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Modelling noise annoyance moderators

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TECHNICAL NOTE

Modelling noise annoyance moderators

Performed for CEDR, Conference of European Directors of Roads

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OVERVIEW

Title	Modelling Noise annoyance moderators
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Summary

This report has been produced as a part of the FAMOS project, FActors MOderating people's Subjective reactions to road noise. The project is financed by the Conference of European Road Directors (CEDR). This report is a delivery of work package 3 in the FAMOS project.

The overall objective of FAMOS is to quantify how different factors (moderators) modify people's subjective reactions to road traffic noise. Therefore, the purpose of the modelling reported here, was to establish models for the effect of moderators in various context and use case situations.

A modelling methodology is developed and suggested for analysing the influence of moderators of annoyance from road traffic. The model is based on input in the form of raw data from two Danish questionnaire surveys from the Danish Road Directorate. The two Danish studies are of excellent quality both in terms of included questions, questionnaire design, high number of participants, and data quality as well as the methodological approach that follows the current ISO 15 666 standard for such investigations. Within the project effort has been made to collect data from other sources, but it turned out (during the work of WP1) that it is not at all easy to get access to raw data from former questionnaire surveys from other countries.

An analysis approach with a multiple regression model having many moderators and interactions led to models able to account for a significant amount of the variance in the data (70% – 77%). It shows that many moderators and the interactions between them are needed to account for the complex influences of annoyance for people affected by road traffic noise. The benefit of a multiple regression model rather than modelling the effects separately provides an outcome better suited for prediction of annoyance for neighbours to road traffic noise. It also makes it possible to model the relative importance of the moderators when more are in play at the same time.

The effect of specific moderators is expressed as the "annoyance equivalent noise level shift" so that the presence or absence of the moderators is quantified as the increase or decrease in the noise level, L_{den}, which leads to a corresponding shift in annoyance.

From the model the following "annoyance equivalent noise level shifts" are found:

- Orientation of outdoor areas: 10 dB (8.4 – 11.8 dB)
- Access to a quiet side: 10 dB (8.0 – 11.8 dB)
- Special bedroom windows: 10 dB (4.2 – 14.8 dB)
- Causes to annoyance by traffic[1]: 16-17 dB (8.4 – 24.1 dB)

Feeling unsafe corresponds to an annoyance equivalent noise level shift of 5 dB.

The result within the project is not ready-to-use piece of software with user interface for general use, but with the model, the effect of further moderators and interactions than illustrated in this report, can be estimated.

A total of the answers from 6316 respondents are used in the analysis of the two datasets included in this report. The results must be considered valid for Denmark as well as for similar north European countries/regions and they can be considered a first good step towards a model valid for the whole of Europe. Even if the models may not be considered representative for all citizens of Europe, they provide strong evidence for the effect of the moderators that are found significant in this study.

The model is built to make predictions of the average annoyance response on the 0-10 annoyance scale from ISO 15 666. The model may be enhanced to calculate e.g., the percentage of highly annoyed (%HA) from the model findings.

Inclusion of data from more surveys will improve the models and their validity. An important factor for future use will be implementation of uniform questionnaires or at least a larger part of standardized questions covering relevant topics.

[1] This is a general question including: Feeling unsafe at the roads and surroundings, unsafe for children, noise, vibrations, air pollution and dust from the traffic

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1 Preface

This report has been produced as a part of the FAMOS project. FAMOS responds to the questions of the Conference of European Road Directors (CEDR) call in 2018 on Noise and Nuisance: Psycho-Acoustics: Improved Understanding of People's Subjective Reactions to Road Noise.

WHO has estimated that about 1.2 million healthy life-years are lost annually in Europe due to road traffic noise. About half of these can be related to the subjective element: annoyance. This is a huge challenge for the National Road Administrations. Analyses of results from noise surveys reveal that only about 1/3 of the variance in the annoyance response is caused by the noise level itself, whereas the other 2/3 are determined by so-called non-acoustic factors. This means that the annoyance response can be altered within wide limits without doing any changes to the actual noise level. So, when road administrations have used all the technically feasible and economically possible measures, the noise impact can still be reduced by making changes in the non-acoustic factors known to moderate the annoyance response.

FAMOS is the acronym for "FActors MOderating people's Subjective reactions to road noise". The project is carried out over two years and started in December 2019. The project consortium consists of three partners:

- FORCE Technology in Denmark (Project leader)
- LÄRMKONTOR in Germany
- SINTEF in Norway

The objective of FAMOS is to quantify how different factors modify people's subjective reactions to road traffic noise. The project uses scientific methods to find, extract and analyse data from existing annoyance surveys. The most promising findings have been tested experimentally in Work Package WP2 by the use of questionnaire studies, listening testing in the laboratory and soundscape measurements/sound walks.

This report has been produced within Work Package WP 3 of the project, which deals with "Modelling" and is led by the FORCE. This report presents the results of analysis and modelling work performed on large datasets retrieved in Work Package WP1 of the FAMOS project. The purpose has been to perform modelling of the moderators to noise annoyance found in the international literature study performed in WP1 of the FAMOS project. The report is produced by Christer P. Volk from FORCE as Deliverable D.3.1 of the FAMOS project. The report has as a quality control been reviewed by Hans Bendtsen and Torben Holm Pedersen from FORCE and Truls Gjestland from SINTEF. The CEDR Transnational Road Research Programme funded by Belgium – Wallonia, Denmark, Ireland, Netherlands, Norway, Sweden and United Kingdom has financed the FAMOS project.

The results will in Work Package WP4 be used to develop a handbook on how "moderators" can be used by road administrations to reduce noise annoyance.

2 Introduction

The overall objective of FAMOS is to quantify how different factors modify people's subjective reactions to road traffic noise. Therefore, the purpose of the modelling was to establish models for the effect of moderators expressed as dose-response curves for the moderators in various context and use case situations. The aim was to describe the models in practical terms, which use cases they are applicable for and which context variables to control or specify as input and to get reliable output estimates of the moderator effect with a specified uncertainty.

The modelling should concentrate on the most relevant moderators, based on the findings of the former work packages (see Chapter 3).

Based on input from two large questionnaire surveys on perceived noise annoyance, the model can demonstrate the effect of various moderators. The result within the project will not be ready-to-use piece of software with user interface for general use. It will be possible to use the model for input data from more surveys at a later stage after the termination of the FAMOS project.

The model is based on input in the form of raw data from two Danish questionnaire surveys. Within the project work has been done to collect data from other sources, but it turned out (during the work of WP1) that it is not at all easy to get access to raw data from former questionnaire surveys from other countries. Within the framework of the FAMOS project and in cooperation with the Programme Executive Board (PEB) of the FAMOS project it has therefore only been possible to obtain raw data from comprehensive Danish surveys.

3 Moderators

Several factors can change the annoyance from the traffic noise. Reducing the noise is an obvious factor, but many other factors have an influence on the annoyance, se Table 1. Moderators are factors that can change the relation between the noise exposure and the annoyance response.

When all conventional noise reduction measures have been applied, the noise impact can still be reduced by making changes in so called non-acoustic factors. We will interpret the term "non-acoustic factors" as: All factors that do not have an influence on the L_{den} at the most expose façade. This means that some acoustic factors also fall in the category "non-acoustic factors" e.g. noise reducing windows and facades, local noise screens in a garden etc.

In Table 1 acoustic and non-acoustic factors are listed. To some extend these factors has been defined on the background of the international literature survey on moderators to perceived annoyance performed in work package WP1[1]. Some of these factors can be controlled by the road authorities (column A) and some cannot (column B). It has been defined that FAMOS shall have the main focus on the non-acoustic factors that can be controlled by the road authorities (listed in the upper left green cell in the table). At the same time, it has been defined that the outcome of FAMOS should not include factors related to road and traffic (red cell). Some of these may be included for improved modelling (yellow cell).

1: FAMOS	**A: Controllable by NRA**	**For improved modelling**
	Feeling safe in the traffic Trust in authorities/Traffic noise acceptable Communication - expectations alignment Visibility of traffic Visual appearance of noise barriers Vegetation/Greenery Access to silent side (e.g. by filling spaces between buildings) Neighbourhood soundscape	Road type Traffic volume Detached/apartment Noise sensitivity Gender Day, evening night distribution Orientation of dwelling
2: Not FAMOS	**A: Controllable by NRA**	**B: Non controllable by NRA**
	Road and traffic Road type and surface Traffic volume and speed Traffic composition Distance and Noise barriers Day, evening night distribution	**Personal factors** **Residential satisfaction** **Demographic factors** Coping capacity Dependency of sound source Age, education, occupation, income Household size, children Length of residence **Traffic related** Tyres Dust and air pollution **Combined noise** Rail, Air, Industry

Table 1 Factors that can change the annoyance response. The factors of relevance for FAMOS are the ones listed in the green cell A1: Controllable by NRA without changing the road and the traffic.

3.1 Annoyance equivalent noise level shifts

A non-acoustic moderator is of interest as it allows a person's annoyance level to decrease without decreasing the actual noise level. To quantify the influence of a moderator it therefore makes sense to compare it with the equivalent reduction in noise level needed to obtain the same reduction in annoyance level that was introduced by having the moderator. Of course, a non-acoustical moderator might also cause an increase in annoyance level and consequently a standardised term to quantify this influence must be able to describe both situations. That is exactly what the "Annoyance equivalent noise level shift" (L_{eas}) is: The (hypothetical) shift in noise level that will give the same change in annoyance as the presence or absence of a moderator. This is a practical way to express the effect of a moderator. It should not be confused with any actual changes in noise levels. As an example, it could explain why the annoyance level of a resident with a view from his balcony to a large road having 55 dB L_{den} at the façade could experience the same annoyance level as a resident having 60 dB L_{den} at her façade but being unable to see the road and its traffic.

4 Modelling efforts

In this report, a modelling methodology is developed and suggested for analysing the influence of moderators of annoyance from road traffic. The methodology is exemplified through the modelling of two datasets from the Danish Road Directorate ("Vejdirektoratet") that has been made available for the FAMOS project. The literature review in WP1 [1] showed a significant portion of previous studies looking into only a few potential moderators per study, which might overestimate each moderator's influence on annoyance. A more complete model is needed looking at a wide range of potential moderators. The previous studies provide a good basis for selecting relevant moderators. The two Danish studies included questionnaires with many of the moderators suggested in the literature and therefore makes an ideal test case for investigation of the potential benefit of making a more comprehensive statistical regression model, enabling NRA's to predict annoyance from several alternative changes to an environment with neighbours affected by road traffic noise and make choices on an improved informed basis for applying tools to reduce the perceived noise annoyance.

The two Danish studies [3 ,4, 5 and 6] are of excellent quality both in terms of included questions, questionnaire design, high number of participants, and data quality as well as the methodological approach that follows the current ISO standard for such investigations [2]. The results must be considered valid for Denmark as well as similar north European countries/regions and they can be considered a first good step towards a model valid for the whole of Europe, but they are not a sufficient data basis for making a road traffic annoyance model that can provide accurate predictions for all of Europe. While getting data from a representative part of Europe as originally intended, sharing of personal data from questionnaires between research partners is a major challenge. Even more so with the introduction of the General Data Protection Regulation (GDPR) in May 2018. Especially since part of the relevant data for annoyance studies can include personal medical data.

The contribution of this report is also to further investigate the potential of including more moderators and more interactions between moderators in a multiple regression model and further qualify the list of questions of importance to collect in future studies allowing the future creation of a valuable tool for improving the quality of life of hundreds of millions of citizens in Europe affected by road traffic noise.

5 Data for the model

The raw data from two major socio-acoustic surveys from the Danish Road Directorate were made available for modelling in this project by permission from the Danish Road Directorate:

1) Noise annoyance from motorways and urbans roads, [3] and [4]
2) Community response to noise reducing pavements, [5] and [6].

The study on noise annoyance from motorways and urbans roads (performed in 2014) was made with the purpose to find out whether the noise annoyance experienced by residents along motorways is larger than the noise annoyance experienced by residents along urban roads, at the same noise levels. The motorways include sections of a total length of 200 km (10 % of the Danish motorway network) that affect residential areas by noise in large cities (Aalborg, Odense, and Copenhagen), and affect both urban communities and dwellings in rural areas throughout Denmark. The urban roads include 20 sections in the three large cities in Denmark (Copenhagen, Aarhus, and Odense). The sections in cities are both urban roads with little traffic, shopping streets and large, busy through roads. The questionnaire contained 30. The national road administrations mainly have the responsibility for motorways and other main roads. To reflect this, it has therefore been decided in this report, only to analyse the subset of data on motorways.

Please note: This report is technical in its statistical descriptions and require knowledge of the fundamentals of statistics and of regression modelling in particular.

It requires understanding of technical terms such as:

- Generalized linear regression
- Transformations
- Terms (in a regression model)
- Response variable
- Explaining variables
- Main effects
- Interaction effects
- Model reduction
- Model assumptions
- Akaike Information Criterion
- Statistical significance
- p-value
- F-value

The study on community response to noise reducing pavements were performed before (in 2007) and after (in 2008) the pavement on two major roads (Frederikssundsvej including some neighbouring roads and Kastrupvej) in Copenhagen was renewed with noise reducing thin layer asphalt. The questionnaire contained 40 questions (see Appendix 1) and the methodology used for the survey was similar to the motorway study.

The road surfaces in the before situation were 8 years old asphalt concrete having 11 mm maximum aggregate size. In the after situation the pavements were new noise reducing thin asphalt layers. At the repaved roads, an average noise reduction of 4 dB was measured.

The number of respondents in the studies can be found in Table 2.

Study	Year	Number of respondents		Total
Noise annoyance from motorways and urban roads	2014	Motorways: 3446	Urban roads: 3315	6761
Noise reducing pavements (Copenhagen dataset)	2007 and 2008	Before: 1330	After: 1540	2870

Table 2 Number of respondents in the studies which is the data basis for the modelling. Data from the green shaded cells (6316 respondent) are included in the modelling.

A total of 6316 respondents are included in the analysis of the two datasets included in this report. This is a very high number of respondents and much higher than what is seen in many other international annoyance surveys [7]. Note, that in the remaining sections of this report, the "Noise annoyance from motorways and urban roads" is referred to as the "motorway" dataset (as only the motorway responses were included) and the "Community response to noise reducing pavement" is referred to as the "Copenhagen dataset ".

5.1 Questionnaire content and Common questions

Both questionnaires in the two studies have the questions divided into sections with headings describing their topics, which gives a nice overview, as shown here.

Noise annoyance from motorways	Copenhagen dataset
Questions about different type of annoyance from traffic (Q1-Q2)	Questions about different type of annoyance from traffic (Q1-Q2)
Questions about noise (Q3-Q17)	Questions about noise (Q3-Q10)
	Questions about what to do to reduce traffic noise (Q11-Q14)
Questions about the residence (Q18-Q23)	Questions about the residence (Q15-Q24)
Questions about yourself (Q24-Q30)	Questions about yourself (Q25-Q40)

Table 3 The types of questions in the Motorway and the Copenhagen dataset. The question topics and their numbering used for the Copenhagen dataset can be seen in Appendix 1.

The questions and the numbering of these are shown in Danish in Appendix 1, as they appeared in the original questionnaires. For the Motorway dataset the questions can be found in English in reference [3]

Generally, the "motorway" study has questions in a broader range of topics, such as visual influence and types of vehicles, while the "Copenhagen" study have many questions about the difference between indoor and outdoor and also include more questions on the health of respondents. The two studies have 13-15 questions in common (some a similar, but not identical), which is of interest with regards to the comparison of modelling output of the two later in this report. These common questions are listed in Table 4

For the questions being in both surveys, the response options are not always identical, either because the first study indicated that a certain option was missing (based on comments in the 'Other' response free text field) or for other reasons unknown to the author of this report.

Topic of Question	**Motorway (question number)**	**Copenhagen dataset (question number)**
Overall road annoyance	1	1
Causes to annoyance by road traffic	2	2
12-month Road traffic noise annoyance	3	3
Behaviour changes due to road noise + Activities affected from road traffic	9+11	7
Other frequent sources of noise	6	10
Type of outdoor areas (motorway) / Access to own garden (Copenhagen)	13	23
Activities affected from road traffic when outside	16	9
Acceptance of road noise at home	17	4
Type of bedroom windows	22	20
Type of living room windows	23	17
Birth year	24	25
Gender	25	26
Years in current dwelling	26	27
Noise sensitivity	28	33
Hearing acuity	27	35

Table 4 Common questions in the studies of "Noise annoyance from motorways" (referred to as "motorway" in the table) and "Community response to noise reducing pavements" (referred to as "Copenhagen dataset" in the table).

