Health Effects caused by Urban Air Pollution for the Transport System Plan Scenarios in Helsinki Area - HEAT

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Abstract

We present a review of a research project called "Health Effects caused by Urban Air Pollution for the Transport System Plan Scenarios in Helsinki Area–HEAT" (2002–2004, http://www.fmi.fi/research_air/air_18.html). This project intends to evaluate traffic flows, emissions from mobile and stationary sources, ambient air concentrations, indoor concentrations, exposures to air pollutants and the resulting health effects. We focus on the present situation and the scenarios for the year 2025, as defined in the so-called Transport System Plan (TSP) of the Helsinki Metropolitan Area. The TSP will evaluate environmental impacts for various conceivable traffic and land use scenarios in the area.

The project aims to extend the existing urban air quality modelling system to include also treatments for evaluating the transport of pollutants from outdoor to indoor air, personal exposures and expected health consequences. We also aim to estimate the adverse health effects caused to the population by air pollution, to simulate the burden of disease for each of the TSP scenarios, and to inter-compare their relative public health costs and benefits. The project eventually results in practical recommendations in order to abate and minimise the health effects caused by air pollutants in urban areas.

Introduction

Environmental health research conducted during the 1990's has shown that urban air pollution is a substantially more important threat to public health than was previously evaluated. Studies of long-term exposure to air pollution, especially to particulate matter (PM), suggest an increased mortality (e.g., Woodruff *et al.* 1997), increased risk of chronic respiratory illness (e.g., Dockery *et al*., 1993), and of developing various types of cancer (e.g., Knox and Gilman, 1997).

World Health Organisation (WHO, 1999) has estimated that in Europe air pollution has caused 168.000 (range of estimate 100.000 – 400.000) excess deaths annually; in the United States the corresponding figure has been estimated to be approximately 100.000. The best estimate on the reduction in life expectancy in Central Europe is about 1 year. Künzli *et al.* (2000) estimated that 6 % of all deaths in Austria, France and Switzerland might be associated with exposure of the population to PM air pollution. Especially fine PM is causing a significant burden of disease (BoD) and excess deaths in Europe and North America. However, it is not known, which chemical and physical characteristics of the PM are responsible for these effects, and which source categories are responsible for the most harmful exposures. A reliable assessment of human exposure and the subsequent adverse health effects is therefore crucial in terms of the promotion of public health (WHO, 2000).

The proposed project is cooperation between the Finnish Meteorological Institute (FMI, Helsinki), National Public Health Institute (KTL, Kuopio), Helsinki Metropolitan Area Council (YTV, Helsinki) and University of Kuopio (UKU, Kuopio). The project can be viewed as an extension of several previous research projects by the participants within the consortium "Urban Air and Fine Particles" that is part of the Finnish Research Programme on Environmental Health, financed mainly by the Academy of Finland (SYTTY, 1998-2001).

Objectives of the HEAT project

This project evaluates traffic flows, emissions from mobile and stationary sources, ambient air concentrations, indoor concentrations, exposure to air pollutants and the resulting health effects. The project is based on mathematical modelling, using existing data to create model inputs. We will utilise the revised Transport System Plan (TSP) scenarios for the Helsinki Metropolitan Area for 2000 - 2025. The traffic development in Helsinki Metropolitan Area during years 1966-2020 is presented in Figure 1.

