The Spatial Relationship between Traffic-related Air Pollution and Noise in Two Danish Cities: Implications for Health-related Studies

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Abstract

Air pollution and noise originating from urban road traffic have been linked to the adverse health effects e.g. cardiovascular disease (CVD), although their generation and propagation mechanisms vary. We aimed to (i) develop a tool to model exposures to air pollution and noise using harmonized inputs based on similar geographical structure (ii) explore the relationship (using Spearman's rank correlation) of both pollutions at residential exposure level (iii) investigate the influence of traffic speed and Annual Average Daily Traffic (AADT) on air-noise relationship. The annual average (2005) air pollution (NO_x, NO_2, PM_{10}, $PM_{2.5}$) and noise levels (L_{day}, L_{eve}, L_{night}, L_{den}, $L_{Aeq,24h}$) are modelled at address locations in Copenhagen and Roskilde (N = 11000 and 1500). The new AirGIS system together with the Operational Street Pollution Model (OSPM®) is used to produce air pollution estimates. Whereas, noise is estimated using Common Noise Assessment Methods in the EU (CNOSSOS-EU, hereafter CNOSSOS) with relatively coarser inputs (100 m CORINE land cover, simplified vehicle composition). In addition, noise estimates (L_{day}, L_{eve}, L_{night}) from CNOSSOS are also compared with noise estimates from Road Traffic Noise 1996 (RTN-96, one of the Nordic noise prediction standards). The overall air-noise correlation structure varied significantly in the range $|r_S|$ = 0.01 – 0.42, which was mainly affected by the background concentrations of air pollution as well as non-traffic emission sources. Moreover, neither AADT nor traffic speed showed substantial influence on the air-noise relationship. The noise levels estimated by CNOSSOS were substantially lower, and showed much lower variation than levels obtained by RTN-96. CNOSSOS, therefore, needs to be further evaluated using more detailed inputs (e.g. 10 m land cover polygons) to assess its feasibility for epidemiological noise exposure studies in Denmark. Lower to moderate air-noise correlations point towards significant potential to determine the independent health effects of air pollution and noise.

Keywords – traffic air pollution, traffic noise, relationship, CNOSSOS, OSPM®, residential exposure

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List of abbreviations/acronyms

AADT, Annual average daily traffic; BC, Black Carbon; BioSHARE, Biobank Standardization and Harmonization for Research Excellence in the European Union; CNOSSOS, Common Noise Assessment Methods for the EU Member States; CORINE, Coordination of Information on the Environment; CPR, Central Person Register; CVD, Cardio vascular disease; dB, Decibels; DEHM, Danish Eulerian Hemispheric Model; EEA, European Environment Agency; EU, European Union; GIS, Geographic Information Systems; HDV, Heavy-duty vehicle; LDV, Light-duty vehicle; L_{day}, Day (07:00 – 19:00) A-weighted equivalent continuous noise levels; L_{eve}, Evening (19:00 – 23:00) A-weighted equivalent continuous noise levels; L_{night}, Night (23:00 – 07:00) A-weighted equivalent continuous noise levels; L_{den}, Day-evening-night A-weighted equivalent continuous noise levels (5 dB penalty for evening-time noise, 10 dB penalty for night-time noise); $L_{Aeq,0h\ –\ Laeq,23h}$, Hourly A-weighted equivalent continuous noise levels; $L_{Aeq,16h}$, 16 hours A-weighted equivalent continuous noise levels; $L_{Aeq,24h}$, 24 hours A-weighted equivalent continuous noise levels; MB, Mean bias; N2kR, Nord2000 Road model; NO_x, Nitrogen oxides (µg/m^3); NO_2, Nitrogen dioxide (µg/m^3); OSPM®, Operational Street Pollution Model; ppb, Parts per billion; PM, Particulate matter; PNC, Particle number concentration; PM_{10}, Mass concentrations of particulate matter less than 10 µm in aerodynamic diameter (µg/m^3); $PM_{2.5}$, Mass concentrations of particulate matter less than 2.5 µm in aerodynamic diameter (µg/m^3); r, Correlation coefficient; r_S, Spearman's rank correlation coefficient; r_P, Pearson's correlation coefficient; RMSE, Root-mean squared error; RTN-96, Nordic Road Traffic Noise – 1996 method; SPREAD, Spatial High Resolution Emission to Air Distribution Model; UBM, Urban Background Model; veh/day, Number of vehicles per day; WHO, World Health Organization; WRF, Weather Research and Forecasting Model.

1. Introduction

Road traffic in urban areas gives rise to both air pollution and noise. According to the European Environment Agency, road traffic is the largest source of noise pollution (EEA, 2017) and contributes significantly to air pollution (e.g. NO_x, NO_2, $PM_{2.5}$) in Europe (EEA, 2016a; EEA 2019). There is significant and growing evidence linking various health impacts with exposures to air pollution and noise e.g. cardiovascular disease (Cai et al., 2018; Van Kempen et al., 2018), increased blood pressure and hypertension (Pitchika et al., 2017), diabetes (Eze et al., 2017; Van Kempen et al., 2018), morbidity (Zock et al., 2018) and mortality (Mueller et al., 2018; Nieuwenhuijsen et al., 2018). In addition, many researchers (Stansfeld, 2015; Smith et al., 2017) report confounded health effects due to exposure to either air pollution or noise.

There is a growing number of studies (e.g. Allen et al., 2009; Foraster et al., 2011; Khan et al., 2018b), which reflect upon the need of more scientific knowledge related to air-noise relationship and their so-called combined exposures. Nevertheless, evaluating the combined exposure of both pollutions is one of the biggest challenges of today (Tenailleau et al., 2016), since tools that facilitate such assessments are not yet available or well known to the scientific community (Khan et al., 2018b). Therefore, further research in this context is required to facilitate health-related studies to

(i) improve the understanding of combined and/or independent health impacts (ii) adjust for air pollution in noise studies and vice versa.

Few studies (e.g. Tang & Wang, 2007; Davies et al., 2009; Fecht et al., 2016) have quantified the air-noise correlations. In particular, air-noise spatial associations have been explored (e.g. Weber & Litschke, 2008; Allen et al., 2009; Shu et al., 2014) using personal and/or fixed-site monitoring. However, monitoring activities are unavoidably labour intensive as well as expensive, and not suitable for large health-related studies (Nieuwenhuijsen, 2015). Thus, epidemiological studies on city scale (1 km^2 – 5000 km^2) and/or regional scale (5000 km^2 – 10000 km^2) have to rely on residential exposure estimates from ambient pollution dispersion/exposure models (Beelen et al., 2009; Gan et al., 2012; De Roos et al., 2014; Bilenko et al., 2015).

Recently, we conducted a comprehensive review (Khan et al., 2018b) of tools and techniques related to air pollution and noise exposure assessment. The review included both modelling and monitoring studies, and showed that air-noise correlation structure ($r = 0.05 – 0.74$) varies substantially among studies. In addition, several study parameters e.g. traffic attributes such as annual average daily traffic (AADT) (Foraster et al., 2011; Gan et al., 2012), and traffic speed (Shu et al., 2014), building height (Tang & Wang, 2007; Weber et al., 2014), building density (Foraster et al., 2011; Shu et al., 2014), and modelling technique (Khan et al., 2018) have been highlighted to have a direct influence on air-noise relationship. However, how and to what extent these parameters affect relationship of both pollutants has not yet been studied, in detail. The majority of the health-related studies on noise exposure (e.g. Van Kempen et al., 2017) include air pollution as a confounder, whereas for air pollution studies this is not a standard. Moreover, to our knowledge, little is known about air-noise associations in the Danish context, and no study has been conducted so far explicitly on the spatial relationship of air pollution and noise.

Thus, there are three main objectives of this research work. First, to develop a tool to model exposures to air pollution and noise. Second, to study the correlation between both pollutants and third, to investigate the influence of traffic speed and AADT on air-noise correlations. In this paper, we present results from two case studies in the Danish cities of Copenhagen and Roskilde, as part of our investigation of the relationship between air pollution and noise.

2. Materials and methods

This study analysed the spatial relationship of modelled air pollution and noise levels (annual averages, year 2005) at address locations in the Danish cities of Copenhagen (study site 1, N = 11000), and Roskilde (study site 2, N = 1500). The following sections describe the study sites, modelling of air pollution and noise, and assessment methodologies.

2.1 Study sites

The two study sites (Figure 1) of Copenhagen and Municipality of Roskilde (hereafter, Roskilde) were chosen as modelled noise estimates from one of the Nordic standards, Road Traffic Noise 1996 (RTN-96) (Jonasson & Nielsen, 1996) (see section 2.4 for more details), were available for comparison.

Copenhagen is the capital and most populous city of Denmark. As of January 2018, the urban area of Copenhagen as shown in Figure 1A had a population of 777,218 (502,362 in the year 2005) (Statistics Denmark, 2018). The urban landscape of Copenhagen is dominated by the dense streets and the buildings including major highways (Figure 1A). Whereas Roskilde (Figure 1B) as compared to Copenhagen has a significant variation in terms of land cover, i.e. more open areas and less number of buildings and streets. However, some major highways can also be seen here. The city had a population of 50,046 as of 1 January 2016 (45,807 in the year 2005) (Statistics Denmark, 2016).

