Pauliina Ahtoniemi
Marko Tainio
Jouni T. Tuomisto
Niko Karvosenoja
Kaarle Kupiainen
Petri Porvari
Ari Karppinen
Leena Kangas
Jaakko Kukkonen

Health Risks from Nearby Sources of Fine Particulate Matter: Domestic Wood Combustion and Road Traffic (PILTTI)

REPORT

3 | 2010

REPORT 3/2010

Pauliina Ahtoniemi, Marko Tainio, Jouni T. Tuomisto, Niko Karvosenoja,
Kaarle Kupiainen, Petri Porvari, Ari Karppinen,
Leena Kangas, Jaakko Kukkonen

Health Risks from Nearby Sources of Fine Particulate Matter: Domestic Wood Combustion and Road Traffic (PILTTI)

Pienhiukkasten lähipäästöjen terveysriskit: puun pienpoltto ja tieliikenne (PILTTI)

NATIONAL INSTITUTE
FOR HEALTH AND WELFARE

Authors

Pauliina Ahtoniemi[1)]
Leena Kangas[3)]
Ari Karppinen[3)]
Niko Karvosenoja[2)]
Jaakko Kukkonen[3)]
Kaarle Kupiainen[2)]
Petri Porvari[2)],
Marko Tainio[1)]
Jouni T. Tuomisto[1)]

[1)] National Institute for Health and Welfare (THL), P.O.Box 95, FI-70701 Kuopio, Finland
[2)] Finnish Environment Institute (SYKE), Mechelininkatu 34a, P.O.Box 140, FI-00251 Helsinki, Finland
[3)] Finnish Meteorological Institute (FMI), P.O.Box 503, FI-00101 Helsinki, Finland

ISBN 978-952-245-223-8 (printed)
ISSN 1798-0070 (printed)
ISBN 978-952-245-224-5 (pdf)
ISSN 1798-0089 (pdf)
URN:NBN:fi-fe200912172433

Helsinki University Print
Helsinki, Finland 2010

Foreword

This is the concluding report of the *Health risks from nearby sources of fine particles: domestic combustion and road traffic* (PILTTI) project. PILTTI project was funded by the Ministry of the Environment, Finland, and it was conducted during the years 2006–2008 in concert of three Finnish research institutes:

- National Institute for Health and Welfare (THL) (coordinating institute);
- Finnish Meteorological Institute (FMI);
- Finnish Environment Institute (SYKE).

The aim of PILTTI project was to study in Finland the adverse health effects caused by fine particle air pollution emissions due to traffic and domestic wood combustion. Project was continuation to previous KOPRA project (*An integrated model for evaluating the emissions, atmospheric dispersion and risks caused by ambient air fine particles*) which was conducted during the years 2002–2005.

This report is organized so that first we have extended summary of the main findings in Finnish. After that, we present the methodology, results and conclusions in detail in English. All the Figure and Table captions are both in Finnish and in English. The Steering group of the project is presented in the end of the report.

Esipuhe

Tämä on *Pienhiukkasten lähipäästöjen terveysriskit: puun pienpoltto ja tieliikenne* (PILTTI) -projektin loppuraportti. PILTTI-projekti tehtiin Ympäristöministeriön rahoituksella vuosina 2006–2008. Projekti suoritettiin kolmen suomalaisen tutkimuslaitoksen yhteistyössä:

- Terveyden ja hyvinvoinnin laitos (THL) (koordinaattori);
- Ilmatieteen laitos (IL);
- Suomen Ympäristökeskus (SYKE).

PILTTI-projektin tavoitteena oli arvioida puun pienpolton ja tieliikenteen pienhiukkaspäästöjen terveysvaikutuksia Suomessa. Projekti oli jatkoa vuosina 2002–2005 tehdylle KOPRA-projektille (*Kokonaismalli pienhiukkasten päästöjen, leviämisen ja riskien arviointiin*).

Tämä loppuraportti on organisoitu niin, että alussa on suomeksi laajennettu yhteenveto tärkeimmistä tuloksista. Tämän jälkeen projektin tärkeimmät menetelmät, tulokset ja johtopäätökset esitetään englanniksi. Kaikki kuva- ja taulukko-otsikot ovat sekä suomeksi että englanniksi. Projektin ohjausryhmä esitellään raportin lopussa.

Table of contents

Tiivistelmä

Pauliina Ahtoniemi, Marko Tainio, Jouni T. Tuomisto, Niko Karvosenoja, Kaarle Kupiainen, Petri Porvari, Ari Karppinen, Leena Kangas, Jaakko Kukkonen. Health Risks from Nearby Sources of Fine Particulate Matter: Domestic Wood Combustion and Road Traffic (PILTTI) [Pienhiukkasten lähipäästöjen terveysriskit: puun pienpoltto ja tieliikenne (PILTTI)]. National Institute for Health and Welfare (THL), Report 3/2010. 60 pp. Helsinki 2010. ISBN 978-952-245-223-8 (printed), ISBN 978-952-245-224-5 (pdf)

Tausta

Alailmakehän pienhiukkaset muodostavat yhden suurimmista ympäristöterveysongelmista länsimaissa. Pienhiukkasilla tarkoitetaan ilmassa leijuvia kiinteitä ja nestemäisiä hiukkasia joiden aerodynaaminen halkaisija on alle 2.5 µm. Maailman terveysjärjestön WHO:n (World Health Organization) asiantuntijapaneeli arvioi vuonna 2003, että pienhiukkaset lisäävät kuolleisuutta sekä sydän- ja hengityselinsairauksia (WHO 2003). Eurooppalaisessa CAFE-projektissa (Clean Air for Europe) pienhiukkasten arvioitiin aiheuttavan Euroopassa 300000 ennenaikaista kuolemantapausta vuonna 2000 ja laskevan odotettavissa olevaa keskimääräistä elinikää 6,8 kuukaudella (Watkiss ym. 2005).

Vuosina 2002–2005 KOPRA-projektissa *(Kokonaismalli pienhiukkasten päästöjen, leviämisen ja riskien arviointiin)* kehitettiin kokonaismalli, joka arvioi pienhiukkasten päästöjä, leviämistä, altistumista sekä terveysvaikutuksia Suomessa (Kukkonen ym. 2007). Projektin tarkoituksena oli koota tietoa pienhiukkasten terveysvaikutuksista ja tuottaa tietoa päätöksenteon tueksi. KOPRA-projektissa arvioitiin sekä Euroopan että Suomen primääristen pienhiukkaspäästöjen terveysvaikutuksia niin Suomessa kuin muualla Euroopassa. Primäärisillä hiukkasilla tarkoitetaan hiukkasia jotka vapautuvat ilmaan hiukkasmuodossa.

KOPRA-projektissa Suomen primääristen pienhiukkaspäästöjen arvioitiin aiheuttavan noin 150 ennenaikaista kuolemantapausta vuonna 2000 (Kukkonen ym 2007). Yli puolet ennenaikaisista kuolemantapauksista arvioitiin aiheutuvan puun pienpolton ja tieliikenteen primääripienhiukkaspäästöistä. Tämän vuoksi nähtiin tarpeellisena täsmentää laskelmia näiden päästölähteiden osalta uudessa jatkotutkimuksessa.

Vuosina 2006–2008 PILTTI-projektissa kehitettiin ja täsmennettiin KOPRA-projektin terveysvaikutusten arviointimallia puun pienpolton ja tieliikenteen päästöille. Projektin tarkoituksena oli i) arvioida liikenteen ja puun pienpolton primäärisiä pienhiukkaspäästöjä ja päästöepävarmuuksia 1 km resoluutiolla, ii) arvioida päästöjen paikallista leviämistä ensimmäisen 20 km etäisyydellä päästölähteistä, iii) arvioida ihmisten altistumista Suomessa näiden kahden päästölähteen pienhiukkasille sekä iv) arvioida pienhiukkasten altistumisesta aiheutuvia ennenaikaisia kuolemantapauksia Suomessa. PILTTI-projekti toteutettiin Suomen ympäristökeskuksen (SYKE), Ilmatieteen laitoksen (IL) ja Terveyden ja hyvinvoinnin laitoksen (THL; aiemmin Kansanterveyslaitos) yhteistyönä.

