14th ICBEN 2023 18 - 22 JUNE BELGRADE

14th ICBEN Congress on Noise as a Public Health Problem

Viewer on combined health impacts from road traffic noise and air pollution in urban areas

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ABSTRACT

Noise and air pollution are two of the biggest environmental health risks in urban areas. The ability to monitor, assess and visualise these pollutants is essential for supporting the development of policies and mitigation measures as well as for increasing awareness of these pollutants amongst communities. Although citizens are exposed to a combination of environmental stressors including noise and air pollution, tools and viewers mapping the impact and risks of multiple stressors together are scarce. This paper proposes a methodology for visualising the combined risks of exposure to urban air pollution and road traffic noise. The methodology was applied to 156 cities in Europe. As a result, an interactive viewer was developed showing the combined health impact of air pollution and road traffic noise at 1km by 1km resolution. The impact of air pollution was measured in terms of mortality and the impact of road noise pollution is measured in terms of long-term high annoyance. The viewer is based on data submitted under the Environmental Noise Directive and the Air Quality Directive.

Keywords (3-6): Road noise, Air quality, Combined exposures, Urban noise, Environmental noise management, Noise mapping and visualisation.

INTRODUCTION

Noise and air pollution are the main causes contributing to the environmental burden of disease in western Europe [1,2]. A high proportion of people in Europe are affected by harmful levels of noise and air pollution. Urban areas are the most affected as they have a higher population density, dense transport infrastructure and high demand for mobility[3,4].

Although both pollutants affect people's health through different biological mechanisms, some studies have found that the exposure to combined noise and air pollution can exacerbate the health impacts of individual exposures [5–7]. In addition to this, interventions that reduce the adverse effects of both air pollution and noise have the potential to positively impact a larger number of people and be more cost-effective than those targeting only one environmental stressor[8].

Therefore, the ability to monitor, assess and visualise these two pollutants together is essential for supporting the development of policies and mitigation measures as well as for increasing awareness of these pollutants amongst communities.

Some countries are already moving towards presenting indices based on various environmental domains to support environmental and public health policies[9–11]. Maps presenting environmental loads of combined environmental stressors are also available in some European cities[12,13].

However, although citizens are exposed to a combination of noise and air pollution, tools and viewers mapping the impact and risks of these two pollutants together are scarce. Generally, maps presenting environmental loads have been explored individually or within the same environmental domain (e.g. European Air Quality Index[11,14]).

In order to help urban practitioners and policy makers, as well as to increase awareness of these environmental pollutants, an interactive viewer was developed showing the combined health impact of air pollution and road traffic noise at 1km by 1km resolution. The aims of this paper are the following:

- To develop an approach for building a visualisation tool that aggregates noise and air pollution data across European cities and that capitalises on European Environment Agency (EEA) environmental datasets on noise and air pollution.
- To implement a visual communication tool for citizens and policy makers which provides an insight into the spatial variation in environmental quality in relation to noise and air pollution across European cities.
- To use exposure-response relationships in relation to the health impacts of noise and air pollution to visualise the data and allow the combined assessment of the health risks.

MATERIALS AND METHODS

Road traffic noise data and descriptors

Noise data from roads was obtained from the 2017 Strategic Noise Maps provided by EU countries under the obligations from the Environmental Noise Directive (END)[15]. The datasets used are shapefiles and contain noise contour maps of roads in urban areas of more than 100,000 inhabitants across the EU. The noise indicator used in the contour maps is the 24-

hour annual average noise level with separate weightings for the day, evening and night periods (i.e. L_{den}) using 5 dB bands starting at 55 dB L_{den}. Only information on road noise inside agglomerations is used, as this is the most prevalent source of environmental noise inside urban areas.

