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This paper provides the first estimation of the health burden in terms of disability-adjusted life-years (DALY) of noise from the transport sector in Sweden. Assessments of health impacts of noise on a national level are still rare, but provide valuable tools for policymakers in order to prevent and abate environmental noise exposure.

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Key terms: burden of disease; DALY; disability-adjusted life year; hypertension; myocardial infarction; noise; noise annoyance; railway noise; road traffic; sleep disturbance; stroke; Sweden; transportation noise

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Burden of disease from road traffic and railway noise – a quantification of healthy life years lost in Sweden

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Objectives National quantifications of the health burden related to traffic noise are still rare. In this study, we use disability-adjusted life-years (DALY) measure to assess the burden of disease from road traffic and railway noise in Sweden.

Methods The number of DALY was assessed for annoyance, sleep disturbance, hypertension, myocardial infarction (MI) and stroke using a method previously implemented by the World Health Organization (WHO). Population exposure to noise was obtained from the Swedish Environmental Protection Agency and the Swedish Transport Administration. Data on disease occurrence were gathered from registers held by the National Board of Health and Welfare and Statistics Sweden. Disability weights (DW) and duration were based on WHO definitions. Finally, we used research-based exposure–response functions or relative risks to estimate disease attributable to noise in each exposure category.

Results The number of DALY attributed to traffic noise in Sweden was estimated to be 41 033 years; 36 711 (90%) related to road traffic and 4322 (10%) related to railway traffic. The most important contributor to the disease burden was sleep disturbances, accounting for 22 218 DALY (54%), followed by annoyance, 12 090 DALY (30%), and cardiovascular diseases, 6725 DALY (16%).

Conclusions Road traffic and railway noise contribute significantly to the burden of disease in Sweden each year. The total number of DALY should, however, be interpreted with caution due to limitations in data quality.

Key terms DALY; disability-adjusted life year; hypertension; myocardial infarction; noise annoyance; sleep disturbance; stroke; transportation noise.

Noise emitted from the transport sector is a major environmental health issue, in particular in densely populated urban areas. Results from the second round of noise mappings according to the European Environmental Noise Directive (END) (1) show that at least 136 million residents in Europe are exposed to environmental noise levels of 55 dB L_{den} or higher (L_{den} being the A-weighted 24-hour continuous equivalent sound pressure level, with the evening period (19:00–23:00 hours) increased by +5 dB and the night period (23:00–07:00 hours) increased by +10 dB) (2). The dominating source is road traffic with approximately 125 million exposed persons, followed by railway and aircraft traffic with 8 and 3 million exposed, respectively. In Sweden, the most recent national estimation was based on data for 2011 and indicates that 1.9 million people are exposed to excessive levels of traffic noise: 1.64 million to road traffic, 232 000 to railway, and 18 700 to aircraft noise (3).

In the past decade, there has been a growing concern about the potential health implications following exposure to traffic noise, both among the general public and policy-makers. Populations exposed to excessive noise, starting from around 50 dB L_{den}, typically experience annoyance, difficulties in communicating, reduced concentration, and sleep disturbances. An increasing number of studies also point towards more serious health impacts of long-term traffic noise exposure, in particular on the cardiovascular system (4). A few studies also suggest adverse effects on the metabolic system, such as abdominal obesity (5, 6) and diabetes (7). The impact of environmental noise exposure leads to considerable costs for society, such as increased health

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care expenses, production loss following noise-induced illness etc. Cost-benefit analyses of noise exposure are made on a regular basis in Sweden and indicate a total yearly cost of approximately 1.7 billion euro (3). So far, however, no attempts have been made in Sweden to quantify the burden of disease related to noise from the transport sector on a population level in terms of healthy life years lost. In a report from the World Health Organization (WHO) in 2011, the burden of disease from environmental noise in Europe was assessed in terms of disability-adjusted life years (DALY) (8). Considering some synergistic effects across the outcomes, the results indicated that ≥1 million DALY per year are related to traffic noise in the western part of Europe. The report also stated that environmental noise should be considered not only as a cause of nuisance but also as a concern for public and environmental health.

The objective of our study was to assess the burden of disease related to residential road traffic and railway noise in Sweden, using the method for estimation of DALY previously implemented by the WHO. End-points included in our assessment are annoyance, sleep disturbance, hypertension, myocardial infarction (MI), and stroke.