6 Data reduction and imputation

6.1 Data reduction

For the two studies, data has been converted and reduced from the original dataset. From the study on motorways and urban roads only the subset on motorways was included here, having 3446 respondents. The main task in the data reduction consisted of reducing response options to improve the modelling potential. The original questionnaires used, and the response options can be seen in [6]. The data reduction was done in two ways:

1) By removing response options that led to no additional information.
2) By grouping options.

As an example of this process is a question (8a) on the cause of annoyance: Vehicle type, see Figure 1. The question had 11 response options. Option 10 (Other) and 11 (Don't know) was removed (set to NA) because these options would not help understand the causes of annoyance. Furthermore, four options were grouped into a "Heavy vehicle" category and three other options into an "intrusive vehicles" category, as illustrated in Figure 1. This reduced the number of possible interactions and helped with interpretation of the model outcome. The process is described in more detail in Appendix 1, section 12.1, p. 49. Here it can be seen which response options that were grouped.

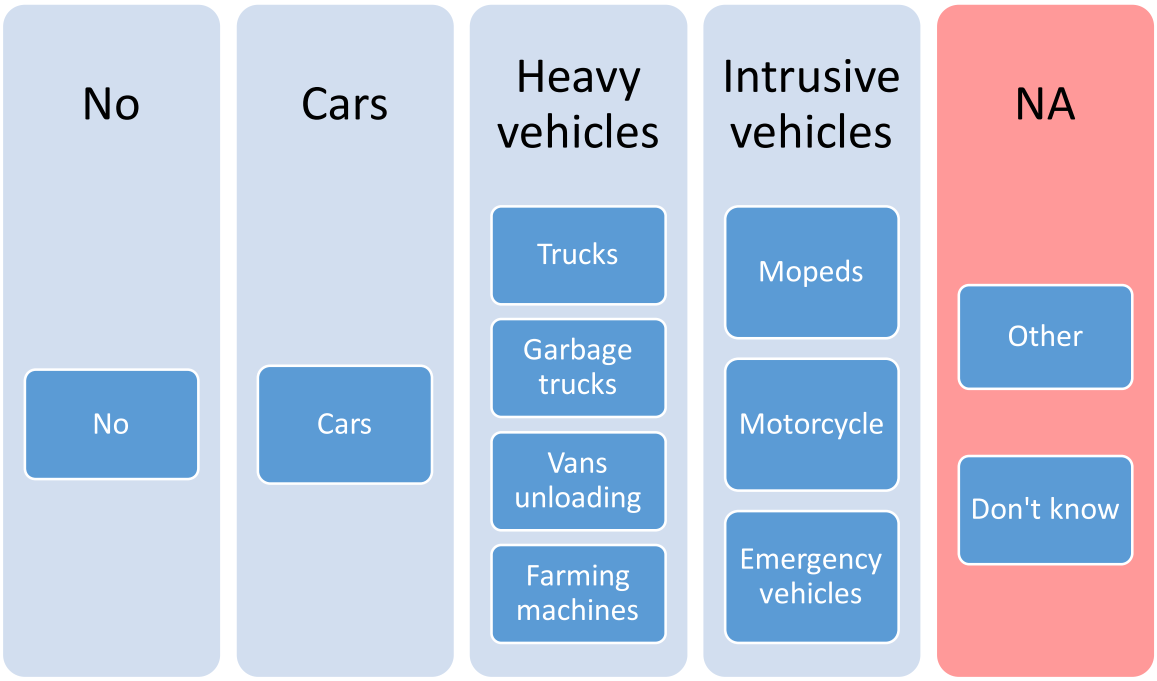

Figure 1 Example of reducing response options for the question on the vehicle type as cause of annoyance. Here reduced from 11 options to 4 options. Darker blue boxes are the original options, and the light blue are the reduced set of options. The light red box is the original options that was recoded as missing response.

6.2 Data imputation

In some cases, the person answering a questionnaire has not given answers to all the questions included. This results in missing data. For the Motorway dataset, a few columns (each column contains responses to one question) also had too many missing data. These columns were removed, as the value of them in the model would be limited. This is a suited approach if the missing values are limited to a few columns in the dataset, but if they are spread across many columns, another approach is needed: *Imputation*. This was the case for the Copenhagen dataset. While 3.5% of the data was missing, the missing data was distributed more evenly across many rows (persons) and columns (question responses). For modelling purposes, a full row of data is discarded automatically by the statistical software **R**, when calculating a regression model, if even one datapoint is missing. This automatic approach would have reduced number of responses from 2564 to 1731 (-32%) and would be a waste of valuable data. If too many datapoints are missing from a single column imputation risks biasing data and therefore it is sometimes best to discard some columns (questions with little information) while imputing missing data in others.

The imputed data (ideally) adds no information but ensures that all rows are kept as the data basis for the model. For numerical data it is for instance common practice to replace missing values with the mean of the column (having responses to the same question). This, however, changes the distribution of the data, which can become problematic if too many values are missing. Another approach, used in the project, is to replace a missing value with a randomly sampled value from the same column. This approach has the advantage of being simple and work for both numerical (continuous and discrete) and categorical (multiple choice) data. More advanced methods exist but requires separate handling of each data type as well as each question's response options. These methods are suited for datasets with a large proportion of missing data.

By applying this data imputation process it was possible to include nearly all responses, also the ones with missing data, in the analysis and modelling work performed.

If done right, data imputation does not increase the uncertainty of despite the added random data (added noise) as it allows much more real data to be included. Furthermore, the systematic trend(s) in the columns having imputed data is unchanged, and thus the effect is almost a model with the same coefficients as if no data was missing, but with a slightly reduced degree of explained variance (as the model fail to predict the added randomness, which is of course not an issue).

7 Modelling type and process

7.1 Dose response curves and logistic transformations

The results from the surveys used may be described as dose-response curves between the self-reported noise annoyance, and L_{den}. The dose-response curves can be expressed as in:

$$A = \frac{u}{1 + e^{-s(E-f)}}$$

Equation 1

Where:

- *A is degree of annoyance*
- *u is the upper limit of A (i.e. u = 10)*
- *s is the slope*
- *E is the noise Exposure, L_{den}*
- *f is the value of E for an annoyance response of 5*

A constructed example of a dose response curve for the average annoyance according to Equation 2 is shown in the left graph of Figure 2.

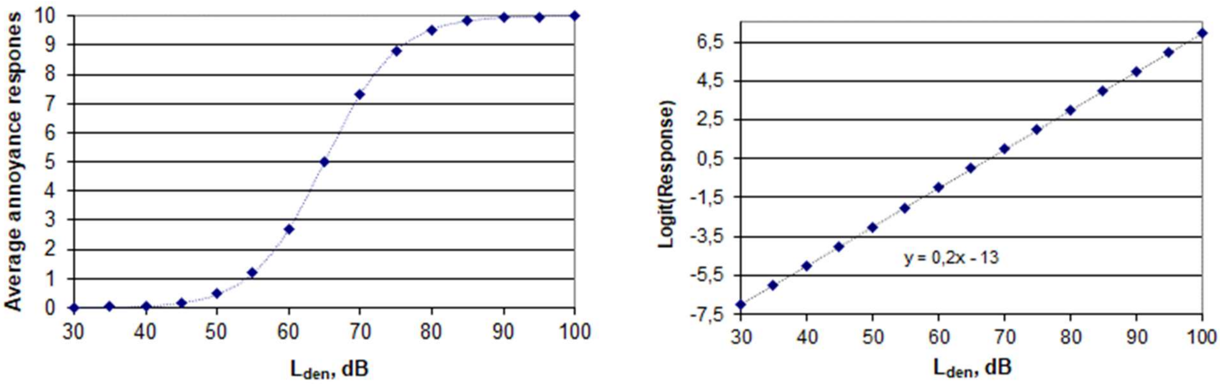

Figure 2 An ideal constructed example (with averaged annoyance on the 0 to 10 scale in 5 dB classes). To the left the average response as function of L_{den}.. To the right the same data, but the response is transformed with the logit transformation.

By transforming the annoyance response with the logit function (see below), the dose response curve can be linearized, which makes it easy to find the constants for the curve shown to the left.

The model used in this report is a general multiple regression model with a logit-transformation of the raw data for the response variable, i.e. the answers to the 12-month average noise annoyance at home according to ISO TS 15 666, [2] as used in the questionnaires. For this question respondents stated their answer on a 11-point numerical scale ranging from 0 to 10 and on a 5-point verbal scale ranging from "Not at all annoyed" to "extremely annoyed". Only the 11-point data was used here, having the highest resolution of annoyance.

The model in this report is based directly on the raw data for the annoyance responses, which requires some considerations and choices that are not needed when operating on the averaged responses.

The logit-function limits predictions to a fixed range, such that predictions cannot exceed the minimum or maximum annoyance. In its basic form it is defined as stated in Equation 2.

$$y_t = \ln\left(\frac{y}{1-y}\right)$$

Equation 2 - Logit-function

where:

$y \text{ is the response variable}$

$y_t \text{ is transformed response variable}$

The logic-function requires the input, y, to be without [0,1]. A generalized version exists, which is suitable for the 11-point Annoyance scale:

$$y_t = \ln\left(\frac{p}{1-p}\right)$$

Equation 3 – Generalized logit-transform

where:

$p = \frac{y-y_{min}}{y_{max}-y_{min}}$

The output of the generalized logit-transform will have $-infinity$ and $+infinity$ at the extremes, thus a choice is needed as 0 and 10 cannot be included if the minimum and maximum of the original scale is used in Eq. 2. One can either exclude 0 and 10 from the dataset being modelled (method 1) or change the limits (method 2). The arguments for excluding 0 and 10 responses, method 1, is that it is the middle part of the scale that is the most important for the logit-transform. Changed limits, method 2, will have to be arbitrarily chosen, having an influence on the slope. The argument for choosing new limits, e.g. -1 and 11 (method 2), is that the full dataset can be included (throwing data away is always controversial). This will have the advantage of keeping data for the case of going from not being annoyed at all to slightly annoyed, which might be a threshold of special importance. Furthermore, in case the model is to be used for modelling the proportion of highly annoyed, including 10 is necessary, as highly annoyed is defined as the responses 8, 9, and 10 in the annoyance scale from 0 to 10.

In this project, both methods were tested and the model with all data (method 2) has a much better fit to the data (Adjusted R^2 of 0.77 vs. 0.61). Therefore, this approach was chosen.

7.2 Regression model

7.2.1 Definition of terms

Some words may have various meanings depending on the context in which they are used. In the succeeding clauses we will use the following terminology:

Terms: In the model the (mathematical) terms are the independent variables with coefficients that describe their influence or effect on the dependent variable, the predicted annoyance.

Coefficients: The multipliers for the variables in the model, that determines the magnitude of their effect on the predicted annoyance.

Independent variables: L_{den}, the moderators, eg. the amount of greenery, the visibility of the traffic, the trust to the authorities etc

Moderators: Variables that change (moderates) the relation between noise level (L_{den}) and the annoyance response. L_{den} is a variable in the model, but not a moderator.

Main moderator: A moderator of significant influence on the dependent variable, annoyance.

Effect: The effect (effect size) of a moderator on the annoyance is expressed as the product of the moderator and a coefficient (coefficient times moderator).

Main effect: A term of significant influence on the dependent variable, annoyance.

Interaction term: A combination of Independent variables, eg.: y * L_{den} * (Amount of greenery) where y is a coefficient. The above-mentioned term is a two-way interaction term

An example with a simple linear model for annoyance could be:

*Annoyance = x*LAeq + y*(amount of greenery) + z*LAeq*(amount of greenery)*

The word "annoyance" is used for the annoyance a person feels, the community annoyance measured by surveys (annoyance response) and the annoyance predicted by the model (predicted annoyance). The meaning will be apparent from the context.

7.2.2 The model

The model consists of a number of terms that describe the effect of variables that affects the annoyance response. Initially the model included all questions from the questionnaire and was then optimized by removing terms. This was done to obtain a model which only have relevant terms that can explain the systematic variation in the data and remove terms with no or only spurious contributions. In this project, the reduction was done in two steps:

1) The number of terms was reduced using the AIC criterion (Akaike Information Criterion) to only include terms, which statistically improve the degree of explained variance.
2) Secondly, all two-way interaction terms of the surviving terms were added and again the AIC criterion used to reduce the model to one having terms and interactions that contributes significantly to the degree of explained variance.

The interactions terms are of especially importance as they are rarely reported in the literature and allows estimation of the combined influence of moderators for a given situation (effect sizes from different moderators cannot simply be added together).

The results from the model are related to the average response on the 0-10 annoyance scale. Often the results from surveys are presented as e.g. the percentage of highly annoyed (%HA), i.e. the percentage of respondents that have answered in the categories 8, 9 and 10 on the annoyance scale.

In Appendix 1 the relations between the average annoyance response on the 0-10 scale and the percentage of Highly Annoyed (%HA), Annoyed (%A) and Little Annoyed (%LA) can be found. It can be seen that e.g. an average annoyance response of 3 corresponds to around 10% Highly annoyed.

In the following two sections (section 8 and section 9) general linear regression models were made on the basis of one dataset per model. This approach was chosen, rather making one model on a combination of the two datasets, as it allows an evaluation of the appropriateness of the method and the datasets. Assuming that the surveys are both general in nature, the resulting models will be similar, if the method is stable. All common factors in the two models can be considered more general and possibly suited for a broader context than that of the individual datasets. This comparison of the models is the topic of section 0.

8 Result: Motorway dataset

The obtained regression model after removing insignificant terms has a high degree of explained variance (adjusted R^2 = 77%) and fulfils all modelling assumptions (see Appendix section 12.2, p. 51), i.e., the model can be trusted both regarding noise annoyance predictions and degree of influence from moderators. Although it is still not able to fully describe the causes of variance in response.

In Figure 4 the correspondence between annoyance responses ("Annoyance") and annoyance predicted by the model ("Predicted annoyance") is shown. Since the annoyance responses were discrete while the predictions are continuous, model predictions were added as a new column to the dataset, then the dataset was split into subset for each annoyance response, and finally the mean estimate and 95% confidence intervals were calculated on the annoyance predictions within each subset.

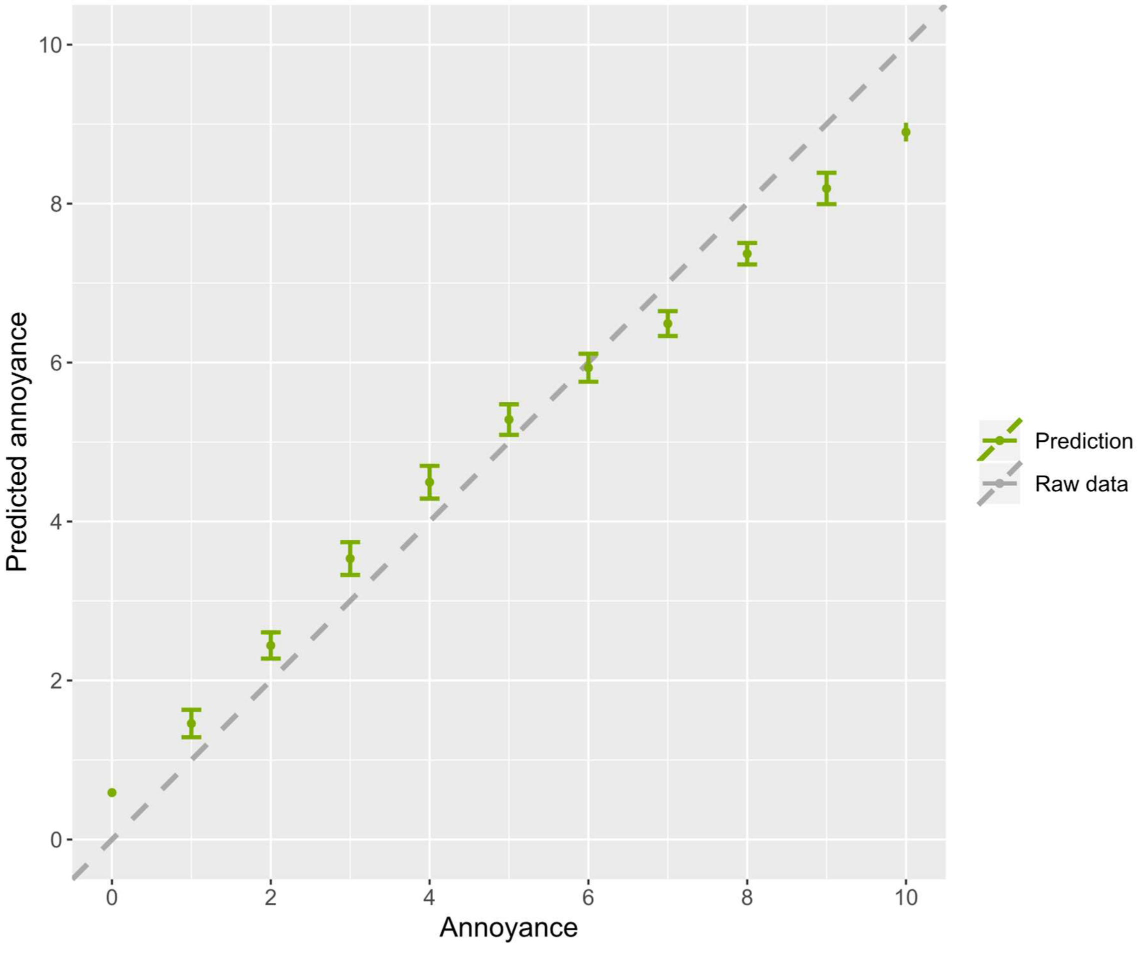

Figure 3 Annoyance vs. Predicted annoyance. Mean value estimates with 95% confidence intervals. For the Motorway dataset subset.