The noise contours were overlaid with a reference grid of 1km x 1km cells. Although the spatial data on noise available is more detailed, for combination purposes with the air quality data, the European grid at 1km resolution was used since air quality data is only available in 1x1km grid resolution. Based on the noise contour maps of urban areas, for each grid cell the percentage of the area that is covered by each of the noise bands, i.e. 55-60 dB; 60-65 dB; 65-70 dB; 70-75 dB; ≥75 dB was derived. The population exposed to each noise band in each grid cell was also derived by overlaying the noise contour maps and the population data from Urban Atlas 2018[16]. Based on the noise data, for each grid cell, different heath impact noise descriptors were estimated (see Table 1).

Table 1 Noise descriptors used in the viewer on combined health impacts from road traffic noise and air pollution in urban areas.

Noise Descriptor	**Description**	**Calculation**
Probability of suffering high annoyance (HA) due to road traffic noise.	Expected risk of suffering high annoyance due to road traffic noise based on exposure-response relationships from the WHO[17] and percentage of the area covered in the cell by each of the noise bands, i.e. 55-60 dB; 60-65 dB; 65-70 dB; 70-75 dB; ≥75 dB.	Probability HA $_{cell}$ = ∑ proportion area covered$_i$ *[(78.927 - 3.1162 x Lden mid band + 0.0342 x Lden mid band ^{2}) /100] where *i* is : 55-59 ; 60-64, 65-69 ; 70-74 ; equal or above 75 dB.
Years lived with disability (YLD) due to high annoyance from road traffic noise.	Years lived with disability based on the number of people highly annoyed due to road traffic noise. Values are derived using exposure-response relationships from the WHO[17]. Exposure data comes from the noise contour maps and population data at cell level from the Urban Atlas 2018[16].	YLD $_{cell}$ = Total HA * Disability Weight Where: Disability Weight =0,02 for High Annoyance[17] Total HA $_{cell}$ = ∑ Number HA per each band Number HA = [(78.927 - 3.1162 x Lden mid band + 0.00342 x Lden mid band ^{2}) /100] *Number of people in Band *i* * Fraction adult population in country where *i* is : 55-59 ; 60-64, 65-69 ; 70-74 ; equal or above 75 dB.

People chronically disturbed by noise can suffer a wide range of negative health effects, including annoyance, sleep disturbance and cardiovascular problems. In the viewer on combined health impacts from road traffic noise and air pollution in urban areas, noise risks are represented using only high annoyance. High annoyance is considered to be a good indicator for measuring adverse health effects of noise as it can be a harbinger of more severe health problems[17]. Therefore, this health end point is used as a proxy for chronic disturbance in the viewer.

Air quality data and descriptors

Concentration maps with annual statistics of $PM_{2.5}$ and NO_2 on a 1*1 km2 grid were used. The annual statistics are estimated using a mapping method ('Regression - Interpolation - Merging Mapping') that combines the monitoring data from rural, urban/suburban background and urban/suburban traffic stations for $PM_{2.5}$ and NO_2 with results from the EMEP chemical transport model and other supplementary data, such as altitude, satellite data, meteorology, land cover and population density[18], using a linear regression model followed by kriging of its residuals. Urban traffic station data was included to take into account hotspots, since traffic is the most important source of NO_2 and an important source of PM in urbanized areas. These maps are created annually for Europe using primarily the air quality monitoring data reported under the Air Quality Directives, and available from the EEA Air Quality e-Reporting database.

The data on concentrations have been overlaid with the grid population data. The population density map used is based on the GEOSTAT 2011 dataset[19]. This data is available on the same grid resolution as the ambient air concentrations and was scaled with the total population data available country-wise from Eurostat to map the population distribution for 2017. The Concentration Response Functions (CRFs) recommended by the WHO in their HRAPIE project report[20] were applied for deriving the health risk descriptors of air pollution for the viewer. These older CRFs were used because at the time of the development of the viewer the new WHO CRFs were not available.

Based on the data described above, for each grid cell, different air quality health descriptors were estimated (see Table 2).

Table 1 Air quality descriptors used in the viewer on combined health impacts from road traffic noise and air pollution in urban areas.

