is generally only mentioned in 4th or 5th place of the decision criteria. The analysis within this Task has shown, that there are (at least for summer tyres) possibilities to equip a vehicle with equally performing tyres on the label values (Wet grip, rolling resistance while having low noise emission). Therefore, consumer awareness of these opportunities needs to be raised. This is because the analyses have shown that a simple tightening of the limits does lead to an improvement on the side of the loudest tyres. But only the noisiest tyres are touched, and with other measures, even consumers with already quieter tyres can be persuaded to fit even quieter tyres. This effect is shown in the analysis of the scenarios, where the scenarios other than limit values adaption shows

Accordingly, the authors suggest, for NRA's to act on raising the awareness of quiet tyres. This can be achieved in different ways:

- Information campaign for promoting quiet tyres
- Financial incentives for the consumer to buy AAA tyres
- Address tyre dealers / tyre houses, to promote AAA tyres. (may be with financial benefits)

[24] https://op.europa.eu/en/publication-detail/-/publication/f4cd7465-a95d-11eb-9585-01aa75ed71a1v

4 Market trends

4.1. Introduction

Task 5.3 deals with new trends in the tyre market and attempts to quantify its likely effect on tyre/road noise emission. The following trends have been identified as important:

- Trends towards larger tyres for heavier and more powerful vehicles (mainly SUVs)
- Trends due to the increased share of electric vehicles; which has an impact on the tyre dimensions
- Trends with more limited speeds; both as maximum speed of vehicles and restrictions on roads
- Trends for truck tyres having lower rolling resistance and replacing dual (double-mounted) tyres with single tyres of larger dimension.

4.2. Larger tyres for heavier and more powerful vehicles

A trend which has during the last decade worried the scientific community dealing with climate change, is that “normal” passenger cars lose market shares to the significantly heavier and larger SUVs. They are also commonly more powerful than the vehicles in the passenger car sector that they replace. For example, in just over 10 years SUVs went from a peripheral 10 % of sales to nearly half of all car sales in Europe today (45 %) (Transport & Environment, 2021). The problem started years before the sales of electric cars became significant, but is more pronounced than ever, now including the electric vehicles as well.

These SUVs need larger tyres to carry the increased weight and also to endure the greater torque during acceleration when the heavier and potentially more powerful vehicle needs to be accelerated at the same or higher acceleration rate.

The larger tyres are usually achieved by increasing the diameter, which also contributes to increasing the road clearance to give the SUVs an impression of having good off-road properties. This does not necessarily mean that noise emission is increased, as it is common view that increased diameter (with other parameters being unchanged) may reduce rather than increase noise. However, the need for more torque and thus stick-slip motions in the tyre/road contact patch will increase noise; both during acceleration but also at constant speed. The authors’ very rough estimate that this trend may account for about 1 dB of increased noise for the considered vehicles when a common car in the market is replaced with an SUV.

Since at least the 1980’s, it has been common that tyre dimensions have been influenced by design and market people in the vehicle industry, in their attempts to give the vehicle an impression of high performance (high speed and high power) and this has led to a fashion of ever wider tyres and tyres with lower aspect ratio, which has not always been optimum for safety and environment and not even for economy. It was not until the first electric vehicles appeared on the market when this trend was (to some degree) broken, as for these vehicles the focus was on achieving a high operating range.

For the last decades ‘driving pleasure’ has been one of the most common arguments in Swedish car advertising. It has generally been treated as the single most important characteristic of each car in test runs reported in the motor press. In this context the definition of driving pleasure focuses on engine power, high speed and driveability (Hagman, 2010). Extra wide and sporty looking tyres seem to be a necessary attribute to achieve such “driving pleasure”. A similar trend has appeared also in other European countries. However, it seems that this marketing argument is not as important nowadays when electric vehicles have become common and fossil-powered vehicles seem to have no grand future.

In the EU noise limit regulation (2009), the larger tyres are allowed extra decibels. For example, changing tyre dimension from 245 mm (width) to 255 mm increases the noise limit from 71 to 72 dB. This may be a further drive for increased noise emission due to the larger and heavier SUVs.

Since the wider tyres in general have higher rolling resistance and thus causes more fuel consumption, this trend is even more negative for CO_2 emissions. Vehicles with wider tyres than necessary, due to attempts to give the vehicle a “sportier” look, may not utilize the environmental performance they could achieve with optimal tyres, and when the safety performance is focused on extremely high and illegal speeds (illegal except on some German motorways), not even the safety performance during “reasonable” speeds is necessarily optimum. Changing to an electric vehicle may not be so attractive for those customers who are very impressed by wide and sporty-looking tyres and who expect the vehicle to emit a certain type of loud noise.

4.3. Increased share of electric vehicles

The trend in Europe for the increased market share of electric vehicles of the M class (essentially passenger cars and SUVs) versus vehicles with internal combustion engines (ICE) is very clear. For example, in Europe the sales of electric vehicles (EVs) increased by 137 % from 2019 to 2020 (EV-Volumes, 2021) By 2035 no new CO_2-emitting cars are supposed to be sold in Europe, instead electric or hydrogen cars should have the full market share. This potentially has an impact on the tyre dimensions, since the EVs in general need low rolling resistance tyres in order to have a driving range which is desired by the owners. Further, the electric vehicles (so far) are a little heavier than their ICE counterparts due to the battery weights. Due to the high torque provided by electric motors at low revolutions, the accelerations from standstill are expected to be higher for an average EV than an average ICE car. The higher load (also increased by heavier tyres) and the higher torque will mean a marginal increase in tyre/road noise emission.

However, another trend is that the lower rolling resistance is achieved by using tyres with increased diameter, at the expense of lower width. This is not only for SUVs but also for sedan-type EVs. As mentioned above, this potentially can lead to lower noise emission, but it depends on how these tyres are designed. As an example, the new Michelin Pilot Sport EV is offered in rim diameters of 19 to 22 inches. The particular tyre 255/45 R19 104W XL “ACOUSTIC” is despite the name, labelled with 72 dB, which is the maximum noise limit for that width class. Even relatively small EVs or PHEVs use 17” rims today. Ten years ago (say), even large cars like Volvo S80 usually had rim sizes of 16 or 17”.

Nevertheless, considering all effects mentioned, as they may balance out, it is unclear what net effect the electric vehicle increased market share will have on tyre/road noise.

4.4. More limited speeds

With the introduction of EVs, there is a quite clear trend that the majority of the normal EVs (excluding extreme sports cars) have a speed limit of 150 km/h rather than the quite common speed limiters set at 170-250 km/h for “traditional” fossil-fuel-driven cars. This opens up for tyres optimized for lower top speeds than today. Vehicles limited to 150 km/h need tyres with speed rating of only T (190 km/h). Maybe speed rating R (170 km/h) would be enough for these EVs, although car tyres are normally not (yet) available for this rating. If tyres need not be optimized for extreme speed performance, they could more easily be optimized for better environmental performance instead (noise and rolling resistance). Of course, if fewer vehicles than presently will drive above 150 km/h (illegally) this means an advantage for noise exposure in addition to potentially quieter tyres.

Another trend is that speed limits on roads are lowered, both for increased safety and for reduction of energy consumption. In some countries, speed limits on highways and motorways are reduced for these reasons and/or speed limits in urban and suburban areas are reduced. That is mainly for reasons of increased traffic safety and for limiting the use of private transportation. For ICE-driven vehicles, lowering speeds to below 50 km/h has very limited or no benefits for fuel consumption, but for EV:s this is an important way to reduce energy consumption and thus increase range, but also for reducing noise emissions.

A special but very important case is the German free speed on certain motorways (Autobahn). On most motorways the speed limits are nowadays down at 130 km/h and even on those without a limit, there is a recommendation to keep a maximum speed of about 130 km/h. On those free speed motorways, it happens often that some cars are driven well above 200 km/h. Germany is the only developed country having some roads without speed limit; most other countries have maximum limits in the range 100-130 km/h. The authors are not aware of any country having a speed limit higher than 130 km/h. It means that tyres must be produced for driving at speeds up to at least 250 km/h (there are even some for higher speeds) which means that optimizations for other parameters, such as noise and rolling resistance, need to be compromised, compared to if maximum speeds were (say) 130 km/h. Thus, the German free speed policy is detrimental to the rest of the world in terms of optimization of tyres for reasonable speeds, not to mention the negative environmental and safety effects it has inside Germany.

Recently, there was a general election to the German Parliament (Bundestag). In the election campaign some parties suggested an end to the free speeds on German motorways. Those parties were successful in the election and are expected to create a new government. Now the eyes are on this process, waiting to see if the promises for removing the free speed policy will be enacted or not, despite expected severe lobbying by the German automobile industry.

Consequently, these speed-related trends are consistently very favourable for noise exposure.

4.5. Truck tyres with lower rolling resistance and with dual tyres replaced by singles

It has been a trend for many years that the very common dual tyre mounting (two tyres of same size mounted together on the same axle on each side of the heavy vehicle) has been gradually exchanged to using either so-called super wide singles, or two-three tyres on one or two extra axles. Generally, this is nowadays implemented almost entirely on semitrailers (unless exceptional load capacity is needed), but it appears now and then also on some trailers for 24 m articulated trucks. An example of the former appears in Figure 4-1.

Figure 4-1: Typical truck with semitrailer from middle Europe.

The tyre configuration for the truck in Figure 4-1 is single tyres on the steering axle, dual tyres on the driving axle and single tyres in the three trailer axles. The drive axle has 4 tyres of dimension 12 R 22.5 (which is common) and the trailer axles have 385/65 R 22.5 (also very common). The 6 trailer tyres can altogether carry a load of up to 27 000 kg. In earlier days this load would more commonly be carried by two axles with dual tyres of size 315/80 R 22.5. So, which is the quietest of these: 8 tyres in dual mounting of 315/80 R 22.5 or 6 tyres in single mounting of 385/65 R 22.5? Unfortunately, such (reliable) measured data have not been found. Furthermore, it is known that tyre width is a factor influencing noise emission, mainly because of the so-called horn effect. Then the question is: what is best of a width of 385 mm or two widths of 315 mm with 50-100 mm spacing between? The answer is not available. However, from a legal point of view, each of these tyres are allowed to emit 73 dB (in single mounting at 70 km/h on ISO surface), which means that the six 385 mm wide tyres may (legally) emit a total sound energy which is 1.2 dB less than that of the eight 315 mm tyres. It is unclear if the trend with fewer but wider tyres (meeting the same noise limit) is actually an advantage which occurs in reality, in terms of noise exposure.

4.6. Conclusions

It is concluded that the time trends appear to have the following effects:

- Trends towards larger tyres for heavier and more powerful vehicles (mainly SUVs): This is increasing tyre/road noise emission; although probably not more than 1 dB.
- Trends due to the increased share of electric vehicles: This effect is unclear; if it points in one direction it is probably a marginal effect.
- Trends due to reduced speeds: This is consistently positive for noise reduction; especially if the new German government introduces a speed limit for all motorways, eliminating the possibility to drive legally on public roads at higher speeds than (say) 130 km/h in the entire Europe and probably in the rest of the world as well.
- Trends for truck tyres having lower rolling resistance and replacing dual (double-mounted) tires with single tires of larger dimension: This effect is unclear; but if the legal noise allowances are utilized, the trend would decrease tyre/road noise emission marginally.

5 Short-term benefits

At the January 2019 meeting of GRB (Working Party on Noise - now GRBP as regulation of tyres has been added) in Geneva, a Working Document was submitted by the Netherlands. This document proposed new limits for the sound emission of tyres (Stage 3 from 2022/2024) and Stage 4 from 2032/2024, see table 3-3) in R117. Normally, Working Documents are up to confirmation or voting by contracting parties before submitting the document to WP.29 for implementing in the appropriate regulations, if approved by GRBP. However, the following conclusion was made after presentation:

"GRB took note of a proposal submitted by the expert of the Netherlands which introduce two extra stages 3 and 4 with limits for the rolling sound emission, wet grip and rolling resistance coefficient (ECE/TRANS/WP.29/GRB/2019/3). The Chair was of the view that, given the ongoing discussion on this issue within the European Union, it would be premature to modify the noise limits at this moment and proposed to revert to this document at a later stage".[25]

Since this meeting, no further discussions on this item has been put forward. In the short-time future, on cannot expect any approval of the Stage 3 and 4 limits. This is also underlined by the tyre industry in their presentation to the GRBP Task Force on vehicle sound (TF VS) at their fourth session in September 2021. In a presentation by ETRTO[26] the timeline shown below on their priorities for the coming years. As the figure show, their priorities is to reduce measurement uncertainties in the present R117, and it is likely that a discussion on new sound limits can start around 2027, if the industry is not challenged in this matter.

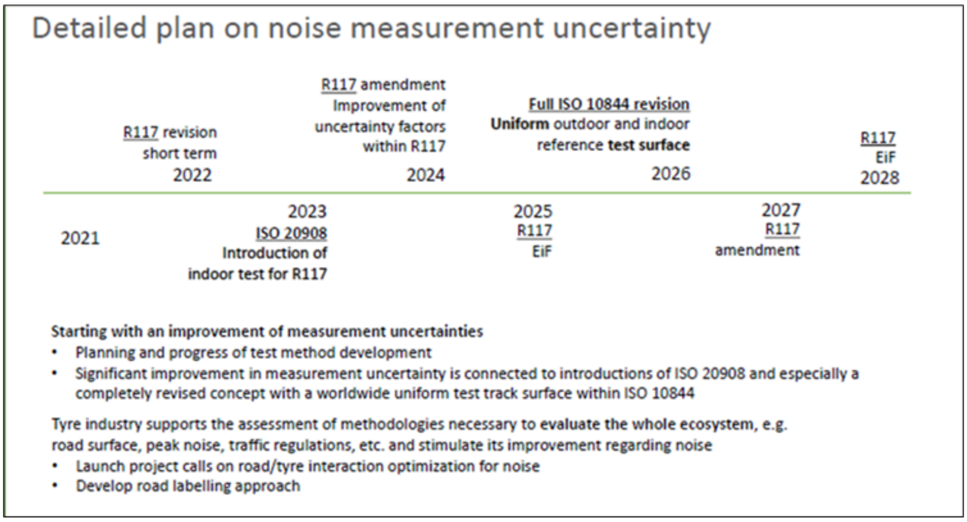

Figure 5-1: Timeline for the priorities of the tyre industry (ETRTO) for improvements of R117 primarily to reduce measurement uncertainty

In spite of the possible shift in the timeline for the introduction of the proposed stage 3 and 4 tyre sound limits, it is valuable to estimate the possible impact of these limits for the number of people exposed to levels of L_{DEN} > 55 dB for the year 2030 (scenario 1, stage 3 limits only). This is shown in the figure below.

[25] ECE/TRANS/WP.29/GRB/67/Minutes (https://unece.org/info/events/event/19250)
[26] (TFVS-04-11 Rev.1 https://wiki.unece.org/pages/viewpage.action?pageId=136446230)

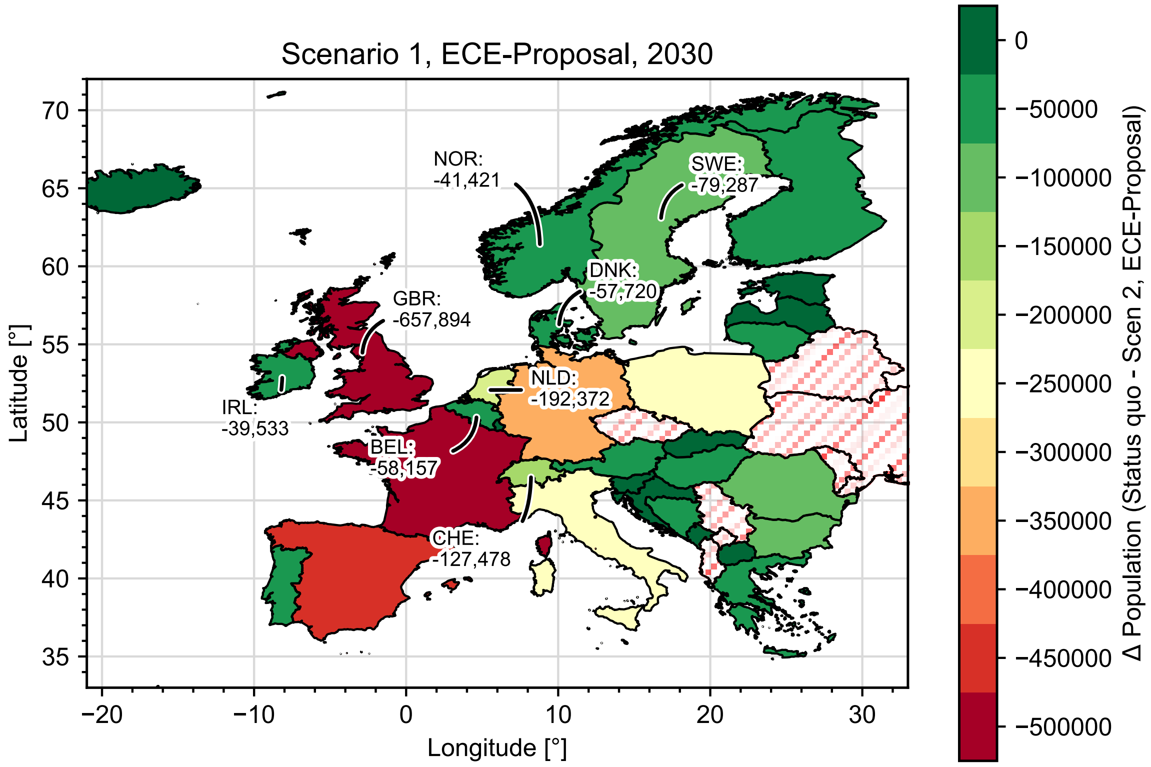

Figure 5-2: Change in the number of people brought below an L_{DEN} of 55 dB by scenario 1.

The calculation shows that the measures have a relevant impact on the number of people affected. For example, for the UK, just under 600’000 people could be brought below the 55 dB L_{DEN} level. For other countries, the benefit is remarkable as well, given that it only involves a tightening of limit values of tyre limit values.

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6 Impediments for tyre manufacturers

This chapter summarises a tyre manufacturers development procedure to create a well performing tyre with quieter that average tyre rolling noise performance. Furthermore, the impediments that comes with such an effort in form of effects on other tyre performance parameters, effects on manufacturing costs and general effects of such a unique approach to develop a tyre with very narrow scope of performance optimization are discussed.

6.1. Prototype for optimized tyre rolling sound performance

One of the most important phases of tyre development process is the determination of the areas of improvements to be concentrated on. It is generally known that some of the performance indicators of a tyre are interconnected via a so-called performance triangle. The triangle consists of three main characteristics of tyre performance parameters. These performance parameters are connected in a way that by altering any of the parameters it has an effect to the other parameters as well. The limiting factor is the area of the triangle which is constant. Such a triangle is depicted in the following Figure 6-1.

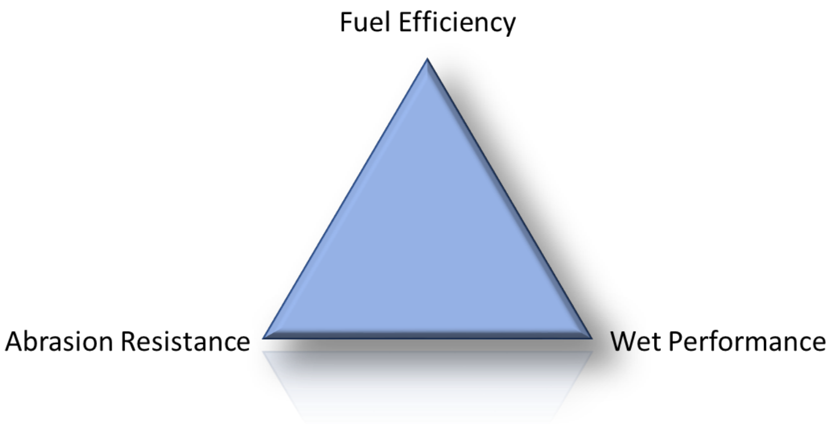

Figure 6-1: Illustration of optimization scope as a triangle as the performance parameters are interconnected. The area of the triangle is constant and optimizing one performance parameter results in an effect on the other parameters as well.