The figure generally shows a good correspondence, but also a curvature causing a slight over-estimating at lower annoyance levels and a slight under-estimation at higher annoyance levels.

The model contains 15 main moderators as well as 11 interaction terms between combined variables. They are listed in Table 5 and Table 6 respectively. Among the main moderators are both identified moderators found in the FAMOS literature study [1] as well as other moderators.

For a linear regression model, the coefficients of the model (i.e., the multipliers that describe the influence of the moderators), would be linearly linked to the response variable, annoyance, but for a model with a non-linear transformation, they are not. Consequently, it is simple to report the relative importance of terms, but more complicated to report the influence as e.g. absolute change in annoyance or equivalent L_{den} shift. To simplify the task, here, the F-value is reported (see Table 5 and Table 6), which estimates the relative variance accounted for by the variables, i.e., the systematic variation. The F-value is tested for significance in an F-test (Wald test) against a model with only the intercept. Furthermore, some examples are given, which quantifies the effect for the given context. A higher F-value corresponds to a larger proportion of variance described by the term. First, the relative influence is discussed.

Surprisingly, the responses to the question *Acceptance of road noise level at home*, has the highest contribution with an F-value of 5.400, i.e., more than twice that of the second largest term, L_{den}, with 2.439. The fourth most important variable, *Causes of annoyance by road traffic*, is the first moderator which road authorities can influence. The reduced response options from this question (see detail in Appendix 1, section 12.1, p. 49) includes:

- Feeling unsafe in traffic
- Noise from traffic
- Vibration from traffic
- Pollution or odour

Among the remaining moderators, which might be influenced by road authorities, is *Annoyance cause: Vehicle type* from the example Figure 1, where the types of vehicles might be restricted, as well as *Time of day with peak annoyance*.

While the interactions are relatively small compared with the largest main effects, sorted by F-value, interactions, are in place 9, 11, 15, 17, 19-22, 24-26, among the full list of terms (again see Table 1 and 2). Meaning that 7 main-effects are smaller than the largest interaction effect: *Acceptance of road noise at home x Access to a quiet side*. This interaction predicts that if a participant answers "No" or "Don't know", their annoyance level will be higher than if they answer "Yes".

The largest main moderator, *Acceptance of road noise level at home*, also has multiple significant interactions. Specifically, with *Access to a quiet side*, *Causes of annoyance by road traffic*, *Types of outdoor areas available*, and *Annoyance cause: Vehicle type*, all of which seems like logical interactions.

Another interesting set of interactions is the two interactions with L_{den}, *Types of outdoor areas available* and *Orientation of outdoor areas*, which can be seen as correction factors in the cases where L_{den} isn't an accurate predictor, namely when outside.

Note: Besides the main question on noise annoyance also Q2 contains a question on whether noise is a source of annoyance. This is the main driver of the results in Q2 so an alternative analysis to the one shown in Table 6 but without Q2 has been made. In this analysis the question "Motorway visible" appears to be significant with an F-value of 253, i.e. a larger impact than access to a quiet side.

Question ID	Main variables	DF	Sum Sq	Mean Sq	F-value	p-value	Significance
17	Acceptance of road noise at home	1	2491.8	2491.8	5400.0	0.000	***
Lden	Lden	1	1125.3	1125.3	2438.7	0.000	***
18	Access to a quiet side	2	211.5	105.8	229.2	0.000	***
2	Causes of annoyance by road traffic	15	1014.9	67.7	146.6	0.000	***
7	Time of day with peak annoyance	7	461.7	66.0	142.9	0.000	***
28	Noise sensitivity	1	45.9	45.9	99.6	0.000	***
9	Behaviour change due to road noise	4	107.6	26.9	58.3	0.000	***
16b	Behaviour change due to road noise, when outside	1	14.5	14.5	31.3	0.000	***
8a	Annoyance cause: Vehicle type	8	87.1	10.9	23.6	0.000	***
16a	Activities affected from road traffic when outside	7	40.2	5.7	12.5	0.000	***
13	Types of outdoor areas available	1	5.4	5.4	11.7	0.001	***
11	Indoor activities affected from road traffic	7	36.5	5.2	11.3	0.000	***
14	Orientation of outdoor areas	3	10.1	3.4	7.3	0.000	***
6	Other frequent sources of noise	1	3.3	3.3	7.2	0.007	**
22	Type of bedroom windows	1	1.5	1.5	3.2	0.075	.

Table 5 Motorway dataset. Regression model main effects. Sorted by F-value.

Question ID	Interaction effect IDs	DF	Sum Sq	Mean Sq	F-value	p-value	Significance
17:18	Acceptance of road noise at home Access to a quiet side	2	26.9	13.4	29.1	0.000	***
12:22	Main road noise source visual Type of bedroom windows	1	9.7	9.7	21.1	0.000	***
Lden:13	L_{den} Types of outdoor areas available	1	3.5	3.5	7.5	0.006	**
17:2	Acceptance of road noise at home Causes of annoyance by road traffic (Scale)	13	43.5	3.3	7.3	0.000	***
17:13	Acceptance of road noise at home Types of outdoor areas available	1	2.3	2.3	5.0	0.026	*
18:13	Access to a quiet side Types of outdoor areas available	2	4.5	2.3	4.9	0.007	**
17:8a	Acceptance of road noise at home Annoyance cause: Vehicle type	8	18.1	2.3	4.9	0.000	***
6:7	Other frequent sources of noise Time of day with peak annoyance	7	14.9	2.1	4.6	0.000	***
18:22	Access to a quiet side Type of bedroom windows	2	2.6	1.3	2.8	0.058	.
7:8a	Time of day with peak annoyance Annoyance cause: Vehicle type	53	69.3	1.3	2.8	0.000	***
Lden:14	L_{den} Orientation of outdoor areas	3	3.5	1.2	2.5	0.055	.

Table 6 Motorway dataset. Regression model interaction effects. Sorted by F-value. The notation xx:yy describes the interaction term between xx and yy.

8.1 Main effect dose-response curves (Motorway dataset)

All plots in this section have the response variable, 12-month average road traffic annoyance on the 0-10 scale, on the y-axis and a main effect on the x-axis, e.g. L_{den}. The plots show the estimated mean with 95%-confidence intervals of the raw responses ("Raw data") in the motorway dataset and the model prediction ("Prediction"), with 95%-confidence intervals. At all points on the curve where the confidence intervals of the averaged raw data and the prediction overlaps, the model estimates the effect as well as can be done with the uncertainty of the data. Note, that this type of plot can only be made for the few moderators with a numerical response type and plots were made purely for moderators contributing to the model (i.e. being in Table 5 or Table 6).

Figure 4 shows the influence of the moderator *acceptance of road noise level at home* on annoyance. The prediction is based on the same dataset, as the prediction model, which implies that the curve might look different for different datasets, with different distributions and combinations of the 16 moderators included in the model[2]. The figure shows a large shift in the predicted annoyance from approx. 1 at high acceptance to approx. 8.3 at low acceptance (1.5) in relation to the acceptance of road noise at home. Interactions terms including this moderator (such as 17:18 in Table 6 Motorway dataset. Regression model interaction effects. Sorted by F-value. The notation xx:yy describes the interaction term between xx and yy.might, however, reduce the effect for the individual.

One may wonder whether the L_{den} is the main driver behind the acceptance, i.e. that persons living at low noise levels have a higher score on the acceptance scale. From Figure 18 in Appendix 3 it can be seen that, that is not the case.

[2] *Main road noise source visual* is included as an interaction effect only, but not a main effect, which is why the number of moderators (16) is larger than the number of main effects (15) in the model.

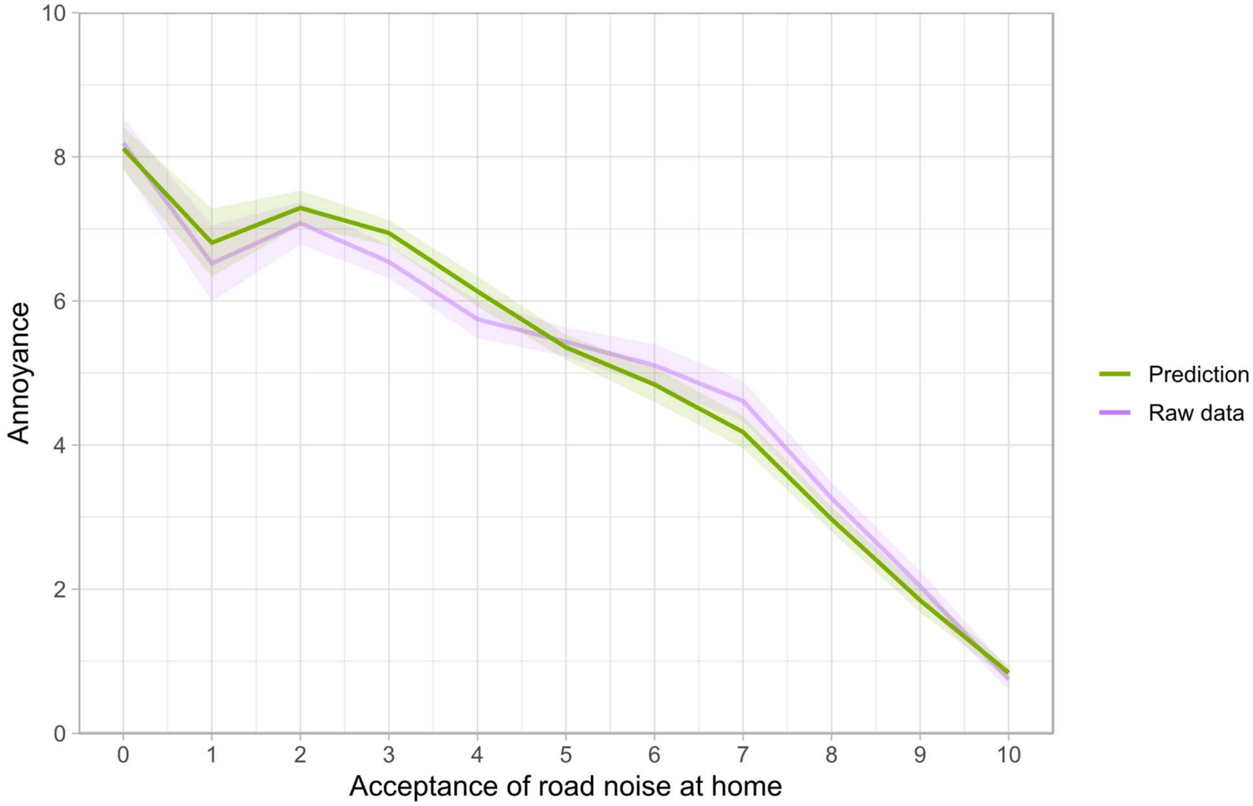

Figure 4 Prediction of annoyance from acceptance of road noise level. Main effect. With 95% confidence intervals. From the Motorway dataset.

For Figure 5, the effect of the variable, L_{den}, on annoyance spans the range 2.8 to 8.1, increasing with the noise level as expected. The assumed s-shaped nature of the dose-response curve has an almost linear relationship within L_{den} range 53-67 dB. The original dataset spans the range from 48 to 77.3 dB, and the prediction was kept within a similar interval to avoid extrapolation outside the valid range of the model.

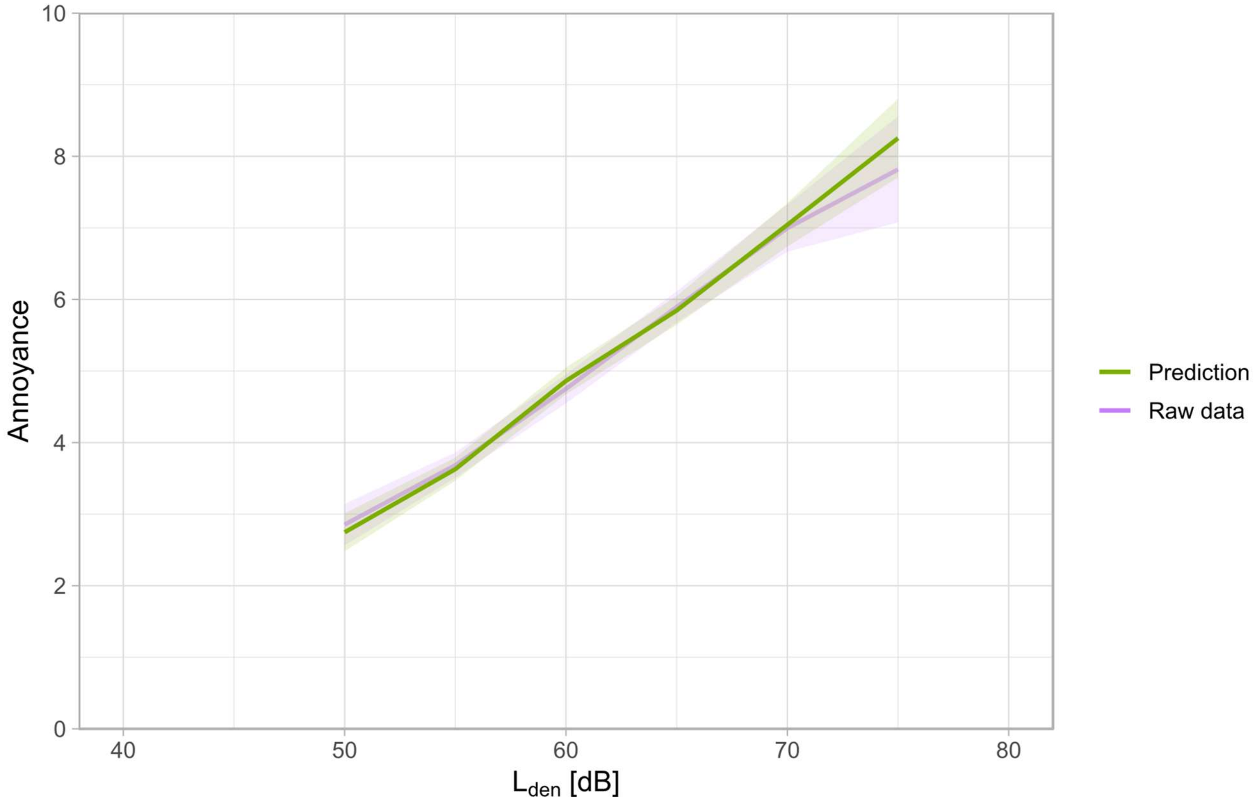

Figure 5 Prediction of annoyance from L_{den}. Main effect. With 95% confidence intervals. From the Motorway dataset.

8.2 Relation to FAMOS literature study

The FAMOS literature study performed in WP1, [1], led to four non-acoustic moderators of main focus listed in the columns of Figure 6. These were selected partly because they had a large effect on annoyance: up to 6 dB (Access to quiet side), 10 dB (Visual/greenery), and 15 dB (Attitudes) in annoyance equivalent noise level shift respectively for the first three columns. While it is currently unknown how large the effect is of the neighbourhood soundscape, the effect has been reported, and might be a moderator that road authorities and municipalities can influence. The smaller boxes in Figure 6 indicate the moderators included in the present dataset, with blue indicating a moderator included in the regression model and red indication that the moderator was excluded from the model, either because it was insignificant or had a too small effect size (F-value). The up to 15 dB reported for "Attitude towards authorities and road owners", were based on direct questions on this subject, while "Acceptance of road noise level at home" is only assumed indirectly related here. In all likelihood many underlying moderators (objective and subject) may influence acceptance of road noise level at home, but general trust in- or attitude towards authorities may be one of these.