Air quality descriptor	**Description**	**Calculation**
Premature mortality risk due to $PM_{2.5}$ annual concentration levels	Expected risk of suffering a premature death based on risk ratios from WHO (2013)[20]. The estimates are derived from annual average $PM_{2.5}$ concentration maps based on data reported to the EEA under the Air Quality Directive in 2017.	$RR_{C\ \mathrm{cell}} = \exp[\,\beta\,(C - C_0)\,]$ where, C is the concentration level the population is exposed to, C_0 the baseline concentration, and β is the concentration-response factor (RR of 1.062 per 10µg/m^3 , C_0 = 0 µg/m^3)
Premature mortality risk due to NO_2 annual concentration levels	Expected risk of suffering a premature death based on risk ratios from WHO (2013)[20]. The estimates are derived from annual average NO_2 concentration maps based on data reported to the EEA under the Air Quality Directive in 2017.	$RR_{C\ \mathrm{cell}} = \exp[\,\beta\,(C - C_0)\,]$ where, C is the concentration level the population is exposed to, C_0 the baseline concentration, and β is the concentration-response factor (RR of 1.055 per 10µg/m^3 , C_0 = 20 µg/m^3)

Years of Life Lost (YLL) due to mortality from $PM_{2.5}$	Years of life lost due to premature mortality from exposure to $PM_{2.5}$ based on risk ratios from WHO (2013) [20]. The estimates are derived from annual average $PM_{2.5}$ concentration maps based on data reported to the EEA under the Air Quality Directive in 2017.	$YLL = PAF\ \sum_{a,s} CDR_{a,s} * Pop_{a,s} * LE_{a,s}$ Where PAF is the population attributable fraction, $CDR_{a,s}$ is the crude death rate by sex (s) and age (a) in a particular population due to a specific cause, $Pop_{a,s}$ is the population fraction stratified by age and sex, and $LE_{a,s}$ is the average time a person is expected to live, based on the year of their birth, sex (s) and age (a).
Years of Life Lost (YLL) due to mortality from NO_2	Years of life lost due to premature mortality from exposure to NO_2 based on risk ratios from WHO (2013) [20]. The estimates are derived from annual average $PM_{2.5}$ concentration maps based on data reported to the EEA under the Air Quality Directive in 2017.	$YLL = PAF\ \sum_{a,s} CDR_{a,s} * Pop_{a,s} * LE_{a,s}$ Where PAF is the population attributable fraction, $CDR_{a,s}$ is the crude death rate by sex (s) and age (a) in a particular population due to a specific cause, $Pop_{a,s}$ is the population fraction stratified by age and sex, and $LE_{a,s}$ is the average time a person is expected to live, based on the year of their birth, sex (s) and age (a).

Mapping combined risks and impacts

Two types of descriptors for representing the combined risks and impacts were calculated for spatial units of 1 x 1 km (see Table 3). The first descriptor is used to represent the combined risk to health from road traffic noise and air pollution. This combined pollution-risk descriptor is targeted at citizens, as the cells show the environmental quality of the neighborhood in terms of noise and air pollution. The second descriptor is used to represent the total health burden from road traffic noise and air pollution in terms of DALYs. This descriptor is targeted at policy makers and practitioners as it identifies areas in the city where large numbers of people are exposed to high levels of road noise and air pollution. Thus, it may be used to identify areas where interventions benefit the highest number of people.

Table 3 Combined noise-air descriptors used in the viewer on combined health impacts from road traffic noise and air pollution in urban areas.

Combined descriptor	**Description**	**Calculation**
Combined health risk ($PM_{2.5}$ + Road noise)	This descriptor shows both risks together and it is calculated using the premature mortality risk due to $PM_{2.5}$ annual concentration levels described in Table 2 and the probability of suffering high annoyance due to road traffic noise described in Table 1.	Combined health risk = ($RR_{C\ \text{cell}}$ -1) + (probability HA $_{\text{cell}}$ *0.02). A weighting of 0.02 on probability of high annoyance risks is applied in order to recognise the fact that premature death is a more severe health outcome. This