Similar kind of relations between different tyre performance parameters can be found also on wider scope of tyre performance indicators. Tyre properties such as tyre rolling noise against vehicle interior noise and tyre handling performance against tyre ride comfort have similar kind of opposing behaviour. It is very typical in tyre development that the end result of a development process is a compromise of tyre performance properties with a bias towards improving one or two predetermined parameter and tyre performance property at a time.

6.1.1. Definition of optimization strategies

The task of developing a rolling noise optimized tyre was started by studying existing development test data and determining the best possible starting point for different versions of the prototype. Based on the study a two-stage approach was chosen to be used to produce rolling noise optimized tyres.

1. Disruptive improvement by introducing a tread pattern which is favourable for rolling noise performance of a tyre
2. Two additional and incremental improvements by increasing the amount of vibration damping using redesigned rubber components in tyre structure

A total of three prototype tyres were produced. A typical representant of protype tyres market segment was used as a refence in testing.

6.2. Tyre characteristics of optimized tyre

All the tyres tested belong to a high-performance summer tyre segment, thus the tyre in question are generally optimized for good handling characteristics in all conditions, safety, especially for wet driving conditions. In general, when optimising high performance in handling and wet performance, increased rolling resistance is observed. Rolling sound noise performance as well as the aquaplaning properties of the tyre are highly dictated by the design of tread pattern. Typically, these two performance parameters of a tyre are presenting opposing behaviour in relation to modifications to tread pattern design. Analogue in this interconnection of different performance indicators is that to obtain good aquaplaning performance for a tyre a non-restricted passage or passages for the water to get out of the contact path of a tyre is needed to be included in the tread pattern design. Preferably the passages are arranged in a way which guides the water to the sides of the tyre out of the path of the tyre. This design of a tread pattern also enables the air to flow freely out of the contact path of the tyre which then turns into acoustic vibration.

Aquaplaning is one of the key parameters in defining the tyre’s total wet condition performance and safety. This leads to a situation where the bias between rolling noise performance and wet condition safety needs to be defined during the tread pattern design of a new tyre. Initial bias in reference tyre of this study is set toward wet condition performance.

For the rolling noise optimized tyre, a tread pattern design with modifications improving the rolling noise properties were chosen to act as a base (PRT-1). This represents a disruptive improvement as the tread pattern design has a strong influence on the rolling noise performance. On this base, two additional prototypes were prepared using redesigned rubber components in the tyre structures (PRT-2 & PRT-3). The fundamental idea was to increase the amount of damping material in the tyre so that the added viscoelasticity would dissipate as much of the tyre’s structural vibration turning in to noise as possible. The respective rubber compounds used as additional damping material were chosen according to their abilities to dissipate energy.

The tyre size in the test was 235/60R18 with a speed index of H and load index of 107. Many of the vehicle in *Compact luxury crossover SUV*s are using this tyre size. The SUV segment is one of the most popular segments of today’s passenger car market in Europe having 38% market share with 5.9 million units sold in year 2019 (ACEA, 2020)

Detailed descriptions of each tyre used in this experiment are elaborated in Table 6-1.

Table 6-1: Descriptors of the three prototyped tyres

Description	Short name	Tyre weight (kg)	Notes
Reference tyre	REF	13.3	Normal producibility
Prototype tyre 1	PRT-1	13.3	Normal producibility
Prototype tyre 2	PRT-2	15.4	Producibility on upper limit of component manufacturing, normal tyre buildability
Prototype tyre 3	PRT-3	17.6	Producibility beyond upper limit of component manufacturing, extremely compromised tyre buildability

6.3. Performance testing of the noise optimized tyre

The three different produced tyres were tested for their rolling noise levels. In addition to the rolling noise test, a set of other different performance tests was applied. Most comprehensive amount of testing was done for REF and PRT-1. This was dictated by the resources available for performing these tests. PRT-2 and PRT-3 are differing too much from the production specification of the base product and there would have been too many manufacturing rounds needed to be able to produce valid protype specimens to be used in tests such as highspeed handling without risking the safety of the test driver. Also, the knowledge from the past R&D testing was used to determine which modification has an effect to what particular test to be able to neglect some of the tests performed for PRT-2 and PRT-3.

The tyre performance test results are depicted in Table 6-2. In this table, the measurement results are depicted as a unified index. In this case, a higher value indicates better performance. Attention has to be given, when comparing different indexed columns amongst each other, as the scaling of different column indices is different and cannot be compared or weighed against each other.

Table 6-2: Tyre performance test results for the developed tyres within this task. The values represent calculated indexes according to the respective standard. Attention should be given, by comparing different columns as scaling might be different.

Tyre ID	Dry Road Handling (<120 km/h)	Vehicle Cabin noise	Pass-By Noise (R117)	Rolling Resistance (R117)	Wet Braking (R117)	Aqua-planing (Long)	Aqua-planing (Lat)	High Speed Handling
REF	100	100	100	100	100	100	100	100
PRT-1	107.7	101.1	103.0	106.0	97.5	100.3	99.9	108
PRT-2	96.2	100.2	103.8	96.2				
PRT-3	103.8	99.4	104.0	83.4				

In general, the test results have shown significant differences in the tested tyre performance measures of the tested tyres. Both development steps, the change of tread pattern and the incremental addition in the tyre's damping via increased thickness in structural components of the tyre impacted the tyre performance.

It can be clearly seen that the introduction of a new tread pattern has a disruptive effect on many of the performance indicators of a tyre without having too much negative effect on any measured performance parameters.

Rolling sound test results were collected for the tyres in dB(A) according R117 (after temperature correction Annex 3 paragraph 4.3, without uncertainty correction Annex 3 paragraph 4.4) and are presented in Table 6-3.

Table 6-3: Rolling noise characteristics of the studied tyres (Pass-by-Noise) according R117

Tyre ID	Pass-By Noise (R117 dB(A))
REF	73.1
PRT-1	71
PRT-2	70.4
PRT-3	70.3

There is a significant improvement in the rolling noise tyre performance. Thereby, the tread pattern seems to be the most influential source of improvement and the structural modifications of a tyre are showing more of incremental betterments in rolling noise performance of a tyre.

6.3.1. Handling performance and safety (subjective)

Tyre handling comprehends the logical and predictable behaviour of a tyre under different kind of driving manoeuvres on a test track. In handling testing the tested tyres are driven on various driving speeds, finally bringing it up to the speeds according to the performance category of the tyre to ensure that the driveability and safety of the tyre is adequate in all driving situations. In this experiment the quality of the tyres PRT-2 and PRT-3 were such that only the speed covered up to 120 km/h were tested for handling performance.

According to the accomplished testing, the changes to the tread pattern which had an improving effect to the rolling sound performance had an equal effect on the handling properties of the tyre at dry conditions. Introduction of extra damping rubber to the tyre structure makes the handling performance drop at first, and afterwards to improve a bit after even more additional rubber is introduced to the tyre's structure (PRT-3). The subjective description of the tyres tested is consistent with the objective values and there are no individual areas of handling that deviate greatly from the norm.

Wet grip and aquaplaning are the most crucial measures of summer tyre's safety. Aquaplaning, which is mostly dictated by the tread pattern design, does not vary much between REF and PRT-1. Wet grip, on the other hand, decreases significantly after the introduction of a new tread pattern. The changes to the tyre structure done for PRT-2 and PRT-3 are such they have not been recognized as influential factors in aquaplaning nor wet grip performance and thus were left out of the test program.

6.3.2. Fuel economy (R117)

Measured rolling resistance was shown to improve with the introduction of the improved tread design (PRT 1 had a coefficient of 8.37 which was better than Reference tyre 8.9). Further improvements in rolling noise, respectively the additional damping had a significant impact on rolling resistance and thus on fuel consumption. The rolling resistance coefficient increased from 8.37 to 9.22 and 10.37 for the prototype tyres.

The tyre size was 235/60/R18, which is a typical tyre size for large SUV cars like a Porsche Cayenne, Audi Q5, BMW X5. To illustrate the effect of changing the respective change in rolling resistance on the emitted carbon dioxide (CO_2) emissions in g/km, a simulation was performed using a Porsche Cayenne as an example.

In Figure 6-2 it is depicted, that the absolute emissions (left y axis) increase exponentially with increasing driving speed but the order of the tyres (different rolling resistance remains the same). The increase in the total amount is given by the quadratic increase in air resistance. This causes the comparison of emissions (right y axis) to be higher at lower driving speeds than on higher driving speeds: At 40 km/h there is a difference of 7% - 17% in carbon dioxide emissions in favour of lower rolling resistance. At 120 km/h the difference is only 2% - 5% (but at a higher absolute level).

6.4. Impediments of quieter tyres

The performance of a tire has an opposing reaction to improvement of rolling noise performance when rolling resistance and wet surface safety are concerned. The modifications to the tread pattern design which are in favour of rolling noise are showing negative effect to the wet grip of the tire. Modifying tire structural components to be in favour of better rolling noise performance have a negative impact on rolling resistance and tire handling as well as ride comfort performance.

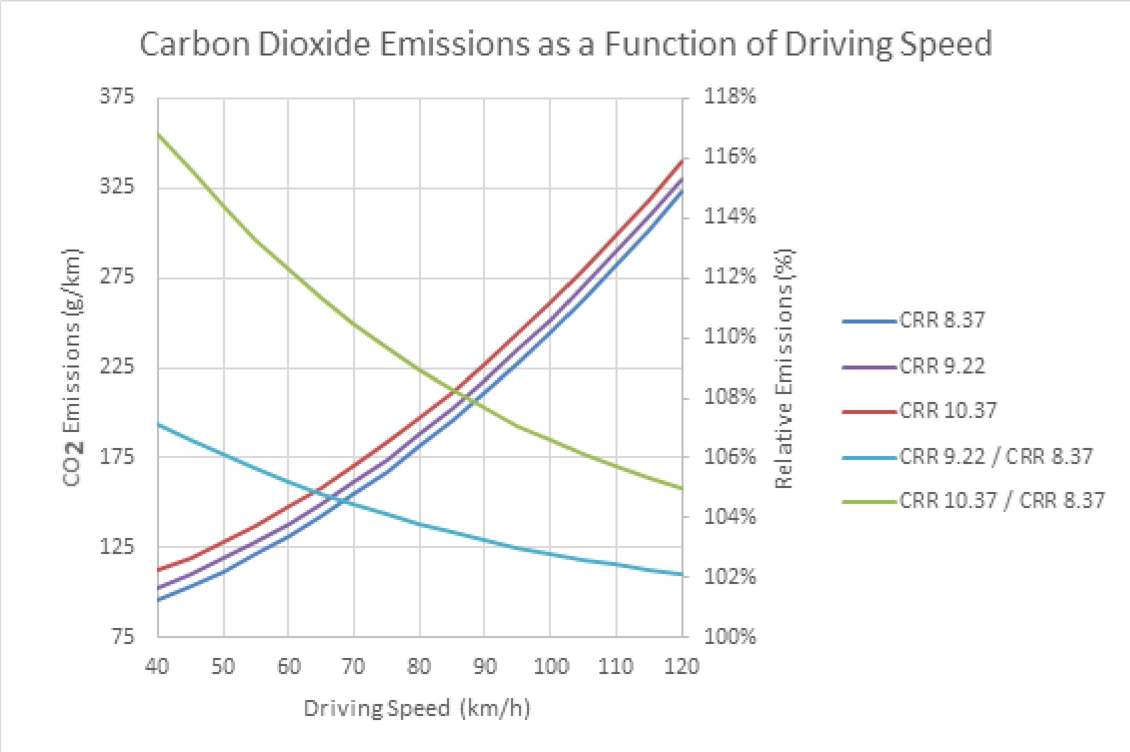

Figure 6-2: Simulated CO2 emissions of prototype tires

Direct impediments of quieter tires for consumers would result in higher energy consumption, negative effects on ride comfort and safety performance on wet surfaces. The best compromise according to this experiment would be a tyre with redesigned tread pattern. The only drawback of rolling noise improving tread pattern design is the reported negative effect on wet grip performance. Further rolling noise performance improvements by tire's structural modifications have a drastic negative influence on many of the key characteristic of tire performance.

From manufacturing point of view there are no impediments in manufacturing tires with the tread pattern design of prototype tires of this experiment. Raw material costs of a tire go up by 16% with modifications used on PRT-2 and 34% with PRT-3.

The impediments on other performance properties of the tire are not justified just by improvement in one tire performance property alone when considering the modifications used in PRT-2 and PRT-3.

6.5. Tonal properties of tyre/road noise

For certain types of noise emission or immission corrections for prominent tonal components in the noise are applied, adding a certain number of decibels as a penalty when the noise level is compared to some limit or reference. Tonal components can be heard in noise from tyres too, but not in general.

Two types of tonal components are considered as potentially disturbing (both are much more extensively described and illustrated in [Sandberg & Ejsmont, 2002]):

- Tube resonances in the tyre cavity; with a resonance frequency depending on sound pressures inside the cavity with a wavelength fitting the cavity length (on turn inside the tyre). This can give an easily audible tone inside the vehicle cabin but is rarely audible outside the vehicle. Tyre manufacturers are assigning substantial resources to reduce the effect of this tonal property. This is normally a negligible effect for tyre noise emission to the roadside.

- Resonances in the tyre tread, due to constant periodicity (pitch) of the tread blocks or tread grooves, or a pipe resonance (such as in musical pipe instruments) in longitudinal groves in the tread. Normally, tyre companies assign substantial resources to get rid of such resonances by “randomizing” the tread block and/or groove dimensions around the tyre circumference, and/or by designing them with certain angles with respect to the edges in the tyre/road contact patch. Pipe resonances can be eliminated by “ventilating” the grooves by cross-grooves in certain manners. This is an advanced science which is usually successfully applied.

Nevertheless, the tread resonances are sometimes audible. For car tyres, this may (although not often) be the case for some inexpensive winter tyres and for truck tyres it is the case for some retread tyres but can also occur for premium original equipment brands. One example of the latter appears in [van Blokland et al, 2015] where, in a selected sample of two truck tyres, a truck tyre from a leading tyre manufacturer was detected as having prominent tonal components.

However, to properly detect such tonal components, the tyre labelling measurement procedure (coast-by) is not suitable, as the potential tone(s) will change its frequency during the coast-by due to the so-called doppler effect. Instead, a method similar to the CPX method or measurement on rotating drums is needed.

Before one can suggest if and how to deal with this problem, the severity of the problem must be investigated. This was proposed as a follow-up in the NordTyre project [van Blokland, 2015], by further analysing the comprehensive truck tyre noise data already collected in Part 3 of the NordTyre project, but it was never funded.

STEER proposes to conduct this new and deeper analysis of the NordTyre truck tyre data, as proposed in [van Blokland, 2015]. If the tonal problem appears to be severe, a method to detect such components in connection with tyre labelling measurements, or by supplementing them, should be worked out.

6.6. Tyre/road noise on wet roads

Roads are wet during a substantial proportion of the time; depending on the climate and weather. Tyres may rank quite differently in wet than in dry road conditions, since in wet conditions there are additional and changed generation mechanisms. Those will depend on the rubber compound and drainage properties of the tyre treads (and of course also on the water depth on the road). The problem is so complicated that little research on this is done, and it seems to be difficult to produce any reproducible testing conditions with a wet surface.

For example, if microphones were set-up on both sides of the wet grip testing track (UN ECEC R 117), noise measurements could be done in the same way as for the regular noise test. However, it should be checked if such conditions may be reproduceable. The mentioned laboratory facilities at VTI in Sweden and BASt in Germany could also be considered for research on wet versus dry surface noise emission; even while varying temperatures from 5 to 20 ^{o}C. This could be funded by NRA:s.

Consequently, there are significant research needs with regard to testing on wet roads and to determine how important it would be to do so.

6.7. Conclusion

With modifications to the tyre design, it is technically possible to improve rolling noise performance of a tyre. But this performance does not come without impediments. The most complicated, but also effective way of introducing improvements comes in the form of tread pattern design modification. The tread design characteristics dictate many performance measures of the tyre, on both dry and wet roads, and also gives the visual look of a tyre. However, the manufacturing of tyre moulds is a time consuming, expensive and delicate work.

7 RFID chip benefits

7.1. Information about RFID chips

Radio frequency identification (RFID) systems uses electromagnetic fields to automatically identify and track chips in tags attached to objects. An RFID system consists of a radio transponder, receiver and transmitter. When triggered by an electromagnetic pulse from a nearby RFID reader, the tag transmits digital data stored in the chip back to the reader.

Tags contain a microchip, an antenna and a substrate. There are three types of tags: passive, battery-assisted passive and active. Passive tags receive their power from the RFID reader's interrogating radio waves. Battery-assisted passive tags include a battery which gives them more power than the radio waves transmit, or can be used with much weaker radio waves, and is activated when a reader tries to read the chip. Active tags also contain a battery, but unlike the battery-assisted passive tag, it transmits its data periodically. The use of batteries in the tags means that these tags can be read at a much greater range from the RFID reader without a radio signal that is exceptionally strong (the latter of which may create electromagnetic disturbances). The range may be up to two hundred meters for active tags, but passive ones have a range of a few decimeters or a meter.

Microchips may be extremely small; for example, there is one chip at the size of only 0.05 mm × 0.05 mm.

The readers can be either active or passive. Active readers transmit signals to the tags, which may be of any of the three types mentioned above. Passive readers transmit no signal; instead rely on the active tags to activate them.

ISO, IEC, ASTM International are examples of organizations which have established standards for RFID systems. Especially, the frequency range of the radio waves must be regulated, together with limiting power to protect for effects on humans and animals. As is not uncommon, some systems used in USA are not compatible with those in Europe and Japan, and vice versa. Another problem worth mentioning is consumer privacy.

RFID tags are already standard in credit cards and passports – also used in burglary alarm systems. A common use is to protect products from theft in shops. RFID systems have become popular in electronic toll systems for highways. For example, in USA the E-ZPass is an often-used electronic toll collection system based on RFID.

Figure 7-1: Example of implementation of E-ZPass RFID system in Virginia, USA (2019).

Similar systems are used in Turkey, called HGS “Fast Passing System” and OGS “Automatic Passing System”. The vehicles are equipped with either an electronic-chip sticker or card (in HGS) or a toll transponder (in OGS) mounted at the top of the windshield; see Figs. 7.2-7.3. These devices communicate with toll-tracking equipment mounted above the roadway, record the passage, and charge the toll to the vehicle’s account. The sticker costs less than a US dollar, the OGS unit costs appr. 5 dollars.

An RFID system is also used on the Öresund Bridge, for automatic toll payment without stopping. The system uses commercial platforms by names such as EasyGo, EasyGo+, ÖresundBizz, etc. To some extent these systems work also in other European toll locations.

Figure 7-2: The Turkish HGS and OGS systems based on RFID, implemented on toll bridge over the Bosporus.

Figure 7-3: A sticker with a passive RFID chip for the Turkish HGS system (above) to be put on the windscreen and an OGS active unit (below), also to be put on the windscreen. The actual size of the sticker is appr. 100 mm wide and the OGS unit appr. 60 mm wide. In both cases the formal numbers have been hidden. Both are linked to some bank account.