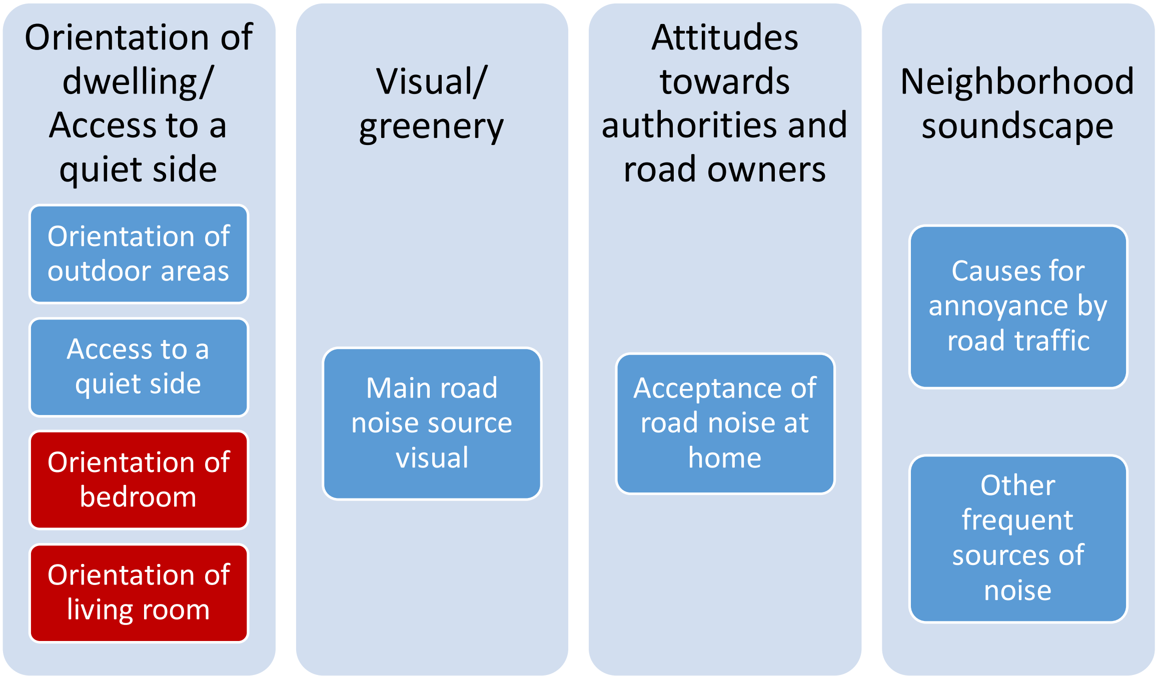

Figure 6 The moderators of focus in the FAMOS literature study in the light blue columns with boxes of questions from the Motorway dataset. Blue boxes are questions included in the model, and red boxes are questions excluded from the model.

In the following three subsections, the influence of these moderators (attitude towards authorities… excluded[3]) are exemplified. The plots are based on the full prediction model influence all main- and interaction terms. Predictions are based on the original dataset, which is then split up in groups based on the moderator options in question and subgroups of 5-dB L_{den} bins. Notice that differences between options, will include all differences between these groups and subgroups in the dataset. The assumption is thus, that subgroups are balanced on all other factors to a degree where the moderator under investigation will be the main driver of the differences.

Notice that if a subset of data for a given combination of the 5-dB L_{den} bin and the moderator did not have more than 20 observations in the dataset, which the prediction was based on, the prediction was removed from the plots in these subsections. This was done to avoid predictions based on too few observations that would not be representative of the general population and could lead to confusing in interpretation of the plots.

8.2.1 Effect size of Orientation of dwelling / Access to a quiet side

In Figure 7, the predicted influence of orientation of outdoor areas in relation to road traffic annoyance (Question 14) as a function of L_{den} is shown. Focusing on the green and purple lines first, the effect of having access to an outdoor area away from the motorway noise sources is predicted to reduce Annoyance with approximately two steps on the annoyance scale in the range from 50 dB to 70 dB. Looking at the case, where a citizen has both an outdoor area facing towards the main noise source and away from one (turquoise line), this reduction is (surprisingly) completely gone.

[3] Plot of the influence of "Acceptance of road noise at home" excluded as response rating were on a 0-10 scale, i.e. having too many levels to illustrate trends in plot in a meaningful way due to too few datapoints.

In Figure 8, the predicted influence of access to a quiet side (Question 18) in relation to the road traffic annoyance as a function of L_{den} is shown. Access to a quiet side is also predicted to reduce annoyance by approx. 2 on the annoyance scale independent of the L_{den} noise level.

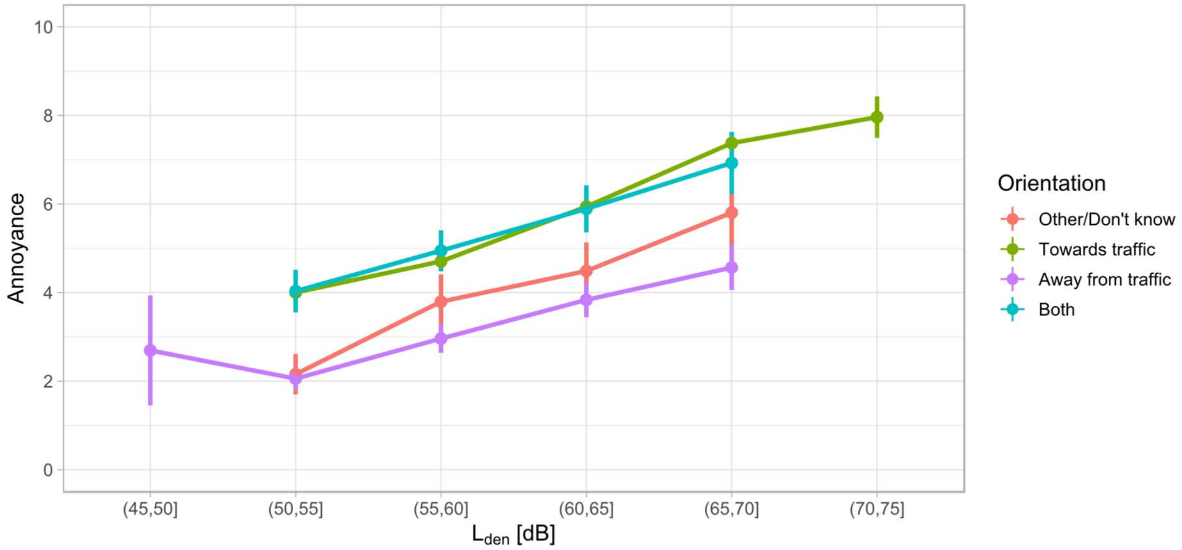

Figure 7 Prediction of Annoyance as a function of L_{den} split into groups of response options of the moderator ***Orientation of outdoor areas*** *(Question 14). Vertical lines are 95% confidence intervals. Notice that the question covered garden, courtyard, and balcony, which is why participants can answer outdoor areas both pointing towards the main road noise source and away from it.*

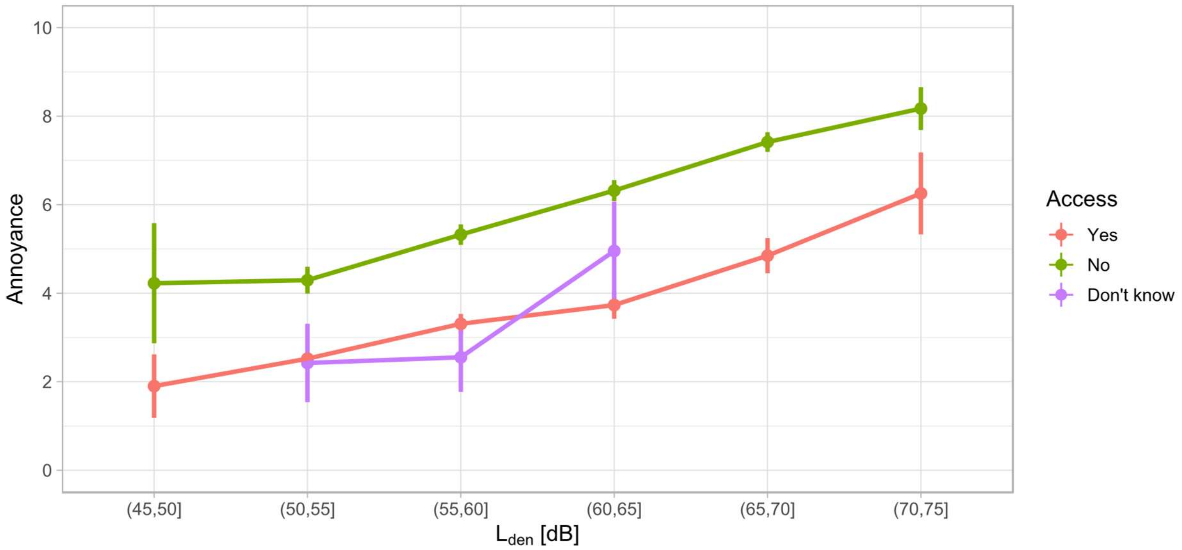

Figure 8 Prediction of Annoyance as a function of L_{den} split into groups of response options of the moderator ***Access to a quiet side*** *(Question 18). Vertical lines are 95% confidence intervals.*

8.2.2 Effect size of Visual road

In Figure 9, is a prediction of the interaction between being able to see the road being the primary noise source and having special windows installed in the bedroom; An interaction found significant in the model, where the visual effect in this analysis was not significant on its own (see Table 6 and the note below). The figure can be trusted between 50 and 70 dB. The trend is that seeing the road increases annoyance by 1 to 2 points on the annoyance scale and that having special windows decreasing annoyance slightly. Both effects are too small on their own to be statistically significant, but combined, the effect of not seeing the road / noise source while having special windows with good insolation decreasing annoyance sufficiently (0.5-2 points on the annoyance scale) to become a significant effect compared to the opposite situation.

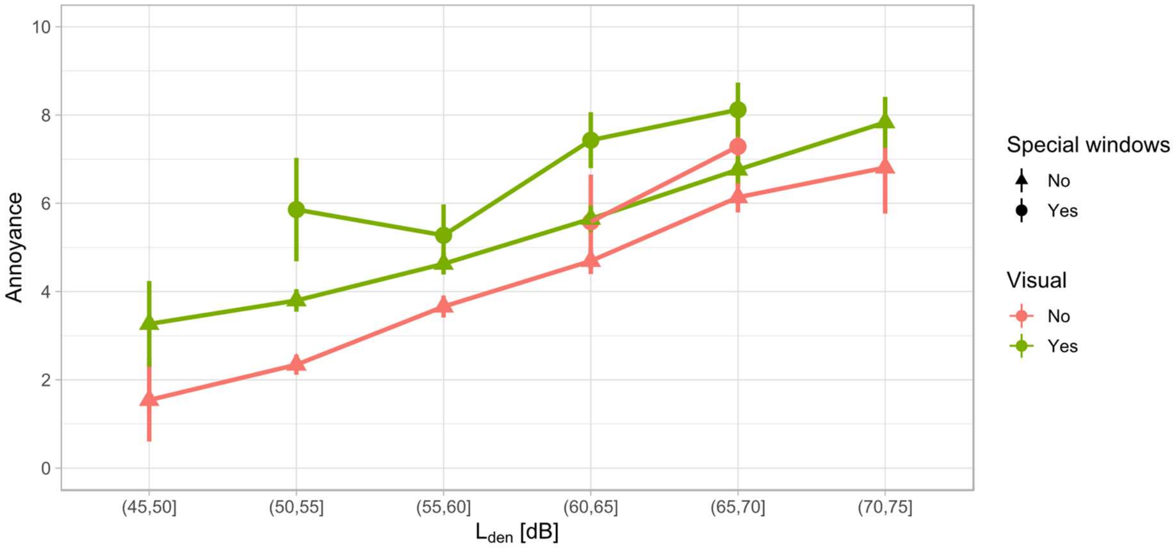

*Figure 9 Prediction of Annoyance as a function of L_{den} split into groups of response options of the interaction **Main road noise source visual** (Question 12) and **Special bedroom windows** (Question 22). Vertical lines are 95% confidence intervals.*

8.2.3 Effect size of Neighbourhood soundscape

In Figure 10 the influence of the moderator on causes of annoyance from road traffic is predicted in the local neighbourhood. The coded option list included: Feeling unsafe in traffic, Noise from traffic, Vibration from traffic, and Pollution or odour, which leads to 16 combinations in total, but in Figure 10, four of these are plotted: 1) No specific causes, 2) feeling unsafe, 3) noise, 4) feeling unsafe and noise. Most noticeable, the feeling of being unsafe leads to a predicted small increase in annoyance (1-1.5 points on the annoyance scale), while noise in the local neighbourhood leads to a very significant increase (3.5-5 points on the annoyance scale) and dominates if both are listed as reasons. Note, that this change is likely too big to be caused by this moderator and its interactions alone. It is likely that the prediction basis in unbalanced in terms of other moderators, exaggerating the increase.

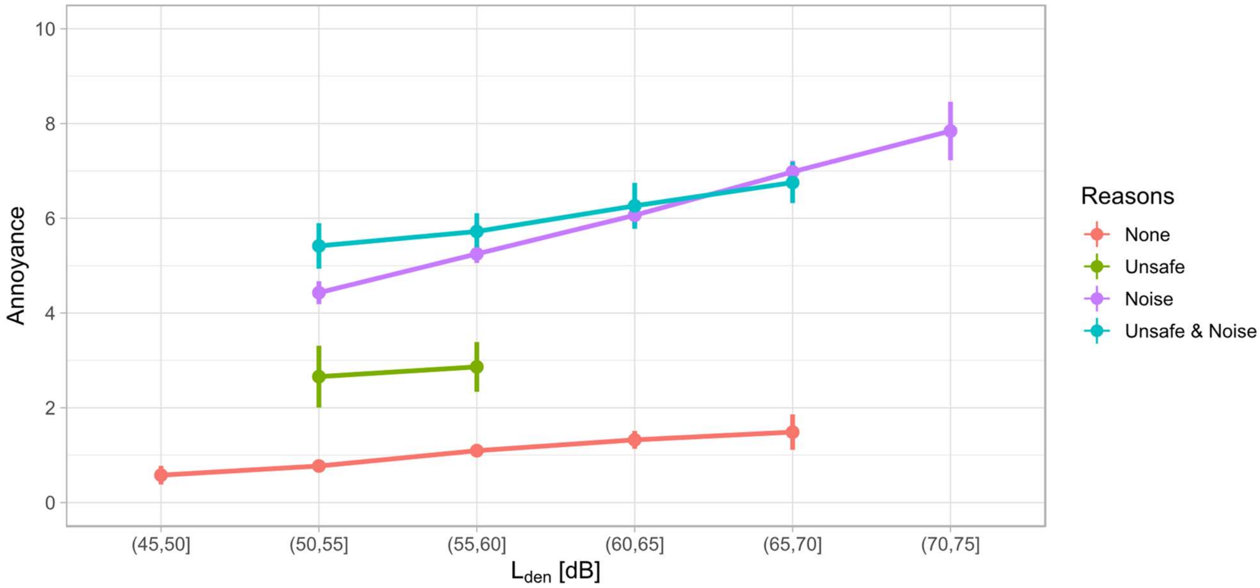

*Figure 10 Prediction of Annoyance as a function of L_{den} split into groups of response options of the moderator **Causes of annoyance by traffic** (Question 2). Vertical lines are 95% confidence intervals.*

8.2.4 Annoyance equivalent noise levels shifts

Looking at the curve of Annoyance vs. L_{den} in Figure 5 at the range 55-65 dB, the shift in the predicted annoyance response is 2.37. This can be used as an approximate slope for estimating annoyance equivalent level shifts for each moderator. This is done in Table 7 below. The shift of average annoyance is the difference in mean values depending on the moderator in question. Since the difference change with L_{den}, the difference is described with an interval. These values can be estimated by looking at the figures in the previous subsections of section 8.2. Note, that these equivalent noise level shifts are not additive, i.e. cannot be summed. Please keep in mind that this table inherits the assumption of the original plots, namely that subgroups are balanced on all other factors to a degree where the moderator under investigation will be the main driver of the differences.