		weighting is based on disability weights for high annoyance from WHO[17].
Combined health risk (NO_2 + Road noise)	This descriptor shows both risks together and it is calculated using the premature mortality risk due to NO_2 annual concentration levels described in Table 2 and the probability of suffering high annoyance due to road traffic noise described in Table 1.	Combined health risk = ($RR_{C\ cell}$ -1) + (probability HA_{cell} *0.02). A weighting of 0.02 on probability of high annoyance risks is applied in order to recognise the fact that premature death is a more severe health outcome. This weighting is based on disability weights for high annoyance from WHO[17].
Total health burden in DALYs ($PM_{2.5}$ + Road noise)	This descriptor shows the sum of years of life lost due to premature mortality caused by exposure to air pollution and the years lived with disability due to noise annoyance. It is calculated using the Years of life lost (YLL) due to $PM_{2.5}$ annual concentration levels described in Table 2 and the Years lived with disability (YLD) due to the number of people highly annoyed from road traffic noise described in Table 1.	Total health burden in $DALYs_{cell}$ = YLL_{cell} from $PM_{2.5}$ + YLD_{cell} from road noise high annoyance.
Total health burden in DALYs (NO_2 + Road noise)	This descriptor shows the sum of years of life lost due to premature mortality caused by exposure to air pollution and the years lived with disability due to noise annoyance. This descriptor is calculated using the Years of life lost (YLL) due to NO_2 annual concentration levels described in Table 2 and the Years lived with disability (YLD) due to the number of people highly annoyed from road traffic noise described in Table 1.	Total health burden in $DALYs_{cell}$ = YLL_{cell} from NO_2 + YLD_{cell} from road noise high annoyance.

RESULTS

The methodology was applied to 156 cities in Europe. As a result, an interactive viewer was developed with Tableau showing the descriptors outlined in the methodology section. For each city, the viewer shows three sets of maps:

- An overview map that shows the health risks of air pollution (mortality) and road traffic noise (high annoyance) separately at 1km x 1km resolution (see figure 1).

- A combined health risks map that shows the combined risk to health from road traffic noise and air pollution in a colour scale that goes from Low to High (see figure 2).
- A total health burden map that shows the DALYs resulting from exposure to road traffic noise and air pollution in a color scale from low to high. This takes into account the risks and the number of people exposed in each cell (see figure 3).