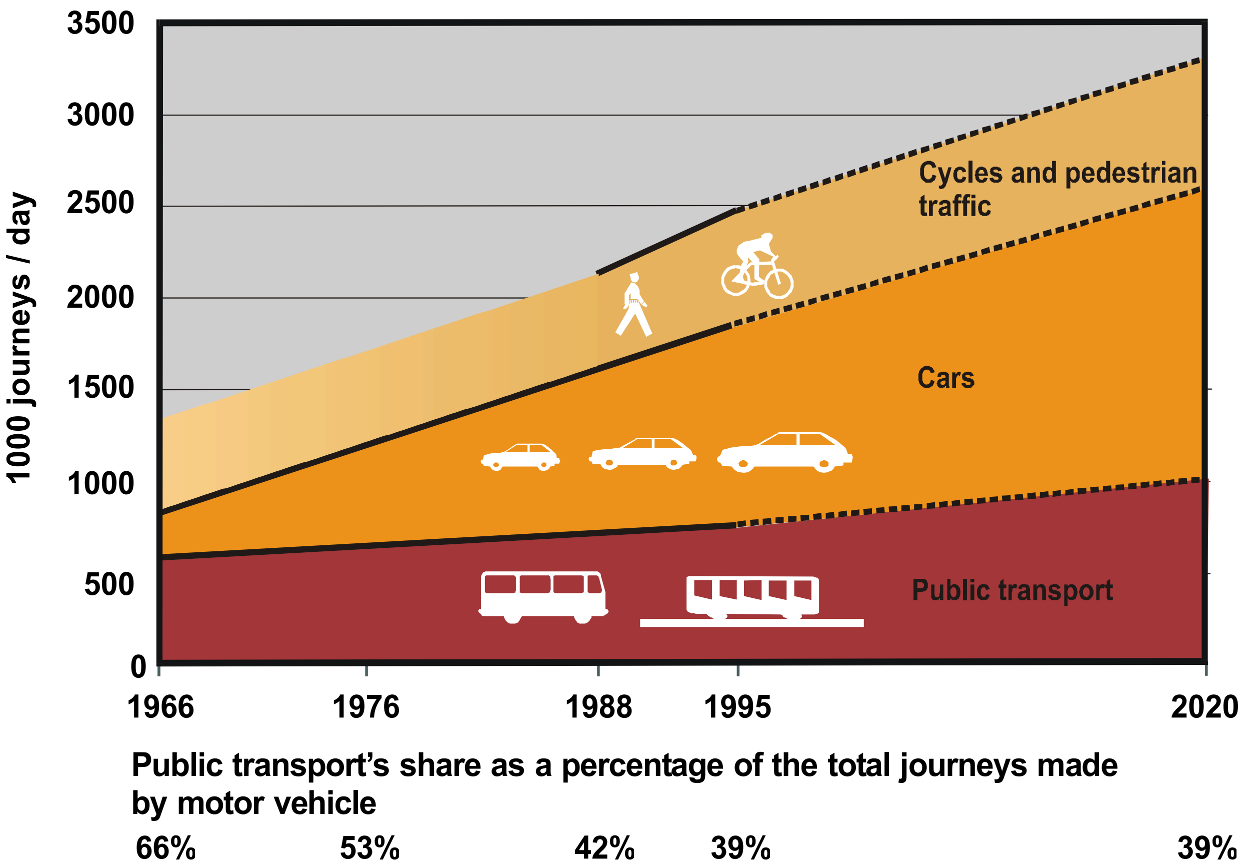

Figure 1. Traffic development in 1966-2020 in the Transport System Plan Scenarios for the Helsinki Metropolitan Area (Helsinki Metropolitan Area Transport System Plan, PLJ 1998).

The methodological objectives include the refining of an existing integrated modelling system (Figure 2.); this contains the evaluation of processes from traffic flow and pollutant emissions to atmospheric dispersion and potential population exposure outdoors (Karppinen *et al.*, 2000a; Kousa *et al.*, 2002). This modelling system is extended to treat the transfer of pollutants from outdoor to indoor air, personal exposure and expected additional BoD. Performance of the mathematical models is evaluated by comparing model predictions with measured concentration and exposure datasets.