Materiaalit ja menetelmät

PILTTI-projektissa käytetty arviointimenetelmä perustuu KOPRA-projektissa kehitettyyn pienhiukkasten kokonaismalliin (kuva 1). Kokonaismallissa arvioidaan pienhiukkaspäästöt, leviäminen, altistuminen ja terveysvaikutukset Suomen alueelle. PILTTI-projektissa laskelmia kehitettiin arvioimalla liikenteen ja puun pienpolton terveysvaikutuksia päästöjen välittömässä läheisyydessä.

PILTTI-projektissa tarkasteltiin neljää pienhiukkasten päästölähdettä:

- Liikenteen suorat päästöt;
- Liikenteen suspensiopäästöt;
- Asuinrakennusten ensi- ja toissijainen puunpoltto;
- Vapaa-ajan rakennusten puunpoltto.

Liikenteen päästöihin kuuluivat kaupunkien ja maantieliikenteen suorat pakokaasupäästöt sekä tien, renkaiden ja jarrujen kulumapäästöt. Liikenteen suspensiopäästöt eli liikenteen tien pinnalta nostattama pöly käsiteltiin leviämistarkasteluissa erillisenä ryhmänä sen erilaisen vuoden sisäisen ajallisen vaihtelun takia (suspensiopäästöt ovat korkeimmillaan kevätaikaan nk. kevätpöly). Puun pienpolton päästöt jaettiin kahteen päästötyyppiin, jossa toisessa olivat asuinrakennusten ensisekä toissijainen puunpoltto (talvipainotteinen) ja toisessa vapaa-ajan rakennusten puunpoltto (kesäpainotteinen).

Tieliikenteen ja puun pienpolton päästöt arvioitiin Suomen ympäristökeskuksen (SYKE) alueellisella päästöskenaariomallilla (Finnish Regional Emission Scenario, FRES), joka kuvaa kaasumaisia ja hiukkaspäästöjä koko Suomen alueelta 1 x 1 km^2:n resoluutiolla. FRES-mallin pienpolton päästölaskenta perustuu uusimpien kotimaisten ja kansainvälisten laitemittausten päästökerroinarvioihin. Liikenteen eipakokaasuperäisten päästöjen ("katupöly") laskentaa kehitettiin tässä projektissa ottamaan huomioon mm. kosteustekijöiden vaikutukset suspensiopäästöihin. Päästöjen alueellisen jakauman arvioinnissa käytettiin rakennus- ja huoneistorekisterin (pienpoltto) ja DIGIROAD-tietokannan (liikenne) tietoja.

Vuoden 2000 päästöarvioiden lisäksi projektissa arvioitiin puun pienpolton ja tieliikenteen pienhiukkaspäästöjen kehitystä vuoteen 2020 mennessä. Pienhiukkasten päästöarviot perustuvat Suomen kansalliseen ilmastostrategiaan (Hildén ym. 2005) ja arvioihin eri pienhiukkaslähteiden päästökertoimien muutoksesta vuoteen 2020 mennessä.

Pienhiukkasten leviäminen laskettiin Ilmatieteen laitoksella kehitetyllä kaupunkimallilla UDM-FMI (Urban Dispersion Modelling system), joka sisältää meteorologisen esiprosessorin ja leviämismallin. Leviämismalli perustuu Gaussin jakaumaan, ja siihen sisältyvät laskentamenetelmät piste-, pinta- ja tilavuuslähteille. Mallin syöttötiedoksi tarvittava meteorologinen tuntiaikasarja saatiin meteorologisella esiprosessorilla käyttäen lähtötietona IL:n sää- ja auringonpaistehavaintoja 10 asemalta (Helsinki, Turku, Lappeenranta, Jokioinen, Kankaanpää, Jyväskylä, Kuopio, Oulu, Rovaniemi ja Sodankylä) sekä Jokioisten ja Sodankylän luotaushavaintoja. Laskelmissa käytettiin vuosien 2000–2003 meteorologisia aineistoja.

Leviämismallilla laskettiin lähde-kohde-matriiseja eli yksikköpäästön leviämistä. Päästölähteenä oli 1 x 1 km^2:n suuruinen pintalähde laskenta-alueen keskellä, ja laskenta-alueen koko oli puun pienpoltolle 40 x 40 km^2:n ja tieliikenteelle 20 x 20 km^2:n suuruinen. Matriisit laskettiin neljälle eri päästöluokalle: asuinrakennusten ja vapaa-ajanrakennusten pienpolton päästöille sekä tieliikenteen suorille ja epäsuorille eli suspensiopäästöille. Päästöjen käsittelyssä otettiin huomioon vuoden ja vuorokauden sisäinen päästövaihtelu. Päästökorkeudeksi oletettiin pienpoltolle 7,5 m ja liikenteelle 2 m. Mallilaskelmilla saadut yksikkömatriisit yhdistettiin päästöarvioon kertomalla kunkin ruudun päästö leviämismatriisilla ja laskemalla näin saadut pitoisuuskentät yhteen.

Altistuminen liikenteen ja puun pienpolton pienhiukkaspäästöille laskettiin yhdistämällä pitoisuuskentät väestötietoihin. Väestötietoina käytettiin koko Suomen kattavaa 250 x 250 m^2 resoluution tietoja vuodelta 2004. Lisäksi arviointiin eri päästölähteille päästö- altistumissuhde niin kutsutulla saantiosuus menetelmällä (intake fraction; iF, Bennett ym. 2002). Saantiosuus on se osuus hiukkaspäästöstä joka päätyy ihmisen hengittämäksi. Saantiosuus määritettiin kaavalla

$$iF = \sum_i \frac{(c_i \times Pop_i) \times BR}{Q}$$

missä iF on saantiosuus; c_i on pienhiukkasten pitoisuuden muutos (yksikkö g/m^3) tarkastelualueella; Pop_i on väestön lukumäärä tarkastelualueella; BR on hengitysnopeus; Q on päästönopeus. Hengitysvolyymina käytettiin lukuarvoa 0.00023148 (20/(24*60*60) m^3/s/hlö). Pitoisuus- sekä väestötietojen solujen (i) lukumäärä oli 783900.

Väestön altistuminen arvioitiin koko Suomelle päästösektoreittain.

$$E = \frac{Q_{tot} \times iF}{Pop \times BR}$$

missä E on väestön altistuminen ilmoitettuna pienhiukkasten pitoisuuden keskiarvona (g/m^3); Q_{tot} on kunkin päästölähteen kokonaispäästö (g/s); iF on saantiosuus; Pop on Suomen väestömäärä; BR on hengitysnopeus (m^3/s).

Terveysvaikutusten arvioinnissa käytetty altistumis-vastefunktio pienhiukkasten vaikutuksesta ennenaikaiseen kuolleisuuteen perustui asiantuntijapaneelin tuloksiin. (Cooke ym. 2007, Tuomisto ym. 2008). Paneelissa asiantuntijapaneelin jäsenet arvioivat omaan tietämykseensä perustuen altistusvastefunktioita pienhiukkasille. Altistusvastefunktio kuvaa pienhiukkasaltistuksen aiheuttamaa tilastollista muutosta esim. kuolleisuudessa. Tässä tutkimuksessa käytetty altistusvastefunktio arvioi ei-tapaturmaisen kuolleisuuden lisääntyvän 0,6–1,0 % aina yhtä mikrogramman lisäystä pienhiukkaspitoisuudessa (1 µg/m^3) kohden.

Tulokset ja päätelmät

Suomen tieliikenteen ja puun pienpolton primääristen pienhiukkasten arvioitiin aiheuttavan noin 1 000 ennenaikaista kuolemantapausta vuosittain Suomessa vuonna 2000. 1 000:sta enneaikaisesta kuolemantapauksesta yli 800:n arvioitiin johtuvan liikenteen primäärisistä pienhiukkaspäästöistä.

Tulos poikkeaa huomattavasti KOPRA-projektissa aiemmin arvioidusta 150 ennenaikaisesta kuolemantapauksesta kaikille suomalaisille primäärisille pienhiukkaslähteille yhteensä. Tuloksista nähdään, että tieliikenteen ja puun päästöjen vaikutus korostuu lähialueella verrattuna kaukokulkeutuneen osuuden terveysvaikutuksiin. PILTTI-tulokset eivät kuitenkaan korvaa KOPRA-tuloksia: kaukokulkeumaa muualta Euroopasta ja kaikkia päästölähdeluokkia ei ole käsitelty PILTTI-arvioissa ja laskennassa on otettu huomioon vain leviäminen muutamien kilometrien etäisyydellä päästölähteestä. Laskelmat osoittavat kuitenkin, että käytetty leviämisetäisyys on riittävä kuvaamaan pienpolton terveysvaikutuksista noin 85 %, ja liikenteen terveysvaikutuksista noin 90–95 %.