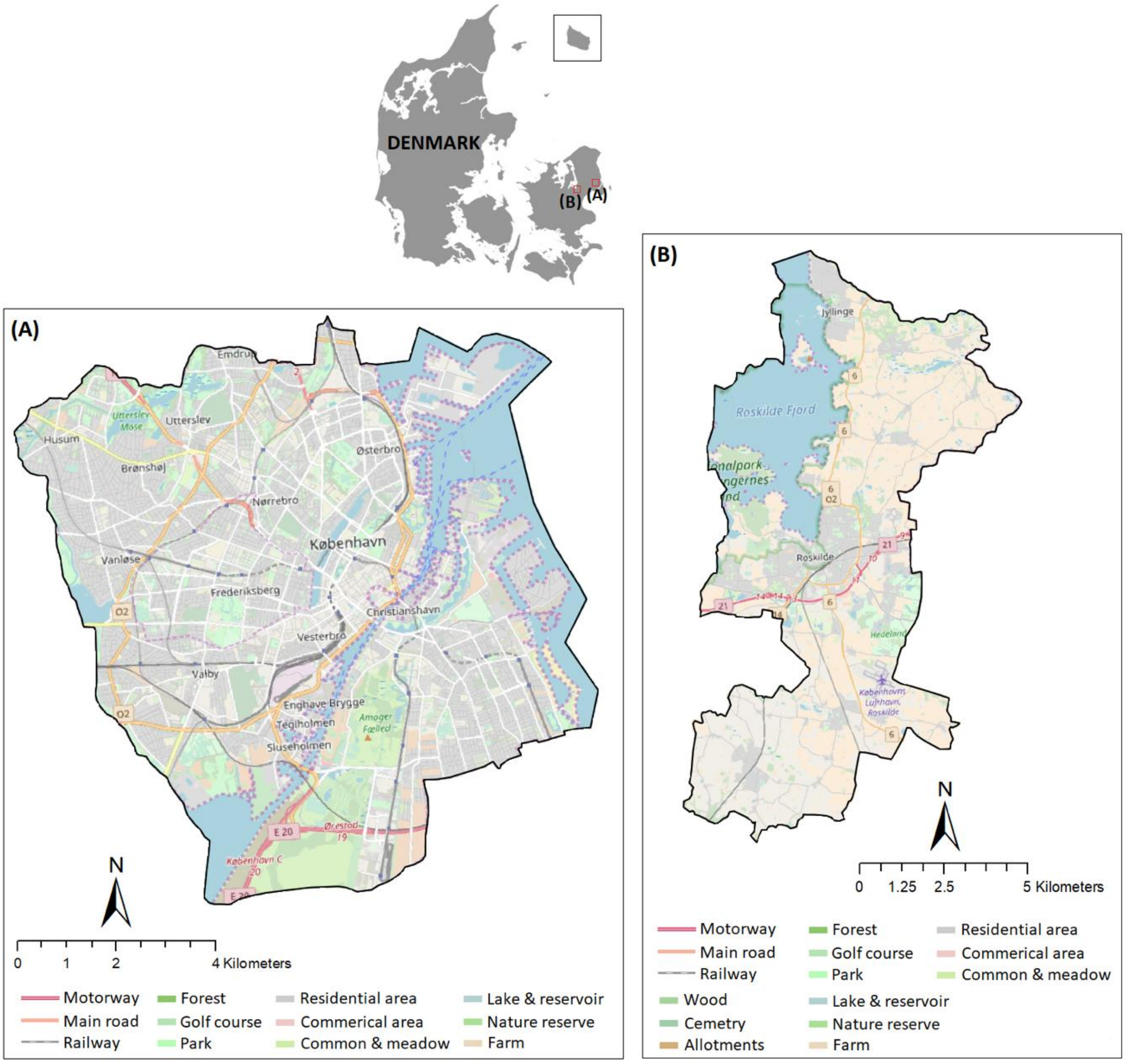

Figure 1: The location of the two study sites in Denmark: (A) Copenhagen and (B) Roskilde (Background map source: OpenStreetMaps).

2.2 Noise model computations

We modelled A-weighted noise (dB) using CNOSSOS (Kephalopoulos et al., 2012), the European Commission's recommended method for strategic noise mapping, which is mandatory for all EU member states after 31 December 2018 (European Commission, 2016a; Kephalopoulos & Paviotti, 2016). Morley et al., (2015) implemented CNOSSOS noise modelling framework (road module) to produce noise exposure estimation for a number of European countries as part of the EU funded

BioSHaRE (Biobank Standardization and Harmonization for Research Excellence in the European Union) project (http://www.bioshare.eu/) (e.g. Cai et al., 2017).

Morley et al., (2015) developed and tested six models (A – F) to analyse the importance of data types in terms of noise prediction. Model A contained the highest resolution and most detailed inputs (e.g. OpenStreet MasterMap® as land cover) typically used for city-scale modelling, whereas, model F contained the lowest resolution inputs (e.g. ~ 100 m CORINE land cover) (EEA, 2016b). Moreover, models B – E showed a gradual shift to coarser inputs by degrading the resolution of one input dataset at a time. Models validation showed a strong linear relationship (Spearman's rank: r_s = 0.74 – 0.91) for lowest to highest resolution models. Interested readers are referred to *Tables 2 and 3, p. 335 – 336,* Morley et al., (2015) for further details.

In this study, mainly due to data availability issues, an approach close to model D is used. That is, the CNOSSOS model algorithm, acquired from Morley et al., (2015), is utilized with AADT (LDV/HDV; there was an option to run with more parameters but these were not available as stated above), buildings footprints with estimated heights, and CORINE land cover. The details regarding model inputs and their sources are as follows.

CNOSSOS requires hourly LDV and HDV values. In Denmark, road traffic information is based on a national road and traffic database in form of a GIS shapefile of road centrelines with most relevant attributes being road width, AADT, HDV share, traffic speed etc. (Jensen et al., 2009a). Information on building footprints is available as a polygon shapefile based on a national dataset (Kort10DK), which is obtained from the Danish Geodata Agency (http://gst.dk/). The building footprints include the estimated building height based on national elevation model having 1 m x 1 m resolution. Geocoded address locations are also obtained from the same agency as a point shapefile.

The above information was used to prepare input datasets (addresses, road network, building footprints with heights) for CNOSSOS. An automatic script written in open-source software

PostgreSQL (hereafter, Postgres) (PostgreSQL Global Development Group, 2018), and hourly traffic composition profiles of the Operational Street Pollution Model (OSPM®) (Berkowicz, 2000a; Kakosimos et al., 2010) were used to estimate hourly LDV, HDV, and traffic speed for each street. In addition, CORINE land cover data (version 2012), freely available from the European Environment Agency (EEA, 2016b), was used to include several categories of land cover (e.g. urban fabric, open space with little or no vegetation) with a spatial resolution of 100 m.

The CNOSSOS model also takes into accounts for meteorology in terms of an annual average temperature, and a proportion of time in which a receptor is downwind of each source (i.e. in a favourable direction for sound propagation) (Kephalopoulos et al., 2012). These data were derived from the Danish Air Quality Monitoring Programme (Ellermann et al., 2018). Due to relatively small size of study areas (Figure 1), meteorological conditions (temperature and wind speed) were considered to be the same for all address locations. Furthermore, the CNOSSOS algorithm required address points at 1 meter in front of the building façade. Thus, another Postgres script was used to move all address points (both study sites) from the inside of the building polygons to the required locations.

CNOSSOS has already been tested in some of the Nordic countries; e.g. Finland (Kokkonen et al., 2016; Maijala & Kontkanen, 2016) and Sweden (Larsson, 2016). These studies suggest a few adjustments to CNOSSOS in terms of sound power coefficients, surface corrections etc. for its use in the Nordic countries. Thus, we made three changes in the CNOSSOS script. First, we used sound power coefficients of the standard Nordic noise prediction method i.e. Nord2000 Road (N2kR) (Danish EPA, 2006), instead of the default CNOSSOS coefficients. The Nordic sound power coefficients were taken from Jonasson (2006). It was done to reflect upon the dense asphalt concrete (DAC) road surface conditions as suggested in the literature (see Kragh, 2011 for more details). Second, temperature correction coefficients (0.10, 0.05), also obtained from Jonasson (2006), were used instead of the default values. Third, we manually updated the AADT values in the

CNOSSOS script for minor roads to 200 vehicles a day. The figure is based on the Danish road and traffic database (Jensen et al., 2009a; 2019).

The CNOSSOS model is implemented in Postgres via its spatial extension, PostGIS (PostGIS, 2018). The geometric operations involved in the model algorithms are provided in Morley et al., (2015), and are not described in detail here. In short, through various spatial operations, noise levels at source and receptor (propagation along ray paths) are calculated and logarithmically summed together to produce the final noise estimate.

The annual average hourly noise levels in A-weighted decibels ($L_{Aeq,0h}$ – $L_{Aeq,23h}$) were modelled. *A-weighting* is the most commonly used frequency weighting (NoiseMeters Inc., 2017), usually denoted by L_A. It covers full audio range (20 Hz to 20 kHz) perceivable by the human ear (IEC 61672-1, 2013; Gracey & Associates, 2017). In addition to above, day-time noise i.e. L_{day} (07:00 – 19:00), evening-time noise i.e. L_{eve} (19:00 – 23:00), night-time noise i.e. L_{night} (23:00 – 07:00), and L_{den} (day-evening-night time noise) were estimated. Furthermore, hourly noise levels were averaged to compute A-weighted 24-hourly noise, $L_{Aeq,24h}$. L_{den} and L_{night} are the recommended noise metrics to assess health impacts due to noise exposure (European Commission, 2016b). To comply with the European Commission's directives (EC, 2007), the receptor point for noise modelling was at 4 meters above the ground.

2.3 Air pollution model computations

The new AirGIS system (Khan et al., 2018c) produces input parameters based on national GIS datasets and handles the dataflow in connection with the Operational Street Pollution Model OSPM®. AirGIS is the final part of DEHM/UBM/AirGIS, the Danish multi-scale human exposure modelling system to estimate air pollution concentrations at high spatial (any address location in Denmark) and temporal (hourly) resolution. The modelling system estimates concentrations for many gaseous and particulate pollution components, while this study uses only NO_x, NO_2, PM_{10} and $PM_{2.5}$.

The new AirGIS system is a substantially revised version of the former system (Jensen et al., 2001). In the former system, an Avenue script for ArcView 3.x together with shapefiles for roads, buildings and addresses was used to generate traffic and street configuration inputs for OSPM®. In the new system this has been re-programmed using Postgres database for management of input data, and PostGIS for calculations as well as using R-scripts as interface. The comparison of the two systems as well as detailed description of the new system is provided in Khan et al., (2018c). Moreover, the new system has been validated in two recent studies for PM_{10}, $PM_{2.5}$, BC (Hvidtfeldt et al., 2018) and NO_x, NO_2, PM_{10}, $PM_{2.5}$ (Khan et al., 2018c). New model validation showed Pearson's correlation coefficient (r_P) in the ranges 0.45 – 0.96 and 0.32 – 0.92 in terms of reproducing temporal (single location, time-series of concentrations, e.g. annual, daily averages), and spatial (various sites, single time period) variation of the observed air pollution levels. The architecture and operation of the new AirGIS system is briefly summarized in the following sub-section.

The coupled DEHM/UBM/AirGIS system estimates the total concentration for each air pollutant based on three contributions, obtained from a chain of dispersion models containing the Danish Eulerian Hemispheric Model (DEHM), the Urban Background Model (UBM) and the Operational Street Pollution Model (OSPM®). The **DEHM** (Christensen, 1997) computes the regional background contributions in a 5.6 km x 5.6 km grid resolution for Denmark. It is a three-dimensional, offline, Eulerian, long-range atmospheric chemistry transport model developed to study transport of air pollution on the Northern Hemisphere. DEHM takes into account the emissions from all source categories including traffic, industrial units, power plants, small-scale combustion etc. (Brandt et al., 2012).

The **UBM** (Berkowicz, 2000b) computes the urban background contributions in a resolution of 1 km x 1 km. It is a multiple source model that uses a Gaussian approach for horizontal dispersion and a linear model for vertical dispersion up to the boundary layer. Whereas, the **OSPM®** computes the street contributions taking the background concentrations from DEHM/UBM as input. OSPM® uses a combination of a plume model for the direct contribution from the traffic source and a box model for the recirculating part of the pollutants inside street canyon environment. In case the address is located along roads having AADT < 500 veh/day, only the urban background concentration is assigned. Otherwise, the street pollution model OSPM® is applied additionally to the urban background (also referred as "total" air pollution concentrations).