7.2. RFID chips in present tyres and its standardization

"*RFID is the hottest topic in the tyre industry right now*" is a statement recently posted by an automotive-focused journalist (Tangeman, 2019). Yes, RFID are already mounted into some tyres and are expected to be introduced in most tyres within the next few years. They are presently being standardized and are thus likely to provide useful data such as dimension and production week.

Goodyear began exploring RFID technology as far back as 1984 and was putting it in tyres around 1993. Michelin, meanwhile, stated "the company is adding RFID chips into their tyres for easier tracking and inventory purposes" and are working to develop sensors "that can provide a wealth of data on the tires as they are out on the road." (USA Today, 2020)

Michelin embeds passive ultra-high frequency (UHF) radio frequency identification tags into tyre side-walls during the manufacturing process. The Michelin RFID tag is typically buried in the tyre during the manufacturing process but can also be integrated into a patch for aftermarket applications. The tag's read range has been optimized for in-tyre use. Michelin has announced plans to equip all its new car tyres with RFID chips by 2023 (https://news.michelin.co.uk/articles/michelin-to-connect-all-its-car-tyres-by-2023). It is unclear what range (distance) these tags will cover.

A tyre tag measuring 43 x 2 x 2 mm, is supplied by the company Avery Dennison, which can be read from a range of up to 11 m depending on its mounting position and the tyre type it is attached to. It is fitted to the tyre side during the vulcanization procedure. China is planning to make the technology mandatory (Tire Technology International, 2021) Some other (earlier) tags are illustrated in Figure 7-4.

It is perfectly clear that the tyre industry has acknowledged the potential benefits and is moving quickly to adopt the technology. One reason is to track their products to get feedback on performance and quality. Another reason is to help trucking companies improve maintenance, as the tyres on their fleet provide data on running distances and inflation pressure and possibly some other parameters. The chips will also be useful in future autonomous driving systems.

The ISO tyre committee, ISO/TC 31, has a WG 10 which is working on a universal standard for RFID in tyres. This committee has already produced four standards:

- ISO 20909:2019 Radio frequency identification (RFID) tyre tags
- ISO 20910:2019 Coding for radio frequency identification (RFID) tyre tags
- ISO 20911:2020 Radio frequency identification (RFID) tyre tags -- Tyre attachment classification
- ISO 20912:2020 Conformance test methods for RFID enabled tyres

The first of the four standards specify requirements for using an RFID tag to individually identify a tyre. Three RFID tyre tag technologies are considered in this document: embedded, patch, sticker. Tyre tags can be used for all tyre categories. The other three standards, provide information for coding, attachment and test methods.

Figure 7-4: Example of early RFID tags for “long range” tyre use.

7.3. Potential future use of RFID tags in tyres for noise-related purposes

RFID stickers (like the one in Figure 7-3) can already be included in the tyre label system, to make it possible to read the label digitally and electronically. Handling and storage of the tyres in this way can be enhanced.

RFID chips of “long range” type, mounted inside tyres, can already be read by sensors at the roadside (passive sensors up to a few meters and active sensors up to some hundred meters) and this may expand further in the future. Passive chips may be made so light that they will not influence the balance of the tyre it is included in. Yet, the toll road implementation shows that even the super-light stickers (Fig. 7.3) can be read at the roadside. If labelling data are included in the RFID chips, this means that one may identify from the roadside the quality of the tyres that passing vehicles have. This may be used **in tolling systems**; for example, to give advantages to vehicles with environmentally friendly tyres. This would give the consumers incentives to choose better tyres.

In principle, it would also be possible to read the tyre labelling for vehicles passing certain spots and estimate an average tyre noise label there. The tyre dimension would also be read. Combining this with the average speed and (a separately known) noise property of the pavement surface makes it possible to establish a kind of “noise quality class” at the spot.

During the regular vehicle testing required in most countries (in many countries annually) reading the tyre data by means of RFID technology may give the testing authorities the possibility to quickly and objectively check the tyres' age, inflation, dimension and other quality parameters; potentially even the tread depths. Too aged tyres and tyres with improper dimensions or load index may be taken away from traffic. This will result in better safety in traffic.

The system may even be extended to indicate if the tyres have studs in the treads; in which case they may be refused to enter certain cities or areas in cities.

7.4. Recommendations

The author recommends the following implementations of RFID technology in tyre-labelling-related procedures be considered:

All C1, C2 and C3 tyres are equipped with an RFID chip that can be read from the roadside and in a testing laboratory.

The information in the chip should include at least the information that is included in the tyre label according to the most recent version, plus the week when the tyre was produced.

Testing laboratories or facilities are equipped with RFID equipment making it possible to read the tyre data. This is then compared with requirements regarding tyre dimensions and load index for the vehicle. Also, too old tyres should be unaccepted or at least the owner should receive a warning. With near-future technology to record the tread depths, also the tread depth can be compared to legal requirements, and the driver could receive a warning when it is close to unsafe limits. Tyres which are not labelled should be subject to extra tests or considerations. In this way, tyre testing in the regular vehicle testing procedure can be objective instead of subjective.

To give vehicle owners increased incentives to purchase low-noise tyres, such tyres should be the only ones allowed in environmentally friendly zones. In case where there are no toll gates that can check this, it will be easy for the police to check if the tyres are acceptable or not in the area if they have an RFID-reading facility installed or available.

The same principle should be used with respect to detection of studded tyres in zones where such tyres are forbidden. This will of course reduce noise exposure, in addition to particle emissions.

In parking areas or buildings, vehicles with low-noise tyres may receive certain favours, such as lower parking fee or special priority.

In toll-road systems, vehicles detected with all tyres of low-noise type can be exempted from the toll. This would greatly increase the incentives to purchase such tyres.

In toll-road systems on motorways or other fast-speed highways, if a tyre with too low tread depth is detected when it is rainy weather, the vehicle may be stopped from entering the road.

8 Winter tyres

8.1. New label to better consider winter tyre safety properties

From 1 May 2021, the tyre regulation has been changed to a partly new one: Regulation (EU) 2020/740. The main reason is that it is clear that wet grip of winter tyres has no relevance for grip on winter roads. To correct for this problem with the old label, the major change is that there is optional labelling of snow and ice friction of winter tyres. Also, the new rules are extended to mandatory cover bus and truck tyres, which was only voluntary before. There is another important change, which is that the three classes of noise emission have been changed to only two; one normal ("B") and one low noise ("A"). The previous class C is no longer legal for new tyres and tyres with noise above the limit are now (strangely) labelled is Class B.

The new label is illustrated in Figure 8-1.

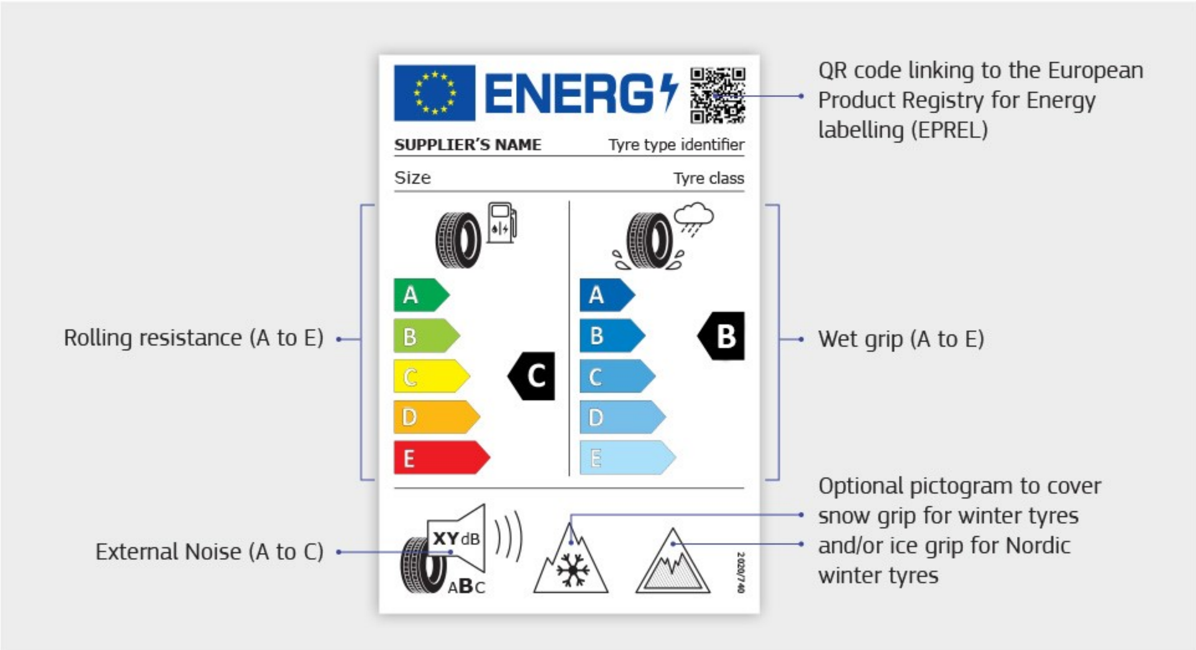

Figure 8-1: The EU tyre label valid from 1 May 2021.

As explained in the figure, winter tyres in general may be labelled with the snow grip symbol and/or Nordic winter tyres maybe labelled with the ice grip symbol. There are no distinguished classes of performance; the symbol is only given to tyres that meet a specified minimum grip on snow and/or ice.

This report deals with noise emission performance. How does this apply specifically to winter tyres; or rather to performance in different seasons vs the label value?

A major problem for the labelling system is that winter and normal tyres (the latter referred to here as "summer tyres") are optimized for operation in very different seasons but are tested and labelled (for noise) under summer or at least not winter conditions; ideally and usually around or above 20 °C. This is potentially a major representativity problem. This issue is discussed in a separate chapter in Deliverable 4.1 which is devoted to representativity and is therefore not copied here.

8.2. Road surface conditions in wintertime vs the ISO 10844 surface

The noise measurements for limits and labelling are of course made on an ISO 10844 surface. But how representative is that with respect to operation of winter tyres? In wintertime road surfaces are sometimes covered by loose snow, packed snow, or ice. Loose snow is favourable as it reduces noise by sound absorption and/or by providing a softer surface to roll on. Packed snow can often become corrugated and then create exceptionally high noise emission; see Figure 8-2. The effect of ice is complicated; it may reduce or increase noise; it depends on what the ice-free surface is.

Figure 8-2: A not uncommon sight on winter roads where de-icing is not applied. These corrugations create extreme tyre/road noise, which is extra annoying due to its character.

As winter maintenance mostly means application of salt (or other de-icing materials), winter roads are more often than summer roads wet or humid due to the melting of snow and ice and the de-icing. Therefore, the part of the time when road surfaces are really dry in wintertime is shorter than in summertime, and wet surfaces are very common in urban and suburban areas, where temperatures are high enough for de-icing to be effective. It follows that the dry ISO 10844 surface is even less representative of road conditions in wintertime than in summertime. It is worth noting that noise emission on wet roads may be quite different for winter versus summer tyres, due to different rubber compounds, different tread patterns and different tyre widths.

Unfortunately, there is no practical or realistic solution to the problem, i.e. to test tyres on special winter roads. Of course, companies which develop winter tyres are always (?) using winter testing facilities in northern Sweden or Finland, but to create winter surfaces sufficiently reproduceable for testing noise is a too difficult challenge. As wet surfaces are so common in wintertime, testing on a wetted surface in a reproduceable way would be desirable, but is not presently realistic. In principle, it could be done on the moving track tyre test facility at VTI, with a fixed amount of water applied on the asphalt, but only at too low speeds (max 30 km/h) and it is a very expensive facility. There is a drum facility at BASt in Germany where one can make tyre tests on a wet surface at high speeds, but also that is an expensive and unique facility.

One may also imagine doing noise measurements simultaneously with the wet grip testing according to UN ECE Regulation R117. If microphones were set-up on both sides of the wet grip testing track, noise measurements could be done in the same way as for the regular noise test. It is not yet known if such conditions may be reproduceable.

8.3. Noise limits for winter versus summer tyres

In the EU regulation (EC) 661/2009, limits for noise emission at type approval are specified. The measurements according to type approval are also used for determining the tyre noise label value. For C1, C2 and C3 tyres, an extra dB is allowed for “snow tyres” (what we here call winter tyres). An exception is for C2 tyres of “traction” type which are allowed 2 extra dB instead of the 1 dB for all other “snow” tyres.

The reason for this extra allowance may be the situation about 50 years ago (and earlier) when it was common that winter tyres had very aggressive tread patterns which caused excessive noise. This is no longer the case. However, our data presented in Fig. 8.3, compared to Fig 2.2, suggest that winter tyres on average are labelled with 0-1 dB higher values than summer tyres. Therefore, it is not time to delete the extra allowance, as too many winter tyres would be above the limit value then.

Nevertheless, the authors are uncertain about what applies to all-season tyres which are becoming more and more popular. Tyre companies are currently devoting substantial resources to development of such tyres. As EU Regulation 661/2009 does not mention all-season tyres, we assume that they are considered to be “normal tyres”; i.e., “summer tyres” in our terminology.

8.4. Recommendations

It should be clarified that all-season tyres are considered to be “normal tyres” (or “summer tyres”) as they are generally used less in winter than in summer seasons. They should not be allowed the extra 1 dB as is allowed for winter tyres. This would be a topic for discussion in the EU Commission regarding the labelling regulation and in GRPB about definition of tyres. NRA:s should be active to influence such discussions.

STEER proposes that more than two noise classes are introduced. Previously it was three classes, now one should get back to three classes, with a range of 2 dB in each one.

At the moment, STEER cannot recommend that tyre noise testing (for labelling) should be made at winter temperatures since we do not know how severe the problem is. No temperature corrections are available for low temperatures. In the future, the solution may be to go indoors with all noise testing, using a laboratory where temperatures can be set at a desired level (say 0 and 20 °C) and tyres are tested at a temperature for which they are designed to operate.

The recommendation is that research is done to study how tyre noise properties change over a wide temperature range, ideally including the temperature range from -10 to +40 °C of air temperature. This should include studying the ranking of various types of tyres based on low vs high temperatures. Such studies may be funded by transport and environmental authorities, such as NRA:s.

One would need to make experiments to determine the performance of tyres in summer temperatures versus winter temperatures and how such performance may differ among tyres. Testing at low temperatures could be made in conjunction with ordinary winter tests in northern Europe if an ISO 10844 surface would be paved there and kept free from snow or ice. Such test may much easier be made in a laboratory setting, with a drum covered by a replica of an ISO surface and where temperature may be varied. It would be possible to do this at the facility of Gdansk University of Technology. This can be funded by for example the Nordic NRA:s.

The same research needs apply to testing on wet versus dry road. It is the same problem as for normal (summer) tyres. Please refer to 6.6 for this discussion.

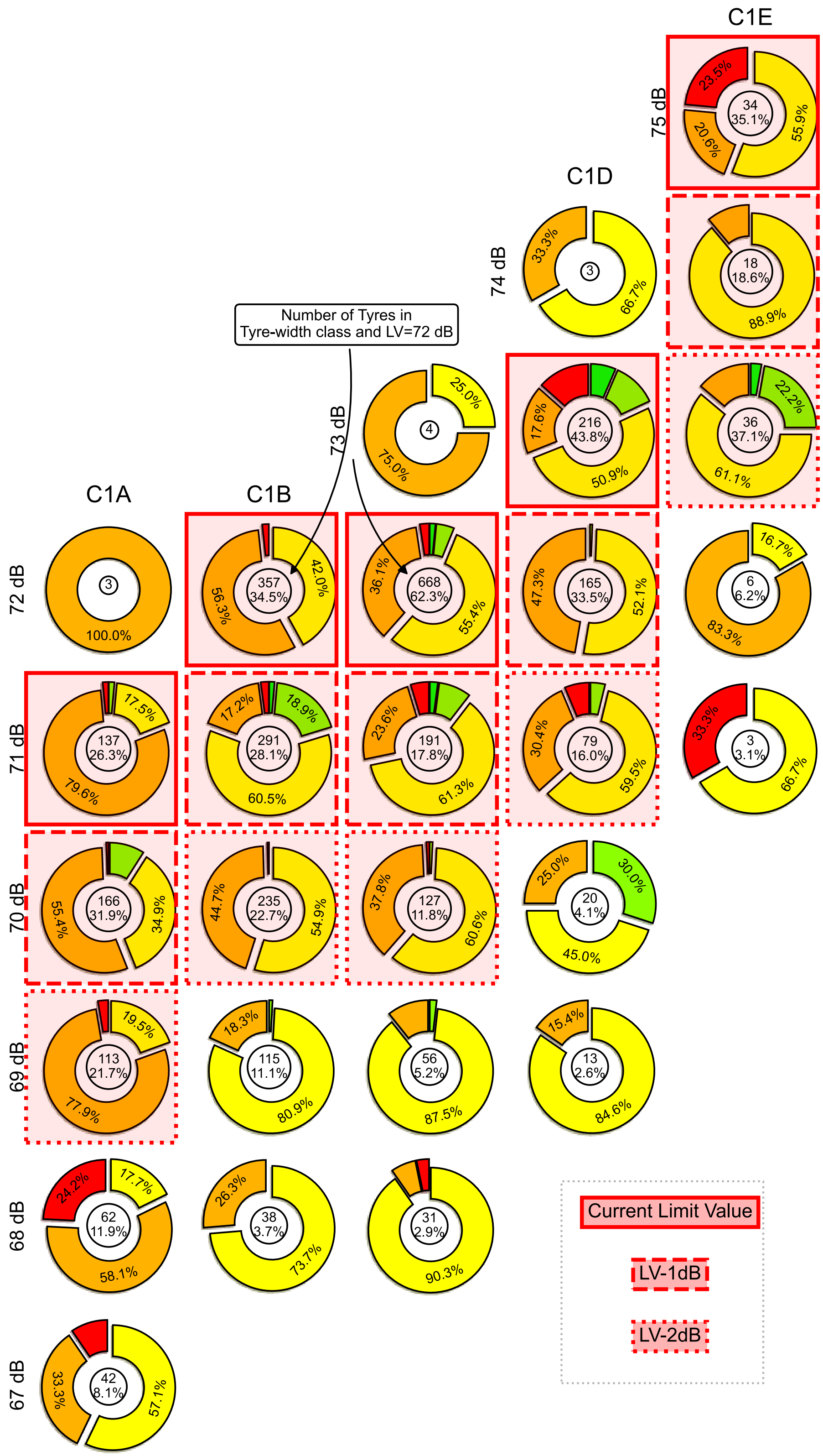

Figure 8-3: Rating of C1 winter tyres sorted according to their tyre width (hypothetical X Axis, rated A-E according to EC 661/2009). On the hypothetical Y-Axis the noise limit values are depicted. *Source of data: Touring Club Switzerland, Illustration and evaluation by the authors, financed by the Swiss Federal Office of the Environment FOEN*[27]

[27] https://www.bafu.admin.ch/bafu/en/home.html

9 Tyre width

9.1. Discussion

The determination of “noise class” depends on how many decibels the noise level is below the noise limit values, according to (EC) No. 661/2009. Since the limits are different for different tyre widths, it means that a rather wide tyre (say 255 mm) may belong to the lowest noise class, despite it is two dB noisier than a not so wide tyre (say 185 mm). The matter becomes more complicated due to the present trend of increased rim diameter that may somewhat counter the previous trend of increased width.