Vuonna 2020 primääristen pienhiukkasten arvioitiin aiheuttavan noin 750 enneaikaista kuolemantapausta Suomessa. Tieliikenteen suorien pakokaasupäästöjen terveysvaikutusten oletettiin laskevan tarkastelujakson aikana noin kymmenesosaan vuoden 2000 tasosta. Suspensiopäästöjen terveysvaikutusten arvioitiin vastaavasti lisääntyvän johtuen liikenteen lisääntymisestä. Puun pienpolton terveysvaikutusten arvioitiin pysyvän vuoden 2000 tasolla ilman uusia rajoitustoimenpiteitä.

Vuonna 2000 primääriset pienhiukkaspäästöt liikenteelle olivat 7 420 ton/vuosi ja vastaavasti puun pienpoltolle 7 580 ton/vuosi. Päästöjen arvioinnissa huomattiin huomattavia epävarmuuksia, etenkin puun pienpolton osalta. Liikenteen päästöjen leviäminen arvioitiin 10 km etäisyydelle lähteestä ja puun pienpolton päästöjen osalta 20 km etäisyydelle lähteestä. Liikenteen pienhiukkaspitoisuudet olivat suurempia lähellä päästölähdettä kuin puun pienpolton pitoisuudet johtuen matalammasta päästökorkeudesta.

Saantiosuuden avulla määritetty päästö-altistumissuhde osoitti suuremman osuuden liikenteen päästöistä päätyvän ihmisten hengitysilmaan kuin puun pienpolton päästöistä. Saantiosuus oli 9,7 miljoonasosaa liikenteen pakokaasu- sekä kulumapäästöille ja 9,5 miljoonasosaa tiepölypäästöille. Asuinrakennusten sekä vapaa-ajan rakennusten puun pienpolton päästöjen saantiosuudet olivat 3,4 ja 0,6 miljoonasosaa. Ero puun pienpolttosektoreiden välillä on merkittävä ihmisten altistumisen ja terveysvaikutusten kannalta.

Väestön keskimääräinen altistuminen maassamme kotimaisten liikenteen ja puun pienpolton primäärisille päästöille oli 2.46 $\mu g/m^3$ vuonna 2000 (kuva 12). Väestön keskimääräinen altistumisesta suurin osa johtui liikenteen primäärisistä pienhiukkaspäästöistä. Väestön keskimääräinen altistuminen asuinrakennusten sekä vapaa-ajanrakennusten päästöille oli alle 1$\mu g/m^3$.

Viitteet

Bennet, D.H., McKone, T.E., Evans, J.S., Nazaroff, W.W., Margni, M.D., Jolliet, O., Smith, K.R. 2002. Defining intake fraction. Environmental Science & Technology 36 (9): 206A-211A.

Hildén M., Karvosenoja N., Kankaanpää S., Ratinen M., Liski J. and Hämekoski K. 2005. Ympäristöarviointi kansallisesta strategiasta Kioton pöytäkirjan toimeenpanemiseksi. Suomen ympäristö 802, Helsinki, Finland.

Kukkonen, J., Karppinen, A., Sofiev, M., Kangas, L., Karvosenoja, M., Johansson, M., Porvari, P., Tuomisto, J., Tainio, M., Koskentalo, T., Aarnio, P., Kousa, A., Pirjola, L., Kupiainen, K., 2007. Kokonaismalli pienhiukkasten päästöjen, leviämisen ja riskin arviointiin – KOPRA. Ilmatieteen laitos Tutkimukset, 1, Helsinki, ISBN 978-951-697-635-1.

Watkiss, P., Pye S., Holland M., 2005. Baseline Scenarios for Service Contract for carrying out cost-benefit analysis of air quality related issues, in particular in the clean air for Europe (CAFE) programme. AEAT/ED51014/ Baseline Issue 5.

1 Introduction

The exposure to fine particles ($PM_{2.5}$, particles with aerodynamic diameter less than 2.5 microns) have been associated with multiple adverse health effects. A World Health Organization (WHO) working group concluded in 2003 that "*The present information shows that fine particles (commonly measured as $PM_{2.5}$) are strongly associated with mortality and other endpoints such as hospitalization for cardio-pulmonary disease*" (WHO 2003). The report also concluded that the long-term exposure to current fine particle levels may lead to reduction in life expectancy. In Europe, the Clean Air for Europe (CAFE) program has estimated that fine particles cause over 300 000 premature deaths annually and that the exposure lowers the average life expectancy of population by 8.6 months (Watkiss et al. 2005). This makes fine particles one of the largest, if not the largest, environmental health problem in Western Countries and a logical target for mitigation legislation.

The KOPRA project (*An integrated model for evaluating the emissions, atmospheric dispersion and risks caused by ambient air fine particles*) developed during the years 2002-2005 an integrated assessment model to assess health risks of primary fine particles in Finland (Kukkonen et al. 2007). The purpose of the project was to provide information and herewith support decision making. In the KOPRA model, the emission, dispersion, and exposure to fine particles were evaluated in Finland using 5 km spatial resolution; the health effects were estimated for the whole population. The KOPRA project concluded that primary fine particle emissions from Finland cause annually 150 premature deaths in Finland (Kukkonen et al. 2007). Over half of the adverse health effects were associated with domestic wood combustion and traffic emissions in Finland.

One of the main conclusions of the KOPRA project was a need to further refine calculations for domestic wood combustion and traffic emissions. Domestic wood combustion and traffic sources have a low emission altitude, and a large share of emissions occur in densely populated urban environments. This is especially true for traffic emissions, while the wood combustion emissions occur both in rural and in urban environments. This has been illustrated in a study where the vicinity of emissions and population was evaluated in Finland (Tainio et al. 2009). The results suggested that there are differences in exposure between domestic wood combustion sub-sectors and that traffic emissions occur mainly near the population hotspots. The small difference in emission-exposure relationship between emission source categories, observed in KOPRA-project, raised the question whether the 5 km spatial resolution used in KOPRA study underestimated the exposure to low emission height emission source categories.

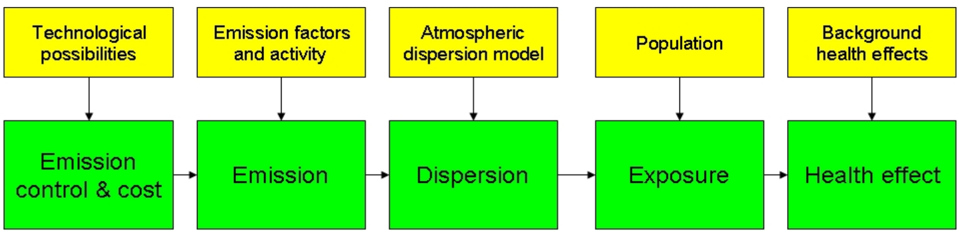
The PILTTI (*Health risks from nearby sources of fine particles: domestic combustion and road traffic*) project further developed the integrated assessment model developed in KOPRA project. The main focus in PILTTI was to estimate the emissions, dispersion and exposure with finer 1 km spatial resolution. This resolution was assumed to catch the population exposure better than the 5 km spatial resolution used in the KOPRA project. The PILTTI-project concentrated on traffic and domestic wood combustion primary fine particle emissions. The specific aims of the PILTTI project were (i) to define the primary fine particle emissions and emission uncertainties for these two emission source categories in 1 km spatial resolution, (ii) to assess local scale dispersion in more detail, up to 20 km from the sources (iii) to estimate exposure due to these two sectors using the so called intake fraction methods, and (iv) to estimate the health effects due to fine particle exposure using premature deaths as the indicator. This project has been conducted in co-operation with Finnish Environmental Institute (SYKE), Finnish Meteorological Institute (FMI) and National Institute for Health and Welfare (THL) during the years 2006–2008.

2 Materials and methods

Overview

The general methodology of PILTTI assessment is based on KOPRA integrated assessment model (Figure 1). The KOPRA model evaluated the emissions, dispersion, exposure, and health effects of Finnish primary fine particles in Finland. The KOPRA assessment estimated also the health effects caused by Finnish particles outside Finland, and health effects in Finland caused by fine particle emissions outside Finland. In PILTTI, we focused only on domestic wood combustion and traffic related primary fine particles emissions in Finland and to the dispersion and exposure near the emission sources (a few kilometres around the source). See emission, dispersion and exposure sections for details.