The emissions database for Denmark, having a high spatial resolution of 1 km x 1 km, is based on the SPREAD methodology (Plejdrup and Gyldenkærne, 2011). The emissions data as well as meteorological datasets (wind direction and speed, air temperature etc.), based on the WRF model (NCAR, 2018), are input to the whole model chain DEHM/UBM/AirGIS.

In terms of GIS inputs, the same road geography and building footprints were used in the noise and air pollution models in order to harmonise input datasets. The GIS input data included address locations with exposure period, streets with traffic attributes (AADT, traffic speed etc.) and buildings with building heights. The detailed working operation of new AirGIS is provided in Khan et al., (2018c). In summary, the input data is imported into a Postgres database with its spatial extension, PostGIS that performs all GIS calculations. Subsequently, input files for OSPM® calculations in the required format are produced. Thereafter, OSPM® runs take place to compute street concentrations.

All OSPM® calculations were performed on hourly basis. To maintain synergy with noise calculations, the receptor points were 4 meters above the ground, that is, at the façade of the building closest to the address point. The modelled air pollution concentrations were averaged annually (year 2005), corresponding to the noise model computations.

2.4 Comparison of RTN-96 and CNOSSOS noise datasets

In this section, information regarding noise comparison data is summarized.

RTN-96 noise estimated data was obtained for both study sites (same address locations) to compare it with CNOSSOS noise estimates. The RTN-96 (Jonasson & Nielsen, 1996) is one of the Nordic noise prediction standards usually available in SoundPLAN Nordic[1] software. The dataset including L_{day} (07:00 – 19:00), L_{eve} (19:00 – 22:00) and L_{night} (22:00 – 06:00) (annual averages, year 2005) was acquired from an earlier Danish project (Sørensen et al., 2014). These averaging times (e.g. L_{night}) were slightly different than the CNOSSOS ones described in section 2.2.

Although, similar GIS data (e.g. road network, building footprints), compared to our noise modelling, was used in noise estimation using RTN-96. The input files used in SoundPLAN software (based on RTN-96), however, were not available. Therefore, it was not possible to compare inputs of SoundPLAN and CNOSSOS. Moreover, noise estimates at several building floors using RTN-96 were available, which was not possible in case of CNOSSOS. Consequently, in this study, only ground floor noise estimates of the two noise models are compared. For the ground level, the height of the RTN-96 calculation points was set to 2 m, whereas the height of the CNOSSOS calculation points was set to 4 m (see section 2.2). Further details of the two datasets are provided in supplementary material (Appendix A).

2.5 Spatial and statistical analyses

We used Spearman's correlation coefficients (r_S) to explore the space and time correlation between modelled air pollution (NO_x, NO_2, PM_{10}, $PM_{2.5}$) and noise (L_{day}, L_{eve}, L_{night}, L_{den}, $L_{Aeq,24h}$) metrics, separating background points (< 500 veh/day) and street/OSPM® points (≥ 500 veh/day). Correlations of background and total (street + background) air pollution with noise were computed to analyse how noise correlate with the urban background and the street levels of air pollution. In addition, the Pearson's correlations (r_P) are computed and provided in supplementary material. To compare CNOSSOS and RTN-96 noise estimates, several statistical measures i.e. minimum (Min), maximum (Max), median (Med), root-mean-squared error (RMSE), mean bias (MB), normalized

[1] See: http://soundplan.dk/

mean bias (NMB) are computed. The definitions of the statistical measures are provided in supplementary material (Appendix B). All statistical analyses were performed in R software version 3.6.2.

2.6 Parameters affecting air-noise correlations

As an innovative part of this research work, we studied the influence of selected study parameters on air-noise correlation. These parameters, which included AADT and traffic speed, are used to perform sensitivity analyses on the air-noise relationship. Due to the large number of address locations (N = 11000), we conducted these separate analyses (test cases) only for the Copenhagen site. These analyses were supplemented by several parallel DEHM/UBM/AirGIS and CNOSSOS model runs. Details are summarized in the following sub-section.

2.6.1 AADT and traffic speed

Five test cases were selected based on AADT in the range 1000 – 30000 veh/day. For each case (e.g. 1000 veh/day), the same AADT was assigned to all roads in the study area, and traffic speed was set to 40 km/h. Subsequently, air (NO_2) and noise pollution (L_{den}) calculations (annual average, year 2005) were performed for all the cases. The Spearman’s correlation coefficients of background and street levels of air pollution (NO_2) with the corresponding noise (L_{den}) levels were computed. The correlations were plotted against AADT values to analyse its influence on air-noise relationship.

Likewise, five cases of traffic speed in the range 40 – 80 km/h were defined. For each case, same traffic speed was assigned to the whole road network, and AADT was set to 10000 veh/day. Air pollution and noise (NO_2 and L_{den}) levels were calculated (annual averages, year 2005) for all cases. Finally, correlation coefficients were computed and plotted against the traffic speed to study its effect on air-noise association.

3. Results and discussions

3.1 Air-noise correlations

This section presents the results of spatial distribution of both pollution levels at address locations (N=11000 and 1500) in the Danish cities of Copenhagen and Roskilde. In addition, air-noise correlations are also presented and discussed.

Figures 2 and 3 show the spatial patterns of modelled noise (L_{den} in dB) and air pollution (NO_2 in ppb) levels in Copenhagen and Roskilde. In terms of NO_2 (Figures 2a and 3a), street points (≥ 500 veh/day) and background points (< 500 veh/day) are shown separately. Let us recall, the street and the background air pollution concentrations are combined (total air pollution) when AADT ≥ 500 veh/day (see section 2.3). In both study sites (Figures 2 and 3), modelled L_{den} and NO_2 levels are higher determined by the promixity to the major roads, and vary generally smoothly close to the minor/less busy roads. Same spatial patterns were observed for other air pollution and noise metrics. The estimated noise (e.g. L_{den}: 44 – 66.2 dB) in Roskilde, however, was generally lower than the ones (e.g. L_{den}: 45 – 70 dB) in Copenhagen. This is due to more number of less busy roads in Roskilde.

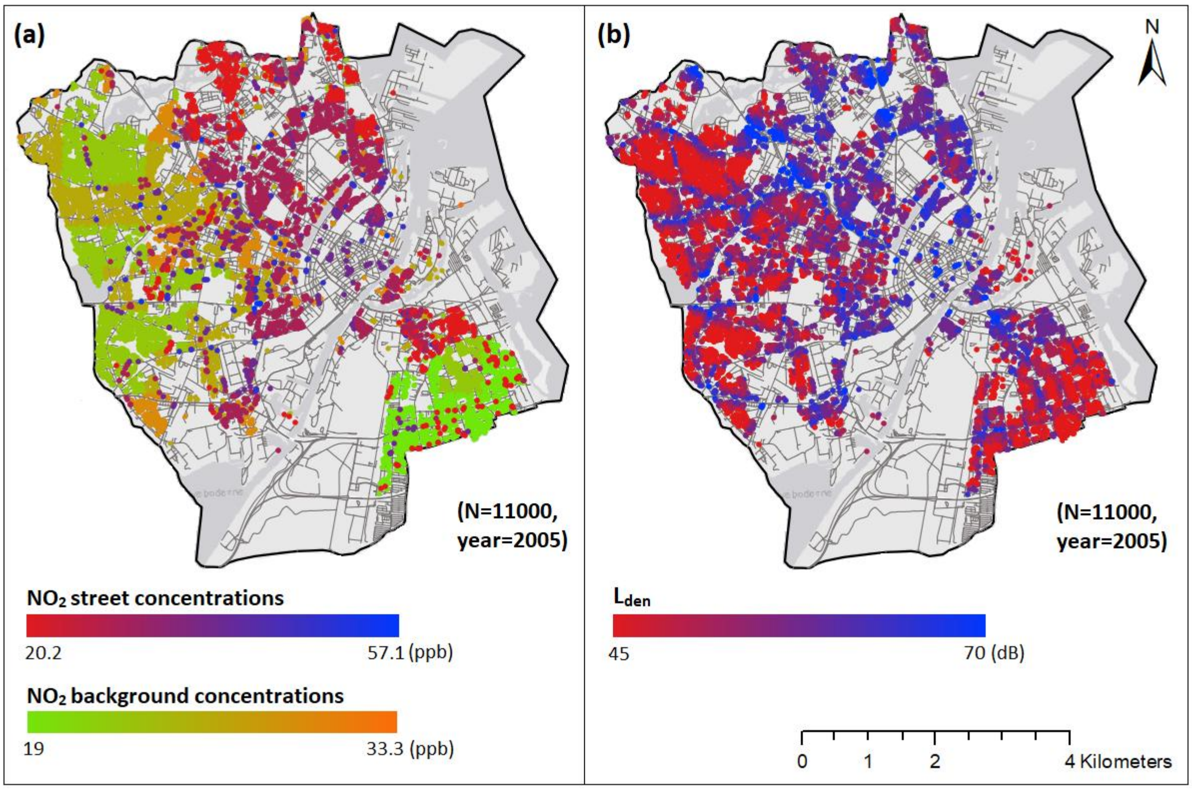

Figure 2: The spatial distribution of (a) air pollution (NO_2 in ppb) and (b) noise (L_{den} in dB) levels at address locations (N = 11000) in Copenhagen, Denmark. For NO_2, left panel (a), receptor points are split into street and background points based on the AADT on the nearby street. The background (N = 7000, AADT < 500 veh/day, no OSPM® applied) (red to blue) and the street points (N = 4000, AADT ≥ 500 veh/day, with OSPM®) (light green to orange) are shown in separate colour scales.