Methods

Definition of DALY

According to the WHO, the burden of disease in terms of DALY in the general population is expressed as the equation DALY = YLL + YLD (8). In this equation, YLL is the number of "years of life lost" calculated by the formula:

$$YLL = \sum_{1} \left(N_i^m \times L_i^m + N_i^f \times L_i^f\right)$$

where $N_i^m(N_i^f)$ is the number of deaths of males (females) in age group i multiplied by the standard life expectancy L_i^m (L_i^f) of males (females) at the age at which death occurs. YLD is the number of "years lived with disability" estimated by the equation YLD = I×DW×D where I is the number of incident cases multiplied by a disability weight (DW) and an average duration D of disability in years. DW is associated with each health condition and lies on a scale between 0 (indicating the health condition is equivalent to full health) and 1 (indicating the health condition is equivalent to death).

To estimate the burden of disease associated to each end-point, we used the following information and data: (i) distributions of road traffic and railway noise exposure within the Swedish population, described both as the A-weighted 24-hour continuous equivalent sound pressure level ($L_{Aeq,24h}$) and as the A-weighted continuous equivalent sound pressure level during the night period, ie, 23:00–07:00 hours (L_{night}); (ii) national data on disease occurrence (survey data on prevalence of hypertension and register data on incidence of MI and stroke); (iii) research-based exposure-response functions or relative risks; and (iv) disability weights and duration.

Exposure distributions

The distribution of road traffic and railway noise exposure within the Swedish population was estimated by Sweco on commission by the Swedish Environmental Protection Agency (Naturvårdsverket) (3). The exposure distributions are based on data from 13 areas included in the second round of strategic noise mappings according to the END (2011) which have been extrapolated to national figures. Estimates of the number of persons exposed are available in 5 dB categories ranging from 45–>70 dB $L_{Aeq,24h}$ for road traffic and 55–>75 dB $L_{Aeq,24h}$ for railway noise. In addition, the number of persons exposed to railway noise in the categories 45–50 and 50–55 dB $L_{Aeq,24h}$ was assessed by the Swedish Transport Administration (Trafikverket).

The distributions of night noise levels are likewise based on the reporting according to the second round of END noise mappings for the year 2011. An extrapolation to the complete Swedish population was made by the Swedish Transport Administration. Furthermore, approximations were also made regarding the number of exposed to night noise levels in the categories below 50 dB (tables 1 and 2).

National data on disease occurrence

The prevalence of hypertension in the Swedish population was assessed in a systematic review performed in 2004 and updated 2007 by the Swedish Agency for Health Technology Assessment and Assessment of Social Services (SBU) (9). Population-based age and sex-specific incidence rates of myocardial infarction and stroke was obtained from the patient registry held by the National Board of Health and Welfare (Socialstyrelsen) and Statistics Sweden (SCB) by a printed report (10) and online database (11).

The population attributable fraction (PAF) for each end-point was calculated using the following equation:

$$\mathrm{PAF} = \frac{(\sum P_i \times RR_i) - 1}{\sum P_i \times RR_i}$$

Where P_i is the proportion of population at exposure level i and RR is the relative risk at exposure level i.

Table 1. Exposure–response relationships for road traffic noise and annoyance [percent highly annoyed (%HA), assuming a risk increase from 50 dBLden], sleep disturbance [percent highly sleep disturbed (%HSD), assuming a risk increase from 45 dBLnight], hypertension, myocardial infarction (MI) and stroke. [RR=relative risk assuming a risk increase from 55dBLden.]

Exposure category	Lden [a]					Lnight [b]		
	Number of exposed [c]	%HA	Hypertension RR	MI RR	Stroke RR	Exposure category	Number of exposed [c]	%HSD
<50	3 141 755	0.00	1.0	1.0	1.0	<45	4 847 157	0.00
50–54	2 422 700	4.67	1.0	1.0	1.0	45–49	2 609 503	4.45
55–59	2 281 100	7.78	1.035	1.040	1.040	50–54	1 244 167	6.63
60–64	991 500	12.39	1.070	1.080	1.080	55–59	583 611	9.56
65-69	473 600	19.24	1.105	1.120	1.120	60–64	169 167	13.22
70–74	156 200	29.07	1.140	1.160	1.160	65–69	25 833	17.63
≥75	16 000	29.07	1.175	1.200	1.200	≥70	3417	22.78

[a] Lden is the A-weighted 24-hour continuous equivalent sound pressure level, with the evening period (19:00–23:00 hours) increased by +5 dB and the night period (23:00–07:00 hours) increased by +10 dB.
[b] Lnight is the A-weighted continuous equivalent sound pressure level during the night (23:00–07:00 hours).
[c] Based on the total population in Sweden for the year 2011 (9 482 855).