It has been reported earlier that there is a clear relation between tyre/road noise levels and tyre width for car tyres (Sandberg, 2008).This is also strongly supported by Figure 2-1 and Figure 8-3. The noise level range due to width is 4 dB, which is close to the range within each width class which is 5 dB (with tyres above limits neglected). There are technical reasons for the width influence, namely that the horn effect which amplifies noise generated at the leading and trailing edges of tyres is more effective the wider the tyre is. Another effect is that wider tyres are generally (but not always) carrying a higher load and are tested with a higher load; something which has an increasing effect on noise levels—albeit a quite small effect.

Since wider tyres are allowed to emit more noise, it may in some cases be tempting to choose a wider tyre than necessary from the performance of the vehicle. This may not happen often, but more commonly styling aspects of the vehicle puts pressure on the manufacturers to use wider tyres than strictly necessary from safety or load-carrying points of view. It simply looks like wider tyres give the cars a sporty appearance, suggesting high power and high-speed capabilities. This trend has been on-going for at least the latest 4 decades and does not seem to end yet. It has had the effect that noise emission has increased just by wider tyres becoming more and more common.

How can this trend be broken? To influence the impression car buyers have of styling and its relation to tyre width, is probably not a way forward. Instead, an obvious way is not to allow higher noise levels for wider tyres. For example, by not allowing on extra dB for width class C1D compared to C1B and C1C summer tyres, about 40 % of the present tyres in C1D would need to be replaced. This may look like a drastic action, but it would probably have a positive effect on safety and energy consumption as the quieter tyres according to Figure 2-2 have better wet grip and energy ratings than the tyres that would be removed. The same applies if the limit noise level for C1E tyres (74 dB) would be reduced by 1 dB. Only 17 % of the C1E tyres would need replacement and the wet grip and energy ratings of the remaining ones would be better. See illustration in Fig. 9.1.

For winter tyres, the information in Figure 8-3 is not sufficient to estimate the effect of similar changes since the wet grip data used there are not very relevant for such tyres on winter roads and there are not yet classes for winter road grip.

9.2. Recommendation

It is recommended that within (say) 5 years, the noise limit of C1D summer and all-season tyres be the same as for the C1B and C1C width classes.

At the same time, it is recommended that C1E summer and all-seasons tyres shall have only 2 dB higher allowance than C1B – C1D tyres.

This would be suitable for discussion in the EU Commission and in GRPB, where NRA:s should be able to have an influence if they act together. Such actions will almost entirely remove the negative effect on noise emission caused by allowing higher noise levels for wider tyres, since the classes C1B, C1C and C1D dominate the tyres on the market and they will all have the same limit and be labelled with the same consistent noise class.

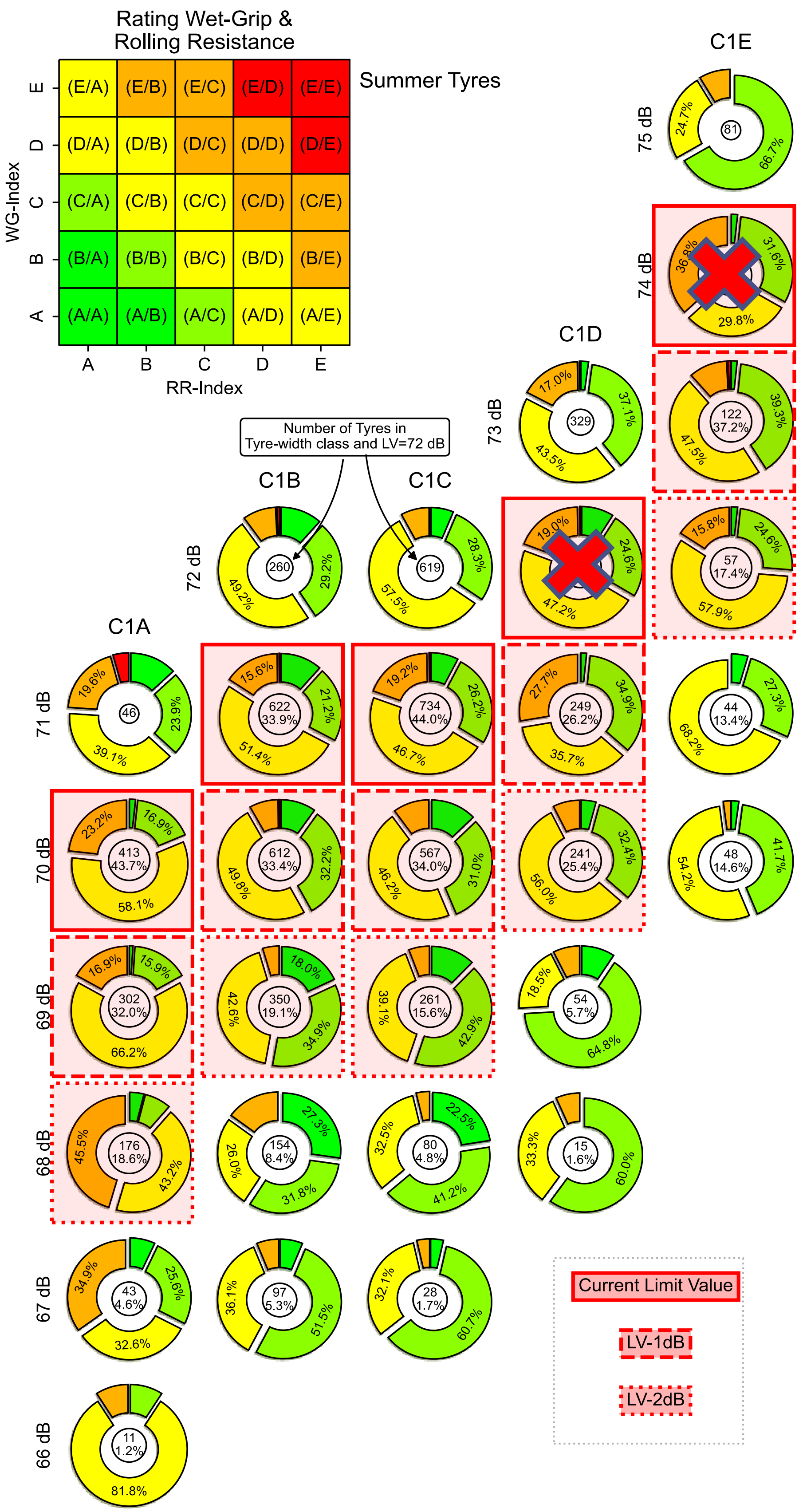

Figure 9-1: Suggested levelling of noise level limits for C1D and C1E tyre widths, by reducing the limits by 1 dB in comparison to the limits of C1B and C1C widths. Note that the remaining tyres have better wet grip and energy labels than the removed tyres. Note also that the tyres above the present limits will be phased out with time.

Additionally, if RFID systems are used as suggested in Chapter 7, it will be possible to detect when vehicle owners have made upsizing to the highest width class (C1E) and then they could be ordered to remove such tyres. This would reduce the problem with upsizing which has a negative effect on safety. This would be a task for NRA:s on a national level.

Finally, on a national level, NRA:s can encourage consumers, when they purchase replacement tyres, that they check the tyre labels and select the brand and dimension (within what is accepted on the vehicle) that gives the best performance instead of selecting the tyres for visual impression or purchase cost.

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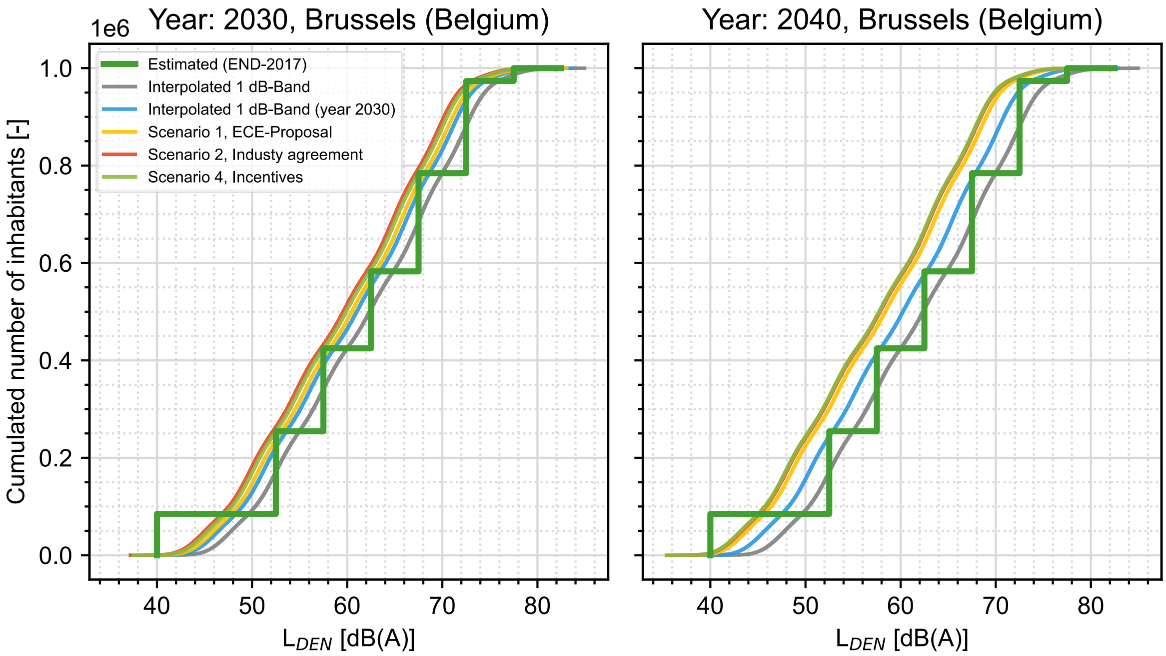
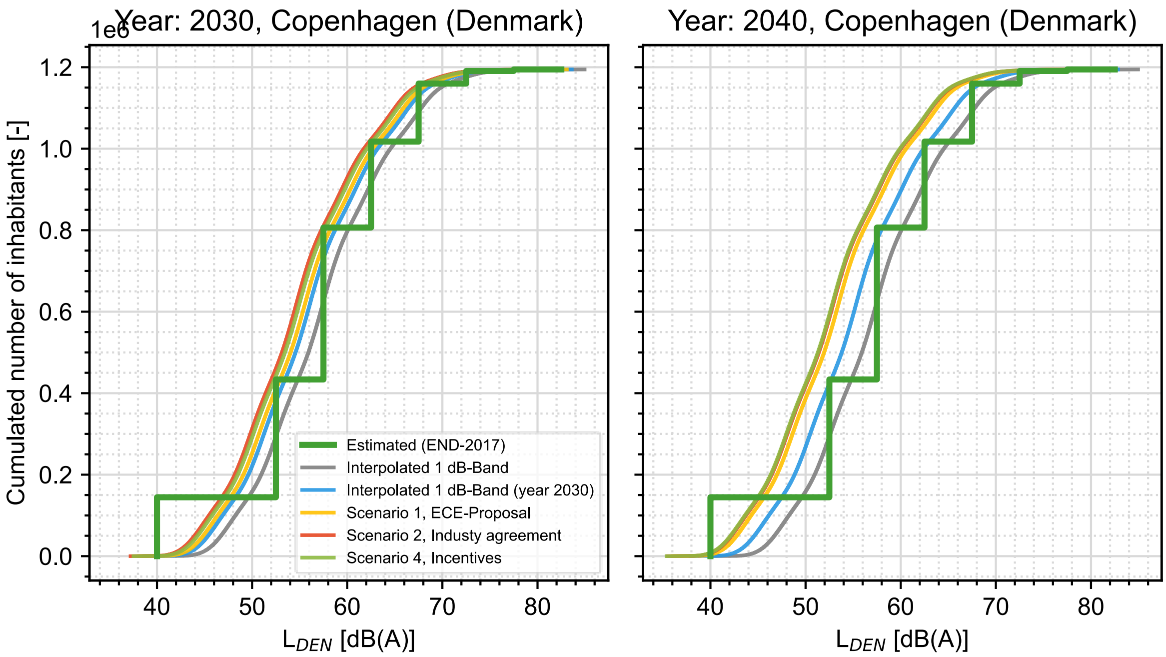
ANNEXES