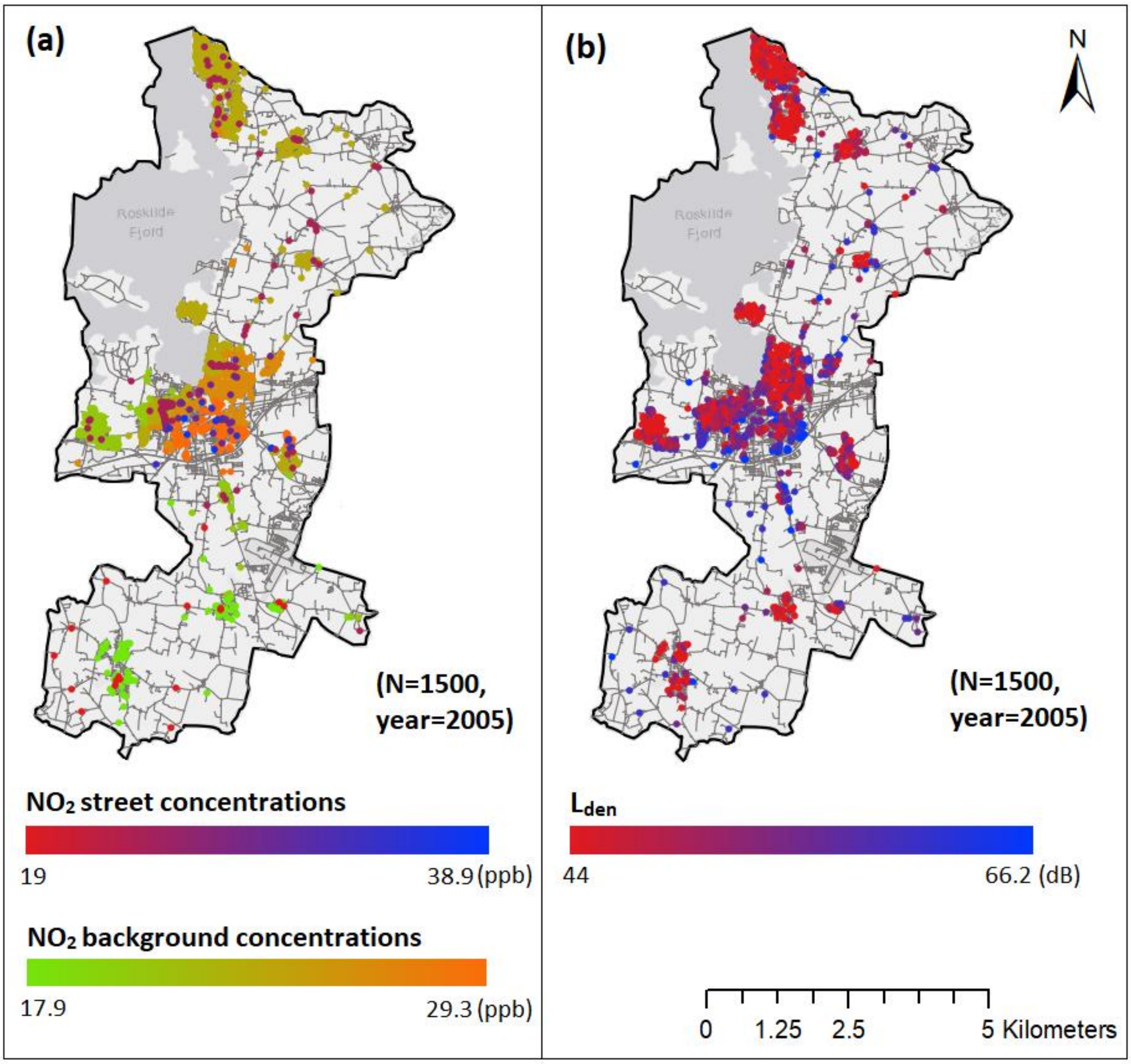

Figure 3: The spatial distribution of (a) air pollution (NO_2 in ppb) (left) and (b) noise (L_{den} in dB) (right) levels at address locations (N = 1500) in Roskilde, Denmark. For NO_2, left panel (a), receptor points are split into street and background points based on the AADT on the nearby street. The background points (N = 7000, AADT < 500 veh/day, no OSPM® applied) (red to blue) and the street points (N = 4000, AADT ≥ 500 veh/day, with OSPM®) (light green to orange) are shown in separate colour scales.

Tables 1 and 2 show Spearman's rank correlations (r_S) among various air pollutants and noise at street sites (≥ 500 veh/day, "total" air pollution and noise), and background sites (< 500 veh/day, background air pollution and noise) in Copenhagen and Roskilde. Pearson's correlations (r_P) are provided in supplementary Tables S1 and S2, appendix C. All computed correlations (Tables 1, 2 and Tables S1, S2) are statistically significant (p value < 0.001). The intra-class correlations (Table 1, both street and background sites in Copenhagen) were very strong for noise metrics (r_S = 0.99); varied significantly for air pollutants (overall r_S = 0.50 – 0.99). Moreover, both PM_{10} and $PM_{2.5}$ ($\mu g/m^3$) correlated poorly (r_S = 0.27 and r_S = 0.24) with L_{den} at street sites (Table 1), and didn't show any association (r_S = 0.04 – 0.06) with L_{den} at background sites. Same correlation patterns were observed between other noise metrics and PM_{10}, $PM_{2.5}$.

The correlations between NO_x and NO_2 (ppb) and L_{den}, at both street and background sites, were moderate with overall range r_S = 0.35 to r_S = 0.41 (Table 1). Vardoulakis et al., (2003) reported that the roadside air pollution concentrations usually consist of two components, the persistent urban background levels and the direct vehicle emissions. Hence, above moderate correlations highlight the background levels of air pollution as one of the key drivers of air-noise relationship, especially in the urban settings. The same was reported by King et al., (2016), who performed combined assessment of both pollutions in New York, the United States.

In Roskilde (Table 2, both street and background sites), the associations were again strong between the different noise metrics (r_S = 0.99); varied significantly among air pollutants (overall r_S = 0.54 – 0.99). Here, PM_{10} and $PM_{2.5}$ correlated negatively (r_S = -0.02 to r_S = -0.14, Table 2) with L_{den}. In addition, correlations between NO_x, NO_2 (street and background concentrations) and L_{den} were generally lower (r_S = 0.16 to r = 0.28) than those for Copenhagen. This is, again, mainly due to more number of less busy roads in Roskilde. Similar patterns of correlations were observed among other noise metrics and air pollutants (Table 2).

Table 1: Spearman's correlation coefficients of noise and total air pollution (street sites: N = 4000, ≥ 500 veh/day) and background air pollution (background sites: N = 7000, < 500 veh/day) in Copenhagen, Denmark. All correlations are statistically significant ($p < 0.001$). NO_x and NO_2 are given in ppb while PM_{10}, $PM_{2.5}$ in µg/m^3. All noise metrics are given in dB.

Street sites in Copenhagen									
	Noise					Air pollutants			
	L_{day}	L_{eve}	L_{night}	L_{den}	$L_{Aeq,24h}$	NO_x	NO_2	PM_{10}	$PM_{2.5}$
L_{day}	-	0.99	0.99	0.99	0.99	0.41	0.42	0.27	0.24
L_{eve}		-	0.99	0.99	0.99	0.40	0.41	0.27	0.23
L_{night}			-	0.99	0.99	0.38	0.39	0.25	0.23
L_{den}				-	0.99	0.39	0.41	0.27	0.24
$L_{Aeq,24h}$					-	0.41	0.42	0.27	0.25
NO_x						-	0.95	0.76	0.68
NO_2							-	0.71	0.66
PM_{10}								-	0.98
$PM_{2.5}$									-
Background sites in Copenhagen									
	L_{day}	**L_{eve}**	**L_{night}**	**L_{den}**	**$L_{Aeq,24h}$**	**NO_x**	**NO_2**	**PM_{10}**	**$PM_{2.5}$**
L_{day}	-	0.99	0.99	0.99	0.99	0.35	0.35	0.05	0.03
L_{eve}		-	0.99	0.99	0.99	0.35	0.36	0.05	0.03
L_{night}			-	0.99	0.99	0.34	0.34	0.06	0.04
L_{den}				-	0.99	0.35	0.35	0.06	0.04
$L_{Aeq,24h}$					-	0.35	0.34	0.05	0.03
NO_x						-	0.99	0.57	0.50
NO_2							-	0.58	0.52
PM_{10}								-	0.99
$PM_{2.5}$									-

Table 2: Spearman's correlation coefficients of noise and total air pollution (street sites: N=200, ≥ 500 veh/day) and background air pollution (background sites: N=1300, < 500 veh/day) in Roskilde, Denmark. All correlations are statistically significant ($p < 0.001$). NO_x and NO_2 are given in ppb while PM_{10}, $PM_{2.5}$ in µg/m^3. All noise metrics are given in dB.

Street sites in Roskilde									
	Noise					Air pollutants			
	L_{day}	L_{eve}	L_{night}	L_{den}	$L_{Aeq,24h}$	NO_x	NO_2	PM_{10}	$PM_{2.5}$
L_{day}	-	0.99	0.99	0.99	0.99	0.27	0.14	-0.02	-0.13
L_{eve}		-	0.99	0.99	0.99	0.26	0.13	-0.04	-0.14
L_{night}			-	0.99	0.99	0.27	0.16	-0.02	-0.12
L_{den}				-	0.99	0.26	0.16	-0.02	-0.13
$L_{Aeq,24h}$					-	0.27	0.15	-0.01	-0.12
NOx						-	0.97	0.77	0.66
NO_2							-	0.82	0.70
PM_{10}								-	0.92
$PM_{2.5}$									-
Background sites in Roskilde									
	L_{day}	L_{eve}	L_{night}	L_{den}	$L_{Aeq,24h}$	NO_x	NO_2	PM_{10}	$PM_{2.5}$
L_{day}	-	0.99	0.99	0.99	0.99	0.27	0.27	-0.02	-0.13
L_{eve}		-	0.99	0.99	0.99	0.26	0.26	-0.03	-0.14
L_{night}			-	0.99	0.99	0.27	0.28	-0.01	-0.13
L_{den}				-	0.99	0.27	0.28	-0.02	-0.14
$L_{Aeq,24h}$					-	0.26	0.27	-0.01	-0.13
NO_x						-	0.99	0.64	0.55
NO_2							-	0.64	0.54
PM_{10}								-	0.87
$PM_{2.5}$									-

The air-noise correlations in our study (Tables 1 and 2) generally seem to be lower to moderate. Lower to moderate correlations (contra high correlations) however are an advantage, if one wants to separate the effect of air pollution and noise in epidemiological studies. Similar air-noise associations have previously been documented. Linares et al., (2006) reported noise-NO_x, NO_2 correlation in the range 0.14 – 0.20. Gan et al., (2012) reported weak correlation (r = 0.14) between $PM_{2.5}$ (μg/m^3) and noise. Both above studies were based on measurements of pollution. Tobías et al., (2001) reported moderate noise-NO_2 associations (r = 0.32) in their work. Fecht et al., (2016) also reported moderate noise-PM correlations in the range 0.41 – 0.53; their analyses were based on various geographical units (Postcode level, census areas etc.), and did not distinguish between street and background levels of air pollution.

In addition to above, higher air-noise correlations have also been reported. Sørensen et al., (2014) found Pearson's correlations r_P = 0.62 (NO_2 and L_{den}) and r_P = 0.66 (NO_x and L_{den}), and Pyko et al., (2017) reported r = 0.56 between NO_x and L_{den} in their work. Furthermore, examples of negative air-noise correlation can also be seen in the literature. Shu et al., (2014) reported negative to lower positive PM-noise correlations (-0.36 – 0.12), however, none of the correlations was statistically significant. Likewise, Weber (2009) reported negative correlations (Pearson's: -0.18 and Spearman's: -0.21, not significant for $p < 0.05$) between total PNC and noise.