Table 2. Exposure–response relationships for railway noise and annoyance [percent highly annoyed (%HA), assuming a risk increase from 50 dBLden], sleep disturbance [percent highly sleep disturbed (%HSD), assuming a risk increase from 45 dBLnight], hypertension, myocardial infarction (MI) and stroke. [RR=relative risk assuming a risk increase from 55dBLden.]

Exposure category	Lden [a]					Lnight [b]		
	Number of exposed [c]	%HA	Hypertension RR	MI RR	Stroke RR	Exposure category	Number of exposed [c]	%HSD
<50	8 206 305	0.00	1.0	1.0	1.0	<45	8 388 477	0.00
50–54	696 300	2.01	1.0	1.0	1.0	45–49	596 933	2.30
55–59	348 150	3.91	1.035	1.040	1.040	50–54	283 889	3.34
60–64	153 200	7.21	1.070	1.080	1.080	55–59	142 556	4.77
65–69	59 200	12.45	1.105	1.120	1.120	60–64	50 778	6.57
70–74	17 600	20.18	1.140	1.160	1.160	65–69	17 111	8.76
≥75	2100	20.18	1.175	1.200	1.200	≥70	3111	11.32

[a] Lden is the A-weighted 24-hour continuous equivalent sound pressure level, with the evening period (19:00–23:00 hours) increased by +5 dB and the night period (23:00–07:00 hours) increased by +10 dB.
[b] Lnight is the A-weighted continuous equivalent sound pressure level during the night (23:00–07:00 hours).
[c] Based on the total population in Sweden for the year 2011 (9 482 855).

Value of DW and disease duration

In general, we have used the same DW for the outcomes as indicated by the WHO in its 2011 report "Burden of Disease from Environmental Noise" for annoyance and sleep disturbance (8) and in its report "Global burden of disease 2004 update: Disability weights for diseases and conditions" for stroke and MI (12). However, the DW suggested for hypertension in the 2011 WHO report was very high and not well established. We therefore revised the DW for hypertension so that only severe hypertension in our study was calculated with a high DW (equal to MI). Mild and moderate hypertension where given lower DW factors.

The following DW factors have been used: highly noise annoyed=0.02 (with sensitivity values of 0.01 and 0.12), highly sleep disturbed=0.07 (sensitivity values 0.04 and 0.10), mild hypertension=0.00, moderate hypertension=0.02 (same as noise annoyed), severe hypertension=0.395, MI (treated)=0.395, acute stroke=0.92 and chronic effects of stroke (treated)=0.171.

Since hypertension is in the causal pathway leading to both MI and stroke, PAF of MI and stroke caused by hypertension were deducted from the total number of DALY.

For the prevalent outcomes, ie, annoyance, sleep disturbance and hypertension, as well as for MI, the duration was set to a year. For stroke, the duration of the acute phase was set to 28 days and for the chronic effects to 6.16 years for men and 5.61 years for women, corresponding to the average remaining life expectancy for each sex respectively.

Exposure–response relationships

To calculate the number and percentage of highly noise-annoyed persons (%HA) in Sweden, we used established exposure–response functions for road traffic and railway noise and annoyance presented in the EU paper on transportation noise and annoyance (13). Consequently, %HA at different levels of road traffic and railway noise was estimated for each 5 dB noise interval using the following equations:

Road traffic:

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

Railways:

$$\%HA = 7.239 \times 10^{-4}(L_{den} - 42)^3 - 7.851 \times 10^{-3}(L_{den} - 42)^2 + 0.1695\,(L_{den} - 42)$$

Since the Swedish population exposure data was estimated in $L_{Aeq,24h}$, a transformation to L_{den} was made assuming $L_{den} = (L_{Aeq,24h} + 4.5$ dB) (14). For railway noise, $L_{den} = (L_{Aeq,24h} + 6$ dB) was assumed.