A. Distribution of END-Noise Levels for selected agglomerations

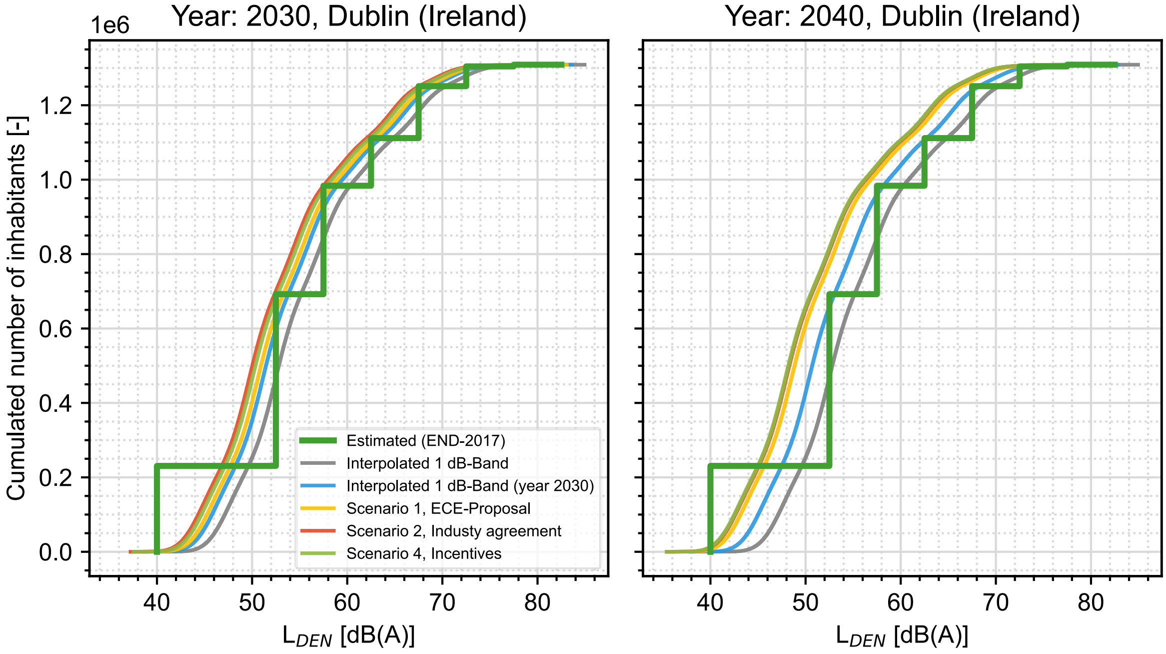
A.I. Belgium



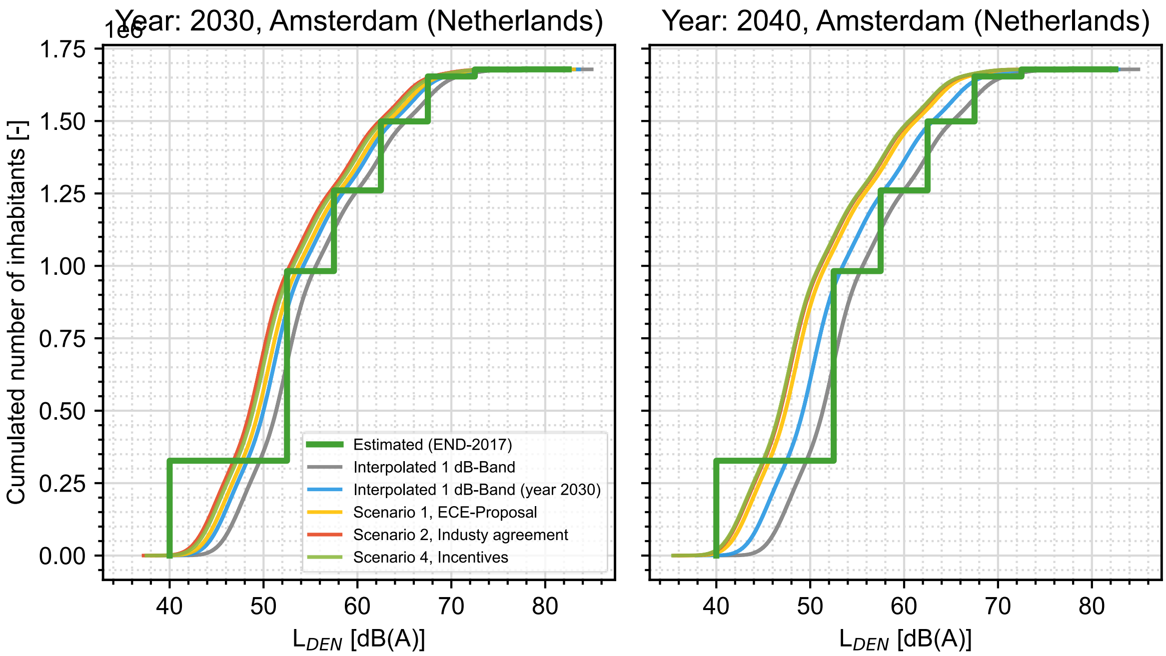
A.II. Denmark



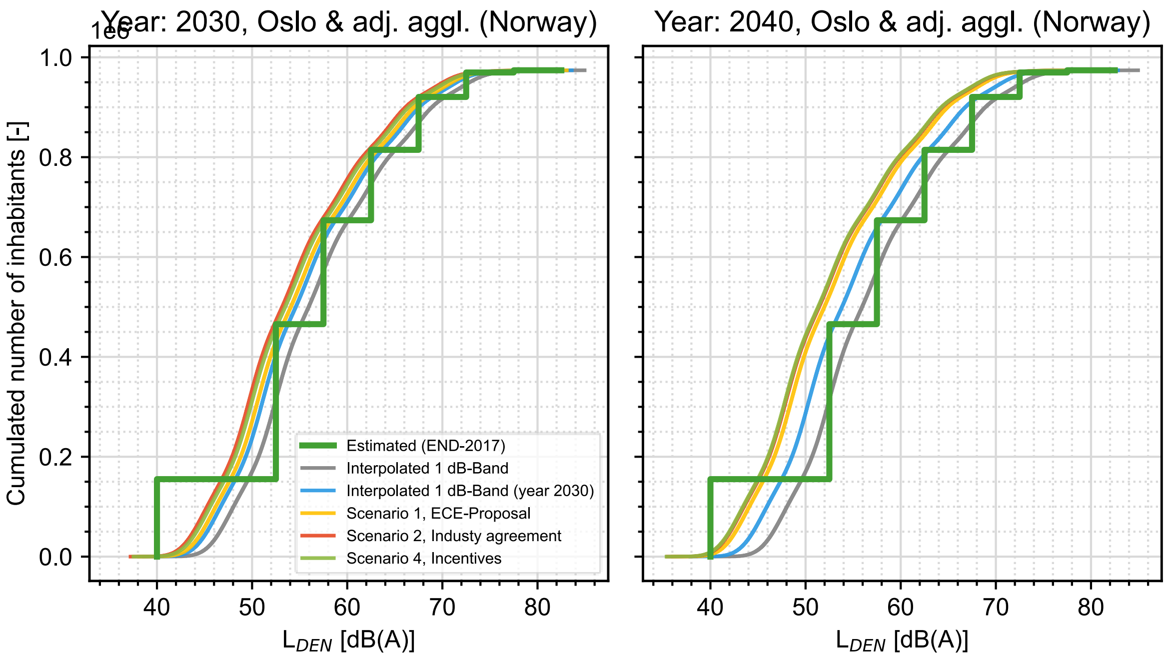
A.III. Ireland



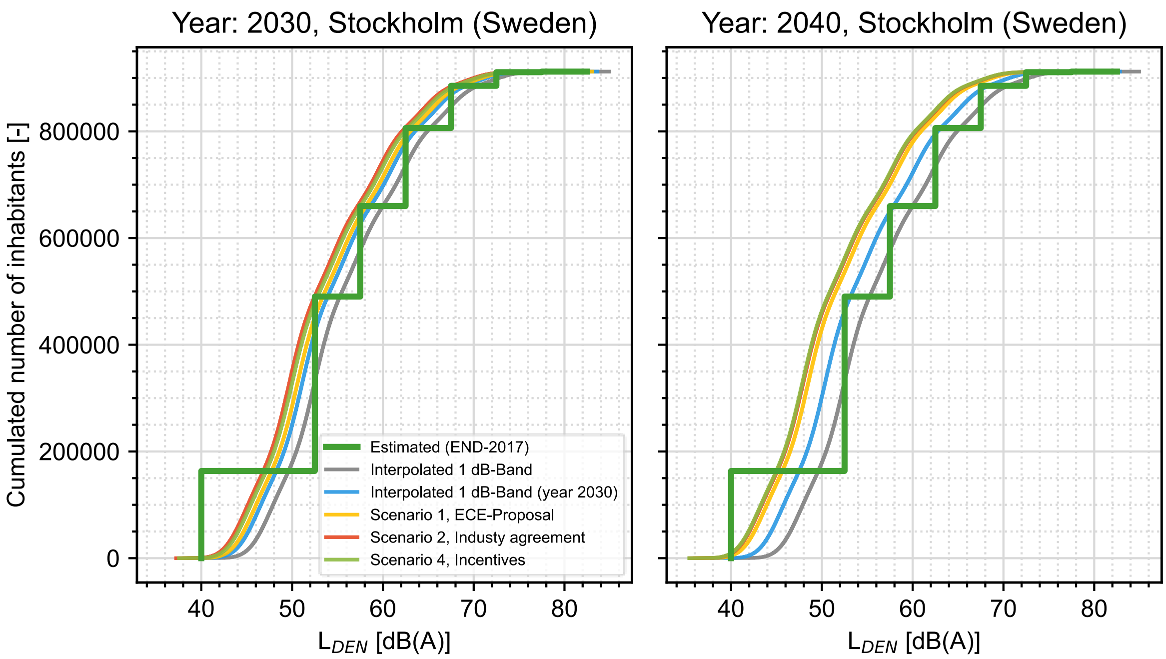
A.IV. Netherlands



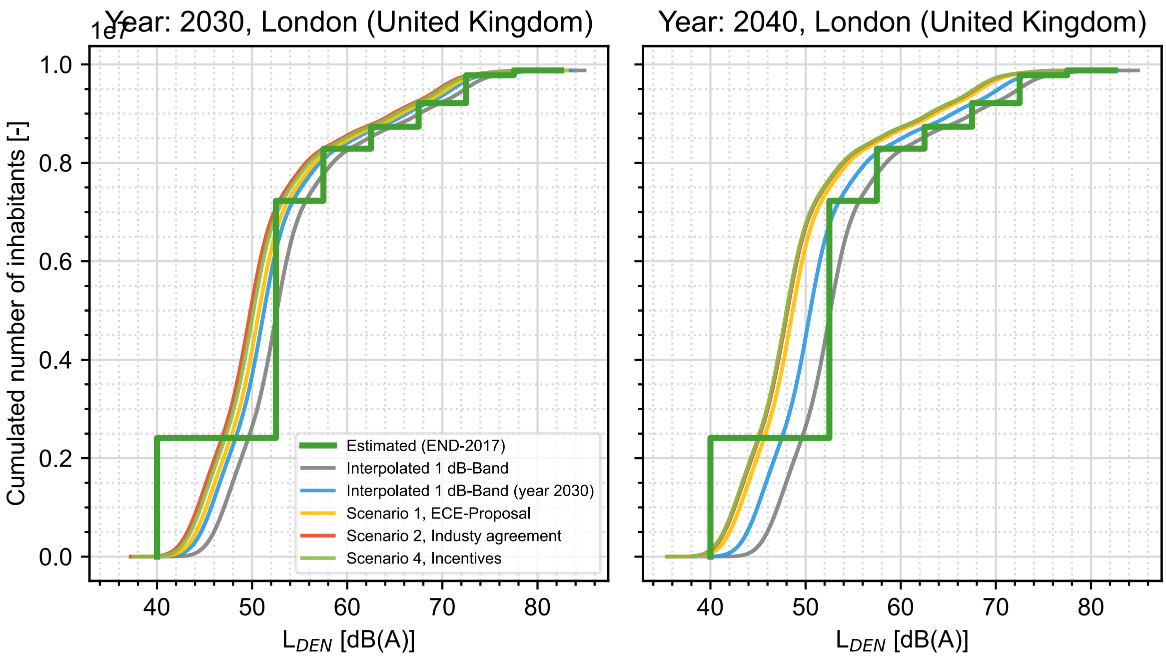
A.V. Norway



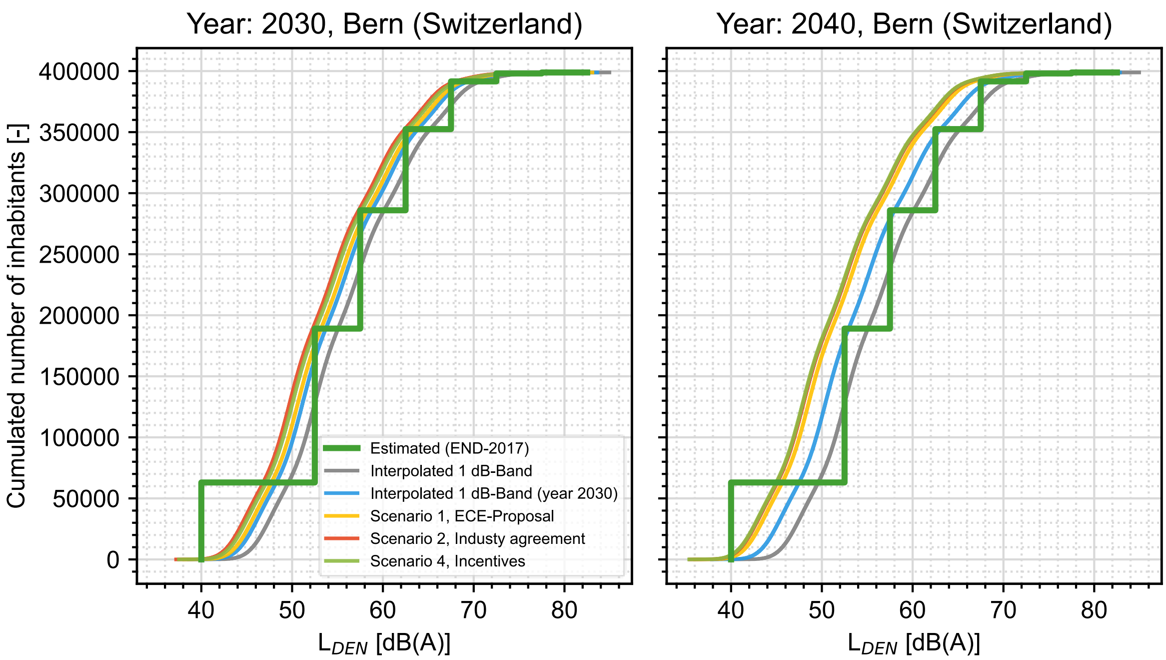
A.VI. Sweden



A.VII. United Kingdom



A.VIII. Switzerland



B. Scenario definition

The scenarios were defined according to the following reductions. As a reduction in the limit values only affects the tyres that have the limit values, the total effect on the fleet is reduced. The reduction was calculated by omitting this noise class and distributing these tyres on the existing distribution. Thus, the total reduction in noise level is calculated by the weighted noise level of the new distribution of available tyres on the market. The underlying distribution is taken from the evaluation of the tyre list according to 2.2, page 16.

Accordingly, a limit value reduction of 1 dB does not correspond to a overall reduction of 1 dB of the noise levels:

B.I. Scenario 1, ECE-Proposal

Year	C1	C2	C3
2021	0.00	0.00	0.00
2022	0.00	0.00	0.00
2023	0.65	0.65	0.00
2024	0.65	0.65	1.32
2025	0.65	0.65	1.32
2026	0.65	0.65	1.32
2027	0.65	0.65	1.32
2028	0.65	0.65	1.32
2029	0.65	0.65	1.32
2030	0.65	0.65	1.32
2031	0.65	0.65	1.32
2032	2.06	1.32	1.32
2033	2.06	1.32	1.32
2034	2.06	1.32	2.88
2035	2.06	1.32	2.88

B.II. Scenario 2, Industry agreement

The industry agreement results in a reduction of the total fleet. It is assumed, that this will amount to 1 dB for C1 tyres in 2023. In 2032 a second stage is introduced with another 1 dB reduction (C1).

Year	C1	C2	C3
2021	0.00	0.00	0.00
2022	0.00	0.00	0.00
2023	1.65	1.65	1.00
2024	1.65	1.65	2.32
2025	1.65	1.65	2.32
2026	1.65	1.65	2.32
2027	1.65	1.65	2.32
2028	1.65	1.65	2.32
2029	1.65	1.65	2.32
2030	1.65	1.65	2.32

2031	1.65	1.65	2.32
2032	3.06	2.32	2.32
2033	3.06	2.32	2.32
2034	3.06	2.32	3.88
2035	3.06	2.32	3.88

B.III. Scenario 4, Potential incentives to consumers

Year	C1	C2	C3
2021	0.00	0.00	0.00
2022	0.00	0.00	0.00
2023	0.73	0.73	0.73
2024	0.81	0.81	0.81
2025	0.89	0.89	0.89
2026	0.98	0.98	0.98
2027	1.06	1.06	1.06
2028	1.14	1.14	1.14
2029	1.20	1.20	1.20
2030	1.24	1.24	1.24
2031	1.29	1.29	1.29
2032	2.76	2.76	2.76
2033	2.81	2.81	2.81
2034	2.87	2.87	2.87
2035	2.92	2.92	2.92