	Moderator	**Shift of average annoyance**	**Annoyance equivalent noise level shift, dB**
Q14	Orientation of outdoor areas	2.0 – 2.8	8.4 – 11.8
Q18	Access to a quiet side	1.9 – 2.8	8.0 – 11.8
Q12 **Q22**	Main road noise source visual Special bedroom windows	1.0 – 3.5	4.2 – 14.8
Q2	Causes of annoyance by traffic	2.0 – 5.7	8.4 – 24.1

Table 7 Annoyance equivalent level changes for the motorway dataset.

9 Results: Copenhagen dataset

The obtained regression model for the Copenhagen dataset has a high degree of explained variance (adjusted R^2 = 70.8%) and fulfils all modelling assumptions (see Appendix section 12.2, p.51), i.e., the model can be trusted both in terms of noise annoyance predictions and degree of influence from moderators.

In Figure 11 the correspondence between annoyance responses ("Annoyance") and annoyance predicted by the model ("Predicted annoyance") is shown. Since the annoyance responses were discrete while the predictions are continuous, model predictions were first added as a new column to the dataset, then the dataset was split into subset for each annoyance response, and finally the mean estimate and 95% confidence intervals were calculated on the annoyance predictions within each response subset.

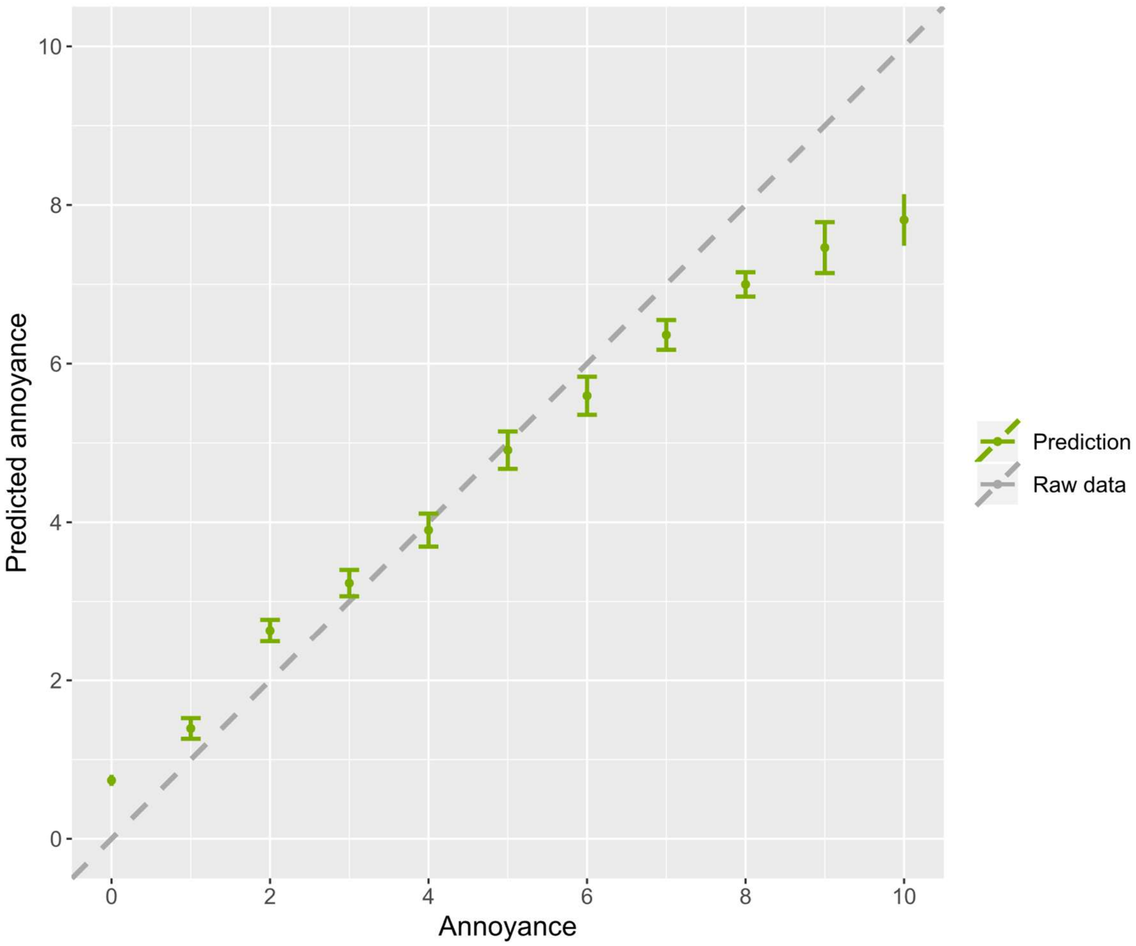

Figure 11 Annoyance vs. Predicted annoyance. Mean value estimates with 95% confidence intervals. For the Copenhagen dataset.

The figure generally shows a good correspondence, but also the same curvature as for the first model for the Motorway dataset causing a slight over-estimating at lower annoyance levels and a slight under-estimation at higher annoyance levels.

The model includes nine main variables (listed in Table 8) and five interaction effects (listed in Table 9).

Question ID	Main variables	DF	Sum Sq	Mean Sq	F-value	p-value	Signif.
Lden	L_{den}	1	711.9	711.9	1571.7	$2.86e^{-267}$	***
04	Acceptance of road noise at home (Yes/No)	1	519.2	519.2	1146.2	$3.02e^{-207}$	***
02	Causes of annoyance by road traffic	13	1296.0	99.7	220.1	0	***
33	Noise sensitivity	1	73.8	73.8	163.0	$3.31e^{-36}$	***
07	Indoor activities affected from road traffic	15	111.5	7.4	16.4	$1.20e^{-41}$	***
11	Noise actions	6	35.1	5.9	12.9	$1.93e^{-14}$	***
30	Windows living room open summer	1	4.6	4.6	10.2	0.001	***
23	Access to own garden	1	4.1	4.1	9.1	0.003	**
31	Windows living room open winter	1	1.5	1.5	3.2	0.074	*

Table 8 Copenhagen dataset. Regression model main effects. Sorted by F-value.

Question ID	Main effects	DF	Sum Sq	Mean Sq	F-value	p-value	Signif.
04:33	Acceptance of road noise at home (Yes/No) Noise sensitivity	1	2.9	2.9	6.3	0.012	*
Lden:04	Lden Acceptance of road noise at home (Yes/No)	1	2.7	2.7	6.0	0.014	*
29:33	Household young kids Noise sensitivity	1	2.5	2.5	5.6	0.018	*
Lden:29	L_{den} Household young kids	1	1.3	1.3	2.9	0.091	.
02:33	Causes of annoyance by road traffic Noise sensitivity	12	15.4	1.3	2.8	0.001	***

Table 9 Copenhagen dataset. Regression model interaction effects. Sorted by F-value. The notation xx:yy describes the interaction term between xx and yy.

9.1 Main effect dose-response curves

All plots in this section have the response variable, 12-month average road traffic annoyance on the 0-10 scale, on the y-axis and a main effect on the x-axis, e.g., L_{den}. The plots show the estimated mean with 95%-confidence intervals of the raw responses ("Raw data") in the Copenhagen dataset and the model prediction ("Prediction"), with 95%-confidence intervals. At all points on the curve where the confidence intervals of the averaged raw data and the confidence intervals of the prediction overlaps, the model estimates the effect as good as possible with the uncertainty of the data. Note, that this type of plot can only be made for the few moderators with a numerical response type and plots were made purely for moderators contributing to the model (i.e. being in Table 8 or Table 9).

The relationship between the variable L_{den} and annoyance is plotted in Figure 12. The shaded areas are 95% confidence intervals calculated for each 5-dB bin starting with the 40 dB bin being an average of the range 37.5 – 42.5. The effect of the variable, L_{den}, on annoyance spans the range 1.4 to 5.9, increasing with the noise level as expected. The original dataset spans the range from 38.0 to 73.3 dB, and the prediction was kept within a similar interval to avoid extrapolation outside the valid range of the model. The expansion of the confidence intervals at 40 dB at 75 dB is a consequence of the dataset including a limited number of datapoints within these two 5-dB bins.

It can be seen that the slope of the linear part of the curve is 0.2 meaning the 1 on the annoyance scale corresponds to a level difference of 5 dB.

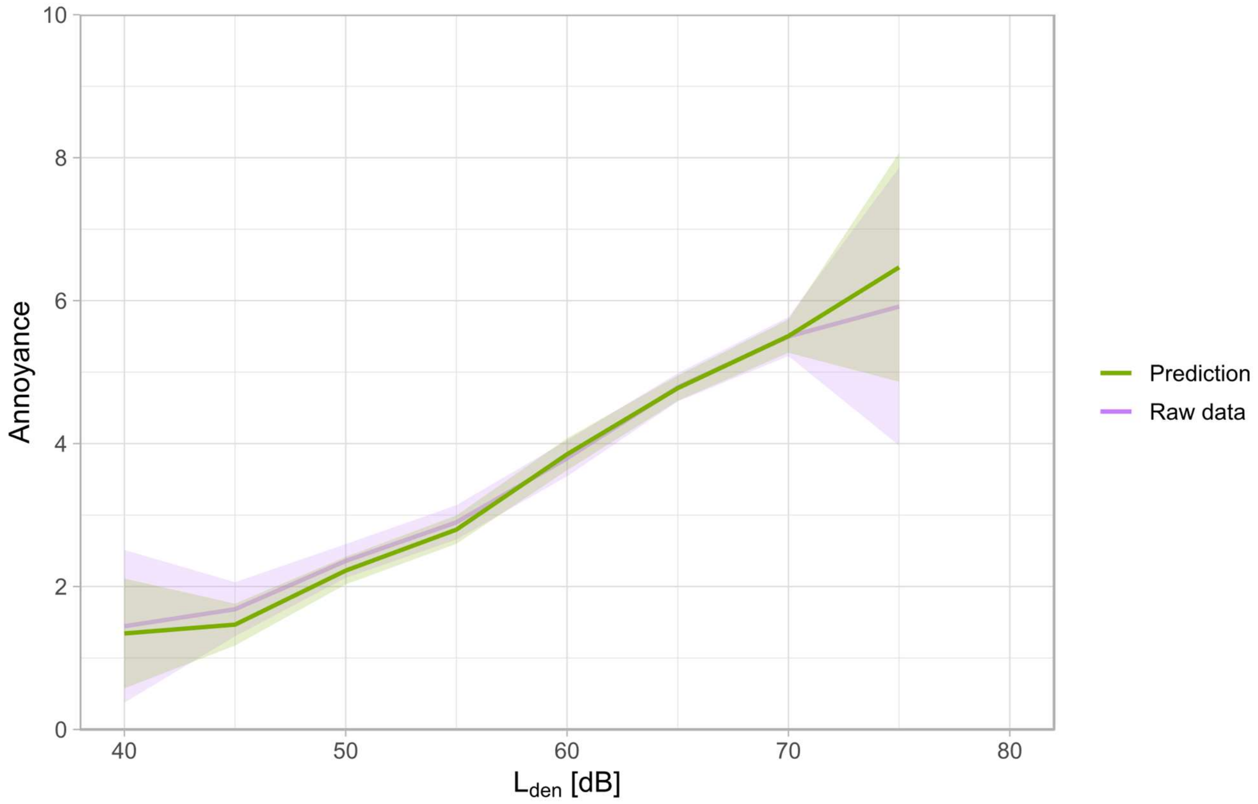

Figure 12 Prediction of annoyance from L_{den} in 5-dB bins*. Main effect. With 95% confidence intervals. From the Copenhagen dataset.*

By comparison with Figure 5 it can be seen that the annoyance from motorways is 1 higher on the annoyance scale than the annoyance for urban roads. This corresponds to an annoyance equivalent noise level shift of 5 dB.

The relationship between the moderator Noise sensitivity and annoyance is plotted in Figure 13. The shaded areas are 95% confidence intervals calculated for each step on the sensitivity scale with the 1 bin being an average of the range -0.5 to +0.5. The effect of the moderator, Noise sensitivity, on annoyance spans the range 1.5 to 7.3, the annoyance increasing with noise sensitivity as expected. The original dataset spans the full-scale range. The expansion of the confidence intervals above 6 on the noise sensitivity scale is a consequence of the dataset including a decreasing number of datapoints at higher noise sensitivity levels.

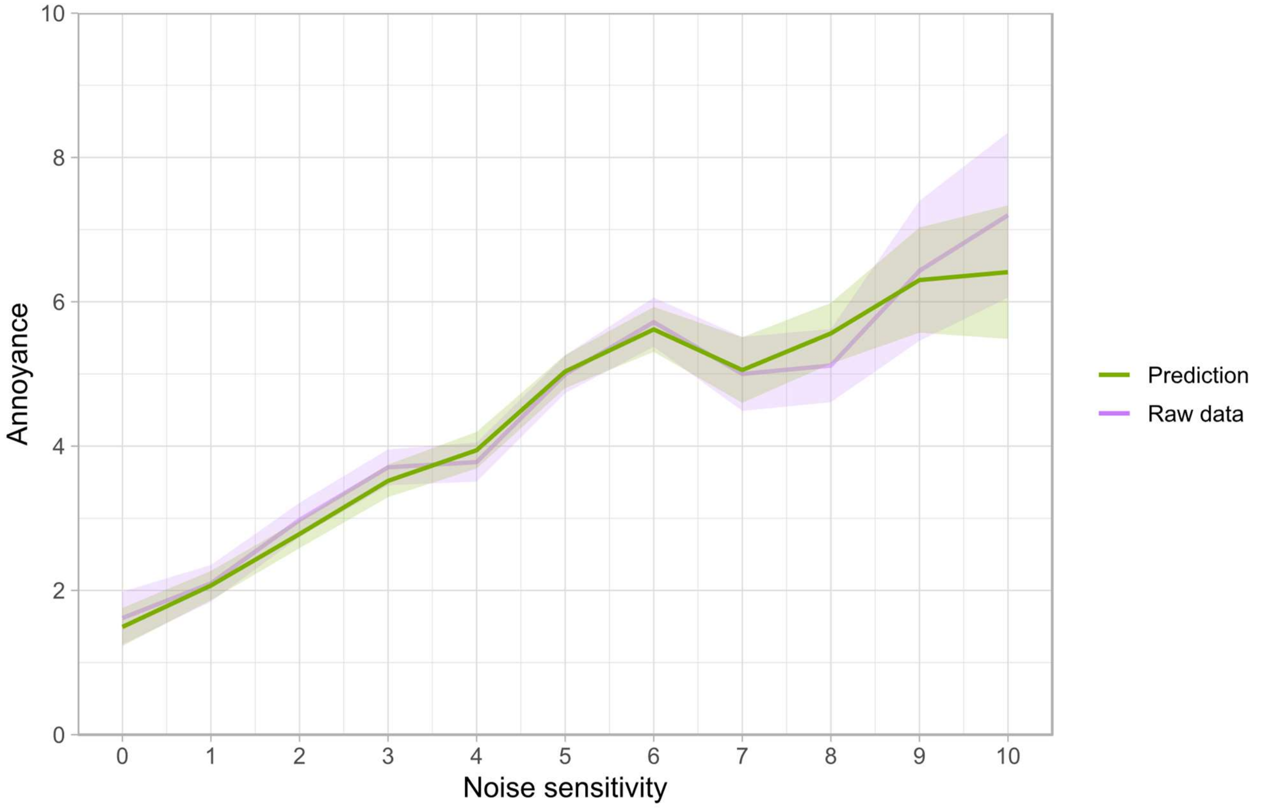

*Figure 13 Prediction of annoyance from **Noise sensitivity**. Main effect. With 95% confidence intervals. From the Copenhagen dataset.*

One may wonder whether the L_{den} is the main driver behind the noise sensitivity, i.e. that persons living at high noise levels have a higher score on the noise sensitivity scale. From Figure 19 in Appendix 3 it can be seen that this is not the case.

9.2 Relation to FAMOS literature study

Similar to the analysis in section 8.2, starting at p. 24, the FAMOS moderators in focus have been investigated in more detail for the model developed on the Copenhagen dataset. An overview is shown in Figure 14.

The plots in Sections 9.2.2 and 9.2.4 are based on the full prediction model for urban roads influence all main- and interaction effects. Predictions are based on the original dataset, which is then split up in groups based on the moderator options in question and subgroups of 5-dB L_{den} bins. Notice that differences between options, will include all differences between these groups and subgroups in the dataset. The assumption is thus, that subgroups are balanced on all other factors to a degree where the moderator under investigation will be the main driver of the differences.