Similar exposure–response relationships are available for night-time noise and sleep disturbance (15). These were used to estimate the proportion of highly sleep disturbed persons (%HSD) at different levels of road traffic and railway noise exposure in Sweden:

Road traffic:

$$\%HSD = 20.8 - 1.05L_{night} + 0.01486(L_{night})^2$$

Railways:

$$\%HSD = 11.3 - 0.55L_{night} + 0.00759(L_{night})^2$$

For hypertension, MI and stroke, we estimated the number of cases attributed to noise using risk estimates from two recent meta-analyses. Based on aggregated data from 24 observational studies, an odds ratio (OR) for hypertension of 1.034 (95% CI 1.011–1.056) per 5 dB $L_{Aeq,16h}$ increase in road traffic noise was reported in 2012 ($L_{Aeq,16h}$ being the A-weighted 16-hour continuous equivalent sound pressure level (07:00–23.00 hours) (16). For MI, we used a RR estimate of 1.04 per 5 dB L_{dn} increase [L_{dn} being the A-weighted 24-hour continuous equivalent sound pressure level, with the night period (22:00–07:00 hours) weighted by +10 dB]. This estimate was based on the results of a meta-analysis on road traffic noise and coronary heart disease, pooling 17 individual effect estimates, in which a RR of 1.08 (95 % CI 1.04–1.13) were found per 10 dB L_{dn} (17). Stroke is the least studied cardiovascular end-point of the three reported in this study. One recent meta-analysis has been performed pooling results from six separate studies, however, there was a large heterogeneity between studies and the findings are not conclusive (18). Therefore, we used an approximate risk increase of 4% per 5 dB, similar to that for coronary heart disease. Since there are no meta-analyses available for railway noise and cardiovascular outcomes, we have assumed equal risk increases as for road traffic (tables 1 and 2).

Results

Based on current available data, we estimated the total number of DALY attributed to noise from the transport sector in Sweden to be 41 033 years (table 3). The majority of these, 36 711 DALY (90%), were related to road traffic noise, and 4321 (10%) were related to railway noise. Sleep disturbance was found to be the main contributor to the disease burden with a total of 22 218 DALY (54%), followed by annoyance with 12 090 DALY (30%) and cardiovascular diseases, 6 725 DALY (16%) (figure 1). Using the sensitivity values of 0.04 and 0.10 as DW for sleep disturbance, the uncertainty in DALY ranged from 12 697–31 740. Similarly, using DW of 0.1 and 0.12 as sensitivity values for annoyance, the number of DALY ranged from 6045–72 539 (no sensitivity values were used for the cardiovascular outcomes).

The percentage of highly sleep disturbed persons was estimated to be 2.98% and 0.37% of the total population (based on population numbers for the year 2011) with regards to road traffic railway noise, respectively. The corresponding percentages for high noise annoyance were 5.85% and 0.53%, respectively. Furthermore, the total number of cases of traffic related cardiovascular diseases (hypertension, MI, and stroke) was estimated to be 0.5% of the total population (road traffic and railway noise combined).

Table 3. Estimations of the number of cases and disability-adjusted life years (DALY) attributed to annoyance, sleep disturbance, hypertension, myocardial infarction (MI) and stroke from road traffic and railway noise in Sweden [a].

	Road traffic		Railway traffic		Total	
	Cases	DALY	Cases	DALY	Cases	DALY
Annoyance	554 490	11 090	50 000	1000	604 490	12 090
Sleep disturbance	282 191	19 753	35 213	2465	317 404	22 218
Hypertension	41 857	1443	6101	210	47 959	1653
MI	831	1946	122	284	953	2230
Stroke	901	2479	132	362	1033	2842
Total	880 270	36 711	91 568	4321	971 839	41 033

[a] Due to rounding of the figures, the sums do not always add up.