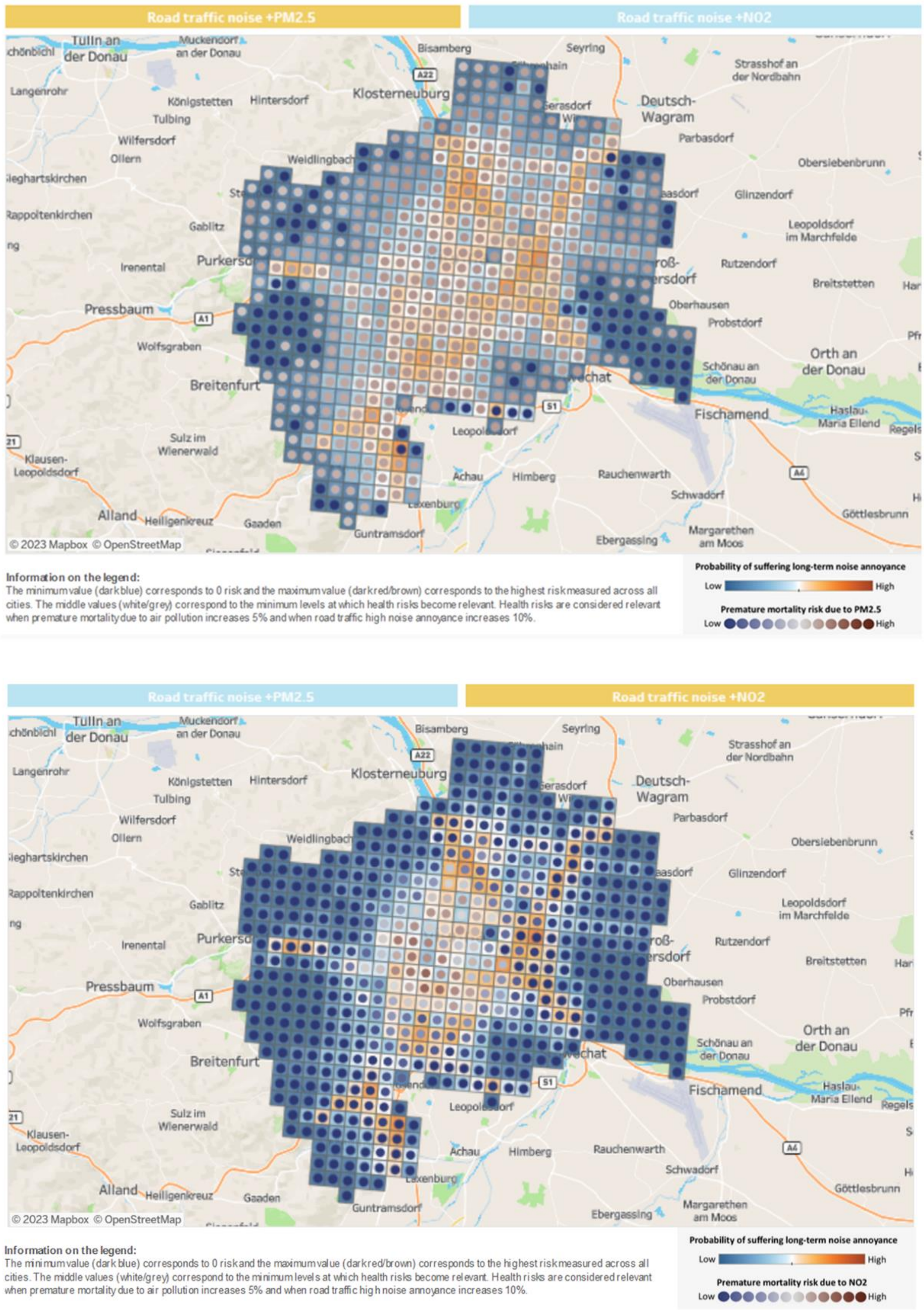

Figure 1 Health risks from road traffic noise (squares) and air pollution (dots) in a grid of 1km

x 1km for the city of Vienna.