C. TRANECAM – Model Results

C.I. Results Base Scenario

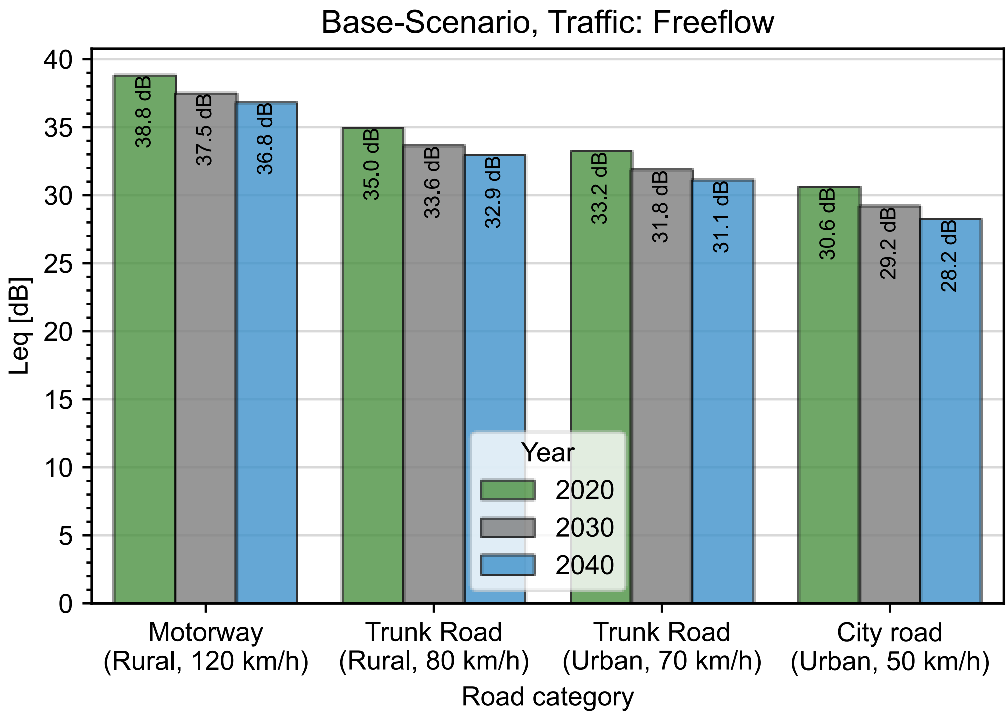


Figure 10-1: TRANECAM Model Results, Base scenario, Traffic: Freeflow

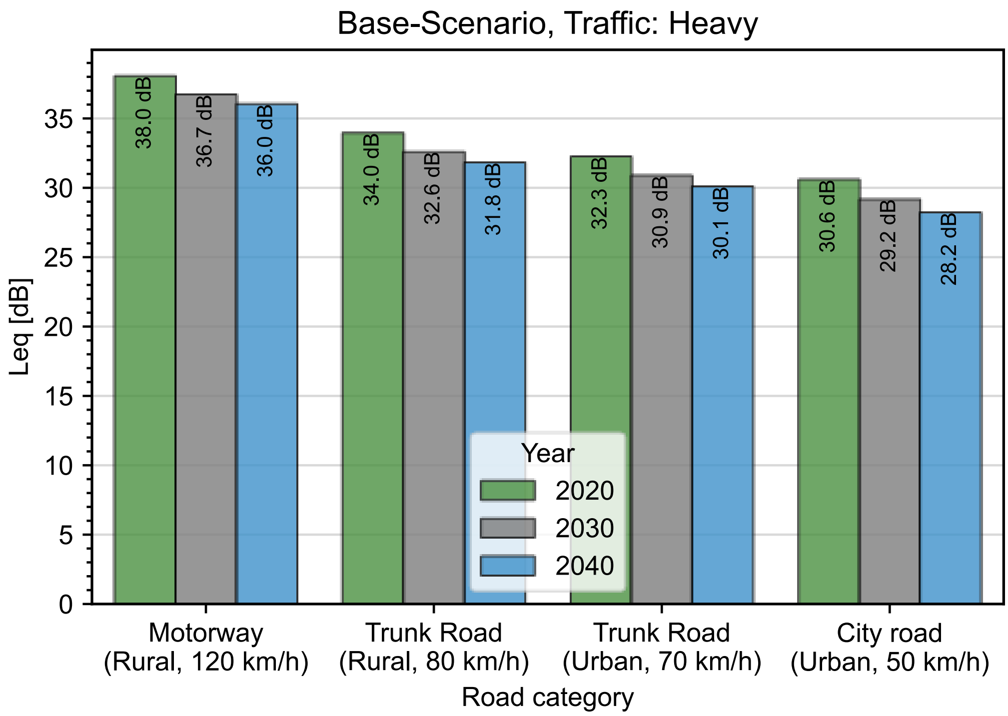


Figure 10-2: TRANECAM Model Results, Base scenario, Traffic: Heavy

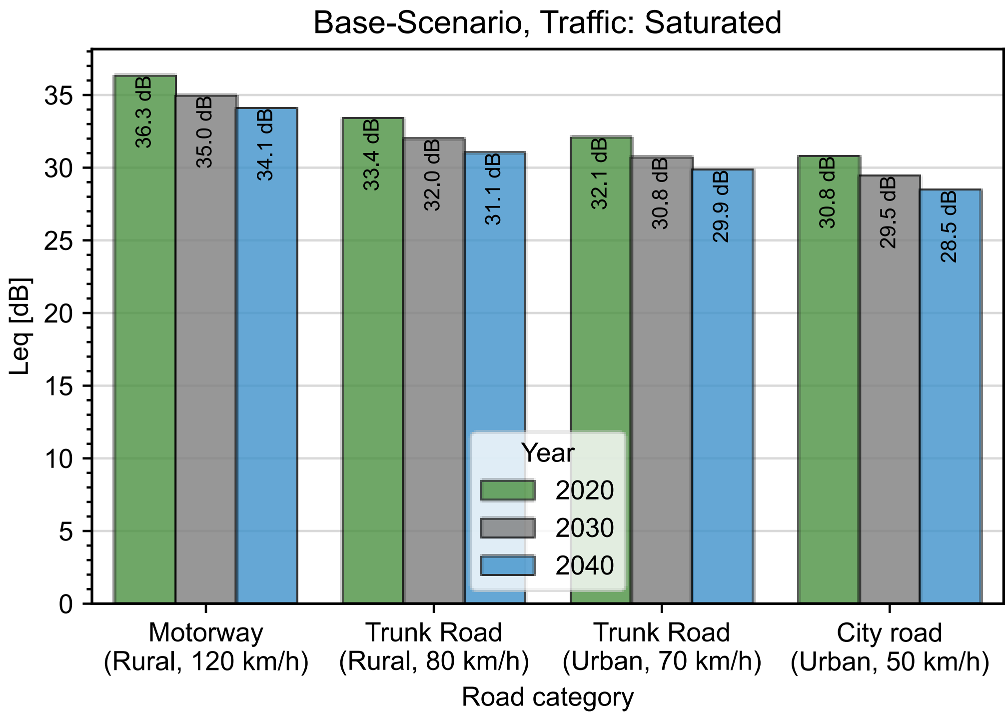


Figure 10-3: TRANECAM Model Results, Base scenario, Traffic: Saturated

C.II. Results ECE-Proposal

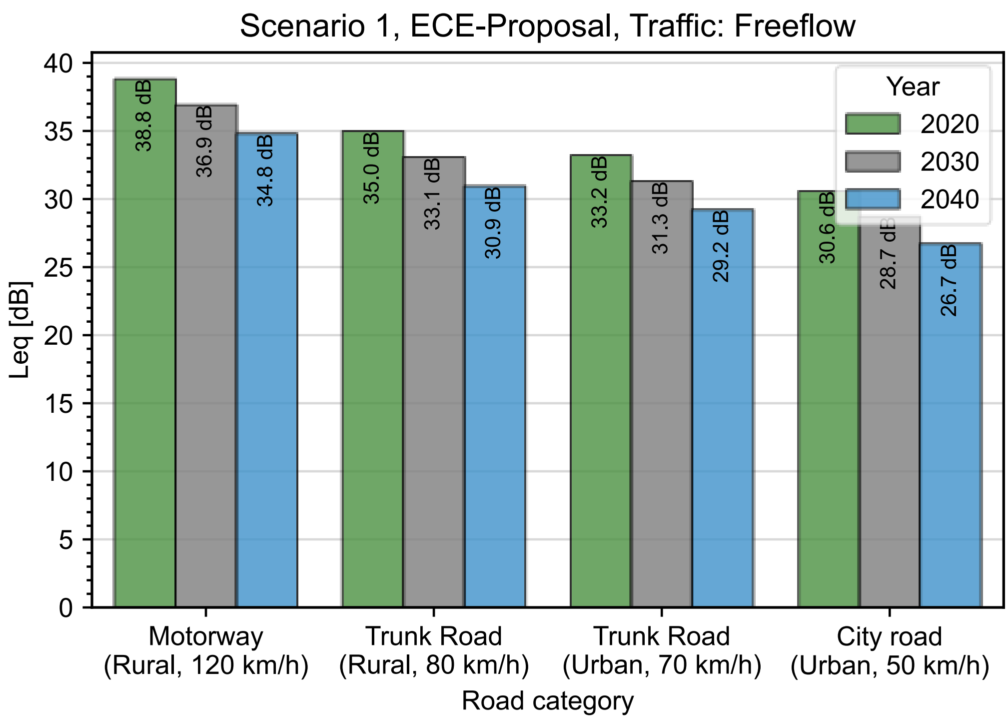


Figure 10-4: TRANECAM Model Results, Scenario 1: ECE-Proposal, Traffic: Freeflow

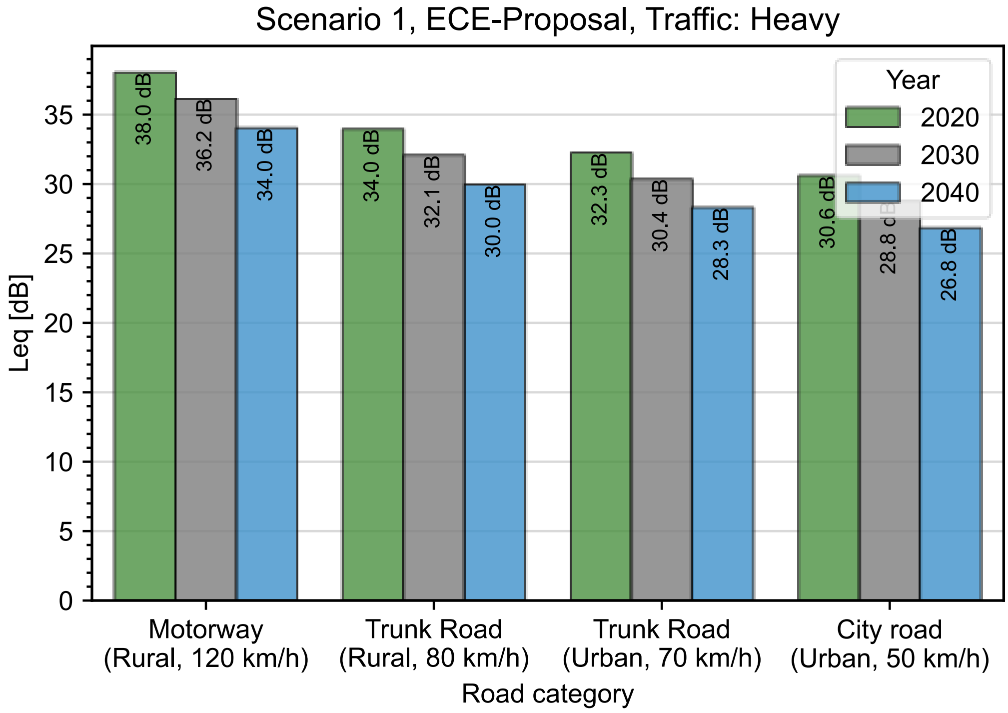


Figure 10-5: TRANECAM Model Results, Scenario 1: ECE-Proposal, Traffic: Heavy

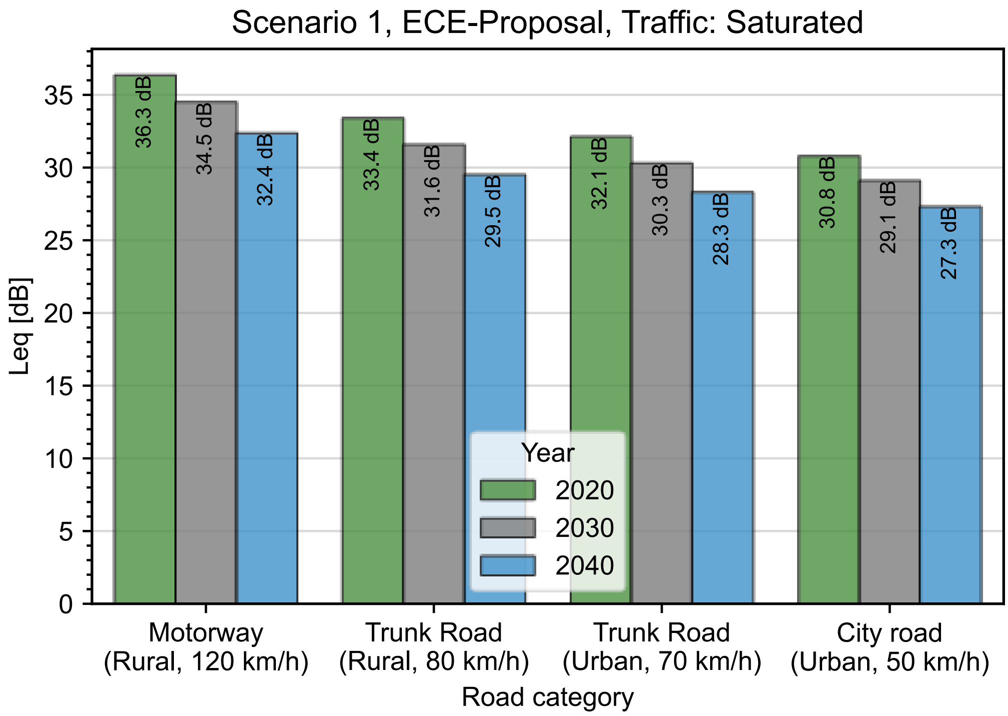


Figure 10-6: TRANECAM Model Results, Scenario 1: ECE-Proposal, Traffic: Saturated.

C.III. Tranecam Model Results Scenario 2, Industry Agreement

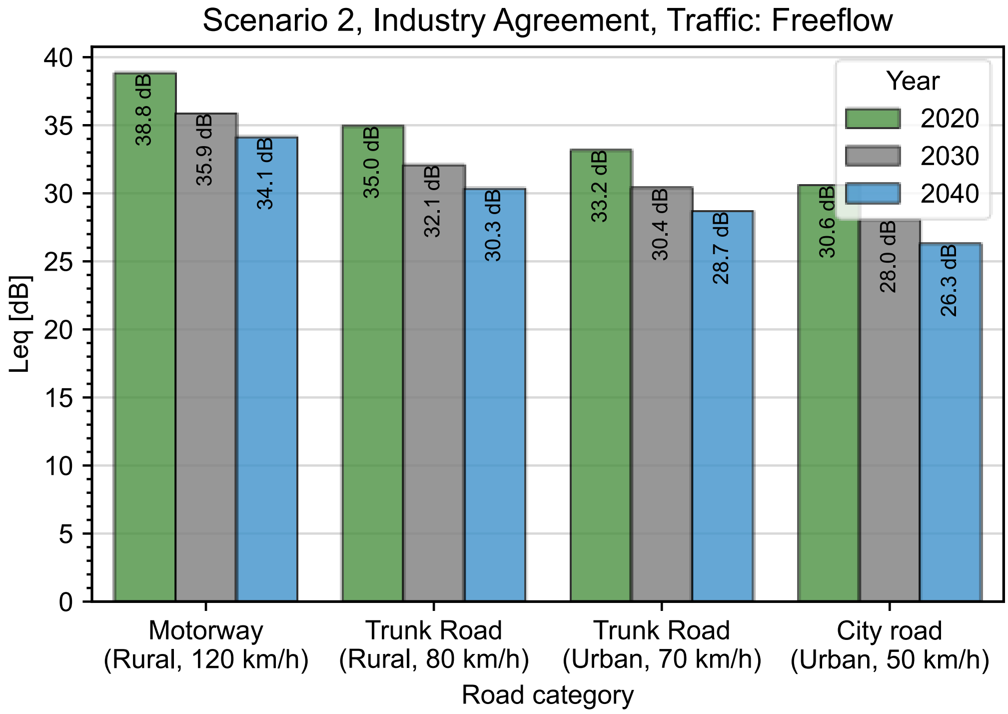


Figure 10-7: TRANECAM Model Results, Scenario 2 Industry Agreement, Traffic: Freeflow

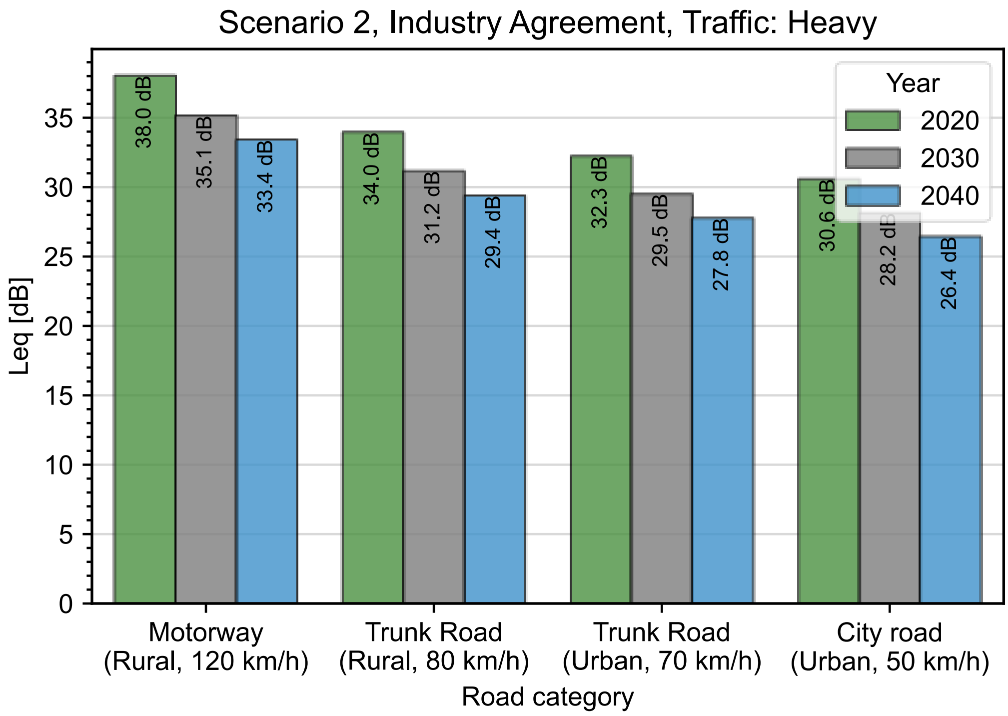


Figure 10-8: TRANECAM Model Results, Scenario 2 Industry Agreement, Traffic: Heavy

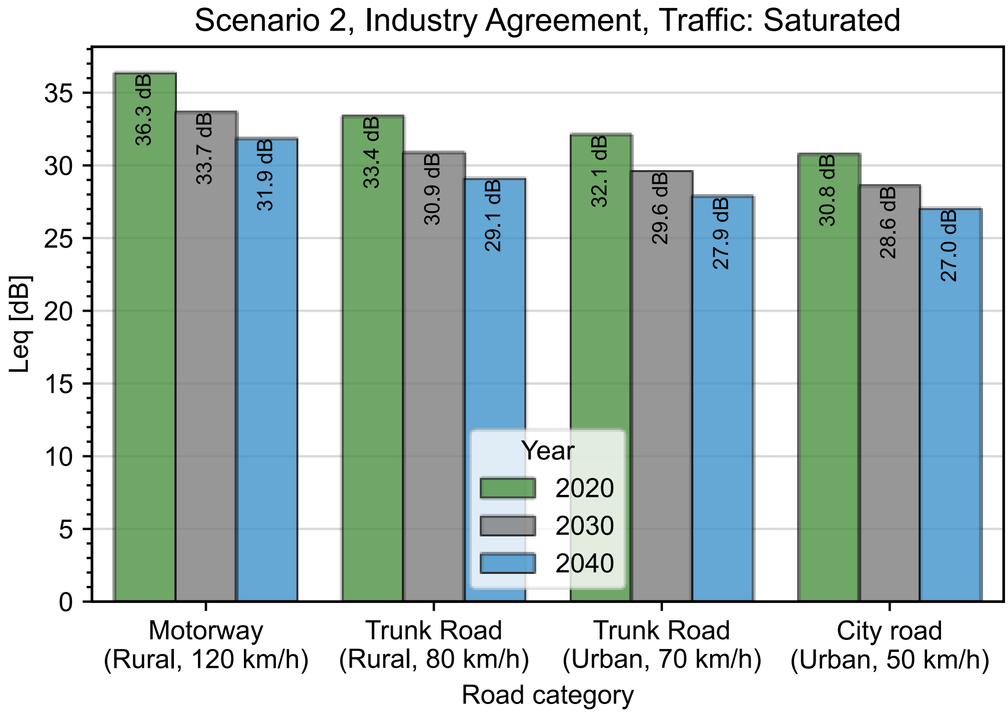


Figure 10-9: TRANECAM Model Results, Scenario 2 Industry Agreement, Traffic: Saturated

C.IV. TRANECAM Model Results, Scenario 4, Consumer incentives

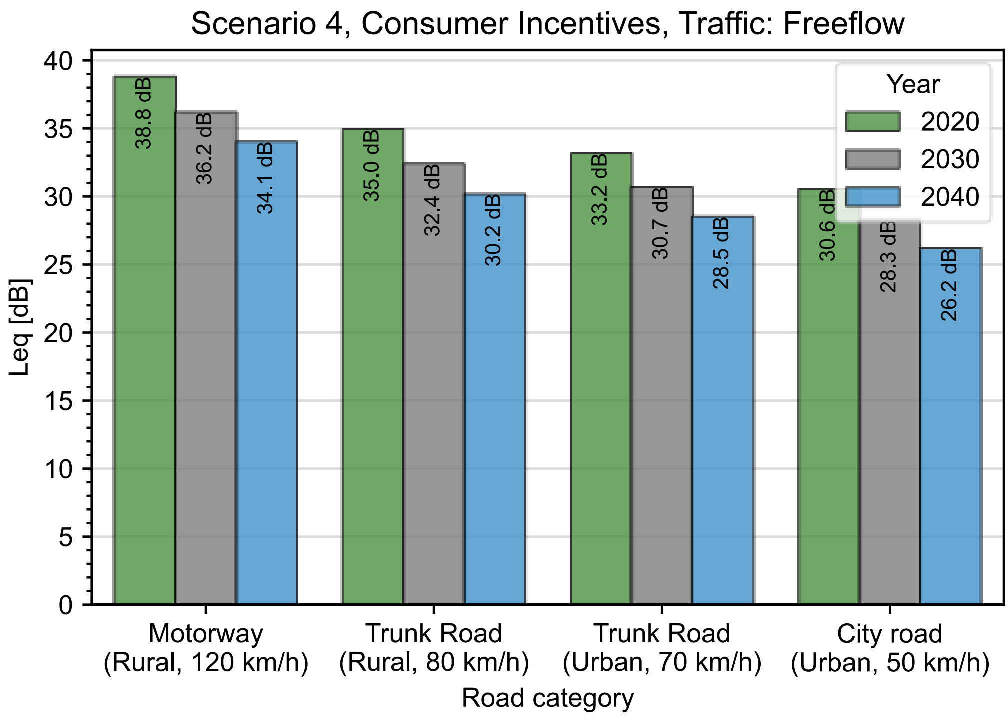


Figure 10-10:TRANECAM Model Results, Scenario 4 Consumer incentives, Traffic: Freeflow

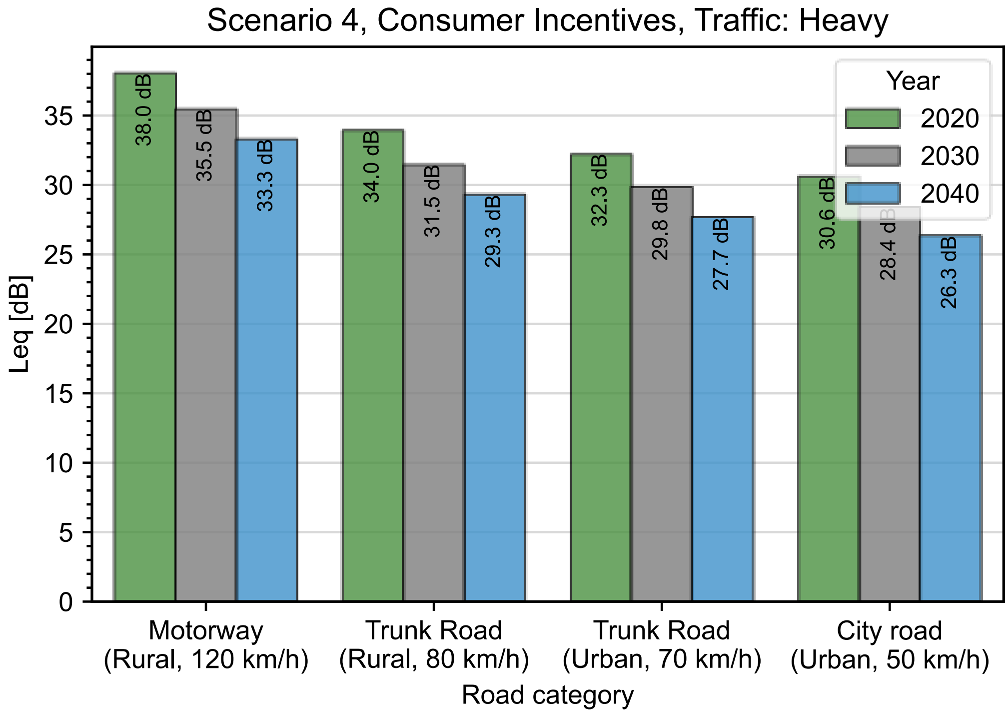


Figure 10-11:TRANECAM Model Results, Scenario 4 Consumer incentives, Traffic: Heavy

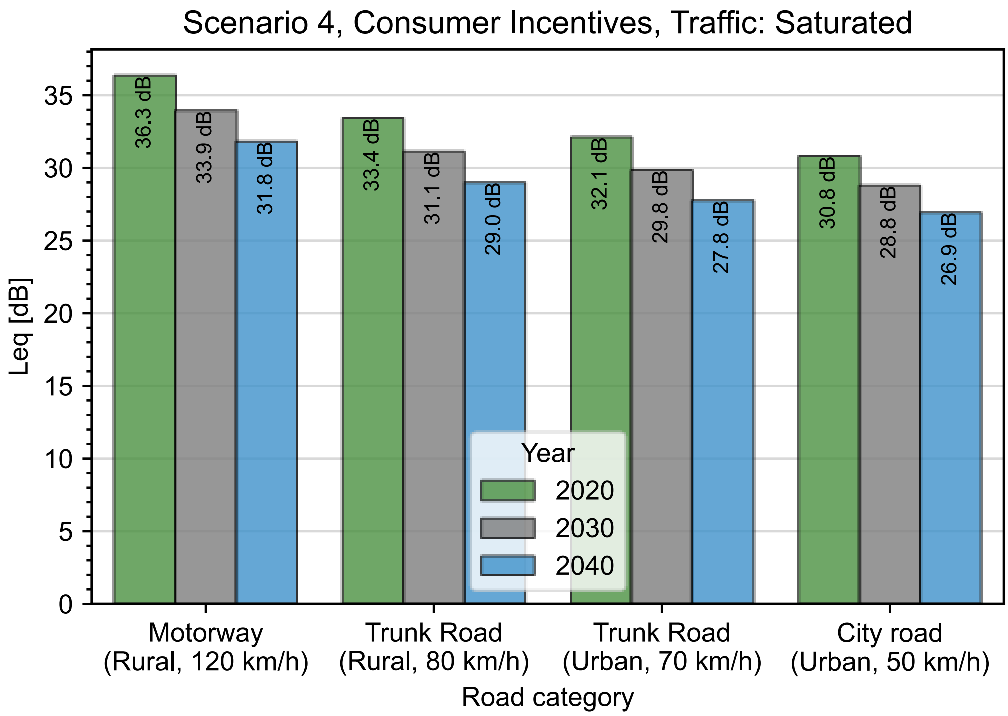


Figure 10-12:TRANECAM Model Results, Scenario 4 Consumer incentives, Traffic: Saturated

D. Results scenario calculation per country

Table 10-1: Calculation results (Distribution of Population according to END-Definition Data from 2017 above road noise thresholds for the 4 calculated scenarios.