Notice that if a subset of data for a given combination of the 5-dB L_{den} bin and the moderator did not have more than 20 observations in the dataset (red boxes in Figure 14) , which the prediction was based on, the prediction was removed from the plots in these subsections. This was done to avoid predictions based on too few observations that would not be representative of the general population and could lead to confusing in interpretation of the plots.

The influence of the two moderators (blue boxes in Figure 14) included in the model are discussed in the next two subsections.

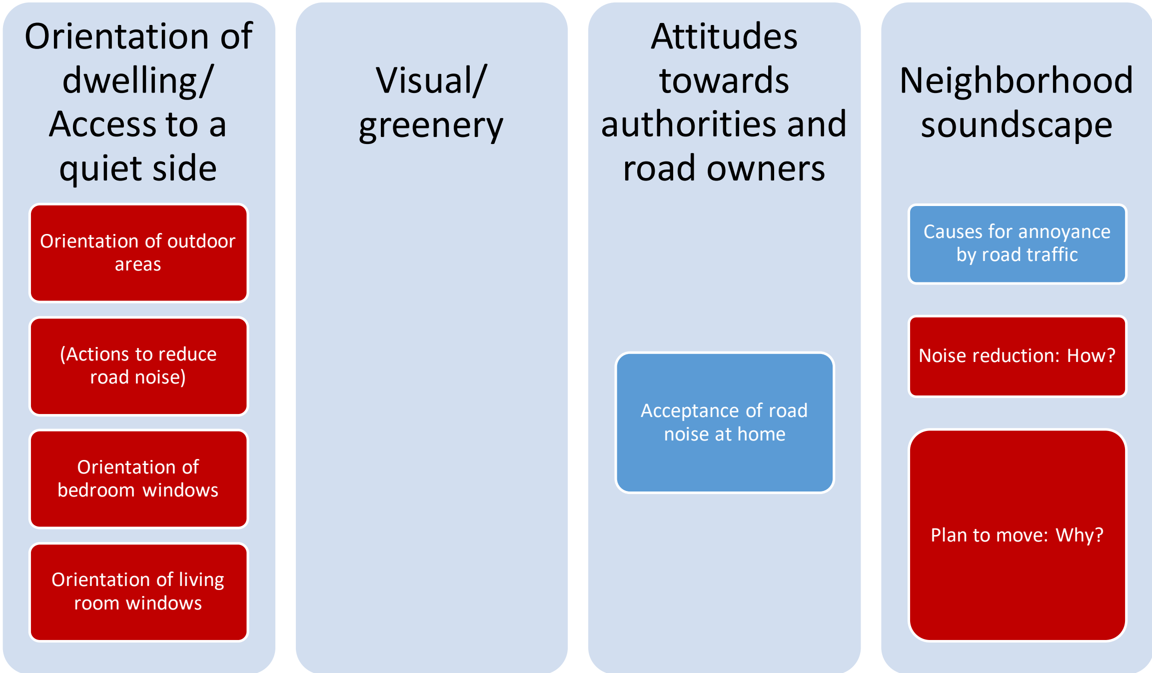

Figure 14 The moderators of focus in the FAMOS literature study in the light blue columns with boxes of questions from the Copenhagen dataset. Blue boxes are questions included in the model, and red boxes are questions excluded from the model.

9.2.1 Effect size of Acceptance of road traffic noise

The relationship between acceptance of road traffic noise, L_{den}, and Annoyance is depicted in Figure 15. It shows an increase of about 4 on the annoyance scale independent of the L_{den} level, which is a very large change. Even larger than the influence of L_{den}, which increases with about 3 for the "No" subset and 1.5 for the "Yes" subset.

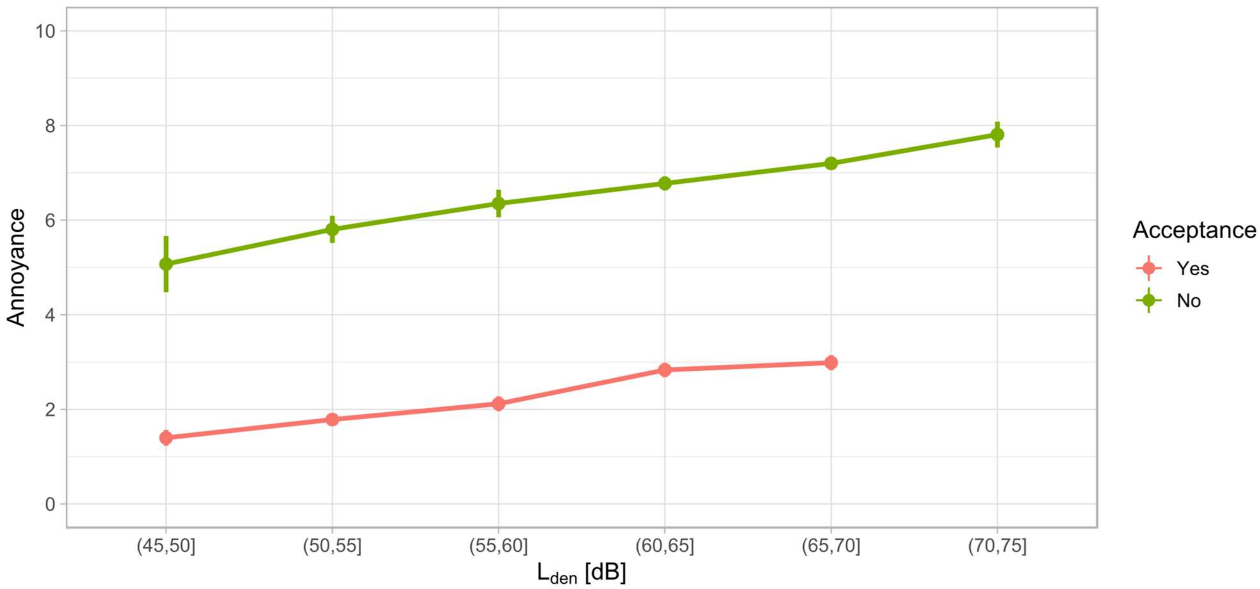

*Figure 15 Prediction of Annoyance as a function of L_{den} in 5 dB intervals split into groups of response options of the interaction **Acceptance of road traffic noise** (Question 4). Vertical lines are 95% confidence intervals. From the Copenhagen dataset.*

9.2.2 Effect size of Causes of annoyance by road traffic

The causes of annoyance from road traffic in the local neighbourhood as a function of L_{den} and Annoyance is depicted in Figure 16. Note that only a subset is shown. Participants could select multiple causes of annoyance, e.g., both "Feeling unsafe" and "Noise/vibration", but here only predictions of the *single cause* cases are plotted for simplicity and because not every combination had sufficient data to make good predictions. In total nine logical[4] combinations are possible.

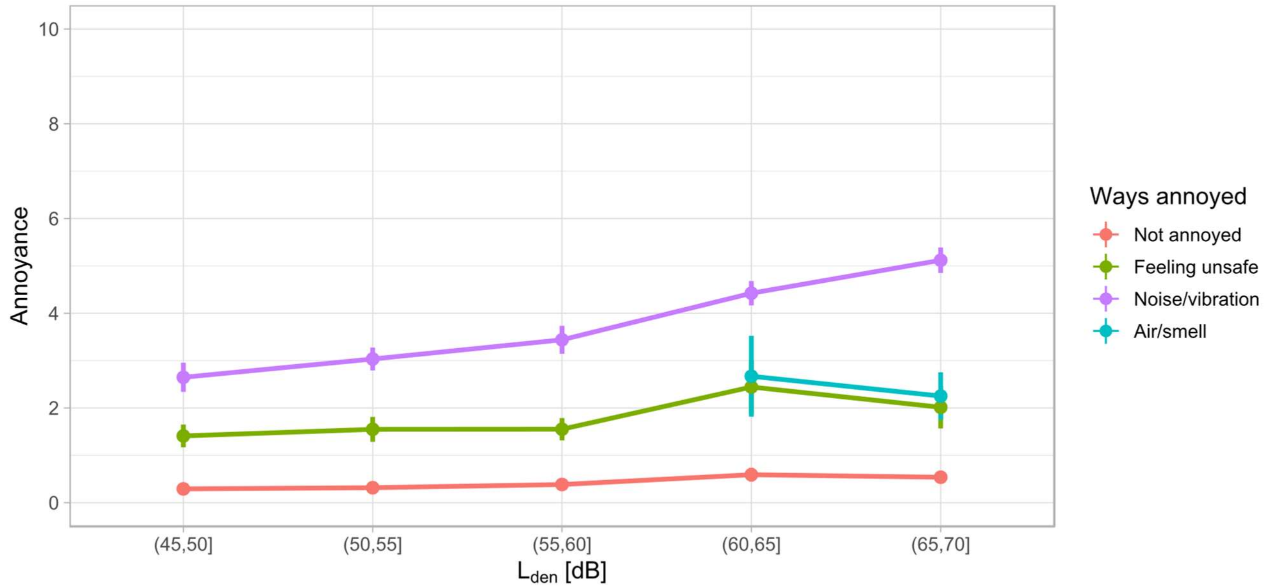

Figure 16 Prediction of Annoyance as a function of L_{den} split into groups of response options of the interaction ***Ways/causes of annoyed by road traffic*** *(Question 2). Vertical lines are 95% confidence intervals. From the Copenhagen dataset.*

From the figure it is seen that Feeling unsafe account for 1 on the annoyance scale which according to Figure 12 corresponds to an annoyance equivalent noise level shift of 5 dB.

It is also seen that the effect of noise and vibration is increasing with the noise level.

9.2.3 Annoyance equivalent noise levels shifts

Looking at the curve of Annoyance vs. L_{den} in Figure 12 at the range 55-65 dB, the shift in annoyance is 1.99 dB. This can be used as an approximate slope for estimating annoyance equivalent level shifts for each moderator. This is done in Table 10 below. Once again, the shift of average annoyance is the difference in mean values depending on the moderator in question. Since the difference change with L_{den}, the difference is described with an interval. These values can be estimated by looking at the figures in the previous subsections of section 8.2. Note, that these equivalent noise level shifts are not additive, i.e. cannot be summed. Again, keep in mind that this table inherits the assuming of the original plots, namely that subgroups are balanced on all other factors to a degree where the moderator under investigation will be the main driver of the differences.

[A] An illogical combination would be "Not annoyed" ***and*** any of other options.

	Moderator	Shift of average annoyance	Equivalent noise level shift [dB]
Q4	Acceptance of road traffic noise	3.8 – 4.3	19.1 – 21.6
Q2	Causes of annoyance by road traffic	2.3 – 4.6	11.6 – 23.1

Table 10 Annoyance equivalent level changes for the Copenhagen dataset.

10 Comparison between models for the two datasets

Out of the 15 common questions in the two datasets,

- one was the response variable, 12-month average road traffic noise annoyance,
- one was excluded (a second annoyance question)
- and 13 were included in the input for the model calculations.

Among the 13, six moderators were found significant in both models. Two of these questions, however, have different response options. In "Acceptance of road noise at home", the first dataset had an ordinal response type (0, 1, …, 10), while the response was reduced to "Yes" or "No" options in the second. The question on "Behaviour changes due to road noise + Activities affected from road traffic" includes the same options, but the Copenhagen dataset also has additional options related to sleep disturbance. Furthermore, the question on "Type of outdoor area" in the motorway dataset is broader than "Access to own garden" in the Copenhagen dataset.

The six common variables are summarised in Table 11. Having these moderators in both models suggest that their influence on annoyance is of a general nature and that their effect may exist beyond the context of these two datasets.

One secondary observation is, that in neither model, the basic demographics of gender and age are included, i.e., they were not found to significantly improve the model. Possibly suggesting that the more specific questions make the demographic questions less relevant or even irrelevant.

The two models share no interaction terms among the 11 interactions in the motorway model and 5 interactions in the Copenhagen model. This shows that the interactions are not stable across datasets and thus not suited for making general recommendations.

Overall, the model on the motorway dataset, might be a more general model due to the type of questions included, where the Copenhagen dataset model was more focused leading to it being less useful to explain the general moderators of annoyance, which is also apparent from the difference in the percentage of explained variance, 77% vs. 70%, in the two models.

TOPIC OF TERM/QUESTION
Acceptance of road noise at home
Lden
Causes of annoyance by road traffic
Noise sensitivity
Behaviour changes due to road noise + Activities affected from road traffic
Type of outdoor areas (motorway dataset) Access to own garden (Copenhagen dataset)

Table 11 Common variables in the two models. All six variables are main effects.

11 Discussion and Conclusions

In this report, a modelling methodology is developed and suggested for analysing the influence of moderators of annoyance from road traffic. The model is based on input in the form of raw data from two Danish questionnaire surveys from the Danish Road Directorate ("Vejdirektoratet") that has been made available for the FAMOS project. The methodology is exemplified through the modelling of two datasets, the "Motorway" dataset and the "Copenhagen dataset"

Within the project effort has been made to collect data from other sources, but it turned out (during the work of WP1) that it is not at all easy to get access to raw data from former questionnaire surveys from other countries. Within the framework of the FAMOS project and in cooperation with the Programme Executive Board (PEB) of the FAMOS project it has therefore only been possible to obtain raw data from the Danish surveys.

The two Danish studies are of excellent quality both in terms of included questions, questionnaire design, high number of participants, and data quality as well as the methodological approach that follows the current ISO 15 666 standard for such investigations.

The studies included questionnaires with many of the moderators suggested in the literature and therefore makes an ideal test case for investigation of the potential benefit of making a more comprehensive statistical regression model, enabling NRA's to predict annoyance from several alternative changes to an environment with neighbours affected by road traffic noise and make choices on an improved informed basis for applying tools to reduce the perceived noise annoyance

The work in this report, shows that using an analysis approach with a multiple regression model having many moderators and interactions led to models able to account for a significant amount of the variance in the data (70% – 77%). It shows that many moderators and the interactions between them are needed to account for the complex influences of annoyance in neighbours affected by road traffic noise.

The overlap in significant moderators in the two modelling efforts (Motorway and Copenhagen) is strong evidence that robust and reliable predictions models can be created and that a good understanding of the fundamental moderators of annoyance is known, even if the complex relationship between still requires further investigation.

While the use of a general multiple regression model worked well in this study, switching to a generalized regression model framework with inherent handling of the logistic (s-curve) nature of annoyance might be more suited approach; Although it requires a deeper understanding of statistics than required for the current methodology.

The benefit of a multiple regression model rather than modelling the effects separately provides an outcome better suited for prediction of annoyance in neighbours to road traffic noise. It also makes it possible to model the relative importance of the moderators when more are in play at the same time.

The model is built to make predictions of the average annoyance response on the 0-10 annoyance scale from ISO 15 666.

The FAMOS moderators

The following moderator categories are of interest for the FAMOS project, of which the first four was selected as the moderator categories in focus and highlighted in this report:

- Orientation of dwelling / Access to a quiet side
    - Orientation of dwelling
    - Access to silent side (e.g. by filling spaces between buildings)
- Visual/greenery

    - Visibility of traffic
    - Visual appearance of noise barriers
    - Vegetation/Greenery
- Attitudes towards authorities and road owners
    - Trust to authorities/Traffic noise acceptable
- Neighbourhood soundscape
- Feeling safe in the traffic

The methodology of the model is exemplified through examples of moderators for which it has been possible to estimate the size of the effect.

Model findings of moderator effects

The model finds -not surprisingly- that the annoyance increases with L_{den}. There is good compliance between the model prediction and the data it is built on, which is a good validity check on the math and statistical principles for the model. The model results are also compliant to the results found in the original simpler models for the same data reported earlier. It can be concluded that the models are trustworthy and representative for the input data.

The models show a large shift in the predicted annoyance from approx. 1 at high acceptance to approx. 8.3 at low acceptance in relation to the acceptance of road noise at home. If one assumes that the acceptance of road noise is related to trust in authorities (i.e. that they have done what is possible to reduce the noise), then this result illustrates that trust to the authorities is a very important moderator.

The up to 15 dB reported in the literature survey in WP1 for "Attitude towards authorities and road owners", were based on direct questions on this subject, while "Acceptance of road noise level at home" is only assumed indirectly related here. In all likelihood many underlying moderators (objective and subject) may influence acceptance of road noise level at home, but general trust in- or attitude towards authorities may be one of these.