Differences in our modelled air pollution and noise levels and subsequently, their correlations are due to the following reasons. First, for address locations close to the major highways (both Copenhagen and Roskilde), estimated noise was high and air pollution was low (see Figure S1, appendix D). Reason being OSPM® does not take into account the contributions from highways as OSPM® calculates for the specific street in question and contribution from highway sources are only indirectly modelled thorough background concentrations (Jensen at al., 2017). This issue is described in detail in Appendix D, supplementary material. Second, some address locations in Roskilde were close to non-traffic emission sources (wood burning, industrial field etc.). In particular, due to wood burning, there was elevated modelled background PM as compared to low noise levels (see Figures S2 and S3, appendix D), which caused low and negative correlations (Table 2). Third, the use of coarser CORINE land cover data may have affected CNOSSOS performance to an unknown extent, which could also contribute to lower air-noise correlations. CNOSSOS, therefore, needs to be further tested with detailed land cover data (once available) in future air-noise assessments.

3.2 Parameters affecting correlations

This section evaluates the influence of AADT and traffic speed on air-noise correlations. The results presented here are based on separate assessments (test cases) conducted only in Copenhagen (N = 11000; annual averages of pollutions, year 2005) (see section 2.6).

3.2.1 Influence of AADT and traffic speed

Figures 4 and 5 show modelled (N = 11000, annual averages, year 2005) NO_2 and L_{den} as well as their correlation (Spearman's rank, r_S) as functions of increasing AADT and traffic speed. As expected, L_{den} increased logarithmically with the increase of AADT (Figure 4), and linearly with the increase of speed (Figure 5). NO_2 increased linearly with AADT, but decreased with speed in the examined speed interval of 40-80 km/h. The latter was, probably, due to the dependence of NO_x emissions on the vehicle speed. In addition, the L_{den}-NO_2 correlation changed from r_S = 0.23 to r_S = 0.32 with the increase of AADT (1000 – 30000 veh/day); it remained nearly constant with respect to increasing speed (40 – 80 km/h). Due to lack of similar studies, it was not possible to compare our findings with the existing literature.

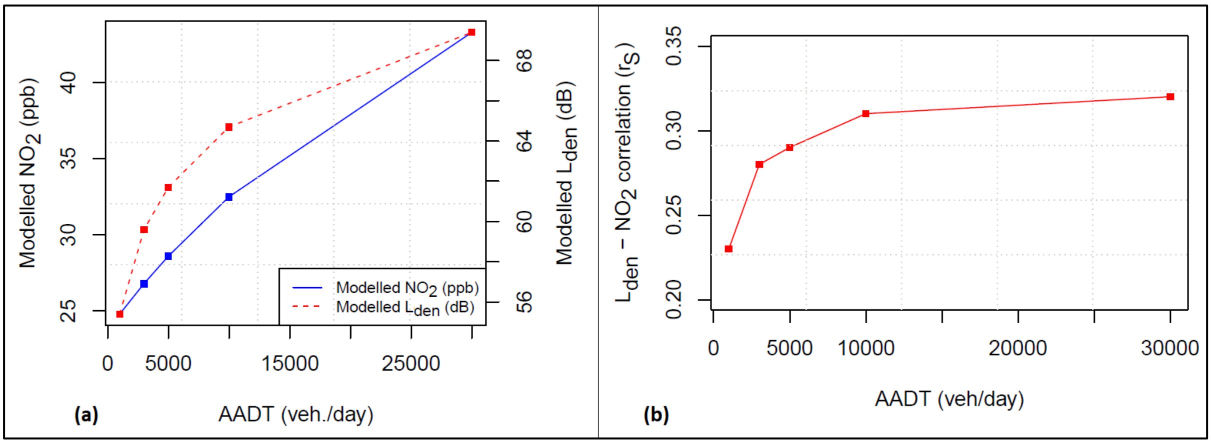

Figure 4: (a) modelled L_{den} (annual average, dB) and total NO_2 (street increment including background) (annual average, ppb) as functions of varying AADT (veh/day) (b) L_{den}-NO_2 correlation (Spearman's rank, r_S) as a function of varying AADT (veh/day). All correlations are statistically significant (p value < 0.001). Both pollution levels and computed correlations are for the fixed traffic speed = 40 km/h in Copenhagen (N = 11000, year 2005).

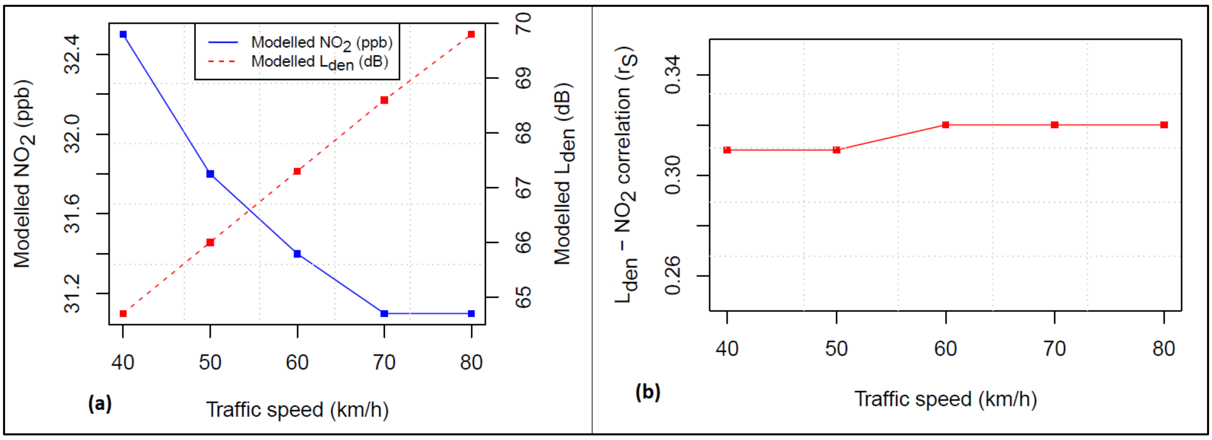

Figure 5: (a) modelled L_{den} (annual average, dB) and total NO_2 concentrations (street increment including background) (annual average, ppb) as functions of varying traffic speed (km/h) (b) L_{den}-NO_2 correlation (Spearman's rank, r_S) as a function of varying traffic speed (km/h). All correlations are statistically significant (p value < 0.001). Both pollution levels and computed correlations are for the fixed AADT = 10000 veh/day in Copenhagen (N = 11000, year 2005).

3.3 Modelled noise: CNOSSOS vs RTN-96

Figure 6 shows the comparison of annual average (2005) modelled noise (L_{day}, L_{eve}, L_{night} in dB) from CNOSSOS and RTN-96 at address locations in Copenhagen and Roskilde (N = 11000 and 1500). Table 3 presents the summary statistics of the modelled noise at same addresses. A strong overall correlation (range r_S = 0.84 – 0.90) can be seen between the modelled noise of CNOSSOS and RTN-96 (Figure 6). In addition, a few notable outliers can also be observed.

There was a significant difference and lower variation in the estimated noise of CNOSSOS (e.g. RMSE: 3.4 – 6 dB, Table 3) as compared to RTN-96 both in Copenhagen and Roskilde (see Table 3, and supplementary Figure S4, Appendix E). It has not been possible to fully explain these differences between RTN-96 and CNOSSOS. One limitation has been the missing access to the input data to the RTN-96 calculations. A number of reasons may be speculated to explain the observed differences. CNOSSOS was run with coarser CORINE land cover and simplified vehicle composition (LDV, HDV) as inputs. Moreover, a difference exists in the heights of the calculation points of the two models (CNOSSOS: 4 meters, RTN-96: 2 meters), and small differences in the time-averaging of L_{eve} and L_{night}.

Furthermore, CNOSSOS modelled noise at one single point (address location) at a time, whereas, RTN-96, for each address location, modelled noise by taking into account the maximum of all façade points (see section 2.4 and Appendix A, supplementary). However, lower variation in CNOSSOS estimated noise compared to RTN-96 indicates some exposure misclassifications. Such exposure misclassifications due to relatively course input data has been found to be problematic in relation to estimation of impacts on health such as myocardial infarction mortality (Vienneau et al., 2019). Therefore, further testing and evaluation of CNOSSOS with detailed inputs is necessary before it may be used for noise exposure assessments in Denmark.