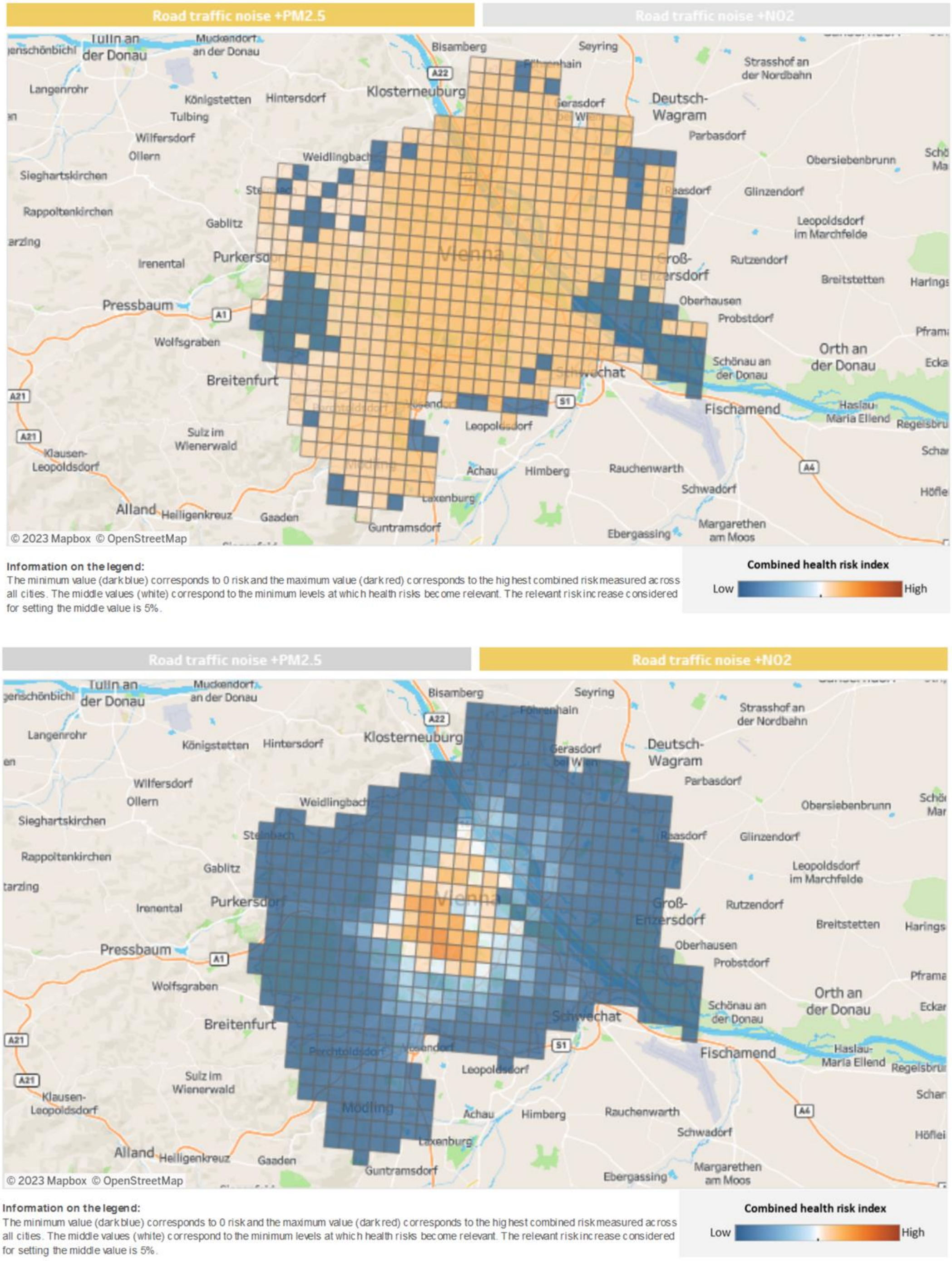

Figure 2 Combined health risks from road traffic noise and air pollution in a grid of 1km x 1km for the city of Vienna