Figure 1: Overview of the KOPRA integrated assessment model (Kukkonen et al. 2007). In PILTTI project the methodology was updated to take into account exposure near the emission source categories.
Kuva 1: KOPRA kokonaismallin rakenne (Kukkonen et al. 2007). PILTTI-hankkeessa kokonaismallia kehitettiin ottamaan huomioon altistuminen päästölähteen läheisyydessä.



Domestic wood combustion and the traffic emissions were divided to two sub-sectors because of different intra-annual temporal variation between sub-sectors, and thus, different dispersion characteristics. The four main emissions sectors were:

- Domestic wood combustion in residential buildings;
- Domestic wood combustion in recreational buildings;
- Traffic emissions (of tailpipe) and direct wear emissions from road, tyres, and breaks;
- Suspended traffic emissions.

The emissions, dispersion, exposure, and health effects were evaluated separately for these four emissions sectors. The integrated assessment model was implemented using Analytica ™ version 4.2. (Lumina Decision Systems, Inc., CA) Monte Carlo simulation program and run with 50 000 iterations.

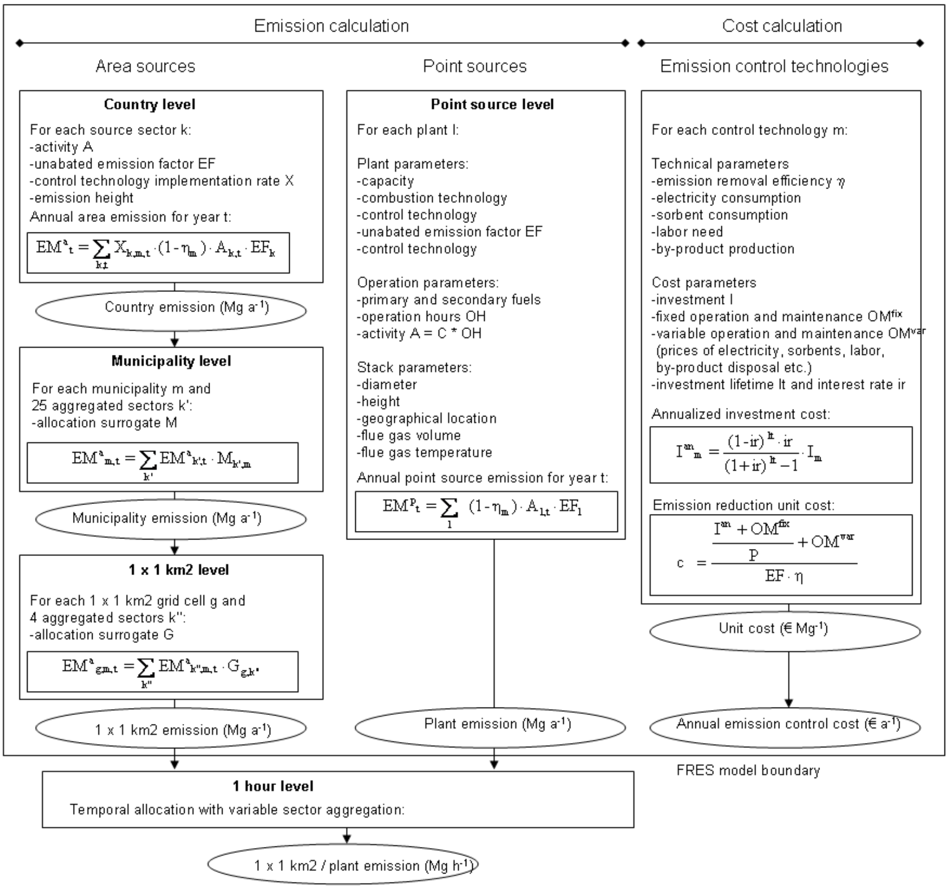
Emissions

$PM_{2.5}$ emissions of domestic wood combustion and road traffic were calculated with the Finnish Regional Emission Scenario (FRES) model of Finnish environment institute (Karvosenoja 2008). The FRES model consists of coherent emission calculation of several gaseous and particulate (TSP, PM_{10}, $PM_{2.5}$, PM_1 and $PM_{0.1}$) air pollutants from anthropogenic sources. The emissions are calculated from the parameters of activity levels, emission factors and emission control technologies (Figure 2). The basic spatial and temporal domains of the model are the country of Finland and one year, respectively, which are then disaggregated to 1 km and 1 hour resolutions, respectively.

The model base year 2000 activity rates are primarily based on statistics information (e.g. Statistics Finland 2008), complemented with additional information for activity disaggregations (e.g. questionnaire studies for domestic wood combustion and vehicle fleet information for traffic). For emission scenario assessment, the estimates of future activities in With-Additional-Measures (WAM) activity pathway of the Finnish Climate Strategy (Hildén et al. 2005) was used. The emission factors are based on Finnish and international measurements and literature (for details, see Karvosenoja et al. 2008). The parameter values for the base year calculation are presented in Tables 2–4.

The country-level emissions are resolved in space and time, i.e. allocated to certain grid and temporal patterns. Spatially emissions are allocated to 1 km resolution using weighting factors: (1) floor areas of wood-heated buildings from building and dwelling register (Mikkola et al. 1999) for domestic wood combustion, and (2) municipality level data from LIISA model (Mäkelä et al. 2002) and vehicle count data of road segments from DIGIROAD data base for road traffic. More complete descriptions of the spatial allocation and data sources are available in Karvosenoja et al. (2005).

Figure 2. Flowchart of the FRES model calculation (Karvosenoja 2008)
Kuva 2. FRES–mallin kaaviokuva (Karvosenoja 2008).



The disaggregation of emissions in time is carried out using typical temporal patterns for different source sectors. Figures 3 and 4 show the temporal patterns used for domestic wood combustion and road traffic, respectively.

The calculation of traffic non-exhaust particulate emissions in the FRES model was updated in this project. The source-specific emissions (EM_s) are calculated from country level annual activity data (A) and particle mass emission factor (EF_s). The emission factors are determined separately for the different sources and particle sizes (i.e. PM_{10} and $PM_{2.5}$) as well as streets and highways. Emissions from brake, tire and road wear are calculated according to Eq. (1):

$$EM_s = A \times EF_s$$

Figure 3. Temporal patterns of domestic wood combustion emissions for (a) monthly and (b) hourly relative variation. Data estimated based on wood use surveys (e.g. Tissari et al. 2007, Nieminen 2004).

Kuva 3. Puun pienpolton päästöjen ajallinen vaihtelu (a) kuukausittain, (b) tunneittain. Tiedot perustuvat selvityksiin puunkäytöstä (esim. Tissari ym. 2007 ja Nieminen 2004)

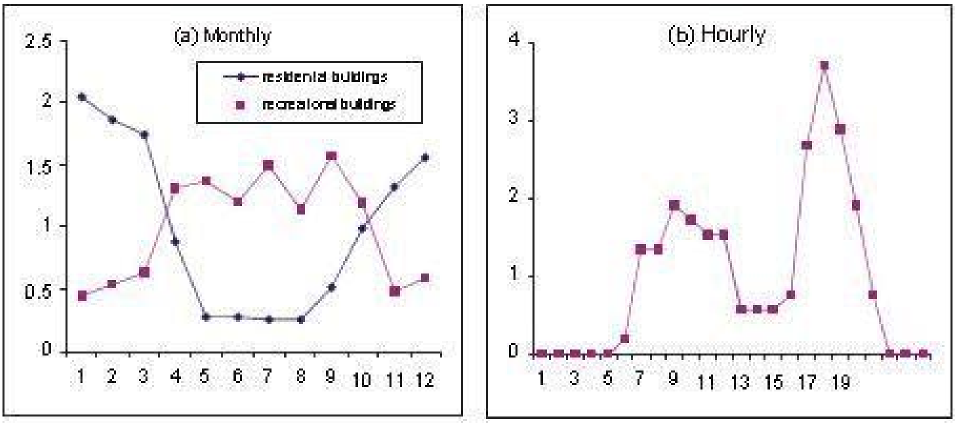


Figure 4. Temporal patterns of traffic emissions for (a) monthly, (b) daily and (c) hourly relative variation. Data from Karasmaa et al. (2003).