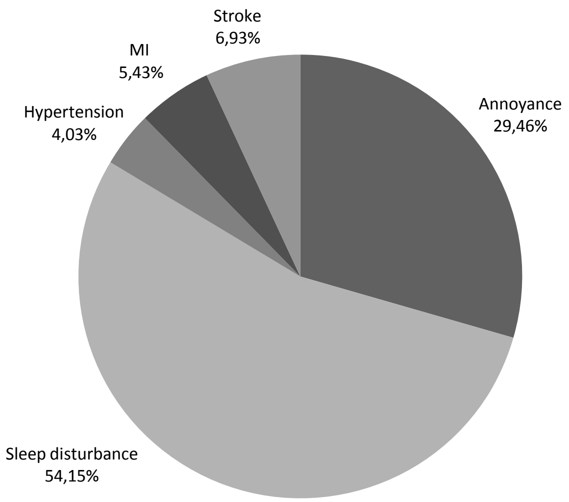

Figure 1. Proportion of DALY attributed to each end-point respectively, for road and railway traffic noise combined.

Discussion

In this study, we have quantified the burden of disease related to road traffic and railway noise from the complete transportation net in Sweden. We estimated the number of DALY attributable to noise for general annoyance, sleep disturbance, and cardiovascular diseases, including hypertension, MI and stroke. In total, traffic noise accounted for 41 033 DALY. Road traffic, which is the dominating source of exposure, accounted for the majority of the disease burden with 90% of the total number of DALY. According to a report by the Public Health Agency of Sweden and Karolinska Institutet (19), the number of DALY from traffic is similar to the burden of disease from a low intake of fruits and vegetables (41 665 DALY), which is the 7th most important contributing risk factor to the overall disease burden in Sweden. A comparison can also be made to the use of tobacco, which in this report accounted for 155 140 DALY.

Of the health outcomes under study, sleep disturbance was found to be the prime contributor to the disease burden of noise, accounting for 54% of the total number of DALY, followed by annoyance, 30%, and cardiovascular diseases, 16%. These results are in line with what was presented for the western part of Europe in the WHO report (8) where, likewise, sleep disturbance was found to be the primary contributor to the disease burden, followed by annoyance and ischemic heart disease. In comparison to the assessment by WHO, we have used more recent input data, both when it comes to exposure (2011 versus 2007) and relative risk estimates. For the assessment of DALY relating to cardiovascular disease in the WHO report, railway noise was not included and MI was used as a proxy for all cardiovascular outcomes, with a disability weight of 0.405. In our investigation, we have included separate assessments for MI (DW 0.395), hypertension (DW 0.02/0.395) and stroke (DW 0.92/0.171), and estimated DALY for road traffic noise as well as for railway noise. Furthermore, whereas the WHO report used a cut-off of 60 dB L_{den} for cardiovascular effects of noise, we used 55 dB L_{den} since more evidence currently support this cut-off (17).

Few other studies have investigated the burden of disease from traffic noise in terms of DALY. However, the Norwegian public health institute made an assessment similar to ours in Norway in 2012 (20). This considered road traffic noise in relation to annoyance, sleep disturbance, and ischemic heart disease (MI) and followed the WHO method closely. The results show that sleep disturbance accounted for 69% of the total disease burden, followed by noise annoyance, 30%, and cardiovascular disease, 1%. Thus, the results are similar to ours as well as the WHO estimations. The estimated number of cases of annoyed (3–6%) and sleep disturbed persons (2–3%) were in the same order as what we estimated for Sweden. Furthermore, the proportion of cardiovascular disease related to noise was estimated to be 0.5%, which is the same as in Sweden; although the Norwegian assessment did not include the contribution from railway noise and were considered highly uncertain due to lack of register data for MI.

It should be noted that the estimates of DALY in this study assumes that the associations obtained in the underlying epidemiological studies are indeed causal. For annoyance and sleep disturbance, there is currently little doubt about causality. However, for the cardiovascular diseases, the evidence is still inconclusive in parts. Furthermore, the estimations of DALY reported here are based on several assumptions and approximations which limits the interpretability of the results. Firstly, the total number of DALY should be interpreted with caution since not all health effects that may be related to noise have been included. For instance, we did not assess the burden of disease for tinnitus, cognitive impairment in children, overweight or diabetes. Moreover, although the estimation of DALY allows health effects of noise to be valued independently through a consistent approach, a certain risk of double counting cannot be excluded since the outcomes are interrelated. Overlap between the outcomes should be investigated and discussed in separate studies in order to be taken into account in future estimations of DALY related to traffic noise.