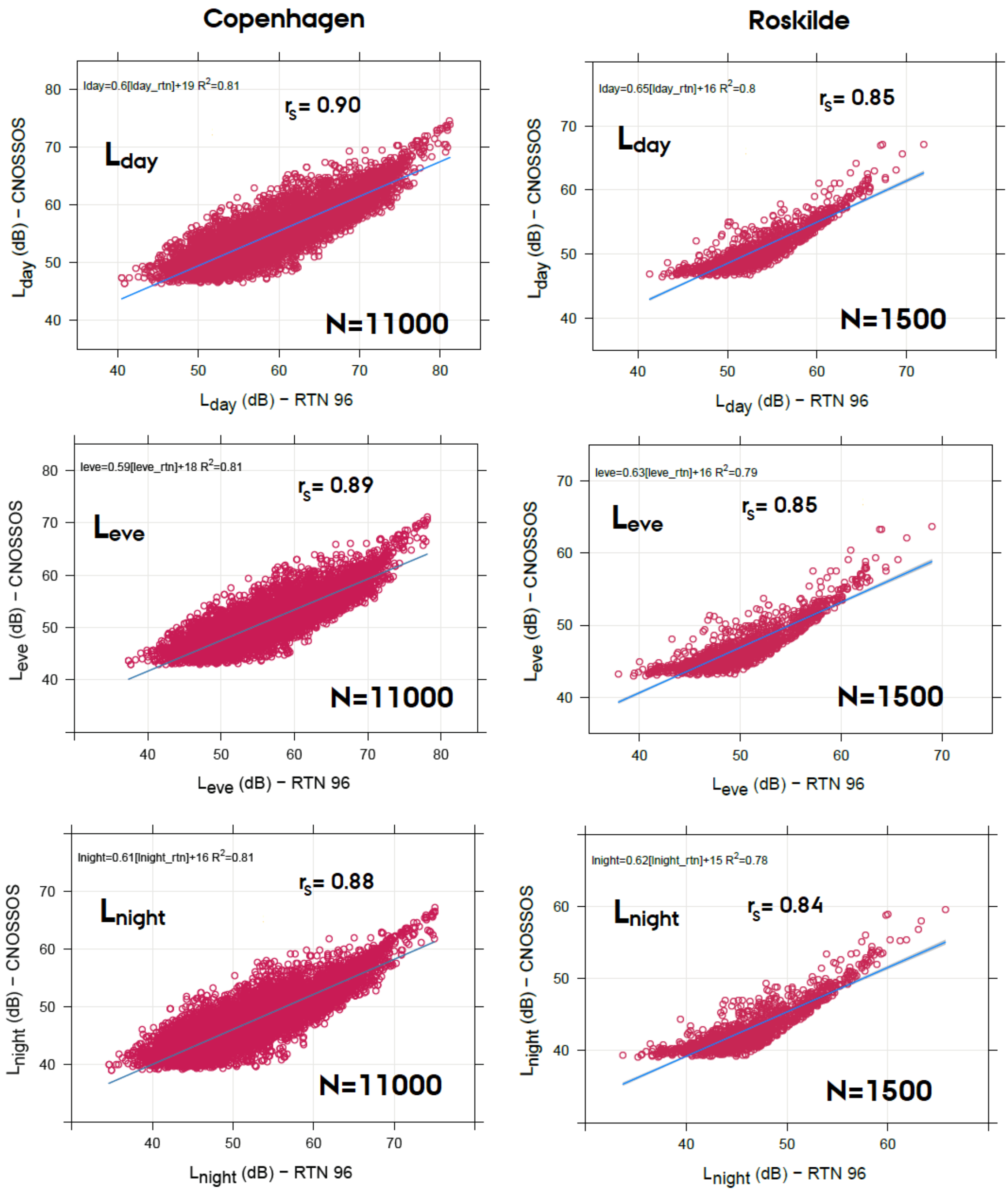

Figure 6: The comparison of the modelled noise (L_{day}, L_{eve}, L_{night} in dB) of CNOSSOS and RTN-96 at address locations in Copenhagen (N = 11000), and Roskilde (N = 1500). The comparison is only for the ground floor noise estimates (annual average, year 2005) with RTN-96 calculation points height = 2 m and CNOSSOS calculation points height = 4 m, r_S = Spearman's rank correlation coefficient.

Table 3: Summary statistics of the modelled noise (annual average, year 2005) of CNOSSOS and RTN-96 for the study sites in Copenhagen (N = 11000) and Roskilde (N = 1500). Note: Med = Median (dB), Min = Minimum (dB), Max = Maximum (dB), r_S = Spearman's rank correlation coefficient, RMSE = Root-mean squared error (dB), MB = Mean bias (dB), NMB = Normalized mean bias.

	RTN-96			CNOSSOS						
	Min	Max	Med	Min	Max	Med	RMSE	MB	NMB	Correlation (r_S)
Copenhagen										
L_{day} (dB)	40.4	81.2	59.8	46.3	74.6	54.8	5.4	-4.1	-0.07	0.90
L_{eve} (dB)	37.3	78.1	56.4	42.8	71	50.9	6	-4.9	-0.08	0.89
L_{night} (dB)	34.5	75	52.5	38.9	67.1	47.1	5.9	-4.8	-0.09	0.88
Roskilde										
L_{day} (dB)	41.3	71.9	52.5	46.4	67.1	49.7	3.4	-2.6	-0.05	0.85
L_{eve} (dB)	37.9	69	49.2	42.9	63.6	45.8	3.8	-3.1	-0.06	0.85
L_{night} (dB)	33.7	65.7	45.4	39	59.5	41.9	3.8	-3.1	-0.06	0.84

4. Strengths and limitations

This study explicitly explores the spatial relationship of air pollution and noise at residential addresses in Denmark, and investigates the influence of selected parameters on this relationship. Moreover, the use of harmonized input data based on the similar geographical structure led to the development of a tool to model both exposures at the same time. This is particularly important because published literature (e.g. European Commission 2016c; Khan et al., 2018b) highlights the need of such tools to facilitate health-related studies. Furthermore, noise estimates from CNOSSOS with relatively coarser input data are compared to the RTN-96 calculated noise, which is one of the noise prediction standards in the Nordic countries.

Our study also has limitations. The use of coarser inputs such as 100 m CORINE land cover, simplified vehicle composition (LDV, HDV) in noise modelling using CNOSSOS, as compared to the higher quality (and resolution) input data in RTN-96 (as well as air pollution estimation). In addition, with regard to comparison between CNOSSOS and RTN-96, there is a number of differences in input data. All above may explain the lower levels of noise and much lower variation seen for CNOSSOS. Moreover, air pollution contributions from highways are not properly described in OSPM®, as highlighted above. This may also introduce errors in air pollution estimates.

There was an offset of 1 m between the noise calculation points of the CNOSSOS and the RTN-96. Thus, a comparison of their estimated noise at same address locations was not possible. Lack of measured noise data, due to inherent problems with estimation of noise for validation of modelled values, made it impossible to evaluate CNOSSOS model performance against field measurements. Also, the results presented here are based on air-noise assessments conducted in a relatively small geographical area (both sites), and for selected address locations in a single year 2005.

5. Conclusions

In this study, the spatial relationship of air pollution and noise has been investigated at address level, in the Danish cities of Copenhagen and Roskilde. In conjunction, a tool based on the new AirGIS system (DEHM/UBM/AirGIS) together with the OSPM®, and the CNOSSOS has been developed, and used to model exposure to both types of pollution using datasets based on similar geographical structure. Overall, correlations were weak, and moderately stronger at sites in proximity to traffic than background sites. In some cases in Roskilde, air-noise correlations were negative mainly due to the influence of wood burning. In summary, Spearman's rank air-noise correlation varied significantly in the range |0.01 – 0.42|, which suggests a potential to determine the independent health effects of both stressors.

The background concentrations of air pollution have significant influence on street-level air pollution, and subsequently air-noise relationship in urban settings. However, non-traffic emission sources (e.g. wood burning) also affect associations. Among traffic attributes neither AADT nor traffic speed showed substantial influence on air-noise correlation. Moreover, there were significant differences in CNOSSOS estimated noise, in terms of lower noise levels and much lower variation in predicted noise, as compared to RTN-96 noise estimates in both Copenhagen and Roskilde.

6. Outlook

More work needs to be done to (i) further test and evaluate CNOSSOS using higher quality inputs (e.g.~10 m land cover polygons, detailed vehicle composition), and compare its modelled noise with the field measurements to analyse model's feasibility for noise exposure studies in Denmark (ii) address and reduce OSPM® underestimations along highways using specific highway air pollution models.

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Declaration of Competing Interest

The authors declare no competing interests.

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Table 1: Spearman's correlation coefficients of noise and total air pollution (street sites: N = 4000, ≥ 500 veh/day) and background air pollution (background sites: N = 7000, < 500 veh/day) in Copenhagen, Denmark. All correlations are statistically significant ($p < 0.001$). NO_x and NO_2 are given in ppb while PM_{10}, $PM_{2.5}$ in µg/m^3. All noise metrics are given in dB.

Street sites in Copenhagen									
	Noise					Air pollutants			
	L_{day}	L_{eve}	L_{night}	L_{den}	$L_{Aeq,24h}$	NO_x	NO_2	PM_{10}	$PM_{2.5}$
L_{day}	-	0.99	0.99	0.99	0.99	0.41	0.42	0.27	0.24
L_{eve}		-	0.99	0.99	0.99	0.40	0.41	0.27	0.23
L_{night}			-	0.99	0.99	0.38	0.39	0.25	0.23
L_{den}				-	0.99	0.39	0.41	0.27	0.24
$L_{Aeq,24h}$					-	0.41	0.42	0.27	0.25
NO_x						-	0.95	0.76	0.68
NO_2							-	0.71	0.66
PM_{10}								-	0.98
$PM_{2.5}$									-
Background sites in Copenhagen									
	L_{day}	**L_{eve}**	**L_{night}**	**L_{den}**	**$L_{Aeq,24h}$**	**NO_x**	**NO_2**	**PM_{10}**	**$PM_{2.5}$**
L_{day}	-	0.99	0.99	0.99	0.99	0.35	0.35	0.05	0.03
L_{eve}		-	0.99	0.99	0.99	0.35	0.36	0.05	0.03
L_{night}			-	0.99	0.99	0.34	0.34	0.06	0.04
L_{den}				-	0.99	0.35	0.35	0.06	0.04
$L_{Aeq,24h}$					-	0.35	0.34	0.05	0.03
NO_x						-	0.99	0.57	0.50
NO_2							-	0.58	0.52
PM_{10}								-	0.99
$PM_{2.5}$									-

Table 2: Spearman's correlation coefficients of noise and total air pollution (street sites: N=200, ≥ 500 veh/day) and background air pollution (background sites: N=1300, < 500 veh/day) in Roskilde, Denmark. All correlations are statistically significant ($p < 0.001$). NO_x and NO_2 are given in ppb while PM_{10}, $PM_{2.5}$ in μg/m^3. All noise metrics are given in dB.

Street sites in Roskilde									
	Noise					Air pollutants			
	L_{day}	L_{eve}	L_{night}	L_{den}	$L_{Aeq,24h}$	NO_x	NO_2	PM_{10}	$PM_{2.5}$
L_{day}	-	0.99	0.99	0.99	0.99	0.27	0.14	-0.02	-0.13
L_{eve}		-	0.99	0.99	0.99	0.26	0.13	-0.04	-0.14
L_{night}			-	0.99	0.99	0.27	0.16	-0.02	-0.12
L_{den}				-	0.99	0.26	0.16	-0.02	-0.13
$L_{Aeq,24h}$					-	0.27	0.15	-0.01	-0.12
NOx						-	0.97	0.77	0.66
NO_2							-	0.82	0.70
PM_{10}								-	0.92
$PM_{2.5}$									-
Background sites in Roskilde									
	L_{day}	L_{eve}	L_{night}	L_{den}	$L_{Aeq,24h}$	NO_x	NO_2	PM_{10}	$PM_{2.5}$
L_{day}	-	0.99	0.99	0.99	0.99	0.27	0.27	-0.02	-0.13
L_{eve}		-	0.99	0.99	0.99	0.26	0.26	-0.03	-0.14
L_{night}			-	0.99	0.99	0.27	0.28	-0.01	-0.13
L_{den}				-	0.99	0.27	0.28	-0.02	-0.14
$L_{Aeq,24h}$					-	0.26	0.27	-0.01	-0.13
NO_x						-	0.99	0.64	0.55
NO_2							-	0.64	0.54
PM_{10}								-	0.87
$PM_{2.5}$									-

Table 3: Summary statistics of the modelled noise (annual average, year 2005) of CNOSSOS and RTN-96 for the study sites in Copenhagen (N = 11000) and Roskilde (N = 1500). Note: Med = Median (dB), Min = Minimum (dB), Max = Maximum (dB), r_S = Spearman's rank correlation coefficient, RMSE = Root-mean squared error (dB), MB = Mean bias (dB), NMB = Normalized mean bias.