Kuva 4. Liikenteen päästöjen ajallinen vaihtelu (a) kuukausittain, (b) päivittäin ja (c) tunneittain (Karasmaa ym. 2003).

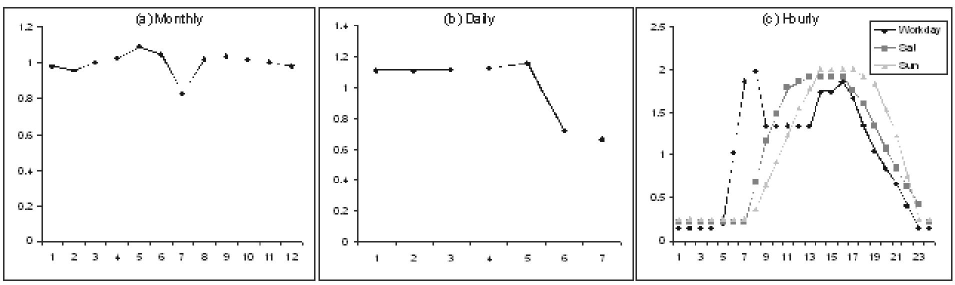


Table 1 compiles the data sources and PM_{10} emission factors and $PM_{2.5}$ fraction for brake, tire and road wear. $PM_{2.5}$ fraction describes the fraction of PM_{10} emissions that are in the size fraction of $PM_{2.5}$. CORINAIR (2003) and Luhana et al. (2004) reported that the emission factors of brake wear and tire wear for highway driving are lower than those for street driving because cornering and braking are more frequent in urban conditions. At this point the road wear factors do not take into account the higher wear rates due to winter time use of studded tires due to lack of reliable emission factors for studded tires. However, winter time use of studded tires and traction sanding result in higher road surface deposits of wear products in spring

(Kupiainen, 2007). This material is suspended in spring and it is taken into account in the monthly evolution of suspension emission factors (Figure 5).

Table 1. PM_{10} emission factors (EF), the fraction of $PM_{2.5}$ and data sources for tire, brake and road wear.

Taulukko 1. PM_{10} päästökertoimet (EF, $PM_{2.5}$ osuudet sekä lähdeaineistot renkaiden, jarrujen ja teiden käyttötiedoille.

		EFs (mg PM_{10} vkm^{-1})		$PM_{2.5}$ fraction	Data sources
		Street	Highway		
Tire wear	Light Duty	7.0	4.5	0.7	CORINAIR, 2003; Boulter et al., 2006
	Heavy Duty	15	9.6	0.7	
Brake wear	Light Duty	7.5	1.4	0.77	CORINAIR, 2003; Luhana et al., 2004; Garg et al., 2000
	Heavy Duty	36	7.0	0.77	
Road wear, summer tire	Light Duty	5.3	5.3	0.19	Chow et al., 1993; CORINAIR, 2003; Luhana et al., 2004; Kupiainen, 2007
	Heavy Duty	27	27	0.19	

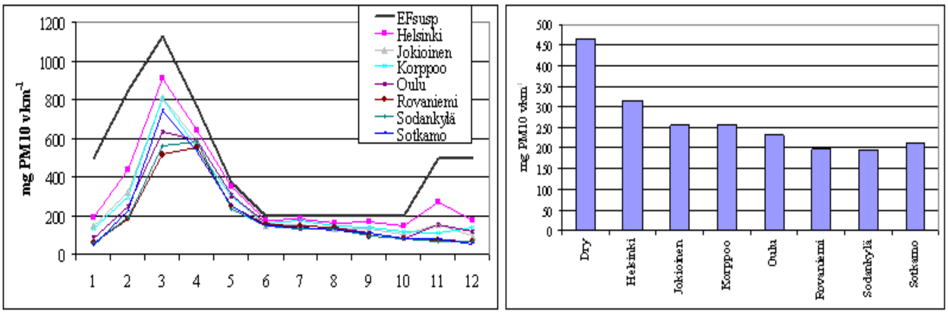
PM emissions from traffic induced suspension (EM_{susp}) are calculated based on Eq. (2), partly following the approach presented by Omstedt et al. (2005):

$$EM_{susp} = A \times (EF_{susp} \times F_{qi})$$

The emission factor (EF_{susp}) in Eq. (2) and Figure 5 represents the highest possible suspension levels observed in dry conditions. These vary during the year so that the emission factor is highest during spring and lowest during summer (see i.e. Omstedt et al. 2005). Based on Etyemetzian et al. (2003) and Gehrig et al. (2004) the emission factors are estimated to be lower in highway environments compared with urban streets. Fqi is a reduction factor related to the moisture content of the surface (for calculation details see Omstedt et al. 2005). Figure 5 shows the reducing effect of moisture on annual PM_{10} suspension emission factor. $PM_{2.5}$ estimated to be approximately 19% of PM_{10} based on data presented by Chow et al. (1994) and Kupiainen (2007).

Figure 5. Monthly average PM_{10} emission factors (mg/vkm) for calculation of suspension emissions from cars. The curves and columns denoted as 'EF_{susp}' and 'Dry' correspond to the emission factors in dry conditions, and the other curves and columns correspond to the emission factors after the moisture correction in different locations.

Kuva 5. Kuukausittaiset keskiarvot PM_{10}-päästökertoimille (mg/vkm) autoliikenteen suspensiopäästöjen laskemiseksi. 'EF_{susp}' ja 'dry' viittaavat päästökertoimiin kuivilla tienpinnoilla ja paikkakuntakohtaiset päästökertoimet viittaavat vastaavilla vähenemäkertoimilla korjattuihin päästökertoimiin.



Dispersion

The atmospheric dispersion model applied in this study was the Urban Dispersion Modelling system developed at the Finnish Meteorological Institute (UDM-FMI). It includes a multiple source Gaussian plume model and a meteorological pre-processor MPP-FMI (Karppinen et al., 1997, 1998).

Meteorology

The meteorological input parameters for the atmospheric dispersion model were estimated with the meteorological pre-processor MPP-FMI. This model uses synoptic weather observations and meteorological soundings, and its output consists of hourly time series of meteorological parameters, including atmospheric turbulence parameters and the mixing height of the atmospheric boundary layer.

In order to have input data representative for different areas in Finland, meteorological observations from ten synoptic weather stations were used in the calculations. The stations selected were Helsinki, Turku, Lappeenranta, Jokioinen, Kankaanpää, Jyväskylä, Kuopio, Oulu, Rovaniemi, and Sodankylä. The corresponding sounding observations were taken from the Jokioinen and Sodankylä observatories. In order to have a meteorologically representative time period, the input data and the calculations included the years 2000 - 2003 for all stations, except for Oulu and Lappeenranta, for which the year 2001 was excluded due to long periods of missing observation data.

Dispersion modelling

The dispersion model of UDM-FMI is an integrated Gaussian urban-scale model, taking into account all source types (point, line, area and volume sources). The model includes a treatment of dry and wet deposition for nitrogen oxides and SO_2, plume rise, downwash phenomena, the dispersion of inert particles and the influence of a finite mixing height. For the selected calculation grid, the system computes an hourly time series of concentrations, and further the annual average concentrations.

In this study, the model was used to calculate source-receptor matrices for inert particles, i.e. the dispersion of an area source emission of unit strength. The size of the source was set at 1 x 1 km^2, corresponding to the resolution of the emission inventory. The source was assumed to be in the centre of a square calculation grid of size 40 x 40 km^2 for domestic wood combustion emissions and 20 x 20 km^2 for road traffic emissions. The interval of calculation grid points was 1 km. The diurnal and seasonal variations were taken into account in generating the hourly time series for the emissions.

The source-receptor matrices were computed for four different emission source categories: domestic wood combustion for residential and recreational buildings, and direct and suspended traffic emissions. The differences between the various emission categories were the different seasonal and diurnal variation of the emissions, and varying source heights. For domestic wood combustion, the emission height was assumed at 7.5 m, and for traffic emissions at 2.0 m, as typical values including both source height and initial plume rise. The concentrations were calculated at the height of 2.0 m.