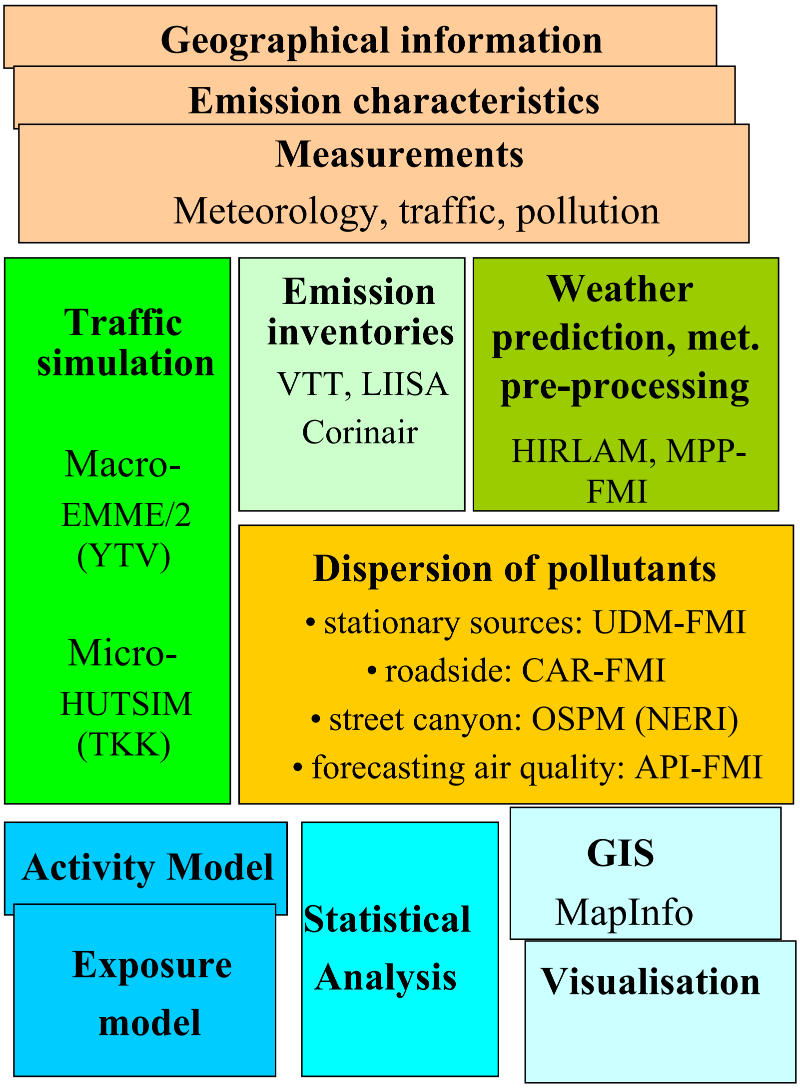

Figure 2. The overall structure of the integrated air quality management system. VTT = Technical Research Centre, FMI = Finnish Meteorological Institute, YTV = Helsinki Metropolitan Area Council, TKK = Helsinki University of Technology.

We also attribute the urban outdoor and indoor pollutant concentrations and personal exposures to the main source categories, with emphasis on primary-combustion originated PM and nitrogen oxides (NO_x). The project also aims to analyse the main determinants of the population exposures to air pollutants. We aim to estimate the BoD caused by air pollution for each of the TSP scenarios in order to compare their relative public health impacts. The scheduled project duration is three years, from 2002 to 2004. The intermediate objectives are the following:

(i) Refinement of the treatments for fine particles and the transport of pollutants from outdoor to indoor air in the integrated modelling system, the source apportionment of relevant EXPOLIS and ULTRA I data, and the selection of suitable risk assessment methods, by the end of 2002,

(ii) Evaluation of traffic flow, emissions, concentrations, exposure of population and BoD for the TSP scenarios, and analysis of the determinants of exposure, using both deterministic and receptor-oriented methods, by the end of 2003,

(iii) Scientific evaluation of the applied deterministic and probabilistic models against experimental data, analysis of the results of various TSP scenarios, and conclusions and recommendations on the best ways to reduce the adverse health effects, by the end of 2004.

The project eventually results in refined methodologies, new predicted results and practical recommendations on the most cost-effective ways in order to abate and minimise the health effects caused by air pollutants in urban areas. Clearly, these methods and results can directly be used to promote the public health.

Main methods and datasets

Modelling of stages from traffic flow to population exposure

We have developed a modelling system for evaluating the traffic flows, emissions from stationary and vehicular sources, and atmospheric dispersion of pollution in an urban area. The dispersion modelling is based on combined application of the Urban Dispersion Modelling system (UDM-FMI) and the road network dispersion model (CAR-FMI), developed at the FMI (Karppinen *et al*., 2000a).

The performance of the modelling system has been evaluated by comparing the model predictions with results of the urban air quality monitoring network of the Helsinki Metropolitan Area Council (YTV) in 1993 (Karppinen *et al*., 2000b) and in 1996 – 1997 (Kousa *et al*., 2001a). The performance of models within the system has been evaluated also against the results of field measurements (e.g., Kukkonen *et al*., 2001a,b, Öttl *et al.,* 2001). This modelling system is an important regulatory assessment tool for environmental authorities; e.g., it has been applied in the environmental impact assessment of the previously defined TSP scenarios (Hämekoski and Sihto, 1996).