Year	Scenario	Country	No Inhab.	LDEN 55-60 dB	LDEN 60-65 dB	LDEN 65-70 dB	LDEN 70-75 dB	LDEN >75 dB	Pop. > 55 dB	% Pop. > 55 dB
2030	Scenario 1, ECE-Proposal	Austria	2’639’822	472’695	613’042	532’940	277’024	85’707	1’981’408	75%
2030	Scenario 1, ECE-Proposal	Belgium	2’283’069	459’832	386’387	342’119	193’198	25’595	1’407’132	62%
2030	Scenario 1, ECE-Proposal	Bosnia and Herzegovina	1’144’636	180’006	51’114	28’500	9’151	521	269’292	24%
2030	Scenario 1, ECE-Proposal	Bulgaria	2’684’996	757’320	711’108	283’088	44’452	3’175	1’799’142	67%
2030	Scenario 1, ECE-Proposal	Croatia	1’209’118	130’692	82’105	43’766	12’182	724	269’469	22%
2030	Scenario 1, ECE-Proposal	Cyprus	430’468	149’076	205’391	29’464	14’771	1’064	399’766	93%
2030	Scenario 1, ECE-Proposal	Czech Republic	2’780’456	708’433	422’425	236’555	95’618	5’786	1’468’817	53%
2030	Scenario 1, ECE-Proposal	Denmark	1’753’248	425’872	268’816	150’430	36’388	3’043	884’548	50%
2030	Scenario 1, ECE-Proposal	Estonia	532’958	95’260	101’446	58’394	13’052	487	268’639	50%
2030	Scenario 1, ECE-Proposal	Finland	2’079’601	232’605	109’879	36’727	8’362	96	387’670	19%
2030	Scenario 1, ECE-Proposal	France	30’205’200	5’642’805	4’410’564	2’790’144	1’029’725	260’304	14’133’542	47%
2030	Scenario 1, ECE-Proposal	Germany	24’486’844	2’196’940	1’479’394	917’057	311’939	29’881	4’935’210	20%
2030	Scenario 1, ECE-Proposal	Greece	1’262’110	177’324	50’890	28’473	9’200	687	266’573	21%
2030	Scenario 1, ECE-Proposal	Hungary	3’189’345	487’578	415’369	317’784	165’851	41’095	1’427’677	45%
2030	Scenario 1, ECE-Proposal	Iceland	267’850	27’844	12’243	3’899	889	10	44’885	17%
2030	Scenario 1, ECE-Proposal	Ireland	1’499’800	259’151	152’200	120’399	36’973	2’919	571’643	38%
2030	Scenario 1, ECE-Proposal	Italy	13’032’989	2’152’621	2’330’146	1’834’979	992’475	283’583	7’593’803	58%
2030	Scenario 1, ECE-Proposal	Latvia	641’007	153’706	172’481	111’754	36’724	3’275	477’941	75%
2030	Scenario 1, ECE-Proposal	Liechtenstein	25’435	9’943	6’296	3’620	1’213	111	21’182	83%
2030	Scenario 1, ECE-Proposal	Lithuania	1’126’250	265’127	231’613	124’557	28’274	3’522	653’093	58%

Year	Scenario	Country	No Inhab.	LDEN 55-60 dB	LDEN 60-65 dB	LDEN 65-70 dB	LDEN 70-75 dB	LDEN >75 dB	Pop. > 55 dB	% Pop. > 55 dB
2030	Scenario 1, ECE-Proposal	Luxembourg	153’410	40’033	40’232	33’897	14’203	1’726	130’090	85%
2030	Scenario 1, ECE-Proposal	Macedonia	798’529	110’075	25’885	14’314	4’491	237	155’003	19%
2030	Scenario 1, ECE-Proposal	Malta	270’004	34’116	31’605	19’958	5’530	748	91’956	34%
2030	Scenario 1, ECE-Proposal	Montenegro	185’937	44’265	50’196	22’112	3’634	41	120’247	65%
2030	Scenario 1, ECE-Proposal	Netherlands	8’259’054	1’394’808	954’651	382’368	33’854	355	2’766’035	33%
2030	Scenario 1, ECE-Proposal	Norway	1’801’600	294’509	207’816	130’724	45’891	4’361	683’301	38%
2030	Scenario 1, ECE-Proposal	Poland	10’009’194	1’776’900	1’194’241	563’901	161’647	16’742	3’713’430	37%
2030	Scenario 1, ECE-Proposal	Portugal	1’452’607	185’693	146’514	93’015	32’485	6’050	463’757	32%
2030	Scenario 1, ECE-Proposal	Romania	5’349’985	752’465	913’328	694’986	309’943	117’289	2’788’010	52%
2030	Scenario 1, ECE-Proposal	Slovakia	665’646	141’550	96’150	47’781	15’436	5’189	306’107	46%
2030	Scenario 1, ECE-Proposal	Slovenia	380’900	72’528	61’956	34’984	7’189	82	176’738	46%
2030	Scenario 1, ECE-Proposal	Spain	20’889’339	3’756’746	3’482’180	2’366’488	1’164’451	373’131	11’142’997	53%
2030	Scenario 1, ECE-Proposal	Sweden	3’367’282	536’943	314’273	132’380	26’224	1’658	1’011’477	30%
2030	Scenario 1, ECE-Proposal	Switzerland	4’240’021	975’575	685’249	391’722	118’063	14’793	2’185’401	52%
2030	Scenario 1, ECE-Proposal	United King-dom	35’738’460	3’756’574	1’863’404	1’447’855	820’286	97’686	7’985’805	22%
2030	Scenario 2, Industry ag-reement	Austria	2’639’822	513’549	619’193	478’079	230’301	57’959	1’899’081	72%
2030	Scenario 2, Industry ag-reement	Belgium	2’283’069	438’516	382’729	322’469	144’424	16’694	1’304’833	57%
2030	Scenario 2, Industry ag-reement	Bosnia and Herzegovina	1’144’636	140’972	45’914	23’819	6’442	312	217’459	19%
2030	Scenario 2, Industry ag-reement	Bulgaria	2’684’996	797’549	615’402	213’275	30’814	1’970	1’659’011	62%
2030	Scenario 2, Industry ag-reement	Croatia	1’209’118	118’058	74’335	35’657	8’559	436	237’044	20%
2030	Scenario 2, Industry ag-reement	Cyprus	430’468	197’555	152’118	26’203	10’608	657	387’140	90%
2030	Scenario 2, Industry ag-reement	Czech Republic	2’780’456	642’611	378’861	206’852	67’820	3’490	1’299’633	47%

Year	Scenario	Country	No Inhab.	LDEN 55-60 dB	LDEN 60-65 dB	LDEN 65-70 dB	LDEN 70-75 dB	LDEN >75 dB	Pop. > 55 dB	% Pop. > 55 dB
2030	Scenario 2, Industry ag-reement	Denmark	1'753'248	387'727	247'882	119'807	25'876	1'916	783'208	45%
2030	Scenario 2, Industry ag-reement	Estonia	532'958	100'671	94'790	46'185	8'968	268	250'882	47%
2030	Scenario 2, Industry ag-reement	Finland	2'079'601	201'784	90'584	28'930	5'649	22	326'968	16%
2030	Scenario 2, Industry ag-reement	France	30'205'200	5'387'578	4'144'755	2'342'647	823'718	175'037	12'873'736	43%
2030	Scenario 2, Industry ag-reement	Germany	24'486'844	1'989'315	1'379'961	772'087	225'700	19'034	4'386'097	18%
2030	Scenario 2, Industry ag-reement	Greece	1'262'110	138'724	45'777	23'780	6'556	427	215'263	17%
2030	Scenario 2, Industry ag-reement	Hungary	3'189'345	470'730	400'897	287'858	133'000	27'607	1'320'092	41%
2030	Scenario 2, Industry ag-reement	Iceland	267'850	23'782	10'001	3'069	601	2	37'455	14%
2030	Scenario 2, Industry ag-reement	Ireland	1'499'800	223'690	153'075	99'937	26'386	1'824	504'912	34%
2030	Scenario 2, Industry ag-reement	Italy	13'032'989	2'238'606	2'268'744	1'666'861	814'283	191'344	7'179'838	55%
2030	Scenario 2, Industry ag-reement	Latvia	641'007	164'773	163'633	93'597	26'434	2'072	450'509	70%
2030	Scenario 2, Industry ag-reement	Liechtenstein	25'435	9'125	5'759	3'038	874	70	18'866	74%
2030	Scenario 2, Industry ag-reement	Lithuania	1'126'250	265'093	212'678	97'966	20'618	2'293	598'647	53%
2030	Scenario 2, Industry ag-reement	Luxembourg	153'410	40'002	40'547	29'751	10'494	1'120	121'914	79%
2030	Scenario 2, Industry ag-reement	Macedonia	798'529	84'022	23'129	11'919	3'151	140	122'360	15%
2030	Scenario 2, Industry ag-reement	Malta	270'004	33'898	30'058	16'165	4'085	489	84'695	31%
2030	Scenario 2, Industry ag-reement	Montenegro	185'937	49'432	44'364	16'823	2'420	9	113'048	61%
2030	Scenario 2, Industry ag-reement	Netherlands	8'259'054	1'317'739	831'850	276'433	21'562	80	2'447'662	30%
2030	Scenario 2, Industry ag-reement	Norway	1'801'600	273'322	194'259	110'742	33'210	2'776	614'310	34%
2030	Scenario 2, Industry ag-reement	Poland	10'009'194	1'665'912	1'051'565	458'913	117'085	10'742	3'304'217	33%
2030	Scenario 2, Industry ag-reement	Portugal	1'452'607	176'550	137'935	77'918	24'924	4'021	421'348	29%
2030	Scenario 2, Industry ag-reement	Romania	5'349'985	806'685	900'911	596'282	267'363	79'705	2'650'946	50%

Year	Scenario	Country	No Inhab.	LDEN 55-60 dB	LDEN 60-65 dB	LDEN 65-70 dB	LDEN 70-75 dB	LDEN >75 dB	Pop. > 55 dB	% Pop. > 55 dB
2030	Scenario 2, Industry ag-reement	Slovakia	665'646	132'802	85'763	38'733	12'932	3'518	273'748	41%
2030	Scenario 2, Industry ag-reement	Slovenia	380'900	71'395	57'664	27'413	4'834	18	161'325	42%
2030	Scenario 2, Industry ag-reement	Spain	20'889'339	3'773'026	3'284'789	2'088'701	973'557	252'564	10'372'637	50%
2030	Scenario 2, Industry ag-reement	Sweden	3'367'282	486'811	272'646	102'452	18'264	1'011	881'184	26%
2030	Scenario 2, Industry ag-reement	Switzerland	4'240'021	913'741	630'607	321'544	86'846	9'625	1'962'363	46%
2030	Scenario 2, Industry ag-reement	United King-dom	35'738'460	3'164'910	1'766'114	1'367'720	607'984	63'253	6'969'980	20%
2030	Scenario 4, Incentives	Austria	2'639'822	499'801	617'437	496'726	245'904	67'026	1'926'893	73%
2030	Scenario 4, Incentives	Belgium	2'283'069	445'739	383'927	329'218	160'813	19'468	1'339'164	59%
2030	Scenario 4, Incentives	Bosnia and Herzegovina	1'144'636	153'919	47'527	25'388	7'337	371	234'542	20%
2030	Scenario 4, Incentives	Bulgaria	2'684'996	784'462	648'024	236'453	35'140	2'325	1'706'404	64%
2030	Scenario 4, Incentives	Croatia	1'209'118	121'976	76'936	38'370	9'749	519	247'550	20%
2030	Scenario 4, Incentives	Cyprus	430'468	181'404	170'286	27'089	12'006	776	391'562	91%
2030	Scenario 4, Incentives	Czech Republic	2'780'456	665'045	393'357	216'773	77'081	4'147	1'356'404	49%
2030	Scenario 4, Incentives	Denmark	1'753'248	400'671	254'868	130'080	29'300	2'253	817'171	47%
2030	Scenario 4, Incentives	Estonia	532'958	98'806	97'092	50'284	10'296	326	256'805	48%
2030	Scenario 4, Incentives	Finland	2'079'601	211'588	97'004	31'491	6'534	36	346'653	17%
2030	Scenario 4, Incentives	France	30'205'200	5'471'715	4'234'646	2'493'033	891'600	202'682	13'293'677	44%
2030	Scenario 4, Incentives	Germany	24'486'844	2'051'408	1'413'277	820'815	254'222	22'321	4'562'043	19%
2030	Scenario 4, Incentives	Greece	1'262'110	151'454	47'364	25'353	7'429	503	232'104	18%
2030	Scenario 4, Incentives	Hungary	3'189'345	476'006	405'803	297'981	143'992	31'974	1'355'756	43%
2030	Scenario 4, Incentives	Iceland	267'850	25'071	10'745	3'340	695	4	39'855	15%
2030	Scenario 4, Incentives	Ireland	1'499'800	235'460	152'697	106'873	29'874	2'149	527'053	35%
2030	Scenario 4, Incentives	Italy	13'032'989	2'208'821	2'290'290	1'723'774	873'930	221'391	7'318'205	56%
2030	Scenario 4, Incentives	Latvia	641'007	161'113	166'711	99'710	29'833	2'434	459'800	72%
2030	Scenario 4, Incentives	Liechtenstein	25'435	9'411	5'938	3'233	986	82	19'651	77%
2030	Scenario 4, Incentives	Lithuania	1'126'250	265'166	219'136	106'875	23'096	2'675	616'947	55%
2030	Scenario 4, Incentives	Luxembourg	153'410	40'039	40'451	31'161	11'729	1'307	124'688	81%
2030	Scenario 4, Incentives	Macedonia	798'529	92'618	23'964	12'722	3'594	167	133'064	17%
2030	Scenario 4, Incentives	Malta	270'004	33'913	30'591	17'441	4'557	570	87'072	32%
2030	Scenario 4, Incentives	Montenegro	185'937	47'705	46'366	18'585	2'808	15	115'480	62%

Year	Scenario	Country	No Inhab.	LDEN 55-60 dB	LDEN 60-65 dB	LDEN 65-70 dB	LDEN 70-75 dB	LDEN >75 dB	Pop. > 55 dB	% Pop. > 55 dB
2030	Scenario 4, Incentives	Netherlands	8’259’054	1’342’593	873’276	311’688	25’286	134	2’552’977	31%
2030	Scenario 4, Incentives	Norway	1’801’600	280’225	198’806	117’461	37’409	3’256	637’158	35%
2030	Scenario 4, Incentives	Poland	10’009’194	1’702’268	1’099’548	493’861	131’712	12’575	3’439’964	34%
2030	Scenario 4, Incentives	Portugal	1’452’607	179’316	140’842	82’995	27’418	4’669	435’240	30%
2030	Scenario 4, Incentives	Romania	5’349’985	787’690	905’616	629’620	281’417	92’072	2’696’415	50%
2030	Scenario 4, Incentives	Slovakia	665’646	135’743	89’255	41’749	13’745	4’066	284’557	43%
2030	Scenario 4, Incentives	Slovenia	380’900	71’752	59’129	29’955	5’598	31	166’464	44%
2030	Scenario 4, Incentives	Spain	20’889’339	3’766’507	3’352’223	2’182’073	1’037’129	292’013	10’629’945	51%
2030	Scenario 4, Incentives	Sweden	3’367’282	503’167	286’578	112’399	20’832	1’198	924’174	27%
2030	Scenario 4, Incentives	Switzerland	4’240’021	934’716	648’971	345’075	97’103	11’231	2’037’096	48%
2030	Scenario 4, Incentives	United King-dom	35’738’460	3’354’248	1’797’009	1’394’994	679’338	73’889	7’299’478	20%
2030	Status quo	Austria	2’639’822	450’107	608’080	562’411	304’033	103’024	2’027’655	77%
2030	Status quo	Belgium	2’283’069	471’240	388’923	352’612	220’352	32’162	1’465’289	64%
2030	Status quo	Bosnia and Herzegovina	1’144’636	202’981	55’075	31’162	10’768	719	300’703	26%
2030	Status quo	Bulgaria	2’684’996	733’163	761’664	324’073	53’951	4’217	1’877’069	70%
2030	Status quo	Croatia	1’209’118	140’259	86’600	48’397	14’401	991	290’648	24%
2030	Status quo	Cyprus	430’468	121’936	232’945	32’904	17’090	1’422	406’297	94%
2030	Status quo	Czech Republic	2’780’456	743’147	448’058	253’860	111’647	7’915	1’564’627	56%
2030	Status quo	Denmark	1’753’248	446’350	281’219	167’678	43’042	3’979	942’268	54%
2030	Status quo	Estonia	532’958	92’705	104’817	65’238	15’650	725	279’135	52%
2030	Status quo	Finland	2’079’601	254’111	121’163	41’535	10’066	214	427’088	21%
2030	Status quo	France	30’205’200	5’800’158	4’559’944	3’040’908	1’155’142	315’148	14’871’300	49%
2030	Status quo	Germany	24’486’844	2’371’062	1’537’278	998’509	363’304	38’582	5’308’735	22%
2030	Status quo	Greece	1’262’110	200’586	54’775	31’140	10’782	912	298’195	24%
2030	Status quo	Hungary	3’189’345	500’007	423’493	334’330	184’597	49’814	1’492’240	47%
2030	Status quo	Iceland	267’850	30’701	13’567	4’416	1’070	23	49’777	19%
2030	Status quo	Ireland	1’499’800	279’874	152’644	131’434	43’376	3’847	611’176	41%
2030	Status quo	Italy	13’032’989	2’112’531	2’359’688	1’927’511	1’094’225	341’847	7’835’801	60%
2030	Status quo	Latvia	641’007	147’259	176’859	121’875	42’882	4’260	493’135	77%
2030	Status quo	Liechtenstein	25’435	10’315	6’613	3’951	1’414	144	22’437	88%
2030	Status quo	Lithuania	1’126’250	264’947	241’772	139’598	33’246	4’436	683’999	61%
2030	Status quo	Luxembourg	153’410	39’840	40’040	36’124	16’351	2’182	134’536	88%
2030	Status quo	Macedonia	798’529	125’738	28’135	15’675	5’294	331	175’173	22%
2030	Status quo	Malta	270’004	34’699	32’417	22’065	6’432	937	96’551	36%
2030	Status quo	Montenegro	185’937	41’412	53’184	25’173	4’454	91	124’314	67%
2030	Status quo	Netherlands	8’259’054	1’447’093	1’022’998	443’807	43’719	791	2’958’407	36%
2030	Status quo	Norway	1’801’600	308’066	215’675	141’942	53’403	5’636	724’721	40%
2030	Status quo	Poland	10’009’194	1’847’484	1’274’490	625’195	189’031	21’440	3’957’640	40%
2030	Status quo	Portugal	1’452’607	193’181	151’302	101’460	37’056	7’430	490’428	34%