The dispersion matrices were calculated as annual averages for the years 2000 - 2003, for the 8 - 10 stations mentioned above, and for the four emission categories, i.e. altogether 152 matrices. The matrices were combined with the data regarding the spatial distribution of emissions to calculate concentration levels due to nearby emissions of wood combustion and road traffic for the whole of Finland. Each emission was multiplied with a source-receptor matrix and the resulting concentration fields were summed up. For most cases, the source-receptor matrix of the nearest station was used, with two exceptions. The border between Oulu and Rovaniemi, as well as in southern Finland the border between the effect of coastal stations (Helsinki and Turku) and inland stations, were redefined in order to achieve a better compliance with the borders of climatic zones.

The effect of wet deposition of particles, not usually taken into account in UDM-FMI, was tested with separate calculations by selecting one station and year with precipitation amount well above average (Lappeenranta 2000). The influence of wet deposition turned out to be negligible in the vicinity of the source. At a distance of 10 km from the source, the difference of the predicted annual average concentration values, assuming precipitation and neglecting it, was below 5%.

Exposure and health effects

Emission-exposure relationship

The emission-exposure relationship for emissions of domestic wood combustion in residential and recreational buildings as well as direct and suspended traffic emissions for entire population of Finland were estimated using intake fraction (iF) concept (Bennett et al. 2002). The iF is defined as "*integrated incremental intake of a pollutant released from a source category and summed over all exposed individuals*" (Bennett et al., 2002). The iF concept was used in KOPRA project and the use of same concept enable direct comparison of results between the studies.

The estimation of iF for air pollution emissions is based on emission, concentration, population and breathing rate data. The emission and concentration data have been described earlier in Emission and Dispersion chapters, respectively. A nominal breathing rate of 20 m^3/day/person (~0.0002 m^3/s/person) was adopted in this study. The population data for Finland was obtained from the Statistics Finland Grid Database (http://www.stat.fi/tup/ruututietokanta/index_en.html). The dataset contained population numbers for Finland on a resolution of 250 x 250 m^2 for 2004. For the iF calculation, the population data was transformed into same spatial resolution with concentration data with ArcMap version 9.2 (http://www.esri.com/).

The intake fraction iFs for a sector s is calculated using equation

$$iF_s = \sum_{i=1}^{n} \frac{c_{s,i} \times Pop_i \times BR}{Q_s}$$

where Qs is the total emission from the sector s, $c_{s,i}$ is the incremental concentration of PM (g/m^3) in a grid cell i (i=1..n in such a way that the grid covers the whole of Finland), caused by Q_s, Pop_i is the population size in the grid cell i, and BR is the average individual breathing rate 20/(24*60*60) m^3/s/person.

Q_s can be divided spatially into the grid cells and described separately for each grid cell as $Q_{s,j}$ (j=1..m in such a way that the grid covers the whole of Finland). The concentration $c_{s,i}$ can also be described as the sum of $c_{s,i,j}$, each of which is an incremental concentration in grid cell i caused by the emission $Q_{s,j}$ from grid cell j. Therefore, we can expand the ratio by $Q_{s,j}$ ($Q_{s,j}$>0) and write

$$iF_s = \sum_{i=1}^{n} \frac{(\sum_{j=1}^{m} c_{s,i,j} \times \frac{Q_{s,j}}{Q_{s,j}}) \times Pop_i \times BR}{Q_s} = \sum_{j=1}^{m} (\frac{Q_{s,j}}{Q_s} \sum_{i=1}^{n} \frac{c_{s,i,j} \times Pop_i \times BR}{Q_{s,j}})$$

In this work, we did not model the concentration c caused by the emission Q_s, but the concentration c^* caused by a hypothetical emission of 1000 kg/a from a representative 1 x 1 km^2 grid cell. We assume that the emissions and concentrations have a proportional relationship, thus

$$\frac{c_{s,i,j}}{Q_{s,j}} = \frac{c^*_{s,i,j}}{1000kg/a} <=> c_{s,i,j} = \frac{c^*_{s,i,j} \times Q_{s,j}}{1000kg/a}$$

Therefore, we can use c^* instead of c and write

$$iF_s = \sum_{j=1}^{m} (\frac{Q_{s,j}}{Q_s} \sum_{i=1}^{n} \frac{\frac{c^*_{s,i,j} \times Q_{s,j}}{1000kg/a} \times Pop_i \times BR}{Q_{s,j}}) = \sum_{j=1}^{m} (\frac{Q_{s,j}}{Q_s} \sum_{i=1}^{n} \frac{c^*_{s,i,j} \times Pop_i \times BR}{1000kg/a})$$

In this work, the grid i did not cover the whole of Finland but only the first 20*20 km^2 or 40*40 km^2 around the emission source categories. The total number of grid cells for the whole Finland (m) was 783900. The intake fractions were calculated with statistical computation and graphic system R version 2.7.0 (The R Foundation for Statistical Computing, http://www.r-project.org/).

Population exposure

The exposure was estimated by back-calculating exposures from iF's. With this method we could estimate the population average exposure for the different emissions sectors and for different emissions scenarios. This methodology assumes that the emission-exposure relationship is linear and that the emission reduction will lower emissions uniformly in Finland. The advantage of this method is that large dispersion datasets are summarized into simple indicator. This enables for example running of multiple scenarios and propagation of uncertainty through the model.

Exposure was calculated as

$$E_s = \frac{Q_s \times iF_s}{Pop \times BR}$$

where E_s is exposure of population as average primary fine particle concentration for sector s(g/m^3); Q_s is total emission concentration for sector s (g/s); iF_s is the intake fraction for a sector s; Pop is number of people in Finland; BR is breathing rate (m^3/s).

In addition we estimated the population average exposure of different subpopulations for primary $PM_{2.5}$ due to emissions from four emission source categories with equation:

$$E_{s,j} = \frac{\sum(c_{s,i} \times Pop_{i,j})}{Pop_{tot,j}}$$

where $E_{s,i,j}$ is population average exposure for primary $PM_{2.5}$ for sector s and for subpopulation j (g/m^3); $c_{s,i}$ is the incremental concentration of PM (g/m^3) in a grid cell i (i=1..n, where n is total number of grid cells), caused by Q_s; $Pop_{i,j}$ is the population size in the grid cell i for subpopulation j; $Pop_{tot,j}$ is total size of subpopulation j.

Population data used in this calculations was the same dataset as in iF calculations. In addition to population densities of total population, the dataset contained population densities for different age, gender and education subpopulations in Finland.

Exposure-response functions

The exposure-response functions for mortality impacts of fine particles were delivered from formal procedure for elicitation of expert judgment study performed for six European air pollution experts (Cooke et al. 2007, Tuomisto et al. 2008). In this expert elicitation study these experts provided quantitative estimates of mortality impacts of hypothetical short- and long-term changes in fine particle concentrations in US and Europe and for several other variables required to evaluate the health effects of fine particles. The experts gave their 5th, 25th, 50th, 75th, and 95th percentiles for each variable. The elicitation procedure has been described in detail in the articles Cooke et al. 2007 and Tuomisto et al. 2008.

We adopted exposure-response functions for non-accidental mortality from this expert-elicitation study. Experts estimated in Expert Elicitation study that mean percentage change in non-accidental mortality, due to 1 $\mu g/m^3$ change in $PM_{2.5}$ concentration, is 0.6% or 1.0%. We used the combination of these two estimates in this study. We assumed no threshold for the health effects of fine particles.

Health effects

The premature death indicator was used to express the adverse health effects of fine particles. The premature death was estimated with equation

$$pM = E \times ER \times BM$$

where pM is additional premature mortality; E is exposure ($\mu g/m^3$); ER is exposure-response function as change in non-accidental mortality due to 1 $\mu g/m^3$ change in fine particle exposure (%); BM is background non-accidental mortality as number of cases. The derivation of exposure and concentration-response functions has been described earlier.

Background mortality statistics for Finland were obtained from World Health Organization Mortality Database. The annual non-accidental mortality (45 182) was calculated by subtracting accidental causes (International Classification of Disease (ICD) codes version 9 E47-E56 and V01-Y89 for ICD-10) from total mortality.