Recently, this modelling system has been extended to contain a model for evaluating the human exposure to ambient air pollution in an urban area. The main objective was to evaluate the population exposure levels and distributions instead of personal exposures of specific individuals. At its present form, the model evaluates only potential exposures. This EXPAND - "EXPosure to Air pollution, especially Nitrogen Dioxide and particulate matter" model was developed by combining the predicted concentrations, the location of the population and the time spent at home, in the workplace and other locations or activities (Kousa *et al*., 2002).

Within the EXPAND model, time-microenvironment activity data from working-age population is obtained from the EXPOLIS-study (Jantunen *et al*., 1998 and 1999). The locations of homes and workplaces have been compiled by YTV, based on data from the municipalities. A schematic presentation of the exposure model is presented in Figure 3.

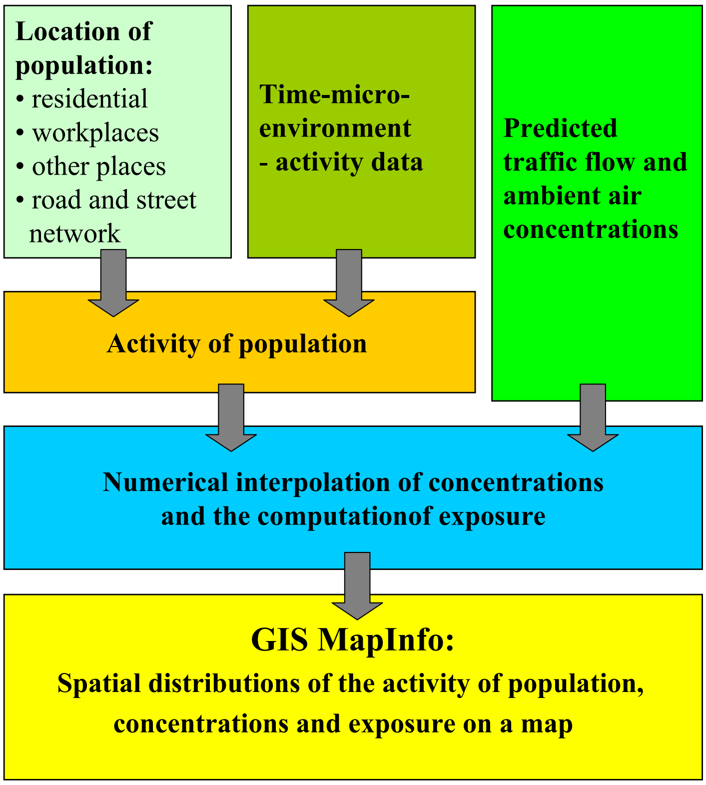

Figure 3. A schematic presentation of the exposure model (Kousa *et al*., 2002).

The computed results can be processed and visualised using the Geographical Information System (GIS) MapInfo. The predicted exposure of NO_2 in the Helsinki Metropolitan Area for 1996 is shown in Figure 4.

The EXPAND model has been designed to be utilised by municipal authorities in evaluating the impacts of traffic planning and land use scenarios. For instance, the Transport System Plan for the Helsinki Metropolitan Area is revised at four-yearly intervals. This model will be used, e.g., to evaluate different scenarios in the new revision of the Transport System Plan.

Concentration and exposure datasets of the EXPOLIS study

The EU-funded EXPOLIS study has produced an extensive database on the concentrations of $PM_{2.5}$, Black Smoke and 30 elements that were analysed by ED-XRF in the University of Basel (e.g., Koistinen *et al.,* 1999), together with the concentrations of CO, NO_2 (Kousa *et al*., 2001b) and 30 VOC's (Edwards *et al.,* 2001) in urban outdoor, residential and workplace indoor air in Helsinki (Jantunen *et al*., 1998 and 1999). The study covers one whole year, and it was conducted on a randomly selected representative sample of 201 25 - 55 year old adults, living and working in the Helsinki Metropolitan Area. In addition to air samples, the study participants filled detailed time-activity diaries and questionnaires concerning (i) the indoor and outdoor environments of their homes and workplaces, (ii) the times, means and duration of transportation, and (iii) the activities and relevant incidences that took place during the study. A comprehensive QA/QC plan was prepared before the study and followed throughout the field work (Jantunen *et al.,* 1999).