Year	Scenario	Country	No Inhab.	LDEN 55-60 dB	LDEN 60-65 dB	LDEN 65-70 dB	LDEN 70-75 dB	LDEN >75 dB	Pop. > 55 dB	% Pop. > 55 dB
2030	Status quo	Romania	5’349’985	728’411	917’617	748’992	335’967	140’101	2’871’088	54%
2030	Status quo	Slovakia	665’646	146’539	102’019	53’014	17’062	6’218	324’851	49%
2030	Status quo	Slovenia	380’900	73’393	64’275	39’230	8’703	182	185’783	49%
2030	Status quo	Spain	20’889’339	3’758’392	3’587’203	2’522’906	1’276’214	447’979	11’592’694	55%
2030	Status quo	Sweden	3’367’282	568’989	338’186	149’897	31’449	2’243	1’090’764	32%
2030	Status quo	Switzerland	4’240’021	1’009’126	716’503	431’431	137’179	18’642	2’312’880	55%
2030	Status quo	United King-dom	35’738’460	4’156’994	1’931’922	1’492’709	938’279	123’795	8’643’699	24%
2040	Scenario 1, ECE-Proposal	Austria	2’639’822	562’206	620’771	409’070	174’209	26’986	1’793’242	68%
2040	Scenario 1, ECE-Proposal	Belgium	2’283’069	412’823	377’392	295’161	86’485	7’660	1’179’521	52%
2040	Scenario 1, ECE-Proposal	Bosnia and Herzegovina	1’144’636	95’852	40’391	18’160	3’343	138	157’884	14%
2040	Scenario 1, ECE-Proposal	Bulgaria	2’684’996	835’733	495’135	132’132	16’405	885	1’480’290	55%
2040	Scenario 1, ECE-Proposal	Croatia	1’209’118	104’874	64’727	25’955	4’462	193	200’211	17%
2040	Scenario 1, ECE-Proposal	Cyprus	430’468	250’116	87’461	23’491	5’691	294	367’053	85%
2040	Scenario 1, ECE-Proposal	Czech Republic	2’780’456	560’227	326’638	170’472	35’502	1’547	1’094’386	39%
2040	Scenario 1, ECE-Proposal	Denmark	1’753’248	340’661	221’568	83’207	14’162	866	660’465	38%
2040	Scenario 1, ECE-Proposal	Estonia	532’958	106’920	85’720	31’572	4’444	113	228’770	43%
2040	Scenario 1, ECE-Proposal	Finland	2’079’601	167’952	67’803	19’977	2’629	2	258’363	12%
2040	Scenario 1, ECE-Proposal	France	30’205’200	5’081’129	3’798’858	1’802’626	584’871	81’316	11’348’799	38%
2040	Scenario 1, ECE-Proposal	Germany	24’486’844	1’789’930	1’254’137	595’770	126’611	8’646	3’775’093	15%
2040	Scenario 1, ECE-Proposal	Greece	1’262’110	94’591	40’329	18’111	3’530	192	156’753	12%
2040	Scenario 1, ECE-Proposal	Hungary	3’189’345	452’558	381’645	250’046	93’807	12’820	1’190’876	37%
2040	Scenario 1, ECE-Proposal	Iceland	267’850	19’369	7’370	2’120	280	0	29’139	11%
2040	Scenario 1, ECE-Proposal	Ireland	1’499’800	183’032	153’325	74’763	14’324	822	426’266	28%
2040	Scenario 1, ECE-Proposal	Italy	13’032’989	2’341’820	2’179’488	1’454’600	600’283	89’012	6’665’204	51%
2040	Scenario 1, ECE-Proposal	Latvia	641’007	176’835	151’337	71’481	14’643	939	415’234	65%

Year	Scenario	Country	No Inhab.	LDEN 55-60 dB	LDEN 60-65 dB	LDEN 65-70 dB	LDEN 70-75 dB	LDEN >75 dB	Pop. > 55 dB	% Pop. > 55 dB
2040	Scenario 1, ECE-Proposal	Liechtenstein	25’435	8’049	5’098	2’335	486	32	16’000	63%
2040	Scenario 1, ECE-Proposal	Lithuania	1’126’250	263’415	188’017	66’358	12’168	1’051	531’009	47%
2040	Scenario 1, ECE-Proposal	Luxembourg	153’410	39’809	40’580	24’521	6’167	513	111’590	73%
2040	Scenario 1, ECE-Proposal	Macedonia	798’529	54’253	20’340	9’026	1’620	61	85’300	11%
2040	Scenario 1, ECE-Proposal	Malta	270’004	33’937	27’899	11’595	2’456	225	76’111	28%
2040	Scenario 1, ECE-Proposal	Montenegro	185’937	55’065	36’870	10’624	1’120	1	103’680	56%
2040	Scenario 1, ECE-Proposal	Netherlands	8’259’054	1’226’035	679’320	153’300	9’794	8	2’068’457	25%
2040	Scenario 1, ECE-Proposal	Norway	1’801’600	248’973	177’057	86’370	18’605	1’260	532’266	30%
2040	Scenario 1, ECE-Proposal	Poland	10’009’194	1’532’300	876’569	334’685	66’602	4’895	2’815’052	28%
2040	Scenario 1, ECE-Proposal	Portugal	1’452’607	167’288	126’692	59’636	16’212	1’860	371’688	26%
2040	Scenario 1, ECE-Proposal	Romania	5’349’985	874’931	876’254	476’263	216’550	37’183	2’481’181	46%
2040	Scenario 1, ECE-Proposal	Slovakia	665’646	121’830	72’934	28’089	10’070	1’639	234’562	35%
2040	Scenario 1, ECE-Proposal	Slovenia	380’900	69’944	51’967	18’368	2’246	2	142’528	37%
2040	Scenario 1, ECE-Proposal	Spain	20’889’339	3’786’413	3’027’043	1’749’253	745’082	117’639	9’425’429	45%
2040	Scenario 1, ECE-Proposal	Sweden	3’367’282	428’386	222’082	67’454	9’576	450	727’949	22%
2040	Scenario 1, ECE-Proposal	Switzerland	4’240’021	836’156	561’700	237’273	51’344	4’412	1’690’885	40%
2040	Scenario 1, ECE-Proposal	United King-dom	35’738’460	2’525’904	1’658’614	1’257’119	355’938	28’934	5’826’510	16%
2040	Scenario 2, Industry ag-reement	Austria	2’639’822	578’567	616’423	382’623	153’767	17’026	1’748’406	66%
2040	Scenario 2, Industry ag-reement	Belgium	2’283’069	404’196	374’043	282’024	66’993	4’823	1’132’078	50%
2040	Scenario 2, Industry ag-reement	Bosnia and Herzegovina	1’144’636	80’896	38’265	16’097	2’331	86	137’675	12%
2040	Scenario 2, Industry ag-reement	Bulgaria	2’684’996	839’641	449’960	104’839	11’765	556	1’406’761	52%
2040	Scenario 2, Industry ag-reement	Croatia	1’209’118	100’102	60’924	22’507	3’126	121	186’780	15%

Year	Scenario	Country	No Inhab.	LDEN 55-60 dB	LDEN 60-65 dB	LDEN 65-70 dB	LDEN 70-75 dB	LDEN >75 dB	Pop. > 55 dB	% Pop. > 55 dB
2040	Scenario 2, Industry agreement	Cyprus	430'468	262'409	66'147	22'352	4'066	185	355'159	83%
2040	Scenario 2, Industry agreement	Czech Republic	2'780'456	529'683	307'272	156'318	24'893	969	1'019'135	37%
2040	Scenario 2, Industry agreement	Denmark	1'753'248	323'603	210'429	70'466	10'330	544	615'372	35%
2040	Scenario 2, Industry agreement	Estonia	532'958	108'402	81'698	26'493	2'983	71	219'646	41%
2040	Scenario 2, Industry agreement	Finland	2'079'601	155'605	59'791	16'874	1'659	1	233'930	11%
2040	Scenario 2, Industry agreement	France	30'205'200	4'960'314	3'648'046	1'610'163	501'047	51'288	10'770'859	36%
2040	Scenario 2, Industry agreement	Germany	24'486'844	1'720'667	1'200'992	531'247	93'862	5'437	3'552'204	15%
2040	Scenario 2, Industry agreement	Greece	1'262'110	79'995	38'225	16'050	2'536	120	136'927	11%
2040	Scenario 2, Industry agreement	Hungary	3'189'345	445'649	372'841	234'943	80'012	8'086	1'141'531	36%
2040	Scenario 2, Industry agreement	Iceland	267'850	17'784	6'452	1'792	176	0	26'204	10%
2040	Scenario 2, Industry agreement	Ireland	1'499'800	170'060	151'679	65'673	10'363	516	398'291	27%
2040	Scenario 2, Industry agreement	Italy	13'032'989	2'370'522	2'135'807	1'370'368	523'375	56'153	6'456'226	50%
2040	Scenario 2, Industry agreement	Latvia	641'007	179'964	145'744	63'428	10'755	590	400'481	62%
2040	Scenario 2, Industry agreement	Liechtenstein	25'435	7'650	4'835	2'078	358	20	14'941	59%
2040	Scenario 2, Industry agreement	Lithuania	1'126'250	261'233	177'692	55'484	9'376	662	504'446	45%
2040	Scenario 2, Industry agreement	Luxembourg	153'410	39'768	40'230	22'500	4'722	323	107'542	70%
2040	Scenario 2, Industry agreement	Macedonia	798'529	44'465	19'275	7'974	1'121	38	72'873	9%
2040	Scenario 2, Industry agreement	Malta	270'004	33'848	26'866	9'991	1'913	141	72'760	27%
2040	Scenario 2, Industry agreement	Montenegro	185'937	56'382	33'967	8'521	706	0	99'576	54%
2040	Scenario 2, Industry agreement	Netherlands	8'259'054	1'186'337	620'706	112'573	6'159	2	1'925'778	23%
2040	Scenario 2, Industry agreement	Norway	1'801'600	240'051	169'777	77'384	13'777	793	501'781	28%
2040	Scenario 2, Industry agreement	Poland	10'009'194	1'477'266	810'879	290'796	49'932	3'079	2'631'953	26%

Year	Scenario	Country	No Inhab.	LDEN 55-60 dB	LDEN 60-65 dB	LDEN 65-70 dB	LDEN 70-75 dB	LDEN >75 dB	Pop. > 55 dB	% Pop. > 55 dB
2040	Scenario 2, Industry agreement	Portugal	1’452’607	163’715	121’740	53’067	13’245	1’172	352’939	24%
2040	Scenario 2, Industry agreement	Romania	5’349’985	896’436	859’489	433’715	197’058	23’466	2’410’164	45%
2040	Scenario 2, Industry agreement	Slovakia	665’646	117’390	68’000	24’443	9’016	1’034	219’883	33%
2040	Scenario 2, Industry agreement	Slovenia	380’900	69’124	49’458	15’240	1’417	1	135’239	36%
2040	Scenario 2, Industry agreement	Spain	20’889’339	3’774’457	2’919’247	1’623’013	661’262	74’224	9’052’202	43%
2040	Scenario 2, Industry agreement	Sweden	3’367’282	406’144	203’162	55’496	6’763	282	671’847	20%
2040	Scenario 2, Industry agreement	Switzerland	4’240’021	806’317	533’347	207’333	39’536	2’777	1’589’311	37%
2040	Scenario 2, Industry agreement	United Kingdom	35’738’460	2’315’421	1’618’046	1’202’740	271’497	18’211	5’425’915	15%
2040	Scenario 4, Incentives	Austria	2’639’822	581’092	615’132	378’129	150’399	15’533	1’740’286	66%
2040	Scenario 4, Incentives	Belgium	2’283’069	402’869	373’321	279’488	63’982	4’399	1’124’059	49%
2040	Scenario 4, Incentives	Bosnia and Herzegovina	1’144’636	78’606	37’895	15’757	2’177	79	134’513	12%
2040	Scenario 4, Incentives	Bulgaria	2’684’996	839’103	442’395	100’609	11’061	507	1’393’675	52%
2040	Scenario 4, Incentives	Croatia	1’209’118	99’303	60’261	21’950	2’923	110	184’548	15%
2040	Scenario 4, Incentives	Cyprus	430’468	263’613	62’927	22’135	3’819	168	352’663	82%
2040	Scenario 4, Incentives	Czech Republic	2’780’456	524’615	304’039	153’879	23’284	884	1’006’700	36%
2040	Scenario 4, Incentives	Denmark	1’753’248	320’816	208’408	68’441	9’746	496	607’907	35%
2040	Scenario 4, Incentives	Estonia	532’958	108’547	80’954	25’687	2’763	64	218’015	41%
2040	Scenario 4, Incentives	Finland	2’079’601	153’542	58’505	16’380	1’513	0	229’940	11%
2040	Scenario 4, Incentives	France	30’205’200	4’939’255	3’620’296	1’579’033	487’574	46’790	10’672’948	35%
2040	Scenario 4, Incentives	Germany	24’486’844	1’709’256	1’191’369	520’605	88’855	4’958	3’515’042	14%
2040	Scenario 4, Incentives	Greece	1’262’110	77’761	37’857	15’711	2’385	110	133’824	11%
2040	Scenario 4, Incentives	Hungary	3’189’345	444’456	371’180	232’304	77’800	7’376	1’133’117	36%
2040	Scenario 4, Incentives	Iceland	267’850	17’522	6’305	1’740	161	0	25’727	10%
2040	Scenario 4, Incentives	Ireland	1’499’800	168’141	151’195	64’191	9’760	471	393’757	26%
2040	Scenario 4, Incentives	Italy	13’032’989	2’374’120	2’127’332	1’355’711	510’844	51’229	6’419’237	49%
2040	Scenario 4, Incentives	Latvia	641’007	180’329	144’696	62’106	10’162	538	397’831	62%
2040	Scenario 4, Incentives	Liechtenstein	25’435	7’584	4’789	2’036	339	18	14’766	58%
2040	Scenario 4, Incentives	Lithuania	1’126’250	260’688	175’838	53’772	8’946	604	499’847	44%
2040	Scenario 4, Incentives	Luxembourg	153’410	39’766	40’130	22’154	4’499	294	106’844	70%

Year	Scenario	Country	No Inhab.	LDEN 55-60 dB	LDEN 60-65 dB	LDEN 65-70 dB	LDEN 70-75 dB	LDEN >75 dB	Pop. > 55 dB	% Pop. > 55 dB
2040	Scenario 4, Incentives	Macedonia	798'529	42'974	19'089	7'801	1'045	35	70'945	9%
2040	Scenario 4, Incentives	Malta	270'004	33'818	26'668	9'735	1'829	129	72'178	27%
2040	Scenario 4, Incentives	Montenegro	185'937	56'510	33'472	8'193	644	0	98'819	53%
2040	Scenario 4, Incentives	Netherlands	8'259'054	1'178'994	610'711	106'356	5'617	2	1'901'680	23%
2040	Scenario 4, Incentives	Norway	1'801'600	238'566	168'457	75'893	13'039	723	496'678	28%
2040	Scenario 4, Incentives	Poland	10'009'194	1'467'400	799'848	283'726	47'379	2'808	2'601'161	26%
2040	Scenario 4, Incentives	Portugal	1'452'607	163'086	120'825	51'998	12'780	1'069	349'757	24%
2040	Scenario 4, Incentives	Romania	5'349'985	899'524	855'825	426'871	193'721	21'409	2'397'350	45%
2040	Scenario 4, Incentives	Slovakia	665'646	116'606	67'157	23'870	8'840	944	217'417	33%
2040	Scenario 4, Incentives	Slovenia	380'900	68'953	48'995	14'745	1'292	0	133'985	35%
2040	Scenario 4, Incentives	Spain	20'889'339	3'770'406	2'899'911	1'601'948	647'377	67'718	8'987'360	43%
2040	Scenario 4, Incentives	Sweden	3'367'282	402'344	199'988	53'619	6'336	257	662'545	20%
2040	Scenario 4, Incentives	Switzerland	4'240'021	801'233	528'295	202'499	37'716	2'533	1'572'276	37%
2040	Scenario 4, Incentives	United Kingdom	35'738'460	2'282'971	1'611'105	1'192'123	258'502	16'610	5'361'311	15%
2040	Status quo	Austria	2'639'822	483'804	614'999	518'186	264'173	77'877	1'959'040	74%
2040	Status quo	Belgium	2'283'069	454'089	385'341	336'880	179'909	22'940	1'379'158	60%
2040	Status quo	Bosnia and Herzegovina	1'144'636	169'192	49'551	27'219	8'397	452	254'811	22%
2040	Status quo	Bulgaria	2'684'996	768'648	685'478	263'767	40'464	2'794	1'761'151	66%
2040	Status quo	Croatia	1'209'118	126'896	79'972	41'543	11'166	630	260'207	22%
2040	Status quo	Cyprus	430'468	162'378	191'167	28'349	13'636	934	396'464	92%
2040	Status quo	Czech Republic	2'780'456	690'808	410'384	228'379	87'962	5'039	1'422'572	51%
2040	Status quo	Denmark	1'753'248	415'602	263'037	142'064	33'409	2'691	856'803	49%
2040	Status quo	Estonia	532'958	96'678	99'692	55'063	11'893	411	263'737	49%
2040	Status quo	Finland	2'079'601	223'606	104'550	34'538	7'595	65	370'355	18%
2040	Status quo	France	30'205'200	5'571'345	4'338'398	2'668'127	972'126	236'011	13'786'007	46%
2040	Status quo	Germany	24'486'844	2'132'140	1'452'088	877'521	287'960	26'546	4'776'255	20%
2040	Status quo	Greece	1'262'110	166'553	49'354	27'188	8'464	605	252'164	20%
2040	Status quo	Hungary	3'189'345	482'567	411'447	309'678	156'844	37'246	1'397'783	44%
2040	Status quo	Iceland	267'850	26'654	11'622	3'665	808	7	42'756	16%
2040	Status quo	Ireland	1'499'800	249'341	152'330	114'882	34'016	2'575	553'145	37%
2040	Status quo	Italy	13'032'989	2'175'032	2'314'252	1'789'492	943'628	257'454	7'479'858	57%
2040	Status quo	Latvia	641'007	156'774	170'167	106'813	33'859	2'902	470'515	73%
2040	Status quo	Liechtenstein	25'435	9'732	6'148	3'461	1'118	98	20'557	81%
2040	Status quo	Lithuania	1'126'250	265'167	226'535	117'282	26'087	3'154	638'225	57%
2040	Status quo	Luxembourg	153'410	40'054	40'325	32'782	13'181	1'544	127'885	83%
2040	Status quo	Macedonia	798'529	102'810	25'035	13'659	4'118	205	145'827	18%
2040	Status quo	Malta	270'004	33'993	31'194	18'926	5'122	671	89'906	33%
2040	Status quo	Montenegro	185'937	45'677	48'649	20'654	3'282	28	118'290	64%

Year	Scenario	Country	No Inhab.	LDEN 55-60 dB	LDEN 60-65 dB	LDEN 65-70 dB	LDEN 70-75 dB	LDEN >75 dB	Pop. > 55 dB	% Pop. > 55 dB
2040	Status quo	Netherlands	8’259’054	1’372’603	921’290	353’147	30’074	240	2’677’354	32%
2040	Status quo	Norway	1’801’600	288’497	204’098	125’277	42’371	3’873	664’116	37%
2040	Status quo	Poland	10’009’194	1’745’552	1’155’341	534’921	149’137	14’913	3’599’864	36%
2040	Status quo	Portugal	1’452’607	182’870	144’190	88’901	30’374	5’461	451’797	31%
2040	Status quo	Romania	5’349’985	766’393	910’427	668’254	298’046	106’774	2’749’893	51%
2040	Status quo	Slovakia	665’646	139’160	93’316	45’289	14’722	4’719	297’207	45%
2040	Status quo	Slovenia	380’900	72’190	60’805	32’918	6’518	55	172’486	45%
2040	Status quo	Spain	20’889’339	3’759’890	3’429’363	2’290’709	1’111’756	339’164	10’930’882	52%
2040	Status quo	Sweden	3’367’282	522’734	302’852	124’107	23’942	1’450	975’084	29%
2040	Status quo	Switzerland	4’240’021	958’900	670’311	372’531	109’311	13’246	2’124’299	50%
2040	Status quo	United King-dom	35’738’460	3’585’283	1’834’929	1’426’214	762’463	87’314	7’696’203	22%