Secondly, the exposure data used in this assessment needs to be improved. The national assessment of the number of persons exposed to excessive road traffic and railway noise ($L_{Aeq,24h}$ levels) in Sweden was based on the END noise mappings performed in larger cities and extrapolated to national figures (3). For railway noise

<55 dB $L_{Aeq,24h}$, there were no information available on populations exposure so for the categories 45–49 and 50–54 dB, the Swedish Transport Administration made approximations of the number of exposed on the basis of the trend among the higher noise categories. With regard to night-time noise, assessments of the number of exposed were likewise available only in areas covered by the END. However, with the assistance of the Swedish Transport Administration, we were able to make reasonable extrapolations to the general population.

The exposure–response relationships used to assess the number of highly annoyed persons in relation to road traffic and railway noise in Sweden were based on synthesis curves presented by Miedema & Oudshoorn in 2001 (21). The functions are derived from 26 separate field surveys on road traffic and 8 surveys on railway traffic performed in Europe, North America and Australia between 1971 and 1993. Norm curves such as these, which are valid for the entire population, are in many cases more suitable for strategic assessments than surveys in local populations or groups. However, standard exposure–response information could lead to inaccuracies in terms of both over- or under estimations (22). In 2012, annoyance rates reported in the Swedish National Environmental Health survey of 2007 were linked to noise levels extracted from Swedish END maps and compared with the European Commission paper on exposure–response curves (23). The results showed a very high agreement between the observed (Swedish) annoyance rates and those predicted by the established exposure–response curves, for road traffic as well as for railway noise. Thus, we believe our estimations of the proportion of highly annoyed person to be valid.

As for annoyance, we used synthesis curves derived from a meta-analysis on night noise and sleep disturbance (24) to assess the number of highly sleep disturbed persons in Sweden. However, since no comparison has been made between Swedish and international data, we cannot rule out some error in our estimations. For instance, the improvements in noise insulation of buildings and the common means of locating bed-rooms towards a quiet side may have led to an over-estimation in the number of highly sleep disturbed persons.

To estimate the burden of disease relating to the cardiovascular outcomes, we used RR estimates derived in recent meta-analyses for hypertension (16) and ischemic heart disease (17). Since very few studies are available on stroke, we assumed that the risk increase is similar to myocardial infarction. A recent meta-analysis, pooling six studies on stroke, showed risk estimates ranging from 0.96 (95% CI 0.70–1.32) to 1.17 (95% CI 0.75–1.29) and an overall relative risk of 1.01 (95% CI 0.96–1.06) per 10 dB L_{den}. In categorical analyses, the risk increased from 1.04 (95% CI0.87–1.24) in the category 55–59 dB to 1.29 (95% CI 0.74–2.24) in the category 70–74 dB. Thus, assuming a risk increase of 4% per 5 dB rise gives an average of these two. However, the DALY estimations for stroke should be interpreted with caution and updated as more certain data becomes available.

The DW factors used in our calculations are mainly based on the WHO recommendations, although some adaptations have been made. Our findings show that the choice of a DW is crucial for the number of DALY assigned to each health outcome and that each DW therefore should be considered carefully. In particular, the DW for annoyance and sleep disturbance are tentative values with high uncertainty level, as shown by the use of sensitivity values in this assessment. Thus, these DW factors may need to be better established by future investigations.

Other generalizations that we have made due to lack of data include similar rates of annoyance and sleep disturbance among men and women and equal risk increases for railway noise as for road traffic noise when it comes to the cardiovascular outcomes. The characteristics of road traffic and railway noise are quite different and at the same average noise level, road traffic noise tends to be more annoying than rail (21). When specific risk estimates are available for railway noise and cardiovascular disease, these should thus be used. Furthermore, we have not been able to take confounding with air pollution into account in this investigation.

In conclusion, our estimations of DALY attributed to road traffic and railway noise in Sweden indicate a significant contribution to the disease burden, in particular concerning sleep disturbance and annoyance, but also with regard to cardiovascular disease. The total number of DALY should, however, be interpreted with caution; mainly because of the restriction in end-points assessed but also due to limitations in data quality.

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