Exposure and health effect scenarios in 2020

Exposure and health effect scenarios were assessed for the year 2020. Exposure and health effects due to domestic wood combustion and traffic emissions were assessed with sum of residential and recreational wood combustion emissions and exhaust and non-exhaust emissions, respectively. Intake fractions of different emission sectors of year 2000 were adopted to this exposure and health effect evaluation (see chapter "Exposure and health effects in 2000"). Thus, we assumed that emission reduction would be applied evenly around Finland so that, for example, traffic emissions would be reduced as much all over Finland. Population projection for year 2020 by Finland area (5 546 772 inhabitants) was obtained from the Statistics Finland's PX-Web databases (http://www.stat.fi/tup/ruututietokanta/index_en.html). Breathing rate and background mortality numbers were obtained from year 2000 (see previous chapters).

3 Results

Emissions

Emissions in 2000

Tables 2, 3 and 4 show the $PM_{2.5}$ emissions of domestic wood combustion, traffic exhaust and traffic non-exhaust in 2000, respectively. Total emissions of the three source-sectors contributed to 7580, 4200 and 3220 Mg/a (ton/a), or 23%, 13% and 10% of the Finnish total emissions of primary fine particles in 2000, respectively.

Wood combustion emissions were estimated for different heating and combustion appliance types in residential and recreational buildings (Table 2). Primary wood heating in residential buildings accounted for 53% of total emissions of the sector. Supplementary wood heating in electricity-heated and oil-heated residential buildings accounted for 29% and wood heating in recreational buildings 17% of total emissions. Of the various domestic combustion appliance sub-categories, the highest emissions were from manual feed boilers operated without accumulator tank, mainly because of their high emission factor. Combustion from other stoves and ovens, mainly comprising of masonry heaters, also had relatively high emissions, but rather because of high levels of activity.

The highest vehicular traffic exhaust emissions originated from light-duty diesel vehicles, contributing 59% of total exhaust emissions (Table 3). Heavy-duty diesel vehicles accounted for 32%, gasoline vehicles being a minor contributor (9%).

Emissions from suspension form clearly a majority of the total non-exhaust emissions with 84 and 92 percent for light and heavy duty vehicles, respectively. Figure 5 shows that suspension emission factors are 4 to 5 times higher in spring (March-April) compared with the summer time emission factors. Sensitivity analysis of the suspension emissions also shows that the use of emission factors that have been estimated only in dry conditions can lead to significant overestimations of total emissions. In our preliminary analysis the reducing effect is approximately 45 percent. This analysis strongly indicates that a reducing factor due to moisture should be included in such emission estimations.

Our analysis does not include the enhanced road wear emissions by the wintertime use of studded tires. This is due to lack of conclusive quantitative data. Kupiainen (2007) estimated based on total material losses from pavement wear that the PM_{10}

emission factors for studded tires could be in the order of 135 to 660 mg vkm^{-1}, however further studies are needed to verify this.

Spatial distribution of the emissions in 1 x 1 km^2 resolution is presented in figure 6. Domestic wood combustion emissions are relatively evenly distributed over the southern and central Finland, supplementary wood heating taking place also to considerable extent in residential areas of the major cities. Road traffic emissions occur mainly near population clusters and along main highways in south-western Finland. In total the emissions from highways are higher compared with streets although the highway emission factors per vehicle kilometre are estimated to be lower. The higher emissions from highways compared with streets are due to the relatively higher mileage and a larger contribution from heavy traffic on highways.

Emission uncertainties

The uncertainties of activity and emission factor parameters have been estimated in Karvosenoja et al. (2008). The main results are presented in Tables 2-4.

In general, uncertainties were bigger for domestic wood combustion than traffic emissions. The emission uncertainties for domestic wood combustion were 2700 Mg/a (ton/a) (lower) and 3800 Mg/a (ton/a) (upper) (95% confidence interval limits), corresponding to 36% and 50% of the total emissions from the sector.

For appliance type sub-categories presented in Table 2, the uncertainties were mainly between 58% down and 100% up. The highest uncertainties in relative terms were for open fireplaces and iron stoves in recreational buildings (approx. 67% down and 130% up), and in absolute terms for manual feed boilers without accumulator tank (1100 Mg/a (ton/a) down and 2000 Mg/a (ton/a) up).

For traffic, uncertainties for exhaust emissions were relatively low, ±300 Mg/a (ton/a), or ±7% of the mean emission value. For the earlier version of non-exhaust emission calculation, the uncertainties have been estimated considerable, 38% down and 52% up (Karvosenoja et al. 2008). For the updated non-exhaust emission calculation uncertainties have not been estimated.

Table 2. The mean values and 95% confidence intervals (CI) of the activities, $PM_{2.5}$ emission factors and emissions of domestic wood combustion in 2000 in Finland (Karvosenoja et al. 2008)

Taulukko 2. Puun pienpolton päästöjen aktiviteetit (PJ/v), $PM_{2.5}$ päästökertoimet (mg/MJ) sekä $PM_{2.5}$ päästöjen keskiarvot (tonnia/a) 95% luottamusvälillä Suomessa vuonna 2000 (Karvosenoja ym. 2008).

	Activity (PJ a^{-1}), mean (95% CI)	$PM_{2.5}$ emission factor (mg MJ^{-1}), mean (95% CI)	$PM_{2.5}$ emission (Mg a^{-1}), mean (95% CI)
Residential buildings (RsB)	**34.2 (30.8--37.6)**		**6270 (3900--9630)**
Primary wood-heated RsB	20.2 (16.6--23.9)		4040 (2470--6350)
manual feed boilers with accumulator tank	5.42 (3.89--7.22)	80.0 (37.6--150)	434 (187--852)
manual feed boilers without accumulator tank	2.67 (1.67--3.87)	700 (329--1310)	1870 (762--3840)
automatic feed wood chip boilers	1.46 (1.01--2)	50.0 (23.5--93.9)	73.0 (31.4—148)
automatic feed pellet boilers	0.102 (0.0693--0.142)	30.0 (14.1--56.3)	3.05 (1.29--6.11)
iron stoves	0.142 (0.0976--0.196)	700 (329--1310)	99.5 (42.1--199)
other stoves and ovens[1]	10.2 (7.86--12.8)	140 (65.8--263)	1430 (634--2780)
low-emission stoves	0	80.0 (37.6--150)	0
open fireplaces	0.163 (0.111--0.224)	800 (376--1500)	130 (54.9--259)
Supplementary wood-heated RsB	14.0 (10.7--17.4)		2230 (1130--4080)
iron stoves	0.212 (0.135--0.316)	700 (329--1310)	148 (59.7--303)
other stoves and ovens[1]	13.6 (10.4--16.9)	140 (65.8--263)	1900 (849--3720)
low-emission stoves	0	80.0 (37.6--150)	0
open fireplaces	0.222 (0.14--0.332)	800 (376--1500)	178 (70.7--370)
Recreational buildings	**5.00 (4.50--5.50)**		**1310 (758--2130)**
iron stoves	0.780 (0.372--1.37)	700 (329--1310)	545 (186--1250)
other stoves and ovens[1]	3.96 (3.19--4.59)	140 (65.8--263)	554 (249--1060)
open fireplaces	0.262 (0.118--0.477)	800 (376--1500)	209 (67.6--488)
Domestic wood combustion TOTAL	**39.2 (35.7--42.6)**		**7580 (4870--11400)**

[1)] incl. masonry heaters, masonry ovens, kitchen ranges and sauna stoves

Table 3. The mean values and 95% confidence intervals (CI) of the activities, $PM_{2.5}$ emission factors and emissions of vehicular traffic exhaust in 2000 in Finland (Karvosenoja et al. 2008).

Taulukko 3. Liikenteen pakokaasupäästöjen aktiviteettien keskiarvot (PJ/a), $PM_{2.5}$ päästökertoimet (mg/MJ) ja $PM_{2.5}$ päästöjen keskiarvot (tonnia/a) sekä 95% luottamusvälit Suomessa vuonna 2000 (Karvosenoja ym. 2008).