The model shows that the annoyance is increasing with noise sensitivity as expected. For a span of noise sensitivity on 0-10 the resulting span on the annoyance 0-10 scale is five steps.

Furthermore, it is found that the annoyance from motorways is 1 higher on the annoyance scale than the annoyance for urban roads. This corresponds to an annoyance equivalent noise level shift of 5 dB, which is in line with earlier findings.

Annoyance equivalent noise level shifts

The impact of specific moderators can be expressed in "annoyance equivalent noise level shifts" so that the presence or absence of certain moderators is expressed as a corresponding perceived increase or decrease in the noise level, L_{den}.

From the model the following "annoyance equivalent noise level shifts" are found:

Motorway dataset:

- Orientation of outdoor areas: 10 dB (8.4 – 11.8 dB)
- Access to a quiet side: 10 dB (8.0 – 11.8 dB)
- Special bedroom windows: 10 dB (4.2 – 14.8 dB)
- Causes to annoyance by traffic[5]: 16 dB (8.4 – 24.1 dB)

[5] This is a general question including: Feeling unsafe at the roads and surroundings, unsafe for children, noise, vibrations, air pollution and dust from the traffic

- Motorway visible

Annoyance equivalent noise level shifts, Copenhagen dataset:

- Acceptance of road traffic noise: 20 dB (19.1 – 21.6 dB)
- Causes of annoyance by traffic: 17 dB (11.6 – 23.1 dB)

Feeling unsafe corresponds to an annoyance equivalent noise level shift of 5 dB.

Usage of the model

Based on input from the two large Danish questionnaire surveys on perceived noise annoyance, the model can demonstrate the effect of various moderators. The result within the project is not ready-to-use piece of software with user interface for general use, but with the model, the effect of further moderators and interactions than illustrated in this report, can be estimated.

It will also be possible input data from more surveys after the termination of the FAMOS project and thereby obtain a more general validity.

The validity and limitations on the results

A total of the answers from 6316 respondents are used in the analysis of the two datasets included in this report. This is a very high number of respondents and much higher than what is seen in many other international annoyance surveys.

The results must be considered valid for Denmark as well as for similar north European countries/regions and they can be considered a first good step towards a model valid for the whole of Europe. At the present stage this may not be a sufficient data basis for making a road traffic annoyance model that can provide representative predictions for all of Europe.

So, even if the models may not be considered representative for all citizens of Europe, they provide strong evidence for the effect of the moderators that are found significant in this study. While the data basis of only two studies may not be sufficient, the Danish studies had a very high quality and covered a broad range of questions many of which were identified in the literature as relevant. The models based on Danish raw data confirms the findings in the literature study, [1], to a very large extent.

What is needed to improve the model and the general validity

The contribution of this report is also to further investigate the potential of including more moderators and more interactions between moderators in a multiple regression model and further qualify the list of "questions of importance" to collect in future studies. This would allow creation of a valuable tool for improving the quality of life of hundreds of millions of citizens in Europe affected by road traffic noise.

As mentioned, the model is built to make predictions of the average annoyance response on the 0-10 annoyance scale from ISO 15 666. It may be enhanced to calculate e.g., the percentage of highly annoyed (%HA) from the model findings.

Inclusion of data from more surveys will improve the models and their validity. An important factor for this will be the use of uniform questionnaires or at least a larger part of standardized questions covering relevant topics.

12 References

[1] Truls Gjestland, "Non-acoustic factors that affect the annoyance response. Deliverable 1.2 in the CEDR FAMOS project," 2020.

[2] ISO, "ISO/TS 15666:2003(E) Akustik – Vurdering af støjgener ved hjælp af sociologiske og socio-akustiske undersøgelser Acoustics – Assessment of noise annoyance by means of social and socio-acoustic surveys Deskriptorer :," p. 26, 2003.

[3] J. Fryd, L. N. Michelsen, H. Bendtsen, L. M. Iversen, and T. H. Petersen, "Noise annoyance from urban roads and motorways. Vejdirektoratet Report 565," 2016.

[4] Jakob Fryd, Lene Nøhr Michelsen, H. Bendtsen, L. M. Iversen, and T. H. Petersen, "Støjgener fra byveje og motorveje, Vejdirektoratet Rapport 551," 2016.

[5] T. H. Pedersen, G. Le Ray, H. Bendtsen, and J. Kragh, "Community response to noise reducing road pavements Vejdirektoratet Report 502," 2014.

[6] T. H. Pedersen and G. Le Ray, "Befolkningsreaktioner på støjreducerende vejbelægninger, Rapport 442," 2013.

[7] R. Guski, D. Schreckenberg, and R. Schuemer, "WHO environmental noise guidelines for the European region: A systematic review on environmental noise and annoyance," *Int. J. Environ. Res. Public Health*, vol. 14, no. 12, pp. 1–39, 2017.

Appendix 1 Questions and numbering of these in the surveys

12.1 Questionnaire on Motorways

Spørgsmål om forskellige gener fra trafikken

1. Hvis du tænker på det seneste års tid, hvor generet er du så af vejtrafik i området, hvor du bor?
2. På hvilke måder bliver du generet af vejtrafik i området, hvor du bor?
   (slet ingen gener, utrygt at færdes på eller ved vejene i området, utrygt for børn at færdes på eller ved vejene i området, støj fra trafikken, vibrationer eller rystelser fra trafikken, luftforurening eller lugt fra bilernes udstødning, støv fra trafikken)

Spørgsmål om støj

3. Hvis du tænker på det seneste års tid, hvor generet eller forstyrret er du så af støj fra vejtrafik, når du er hjemme?
4. 4. Hvis du tænker på det seneste års tid, har du gjort noget specielt på grund af støj fra vejtrafik?
5. 5. Hvis du tænker på det seneste års tid, hvordan generer eller forstyrrer støj fra vejtrafik dig inde i din bolig?
6. Kan du fra din bolig se den vej som er den vigtigste kilde til vejtrafik støj ved din bolig?

7. Er der opsat en støjskærm ved den vej som er den vigtigste kilde til vejtrafik støj ved din bolig?
8. Hvis du tænker på det seneste års tid, hvilke andre jævnligt forekommende støjkilder end vejtrafik er du så generet eller forstyrret af, når du er hjemme?
9. Hvilke typer udeareal har du ved din bolig?
10. Hvilken retning vender haven, gården eller altanen mod?
11. Hvis du tænker på det seneste års tid, hvor generet eller forstyrret er du så af støj fra vejtrafik, når du er ude i haven, gården eller på altanen?
12. Tænk på det seneste års tid. På hvilken måde generer eller forstyrrer støj fra vejtrafik dig, når du er ude i haven, gården eller på altanen?
13. Hvilke perioder på døgnet er du generet af støj fra vejtrafikken?
14. Er der nogen særlige køretøjs typer som er årsag til jævnligt forekommende støjgener fra vejtrafikken om natten?
15. Synes du generelt, at støjniveauet fra vejtrafik ved din bolig er acceptabelt?

Spørgsmål om din bolig

15. Har din bolig en stille side hvor der ikke er støj fra vejtrafik?
16. Vender dit soveværelse mod:
17. Vender din stue/opholdsrum mod:
18. Hvor mange personer bor fast her i din bolig?
19. Er der børn på 10 år eller derunder i hjemmet?
20. Hvilken type vinduer er der i dit soveværelse?
21. Hvilken type vinduer er der i din stue?

Spørgsmål om dig selv

22. Hvilket år er du født?
23. Er du kvinde eller mand?
24. Hvor længe har du boet i din bolig?
25. Hvordan er din hørelse?
26. Hvor følsom er du over for støj?

12.2 Questionnaire for the Copenhagen dataset

Spørgsmål om forskellige gener fra trafikken

1. Hvis du tænker på det seneste års tid, hvor generet er du så af vejtrafik i området, hvor du bor?
2. På hvilke måder bliver du generet af vejtrafik i området, hvor du bor? Sæt eventuelt flere krydser. (slet ingen gener, utrygt at færdes på eller ved vejene i området, utrygt for børn at færdes på eller ved vejene i området, støj fra trafikken, vibrationer eller rystelser fra trafikken, luftforurening eller lugt fra bilernes udstødning, støv fra trafikken)

Spørgsmål om støj

3. Hvis du tænker på det seneste års tid, hvor generet eller forstyrret er du så af støj fra vejtrafik, når du er hjemme? Sæt kun ét kryds.
4. Synes du generelt, at støjniveauet fra vejtrafik ved din bolig er acceptabelt? Sæt kun ét kryds.
5. Hvis du tænker på det seneste års tid, hvor generet eller forstyrret er du så af støj fra vejtrafik, når du er inde i din bolig med lukkede vinduer?
6. Hvis du tænker på det seneste års tid, hvor generet eller forstyrret er du så af støj fra vejtrafik, når du er inde i din bolig med åbne vinduer? Sæt kun ét kryds.
7. Hvis du tænker på det seneste års tid, hvordan generer eller forstyrrer støj fra vejtrafik dig inde i din bolig?
8. Hvis du tænker på det seneste års tid, hvor generet eller forstyrret er du så af støj fra vejtrafik, når du er ude i haven eller gården, på terrassen eller på altanen?
9. Tænk på det seneste års tid. Hvordan generer eller forstyrrer støj fra vejtra- fik dig, når du er ude i haven eller gården, på terrassen eller på altanen? Sæt eventuelt flere krydser.
10. Hvis du tænker på det seneste års tid, hvilke andre støjkilder er du så gene- ret eller forstyrret af, når du er hjemme? Sæt eventuelt flere krydser.

Spørgsmål om hvad der kan gøres ved trafikstøj

11. Har du selv foretaget dig noget for at formindske støjgener fra vejtrafik, her hvor du bor?
12. Hvad mener du der bør gøres for at formindske støjgener fra vejtrafik, her hvor du bor?
13. Hvor meget ville du betale for en halvering af trafikstøjen her, hvor du bor?
14. Hvem bør efter din mening være med til at betale for at formindske støjgenerne her?

Spørgsmål om din bolig

15. Hvem ejer din bolig? Sæt kun ét kryds.
16. Hvornår er din bolig bygget?
17. Hvilken type vinduer er der i din stue?
18. Hvor tætte er vinduerne i din stue?
19. Hvilken retning vender vinduerne i din stue mod?
20. Hvilken type vinduer er der i dit soveværelse?

21. Hvor tætte er vinduerne i dit soveværelse?
22. Hvilken retning vender vinduerne i dit soveværelse mod?
23. Hvilke typer udeareal har du ved din bolig?
24. Hvilken retning vender terrassen, altanen eller haven mod?

Spørgsmål om dig selv

25. Hvilket år er du født?
26. Er du kvinde eller mand?
27. Hvor længe har du boet i din bolig?
28. Hvor mange personer bor fast her i din bolig?
29. Er der børn på 10 år eller derunder i hjemmet?
30. Hvor ofte har du åbne vinduer i stuen om sommeren? Sæt kun ét kryds.
31. Hvor ofte har du åbne vinduer i stuen om vinteren?
32. Har du åbne vinduer i soveværelset om natten?
33. Hvor følsom er du over for støj?
34. Er dit svar i spørgsmål 33 baseret på, at du sammenligner dine egne reak- tioner med andre personers reaktioner?
35. Hvordan er din hørelse?
36. Hvordan er dit helbred?
37. Har du fået stillet nogle af følgende diagnoser hos en læge?
38. Hvad er din/jeres månedlige husstandsindkomst (samlet månedlig indkomst før skat for alle i husstanden – samlet bruttoindkomst)?
39. Har du planer om at flytte til en anden bolig inden for de næste par år?
40. Hvis du har planer om at flytte, hvad er da de vigtigste årsager?

Appendix 2 The relations between annoyance score and percentage annoyed

In Figure 17 the relations between the average annoyance response on the 0-10 scale and the percentage of Highly Annoyed (%HA), Annoyed (%A) and Little Annoyed (%LA) can be seen.

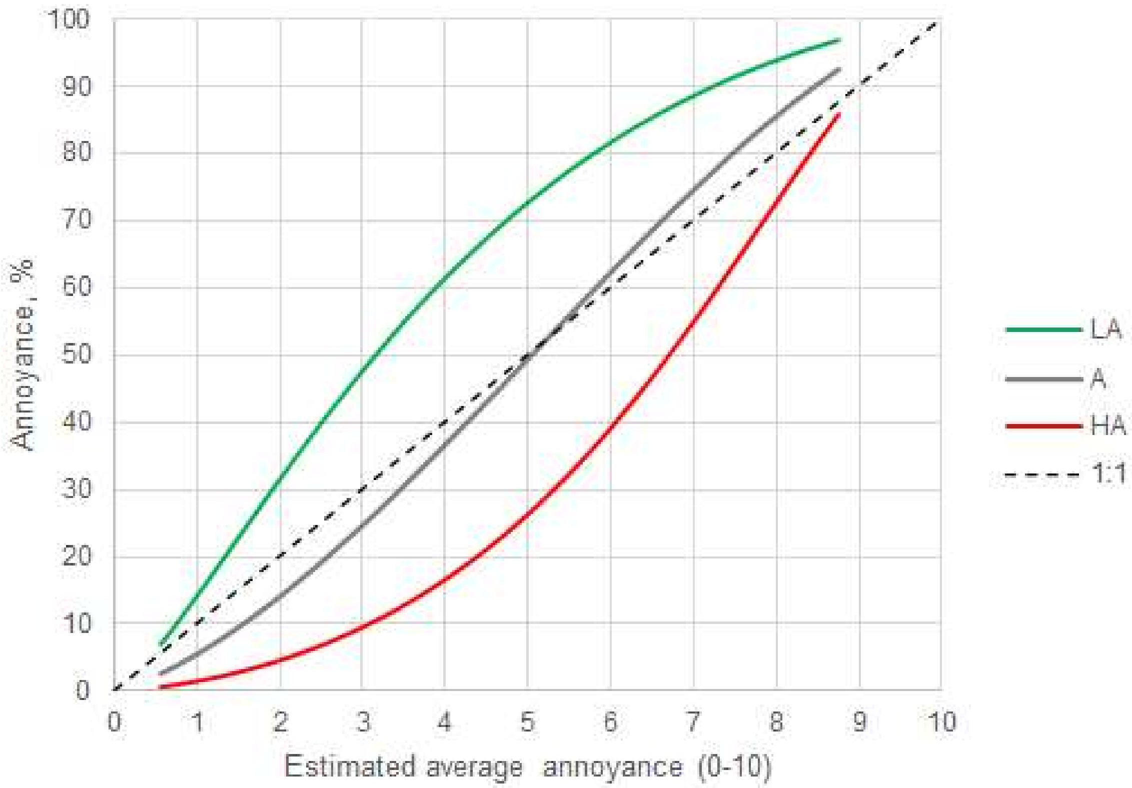

Figure 17 The relation between average annoyance response on the 0-10 scale and the percentage of Highly Annoyed (%HA), Annoyed (%A) and Little Annoyed (%LA).

The graph is based on finding in "T.H. Pewdersen: The "Genlyd" Noise Annoyance Model Dose-Response Relationships Modelled by Logistic Functions", DELTA report AV 1102/07, 2007.