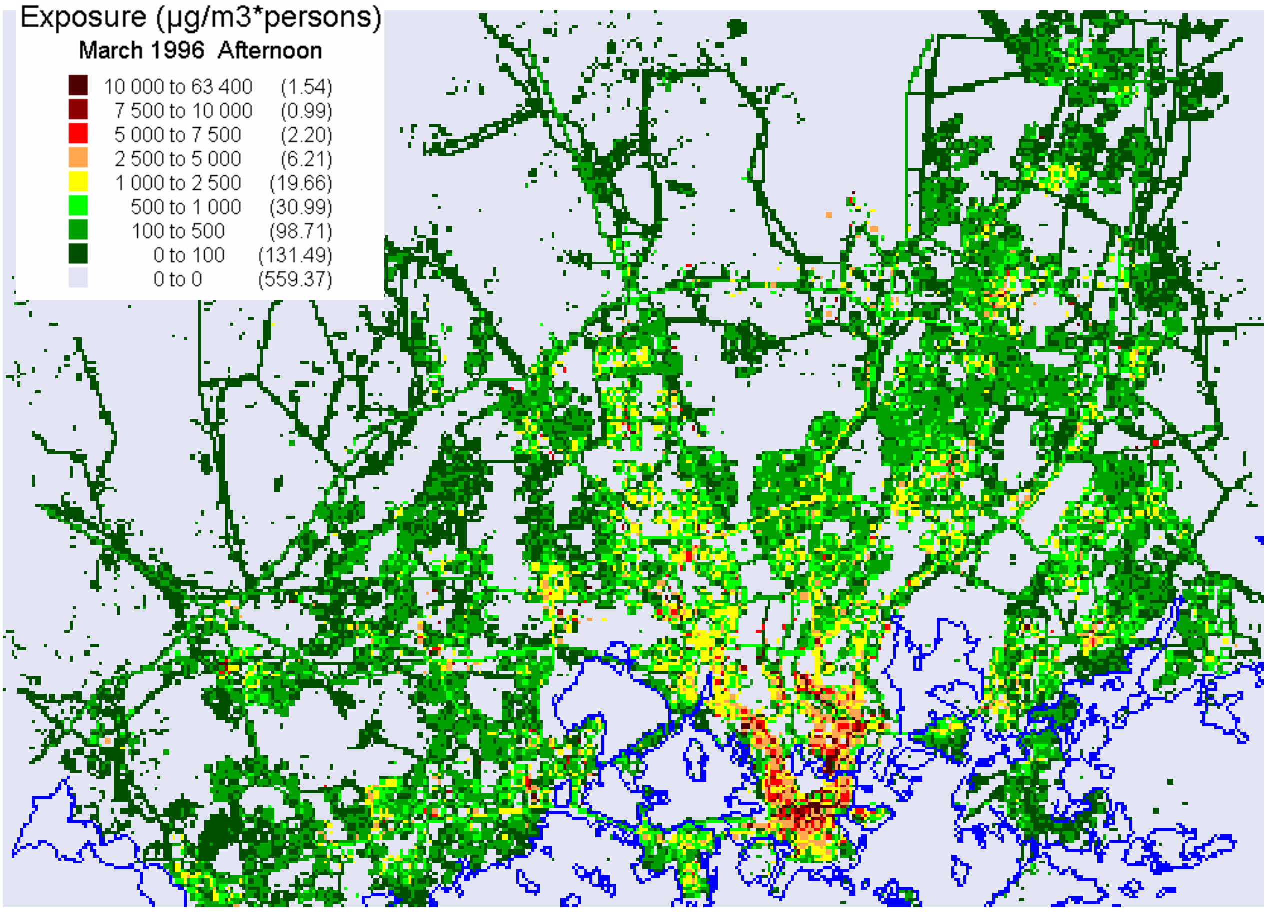

Figure 4. The predicted exposure of population to NO_2 concentrations (µg m^{-3} *persons) evaluated for the afternoon time period, as an average value in March 1996. The values in brackets in the legend refer to the number of square kilometres with the exposure in the selected range. The grid size is 100m * 100 m, the size of the depicted area is 23 km x 16 km, and the solid blue line is the coastline (Kousa *et al*., 2002).