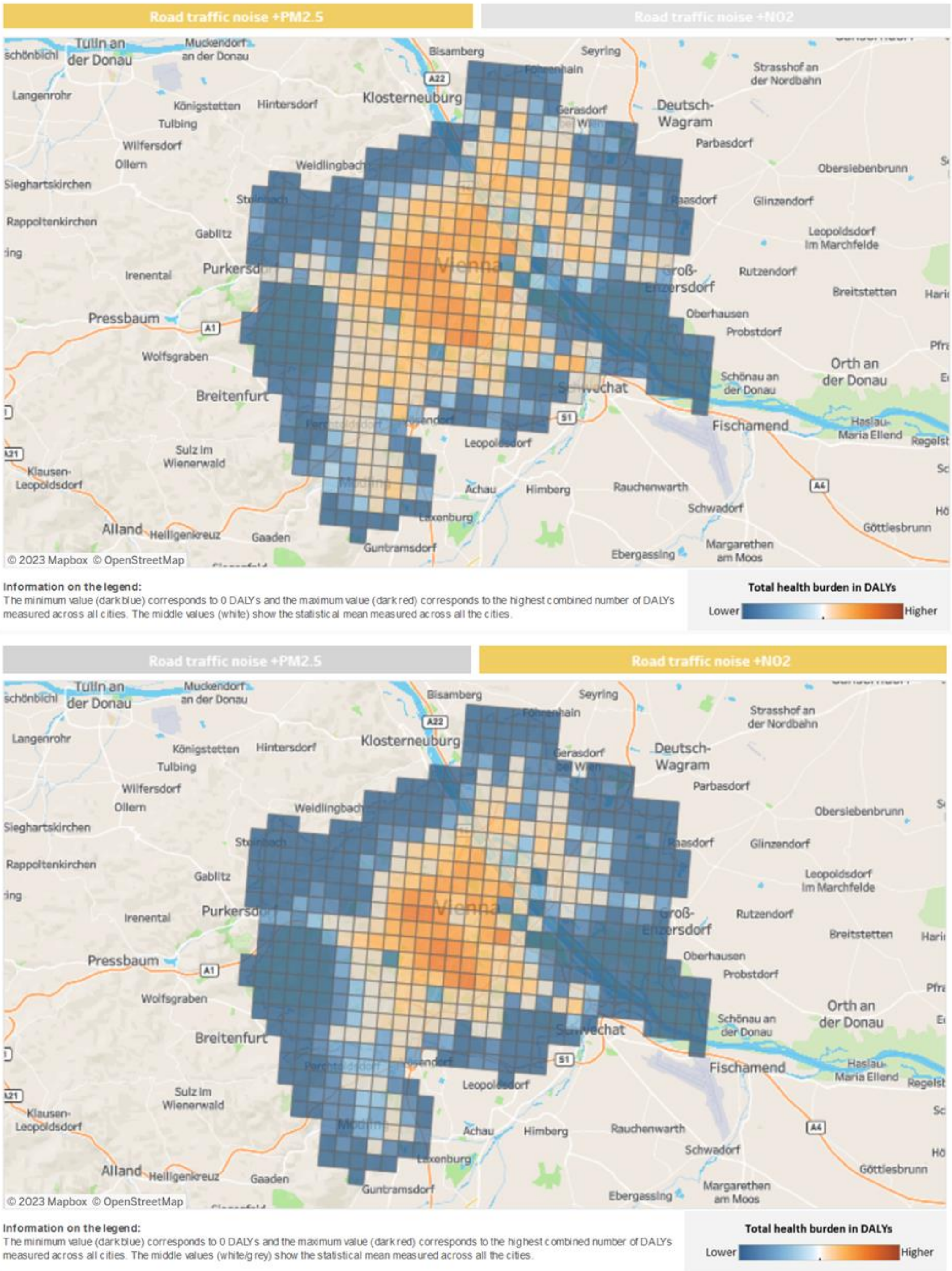

Figure 3 Total health burden from road traffic noise and air pollution expressed in DALYs in a grid of 1Km x 1Km for the city of Vienna.

The full set of city maps can be found in an interactive dashboard: https://www.eea.europa.eu/themes/human/noise/viewer-on-combined-health-impacts. To ensure consistent color coding, the same minimum and maximum values were used for all cities. Therefore, the viewer can be used for comparing the impacts of noise and air pollution across the cities analyzed as well as for comparing areas within one city.

The maps for NO_2 seem to be more correlated with road noise than the maps of $PM_{2.5}$. This is due to the fact that road traffic is the largest contributor to NO2 emissions, as opposed to PM2.5 where the impact comprises also other air pollution sources, e.g. domestic heating, industry, construction, etc.

The maximum probability of being highly annoyed in a cell across the 156 cities was 36% and the maximum risk of premature death was found with $PM_{2.5}$ and was 18%. In terms of DALYs, the maximum value found in a cell was 536 for combined $PM_{2.5}$ and road traffic noise. The minimum value was zero.

Regarding the visualisation of combined risks, it was observed that applying the weighting on noise of 0,02 results in the visualisation being dominated mainly by the risks of air pollution. The visualisation of the total health burden in terms of DALYs is dominated by the population density of the cell.

CONCLUSION

The viewer on the combined exposure to ambient air and noise pollution has several important applications and aims. One is to assess how the two most important environmental pressures affect human health, especially in urban areas where the exposure is highest. Another is to inform and support authorities to develop mitigation strategies and policies that are just and cost-effective. The viewer on combined health impacts from road traffic noise and air pollution in urban areas presents a variety of maps that show the spatial distribution of risks and health burden in urban areas. These maps are intended for citizen awareness as well as for planning and environmental decision-making purposes.

Acknowledgements

The authors would like to thank Esther Mata from Tracasa for her invaluable help with the Tableau software.

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