It can be seen that e.g., an average response of 3 corresponds to 10% Highly annoyed

Appendix 3 L_{den} for acceptance and noise sensitivity

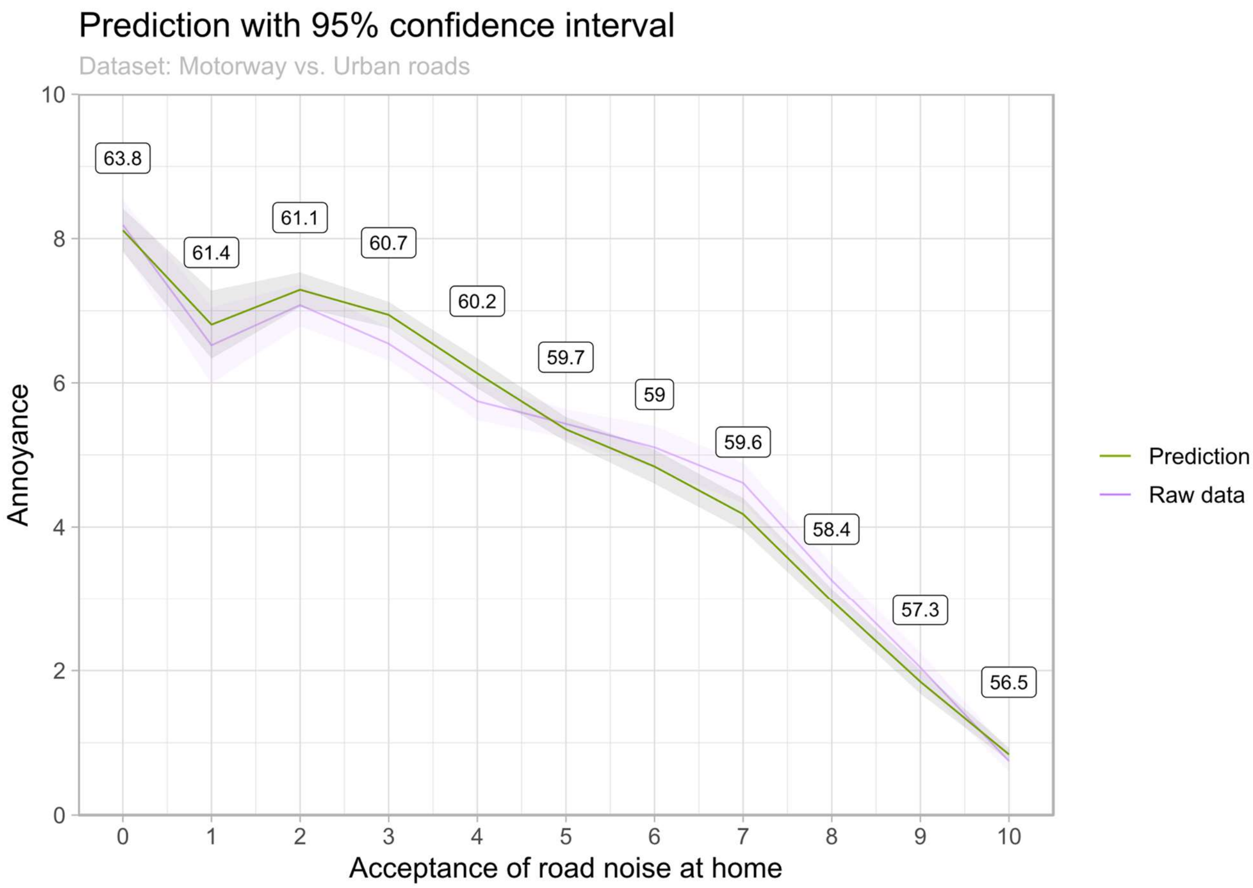

Figure 18 From the Motorway dataset. Prediction of annoyance from acceptance of road noise level. Main effect. With 95% confidence intervals. The numbers in the rectangles indicate the Lden levels in dB for each of the 0-10 categories of acceptance.

It is seen from Figure 20 that there is only a slight variation in the average L_{den} values (7 dB) for the whole span of acceptance categories and annoyance values, so that cannot be the main factor for the variation seen.

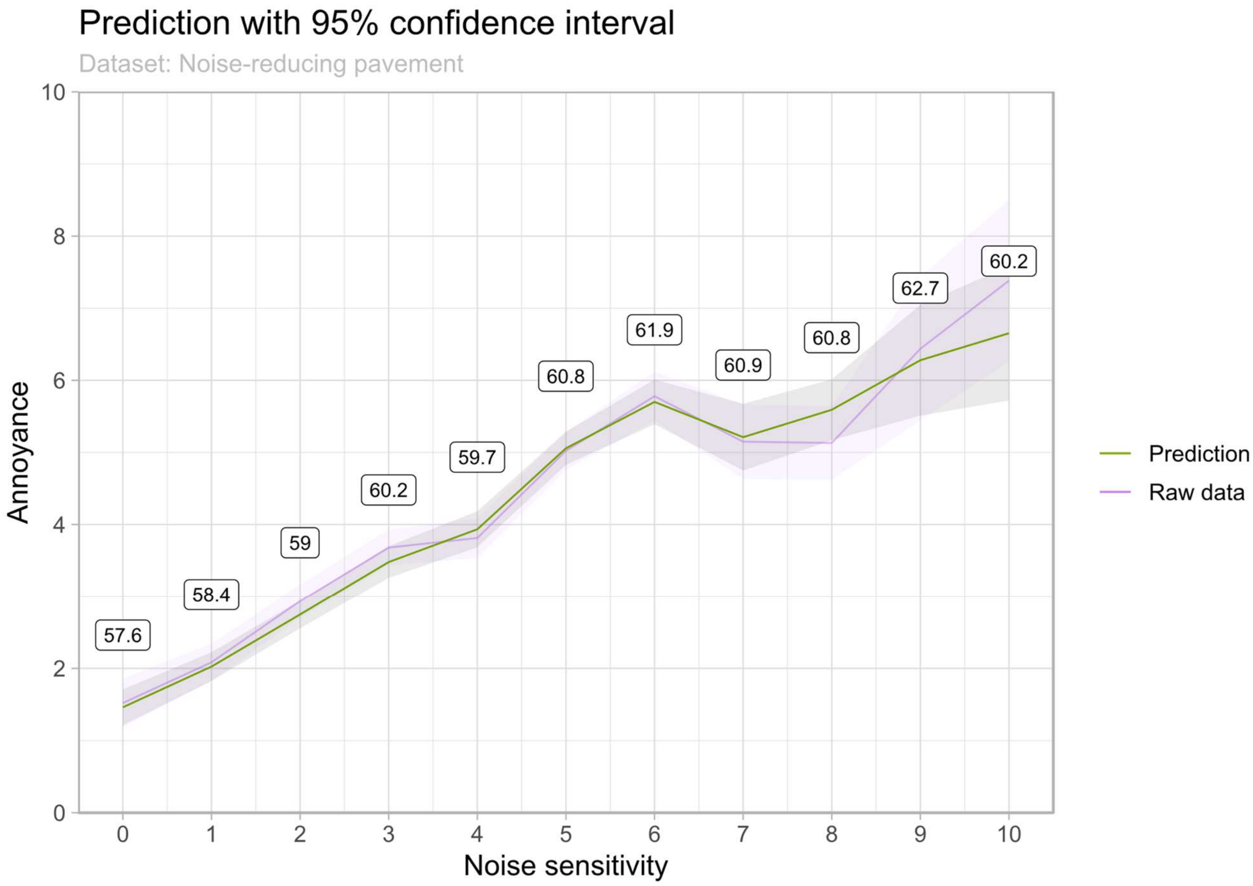

Figure 19 From the Copenhagen dataset. Prediction of annoyance from Noise sensitivity. Main effect. With 95% confidence intervals. The numbers in the rectangles indicate the Lden levels in dB for each of the 0-10 categories of noise sensitivity.

It is seen from Figure 19 that there is only a slight variation in the average L_{den} values (5 dB) for the whole span of noise sensitivity categories and annoyance values, so that cannot be the main cause of the variation seen.

Appendix 4 **Motorway dataset**

12.1 Combined multiple choice levels

Multiple choice answers are by default encoded in a general regression model as separate factors, e.g. for question 2 (the first question in the table), having seven options, these will be encoding as q2_1, q2_2, …, q2_7, each have a 0 or 1 value depending on whether the option was chosen. Since each factor can also have interactions with other factors (other questions), having many options can to a very large pool or combinations. And each combination requires sufficient data to accurately model its influence on the annoyance prediction, which set a very high requirement on the number of data collected as well as to the distribution of responses for each combination. To reduce both the requirements of data size and the complexity of interpretation, many options were merged or removed for this modelling effort. First, "Other" or "Don't know" options were removed. Even if they can explain variance in data, we can interpret the reasons why. Second, options were grouped within a question, based on categories of answers and number of responses for each option. For example, grouping four options for question 8a that could be classified as heavy vehicles (trucks, garbage trucks, vans unloading, farming machines), or reducing options to only one with the vast majority of answers.

These operations are detailed in Table 12 for the motorway dataset. Keeping with the example of question 8a on vehicle types causing annoyance, a respondent responding yes to cars and a garbage truck would be coded as 0110, and a respondent responding being most annoyed during the evening in question 7 would be coded as 010. Looking at the options in Table 12, "q11_101", is describing the influence on annoyance of having communication and sleep activities affected by noise, but not focus activities.

Question ID	**Shorten question**	**Coding**	**Coding category**
2	Causes of annoyance by road traffic	Option 1 or 2 Option 3 Option 4 Option 5	Feeling unsafe in traffic Noise from traffic Vibration from traffic Pollution or odour
6	Other frequent sources of noise	Option 1	No other noise sources
7	Time of day with peak annoyance	Option 1 Option 2 Option 3	Day (7-19) Evening (19-22) Night (22-7)
8a	Annoyance cause: Vehicle type	Option 1 Option 2 Option 3,6,7, or 9 Option 4, 5, or 8	No Cars Heavy vehicles Intrusive vehicles

Question ID	Shorten question	Coding	Coding category
9	Behaviour change due to road noise?	Option 1 Option 3 or 4 Option 7	Open windows less Sleep actions No actions
11	Activities affected from road traffic	Option 1, 2, or 3 Option 4 Option 5 or 6	Communication Focus Sleep
13	Types of outdoor areas available	Option 2	Own garden
14	Orientation of outdoor areas	Option 1 Option 2	Towards road Towards quiet side
16a	Activities affected from road traffic when outside?	Option 1,2, or 3 Option 4 Option 5, or 6	Communication Focus Relax
16b	Behaviour change due to road noise, when outside	Option 1, 2, 3, or 4	Behaviour change
22	Type of bedroom windows	Option 1	Special windows
23	Type of living room windows	Option 1	Special windows

Table 12 Operations conducted to reduce the number of options per questions. Notice that the questions were originally in Danish and that a shorten version of the translated text is shown to provide an basic understanding of the type of moderator.

12.2 Model diagnostics

The model diagnostics below show that all assumptions met for valid models both for the model based on the Motorway dataset in Figure 20 and the Copenhagen dataset in Figure 21.

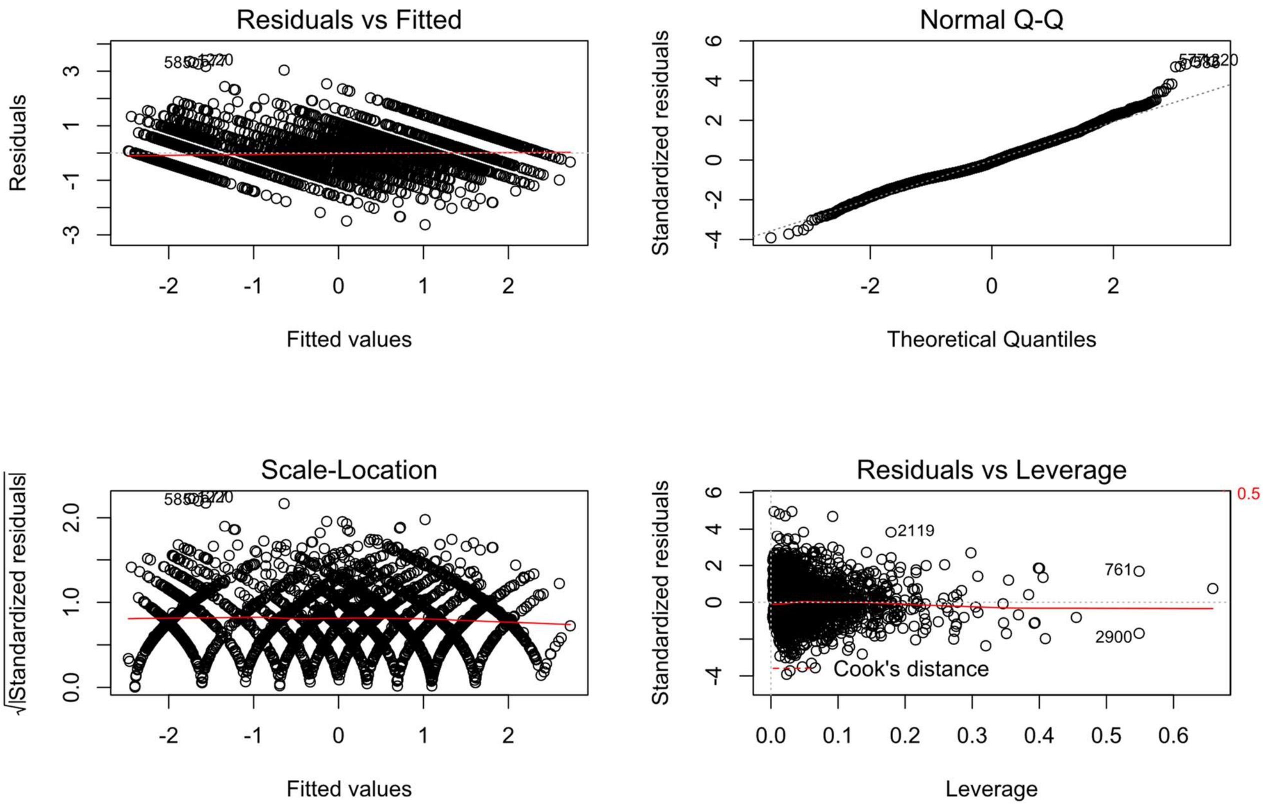

Figure 20 Regression model diagnostics for the motorway dataset. All assumptions met for a valid model with a discrete response variable. A small issue is evident from the Normal Q-Q plot, where all data should ideally lie on the diagonal.

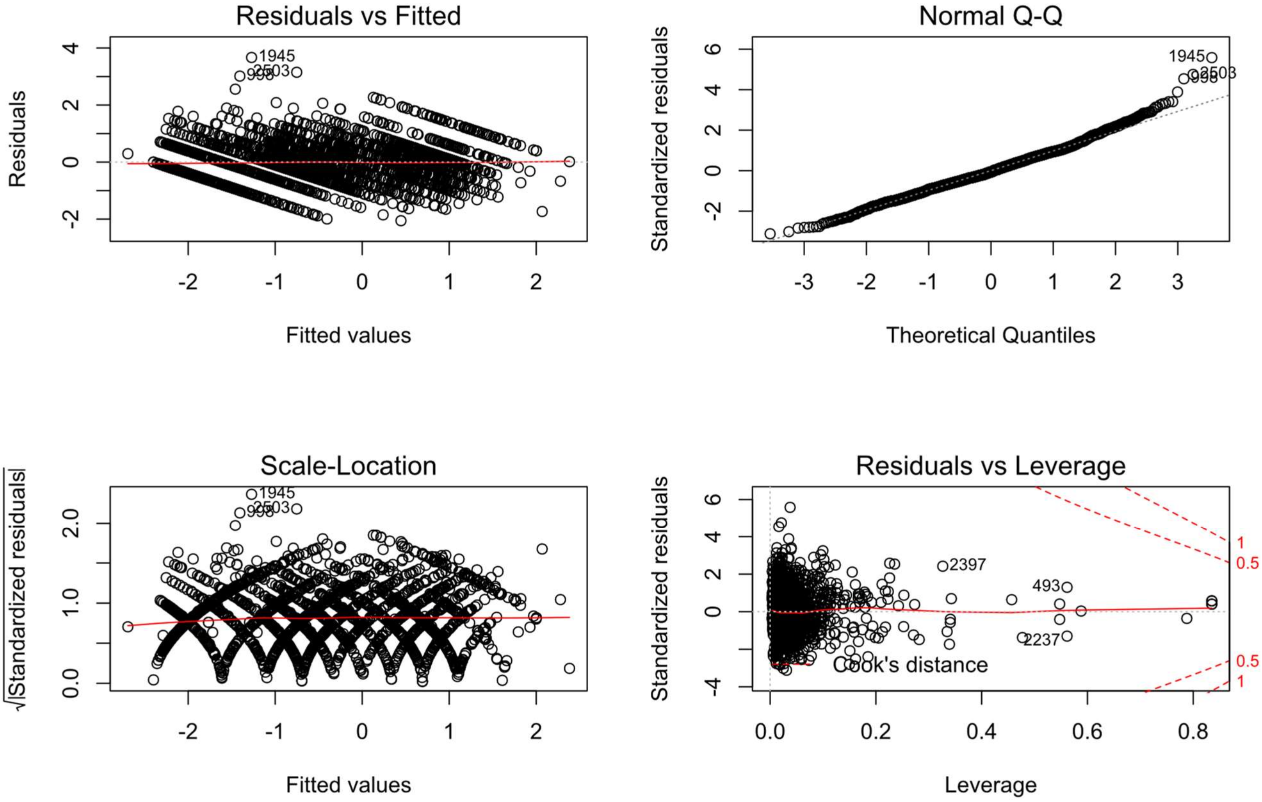

Figure 21 Regression model diagnostics for the Copenhagen dataset. All assumptions met for a valid model with a discrete response variable.