The analyses of the EXPOLIS results show that the exposures are not only determined by the so-called physical factors, such as the location of residence and work, the means of commuting or the occupation (Koistinen *et al*., 2001). Significant exposure differences are also associated with sociodemographic descriptors (such as the level of education, gender and age), irrespective of the location of residence and work, and exposure to tobacco smoke. The other EXPOLIS cities are Athens, Basel, Grenoble, London, Milan, Oxford and Prague, where identical study protocol, identical sampling equipment, and questionnaires were used, but the population samples were smaller, 50 in each city.

Concentration dataset of the ULTRA I study

In the ULTRA I study, an extensive ambient air monitoring campaign was conducted from October 1996 to May 1997 at a fixed monitoring site in Helsinki (Ruuskanen *et al*., 2001). Simultaneously, a six-month follow-up health study was conducted on a group of 57 adult asthmatics. The entire study group resided within a distance of 2 km from the air quality monitoring site, in order to ensure that the measurement would represent as well as possible the pollutant exposure of the study subjects. The aim of the health study was to examine the associations between lung function indices of adult asthmatics and ultrafine PM number concentrations in ambient air. The project was also aimed to improve assessment of exposure to thoracic particles (PM_{10}), by assessing the particle size and number distributions, including ultrafine particles, and the elemental compositions of thoracic particles. The respiratory health of the subjects was monitored daily with peak flow measurements and a symptom and medication diary.

The database from Helsinki comprises outdoor air concentrations of NO_x, CO, SO_2, O_3, PM_1, $PM_{2.5}$, PM_{10}, and absorption coefficients (Black Smoke) for all PM samples. The measurements of PM took place at a height of 3 m in an urban background site, located in a small park in a residential area. The elemental composition of every other $PM_{2.5}$ sample was analysed in the University of Basel, using the same analytical method as in the EXPOLIS study. Data of elemental composition are available for a total of 89 samples and 16 elements. Similar measurements were also conducted in other ULTRA research centres in Erfurt (Germany) and Alkmaar (the Netherlands). Thorough QC/QA procedures were followed throughout the study, as described by Vallius *et al*. (2000).

Workplan and expected results

The traffic flows, emissions, NO_2 concentrations and potential exposures have been previously assessed in the Transport System Plan (TSP) for the Helsinki Metropolitan Area (Hämekoski and Sihto, 1996). This study evaluated the environmental impacts of various conceivable traffic planning and land use scenarios in the area, including ambient air concentrations of NO_2, and the corresponding population exposures.

The TSP will be updated during 2000 – 2002 by the Helsinki Metropolitan Area Council (YTV). The present proposal intends to utilize these new scenarios, which select the year 2000 as the starting point, and define new scenarios for the future. The future scenarios will include a "business-as-usual" scenario for the year 2025, a scenario with an emphasis on the use of private cars and a widely dispersed use of land, and a scenario that assumes a transportation system based on mainly public transport, in which land use is compact. The future scenarios are selected to be clearly different, yet realistic for the foreseeable future. One additional scenario will be developed that aims at a maximum realistic traffic emission reduction in the area.

The project focuses on $PM_{2.5}$ and NO_2. Target populations of this study include: (i) general adult population, (ii) asthmatic adults, (iii) pre-school children, and (iv) chronically ill, but still independently living elderly. Quality-controlled and –assured datasets, as those produced in EXPOLIS and ULTRA, are available for the project; no new measurements are therefore included. Figure 5 presents an overview of the various stages of the project.

The workplan includes the following three workpackages, to be performed during 2002 – 2004.

Workpackage 1. Development and evaluation of deterministic models

This work-package includes the following tasks:

(a) Refinement of the integrated traffic flow, emission, atmospheric dispersion and exposure modelling system, in particular to treat in more detail urban fine PM. Transfer of pollutants from outdoor to indoor is evaluated from the measured concentration ratios, extracted from the EXPOLIS database. The emission coefficients are updated in cooperation with the VTT.