	RTN-96			**CNOSSOS**						
	Min	Max	Med	Min	Max	Med	RMSE	MB	NMB	Correlation (r_S)
Copenhagen										
L_{day} (dB)	40.4	81.2	59.8	46.3	74.6	54.8	5.4	-4.1	-0.07	0.90
L_{eve} (dB)	37.3	78.1	56.4	42.8	71	50.9	6	-4.9	-0.08	0.89
L_{night} (dB)	34.5	75	52.5	38.9	67.1	47.1	5.9	-4.8	-0.09	0.88
Roskilde										
L_{day} (dB)	41.3	71.9	52.5	46.4	67.1	49.7	3.4	-2.6	-0.05	0.85
L_{eve} (dB)	37.9	69	49.2	42.9	63.6	45.8	3.8	-3.1	-0.06	0.85
L_{night} (dB)	33.7	65.7	45.4	39	59.5	41.9	3.8	-3.1	-0.06	0.84

Figure
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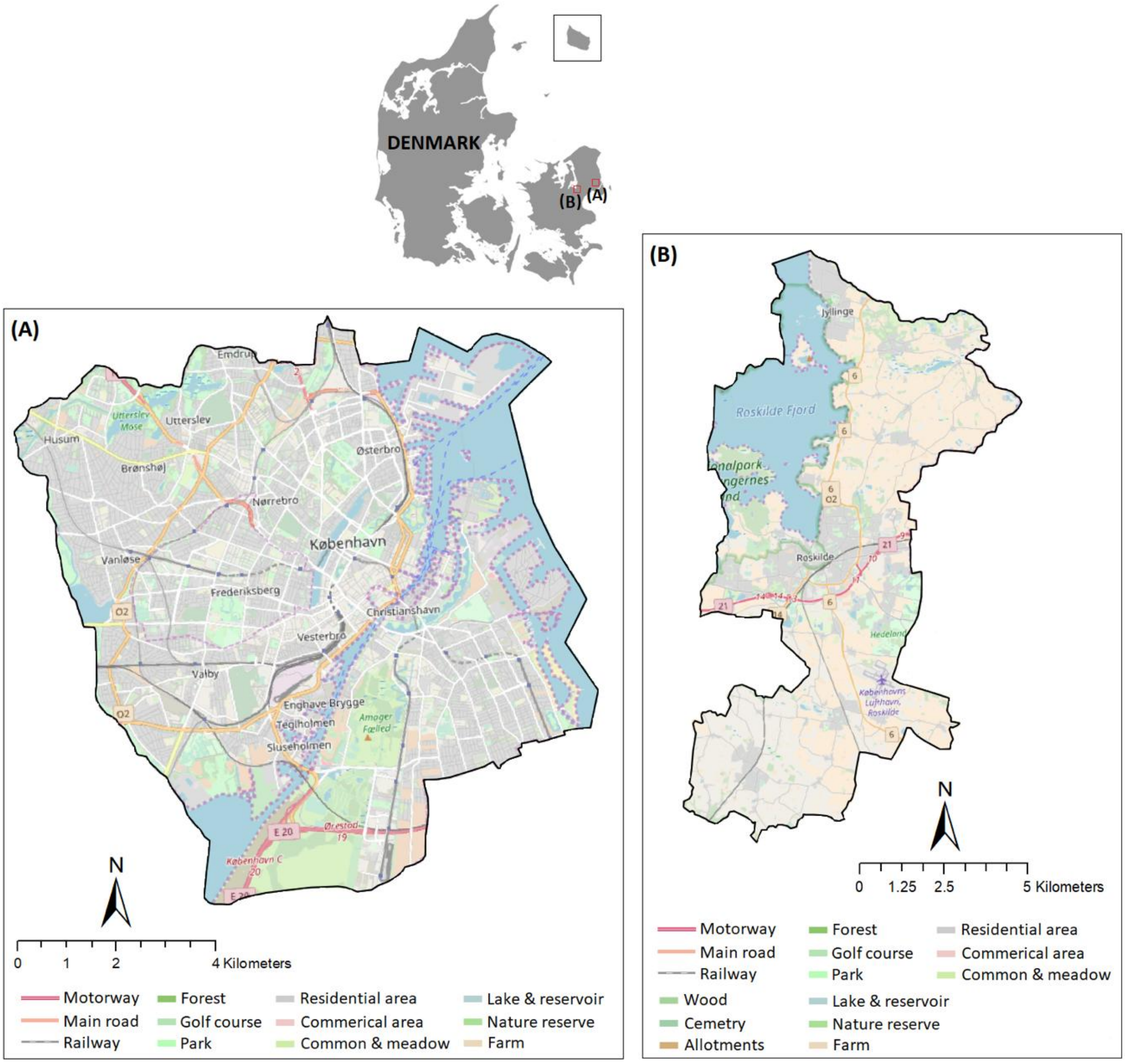

Figure 1: The location of the two study sites in Denmark: (A) Copenhagen and (B) Roskilde (Background map source: OpenStreetMaps).

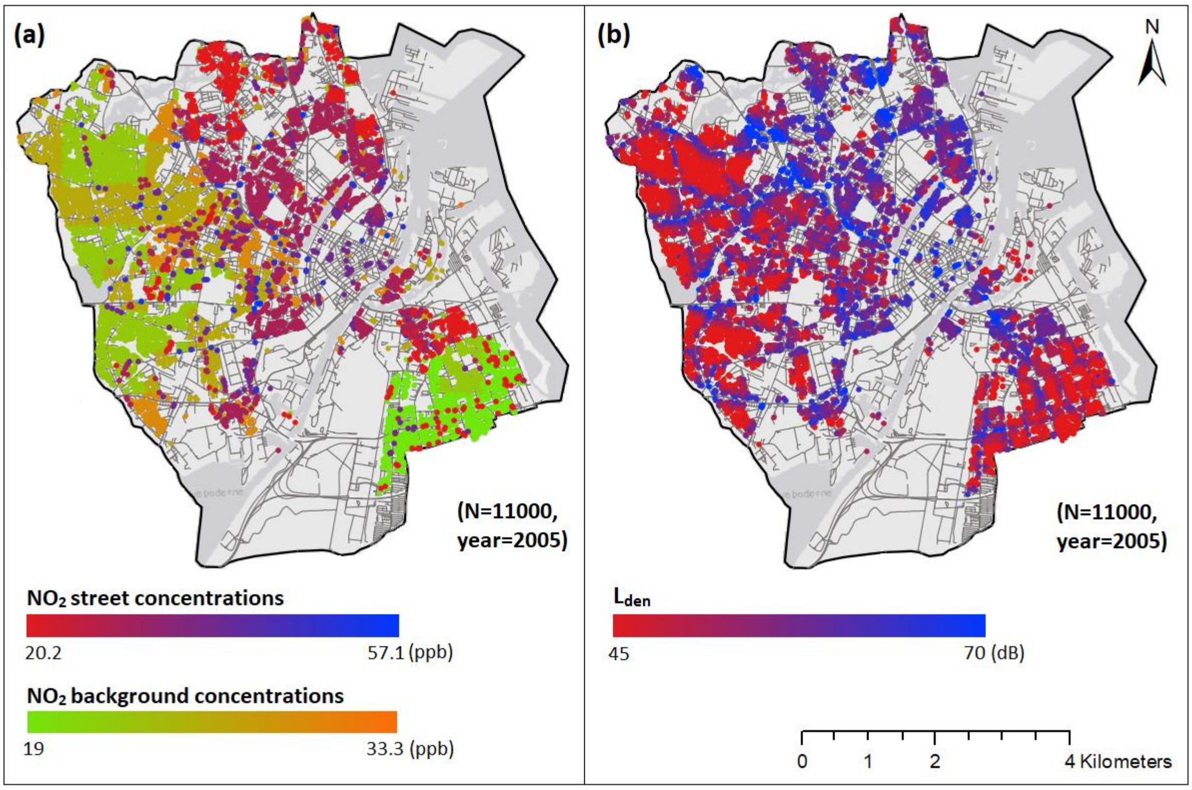

Figure 2: The spatial distribution of (a) air pollution (NO_2 in ppb) and (b) noise (L_{den} in dB) levels at address locations (N = 11000) in Copenhagen, Denmark. For NO_2, left panel (a), receptor points are split into street and background points based on the AADT on the nearby street. The background (N = 7000, AADT < 500 veh/day, no OSPM® applied) (red to blue) and the street points (N = 4000, AADT ≥ 500 veh/day, with OSPM®) (light green to orange) are shown in separate colour scales.

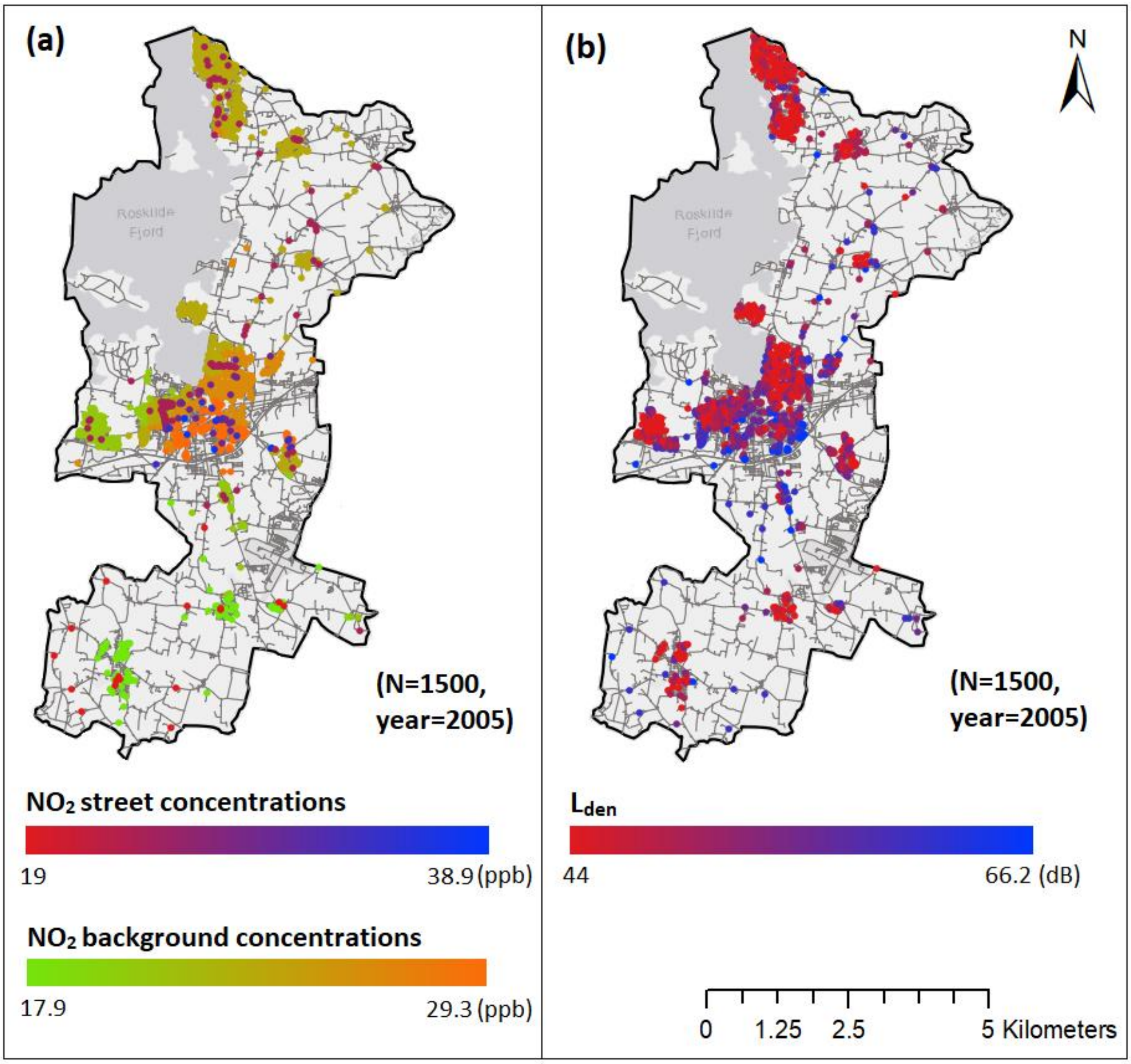

Figure 3: The spatial distribution of (a) air pollution (NO_2 in ppb) (left) and (b) noise (L_{den} in dB) (right) levels at address locations (N = 1500) in Roskilde, Denmark. For NO_2, left panel (a), receptor points are split into street and background points based on the AADT on the nearby street. The background points (N = 7000, AADT < 500 veh/day, no OSPM® applied) (red to blue) and the street points (N = 4000, AADT ≥ 500 veh/day, with OSPM®) (light green to orange) are shown in separate colour scales.

