Transportation Research Part D 52 (2017) 322–339

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

High resolution multi-scale air quality modelling for all streets in Denmark

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ARTICLE INFO

Article history:
Available online 24 March 2017

Keywords:
Air quality
Map
Model
Nesting
Validation
Traffic

ABSTRACT

The annual concentrations of NO_2, $PM_{2.5}$ and PM_{10} in 2012 have for the first time been modelled for all 2.4 million addresses in Denmark based on a multi-scale air quality modelling approach. All addresses include residential, industrial, institutional, shop, school, restaurant addresses etc. The approach is based on a suite of chemistry-transport models all developed at Aarhus University and includes regional modelling, urban background modelling and street modelling. Information about traffic volumes is based on a newly developed national Danish Transport Model, and national travel speed data have been obtained from a recent dataset based on GPS readings of vehicles. Air quality model results are validated by comparisons with measurements obtained from the fixed site monitoring stations under the Danish Air Quality Monitoring Programme. The validation showed that calculated street concentrations of NO_2 for the five available street monitoring stations are within −27% to +12%. The model results were also verified with comparisons with previous model results for NO_2 at 98 selected streets in Copenhagen and 31 streets in Aalborg. The verification showed good correlation in Copenhagen ($r^2 = 0.70$) and fairly good agreement in Aalborg ($r^2 = 0.60$). The target groups for the air quality mapping of all Danish addresses are the general public for information and awareness about air quality, and local and national authorities whom may use the information as a screening tool for air quality assessment. The air quality map has been provided on a WebGIS platform on the internet in September 2016 (http://luftenpaadinvej.au.dk). The air quality map is named AirStreet for Air Quality at Your Street.

1. Introduction

Health effects related to outdoor air pollution include premature mortality as well as a range of morbidities caused by short-term and long-term exposure. The World Health Organization (WHO) has estimated that the global burden of premature death for 2012 is about 3.7 million due to outdoor air (WHO, 2014). The European Environmental Agency (EEA) estimates that the health impacts attributable to outdoor air pollution in Europe (over 40 countries) in 2012 are about 432,000 premature deaths due to $PM_{2.5}$ (long-term exposure), 75,000 deaths due to NO_2 (long-term exposure) and 17,000

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http://dx.doi.org/10.1016/j.trd.2017.02.019
1361-9209/

deaths due to O_3 (short-term exposure) (EEA, 2013). For Denmark the estimate is about 3500 deaths for a population of 5.7 million inhabitants (Brandt et al., 2013a).

The European Union (EU) regulates air quality for selected pollutants based on air quality limit values (EC, 2008), regulates air emissions based on National Emission Ceilings for member states, and furthermore implement source-specific regulation for emission sectors e.g. for road vehicles as part of the overall policy framework of the Thematic Strategy on Air Pollution (EC, 2005).

The legal compliance with limit values is evaluated based on measurements from fixed site air quality monitoring stations, and air quality modelling is regarded a supplementary tool for air quality assessment as it allows for higher uncertainty (EU, 2008). In Denmark, an integrated monitoring approach (Hertel et al., 2007) is taken combining measurements and models where air quality is measured based on a limited number of stations supplemented by modelling at selected streets in two cities under the Danish National Air Quality Monitoring Programme (Ellermann et al., 2015).

The EU directive on air quality and cleaner air for Europe also requires that the member states provide information to the public about air quality (EU, 2008). These requirements focus on dissemination of information based on measured air quality and alerts in the case of exceedance of thresholds, and there are no formal requirements regarding information to the public based on air quality modelling. Member states are requested to provide information about measured air quality on the internet. In addition, it is common that member states provide short-term air pollution forecasts based on meteorological and air quality modelling (see e.g. Zhang et al., 2012). Some member states also provide an air quality index that attempts to aggregate complex information about levels of multiple pollutants into few usually health-related categories for easy communication (e.g. COMEAP, 2011). It is increasingly common to publish air quality maps on the internet based either on measured or modelled air quality, and use this mapping to provide information about the spatial distribution of air quality in the country. In most cases, air quality maps provide information on a relatively coarse resolution based on regional background modelling e.g. 10 km $\times$ 10 km for Europe based on the European Monitoring and Evaluation (EMEP) model (EEA, 2015). Few examples are available for national air quality tools and maps that provide for combined modelling of regional background, urban background and also down to street concentrations. One example is the DEFRA UK-AIR GIS tool that has been developed to allow users to freely view modelled annual air quality data on an interactive website (https://uk-air.defra.gov.uk/data/gis-mapping). The website provides national background maps with a resolution of 1 km $\times$ 1 km and selected roadside maps for 12 key pollutants based on the UK's Pollution Climate Mapping (PCM) model (Williams et al., 2011). Not all roads in the UK are included only approximately 9000 road links that are all in urban areas and are all A roads and Motorways. The tool has been developed for the annual assessment of compliance with the EU air quality Directives and to support local action planning. Another example is the Swedish SIMAIR system that is an internet-based modelling tool developed for use by all Swedish municipalities for air quality assessment. It assists in compliance evaluation with EU limit values enabling municipalities to assess the impacts of local emissions from road vehicles and residential wood combustion (Gidhagen et al., 2009, 2013). SIMAIR has focused on decision-support for municipalities and a national air quality map for public information is not the objective of this model system. Another example of a model chain ranging from regional to street scale has been presented for the city of Antwerp, Belgium where an advanced measurement interpolation model, a bi-Gaussian plume model and a canyon model was used to simulate the street-level concentrations over the city (Lefebvre et al., 2013).

In this paper we present and evaluate a high resolution national air quality map for Denmark based on multi-scale modelling from regional to urban background concentrations and further down to street concentrations. The uniqueness of the model system is that it presents modelled street concentrations for all address locations in Denmark. NO_2, $PM_{2.5}$ and PM_{10} have been selected as indicators for health impacts. NO_2 as annual mean is the only indicator in Denmark that exceeds the EU limit value, and this is observed at one air quality monitoring station at a busy street in Copenhagen (Ellermann et al., 2015). In the current project, the air quality indicators are annual means to provide for the general spatial distribution between areas and streets. The target groups are the general public for information and awareness about air quality at address level to answer questions like: what is the air quality where I live, work, or my children go to school? Other target groups are national and local authorities that may use the information as a screening tool for air quality assessment in relation to e.g. indicative assessment of compliance with air quality limit values, and initial screening in relation to Environmental Impact Assessments of e.g. new development or road projects. The objective is to describe the geographical variation of ambient air quality in Denmark at a very high spatial resolution.

2. Materials and methods

Multi-scale modelling is applied to model annual mean concentrations of NO_2, $PM_{2.5}$ and PM_{10} for 2012 for all addresses in Denmark. Multi-scale modelling is based on the integrated model system THOR (Brandt et al., 2001a, 2001b, 2001c, 2003) and includes modelling of regional background concentrations with the DEHM (Danish Eulerian Hemispheric Model), urban background concentrations with the UBM (Urban background Model) and street concentrations with the OSPM® (Operational Street Pollution Model). DEHM provides regional background concentrations as input for UBM that provides urban background concentrations for OSPM®. All models are driven by meteorological data from the MM5v3.7 numerical weather prediction model. Models and input data are described in the following sections. Furthermore, the sections provide references to publications about the models for more detailed descriptions and validations of these tools.