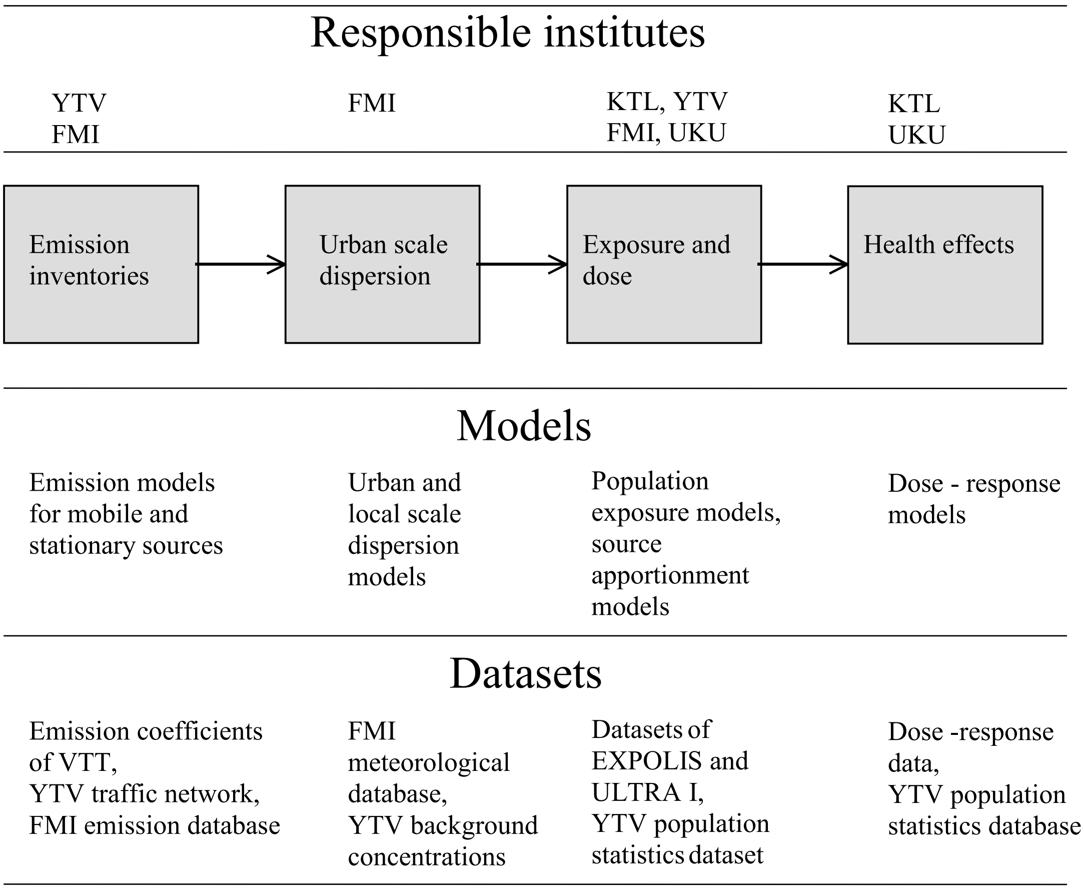

Figure 5. A schematic presentation of the processes to be evaluated in the proposed study, the contributions of the participating institutes, the modelling methods and the experimental datasets. FMI = Finnish Meteorological Institute, YTV = Helsinki Metropolitan Area Council, KTL = National Public Health Institute, UKU = University of Kuopio.

(b) Application of the deterministic modelling methods (described by Karppinen *et al.,* 2000a and Kukkonen *et al*., 2001c) in order to evaluate outdoor and indoor concentrations of $PM_{2.5}$ and NO_2 in the Helsinki Metropolitan Area, for each of the TSP scenarios. The results include hourly averaged concentrations during the selected years (2000 and 2025) computed in a grid network, with a spatial resolution ranging from 50 to 500 m within the area considered.

(c) Scientific evaluation of the models. We will compare the predicted concentrations, exposures and probabilistic exposure distributions with the corresponding measured results from the EXPOLIS and ULTRA I databases. Model validity is evaluated using various statistical parameters that describe the agreement of predictions and data (as the fractional bias, correlation coefficient, index of agreement, etc.).