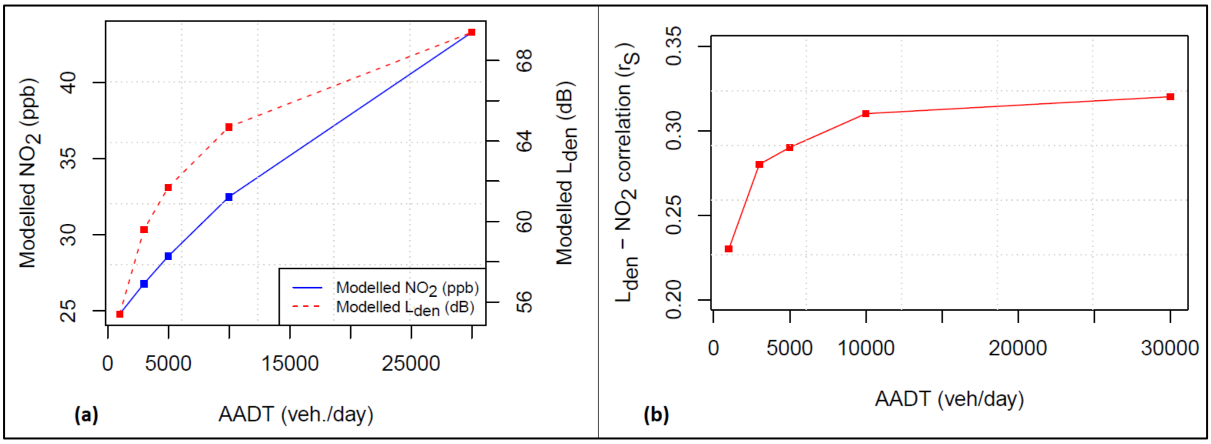

Figure 4: (a) modelled L_{den} (annual average, dB) and total NO_2 (street increment including background) (annual average, ppb) as functions of varying AADT (veh/day) (b) L_{den}-NO_2 correlation (Spearman's rank, r_S) as a function of varying AADT (veh/day). All correlations are statistically significant (p value < 0.001). Both pollution levels and computed correlations are for the fixed traffic speed = 40 km/h in Copenhagen (N = 11000, year 2005).

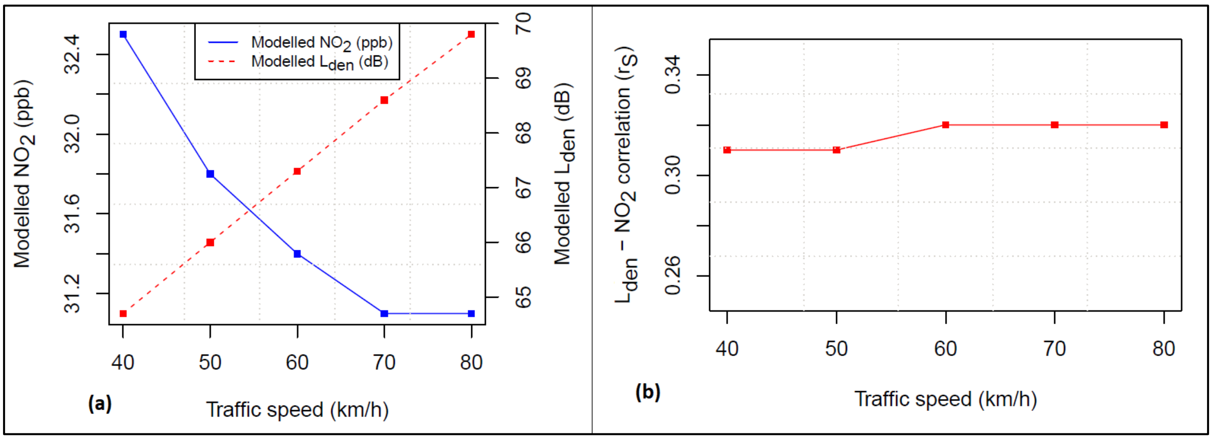

Figure 5: (a) modelled L_{den} (annual average, dB) and total NO_2 concentrations (street increment including background) (annual average, ppb) as functions of varying traffic speed (km/h) (b) L_{den}-NO_2 correlation (Spearman's rank, r_S) as a function of varying traffic speed (km/h). All correlations are statistically significant (p value < 0.001). Both pollution levels and computed correlations are for the fixed AADT = 10000 veh/day in Copenhagen (N = 11000, year 2005).

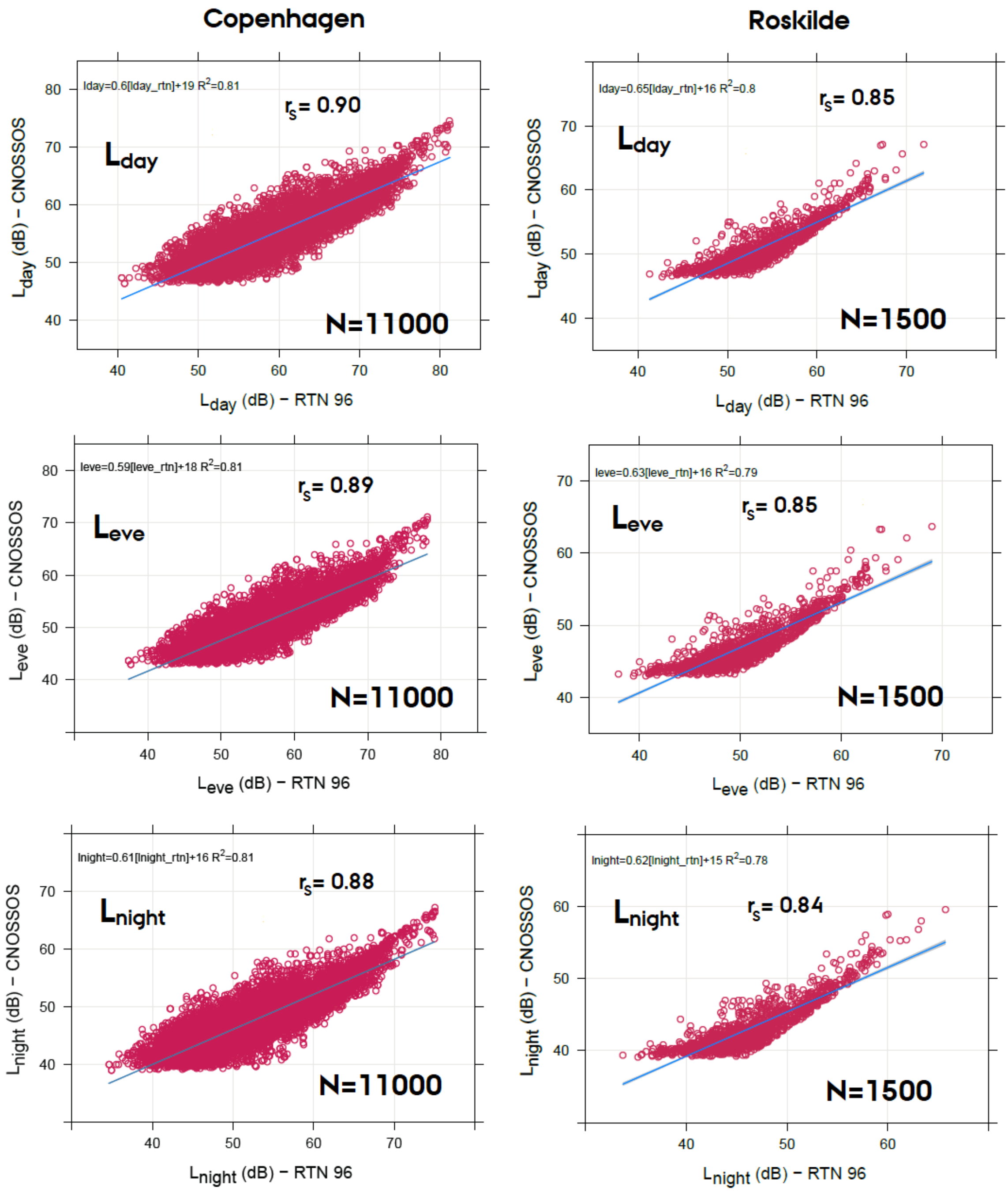

Figure 6: The comparison of the modelled noise (L_{day}, L_{eve}, L_{night} in dB) of CNOSSOS and RTN-96 at address locations in Copenhagen (N = 11000), and Roskilde (N = 1500). The comparison is only for the ground floor noise estimates (annual average, year 2005) with RTN-96 calculation points height = 2 m and CNOSSOS calculation points height = 4 m, r_S = Spearman's rank correlation coefficient.

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***conflict of Interest Statement**

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Credit Author Statement

CRediT authorship contribution statement

Jibran Khan: Conceptualization; Data curation; Methodology; Software; Formal analysis; Writing – original draft. **Konstantinos Kakosimos**: Writing – review & editing; Funding acquisition; Project administration. **Steen Solvang Jensen**: Writing – review & editing; Funding acquisition; Project administration. **Ole Hertel**: Writing – review & editing; Funding acquisition; Project administration. **Mette Sørensen**: Writing – review & editing; Investigation. **John Gulliver**: Software; Investigation; Writing – review & editing. **Matthias Ketzel**: Writing – review & editing; Investigation; Funding acquisition; Project administration.