Workpackage 2. Receptor modelling, and the comparison with deterministic modelling

This work-package includes the following tasks:

(d) The $PM_{2.5}$ and NO_2 exposures that have been measured in EXPOLIS and the $PM_{2.5}$ concentrations measured in ULTRA I are attributed to the main source categories. The source apportionment of ambient $PM_{2.5}$ will be done using a combination of Factor Analysis (FA) and Multiple Linear Regression (MLR) methods (Hosiokangas *et al.*, 1999, Thurston and Spengler, 1985). The FA and Principal Component Analysis (PCA) methods are used to identify quantitatively the most important independent sources, and their contributions to the exposure variation that have been measured with a temporal resolution ranging from 24 to 48 h. The FA and Chemical Mass Balance (CMB) methods are used to determine the contributions from the main source categories to the outdoor, indoor and personally measured concentrations, separately for PM and nitrogen oxides.

(e) The main determinants of the source-specific exposures are assessed from the EXPOLIS data using uni- and multivariate statistical methods. These determinants will also be predicted by the population exposure model EXPAND, and the measured and predicted results are compared quantitatively using statistical techniques.

(f) Probabilistic exposure modelling techniques, that have been developed for evaluating total $PM_{2.5}$ exposures and validated with the EXPOLIS data, are applied for evaluating the exposures from each source category, and again validated using the EXPOLIS and ULTRA I datasets.

Clearly, all receptor-based (i.e., source apportionment) methods produce information only regarding the current year or the past ones. Evaluation of the TSP scenarios for the future relies solely on deterministic methods.

Workpackage 3. Evaluation of the adverse health effects from population exposure

The health risks of urban ambient fine particles ($PM_{2.5}$) are assumed to increase linearly with increasing exposure (WHO, 1999). If a threshold concentration value exists, it is assumed to be located below the currently occurring range of urban air $PM_{2.5}$ concentrations, and it is therefore irrelevant for the relative risk assessments in the present study. Similar linear models are generally applied for the acute and chronic health risks for environmental tobacco smoke (ETS) and the cancer risks of combustion-originated PAH's. Except for the asthmatics, the most straightforward assumption is that air pollution exposure increases the risk of respiratory or cardiovascular morbidity or mortality, or the occurrence of cancer in relative proportion to the underlying risk. This is called 'relative risk projection model', in contrast to 'absolute risk projection model', which assumes that the excess risk is independent of the underlying background risk.

The most authoritative and up-to-date risk estimates or dose/response models for various pollutants will be used in order to model the changes in the expected BoD resulting from the different TSP scenarios. Such risk estimates have been presented by, e.g., World Health Organisation (WHO, 1999), International Agency for Research on Cancer (e.g., IARC, 1989) and U.S. Environmental Protection Agency (e.g., EPA, 1996). The most up-to-date risk estimates will be selected and applied in order to estimate the BoD's for each of the TSP scenarios. We intend to use more selective exposure metrics, compared with the bulk mass of PM_{10} or $PM_{2.5}$, in our estimates of BoD.

This work-package includes the following tasks:

(g) The additional BoD from the exposure to traffic-originated air pollution is simulated for each TSP scenario, separately for each target population, using the most up-to-date risk models available. These outcomes for various scenarios are compared with each other.

(h) Conclusions are drawn concerning the alternative TSP scenarios, in terms of the total population exposure, exposures of vulnerable sub-populations, expected BoD, etc. Recommendations are made on the optimal techniques and policies to reduce the BoD from air pollution.

Conclusions

Air pollution dispersion and transfer from sources to the exposure of an urban population is assessed using deterministic emission and dispersion models, coupled with human activity models. Simultaneously, the measured exposures of the same population are evaluated using receptor modelling. Comparison of the results of these two approaches that look into opposite directions of the same source - receptor chain, yields basic methodological information on the accuracy and reliability of these methods. The utilisation of both of these approaches is expected to provide more versatile, reliable and comprehensive information on the exposure of population and on the resulting health effects. In previous research, these two evaluation methods have been utilised only separately.

The project aims to result in validated modelling tools that can be used in urban air quality management, and for the evaluation and selection of traffic planning policies. Modelling the whole chain of processes from traffic flows to exposure and BoD, provides the decision makers relevant and accurate information in order to compare the relative public health impacts of the alternative TSP scenarios.

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