	Activity [PJ a^{-1}], mean (95% CI)	$PM_{2.5}$ emission factor [mg MJ^{-1}], mean (95% CI)	$PM_{2.5}$ emission (Mg a^{-1}), mean (95% CI)
Gasoline vehicles	**72.2 (71.5--72.9)**		**357 (308--412)**
4-stroke light-duty vehicles[1]	72.0 (71.3--72.7)		324 (276—378)
EURO0	35.3 (34.1--36.4)	6.00 (4.77—7.45)	212 (168--263)
EURO1	11.5 (10.9--12.1)	3.30 (2.62—4.10)	38.0 (30.0--47.3)
EURO2	22.3 (21.3--23.3)	3.30 (2.62—4.10)	73.7 (58.2—91.8)
EURO3	2.88 (2.72--3.05)	0.108 (0.0859—0.134)	0.311 (0.246—0.389)
2-stroke motorcycles & mopeds	0.201 (0.161--0.249)		33.3 (24.4--44.3)
EURO0	0.183 (0.147--0.226)	170 (135—211)	31.1 (22.4—41.7)
EURO1	0.0181 (0.0144--0.0225)	119 (94.6--148)	2.16 (1.56--2.90)
Diesel vehicles	**77.0 (76.2--77.8)**		**3840 (3370--4370)**
Light-duty vehicles[1]	32.0 (28.1--36.2)		2480 (1990--3030)
EURO0	16.6 (14.6--18.9)	111 (88.2—138)	1850 (1410--2360)
EURO1	4.48 (3.89--5.11)	72.2 (57.4—89.6)	323 (247—415)
EURO2	9.61 (8.38--10.9)	28.9 (22.9—35.8)	277 (212--356)
EURO3	1.28 (1.11--1.46)	21.1 (16.8—26.2)	27.0 (20.6--34.7)
Heavy-duty vehicles[2]	45.0 (40.8--48.8)		1360 (1160--1600)
EURO0	11.7 (10.5--12.9)	58.0 (46.1—72.0)	678 (528—858)
EURO1	9.00 (8.08--9.89)	37.1 (29.5—46.1)	334 (260--423)
EURO2	21.1 (19.1--23.1)	15.1 (12.0—18.7)	319 (248—401)
EURO3	3.15 (2.82--3.48)	10.4 (8.30—13.0)	32.9 (25.5—41.7)
Exhaust total	**72.2 (71.5--72.9)**		**4200 (3720--4730)**

[1)] Passenger cars, vans and motorcycles 2) Trucks, buses and other heavy duty

Table 4. The mean values and 95% confidence intervals (CI) of the activities, $PM_{2.5}$ emission factors and emissions of vehicular traffic non-exhaust in 2000 in Finland (Kupiainen et al., manuscript).

Taulukko 4. Liikenteen tie-, rengas- ja jarrupäästöjen aktiviteettien keskiarvot (M-km/a), $PM_{2.5}$ päästökertoimet (mg/MJ) ja $PM_{2.5}$ päästöjen keskiarvot (tonnia/a) Suomessa vuonna 2000 (Karvosenoja ym. käsikirjoitus).

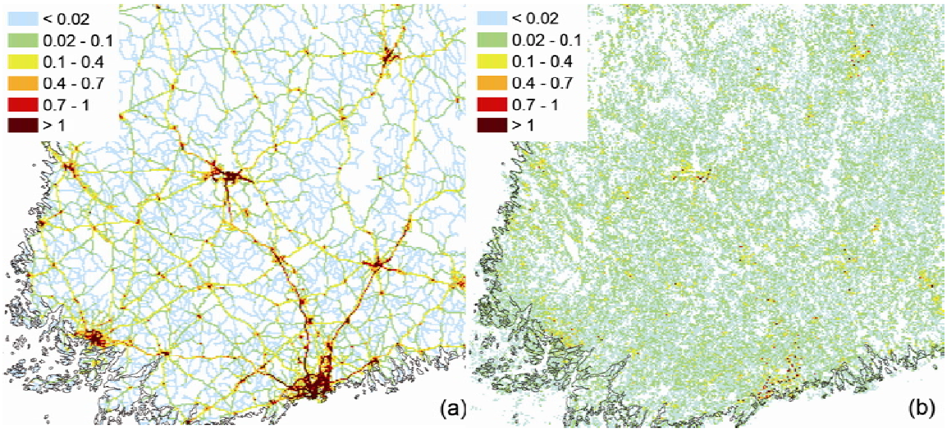
	Activity [Milj. veh-km a^{-1}], mean (95% CI)	$PM_{2.5}$ emission factor [mg veh-km^{-1}], mean (95% CI)	$PM_{2.5}$ emission ($Mg\ a^{-1}$), mean (95% CI)
Light-duty vehicles[1]	**43.0 (40.9--45.1)**		**1985**
Road wear, city streets		1.0	15
Road wear, highways		1.1	28
Tire wear, city streets		4.9	73
Tire wear, highways		3.2	90
Brake wear, city streets		5.8	87
Brake wear, highways		1.1	32
Suspension, city streets		38	726
Suspension, highways		26	934
Heavy-duty vehicles[2]	**3.40 (3.23--3.57)**		**1234**
Road wear, city streets		5	4
Road wear, highways		5	13
Tire wear, city streets		10	9
Tire wear, highways		7	17
Brake wear, city streets		28	15
Brake wear, highways		5	44
Suspension, city streets		344	374
Suspension, highways		241	757
Non-exhaust total	**46.4 (44.2--48.5)**		**3219**

1) Passenger cars, vans and motorcycles

2) Trucks, buses and other heavy duty

Figure 6. Spatial distribution of $PM_{2.5}$ emissions of (a) road traffic (exhaust and non-exhaust emissions) and (b) domestic wood combustion in south-western Finland in 2000. Unit ton/a.

Kuva 6. (a) Liikenteen ja (b) puun pienpolton $PM_{2.5}$ päästöjen alueellinen jakauma lounaisessa Suomessa vuonna 2000. Yksikkö tonnia/a.



Emissions in 2020

The energy pathways used in this report are based on the Finnish Climate Strategy for year 2005. The 2008 Finnish Energy and Climate Strategy predict 25% higher amount of domestic wood combustion than in the 2005 Strategy. The highest increases in domestic wood heating are expected in the form of pellet combustion (25 PJ in 2020) due to economical incentives for pellet heating. This will increase emissions from pellet boilers 500 tons/a. However, total emissions from domestic wood combustion will decrease by 800 tons/a because intensified introduction of pellet heating will considerably accelerate the replacement of old high-emission manual boilers.

Emission scenarios were calculated for the year 2020 (Table 5). For domestic wood combustion, despite the slight increase in activity levels, the emissions decrease slightly because of renewal of combustion appliances to less polluting technologies, e.g. modern masonry heaters and pellet boilers. On the whole, domestic wood combustion will remain a major emission source category in the future with approx. 25% contribution of Finnish total $PM_{2.5}$ emissions.

Traffic volumes are expected to increase in the future that can be seen as increasing traffic non-exhaust emissions. Contrary to that, traffic exhaust emissions will decrease drastically because of strict emission standards for new vehicles (e.g. EC 1998) and renewal of vehicle fleet. Exhaust emissions will be a minor contributor at country level in the future, while non-exhaust emissions will become more important (from 10% contribution in 2000 to 16% in 2020).

Table 5. $PM_{2.5}$ emissions of domestic wood combustion and traffic in 2000 and 2020 in Finland. Unit ton/a (percentage of Finnish total).

Taulukko 5. Vuosien 2000 ja 2020 liikenteen ja puun pienpolton $PM_{2.5}$ päästöt (tonnia/a) Suomessa sekä prosenttiosuus koko Suomen päästöistä.

	2000	2020
Domestic wood combustion	7580 (23%)	6970 (25%)
Traffic exhaust	4200 (13%)	380 (1.4%)
Traffic non-exhaust	3220 (10%)	4380 (16%)
Other anthropogenic sources	17 400 (54%)	16 200 (58%)
Total	**32 400**	**27 900**

[a)] incl. emissions from power plants, industry, other traffic sources, machinery, agriculture, etc.

Emission reduction potential in 2020

Potential for emission reductions with technical measures were studied in the project. For domestic wood combustion, three potential technologies were identified (Table 6):

- intensified switch to low-emission stoves;
- ban on manual boilers without accumulators
- end-of-pipe reduction in boilers.

Table 6. $PM_{2.5}$ emissions in different emission reduction scenarios of domestic wood combustion in 2020 in Finland. In addition to Baseline (assumes no emission reduction measures), three different reduction measure options are considered, plus all measures combined (the last row). Unit ton/a.

Taulukko 6. Puun pienpolton $PM_{2.5}$ päästöt neljällä eri päästövähennysskenaariolla Suomessa vuonna 2020. Yksikkö tonnia/a.

Domestic wood combustion	2020
Baseline	6970
Intensified switch to low-emission stoves	6690
Ban on manual boilers without accumulator	5650
End-of-pipe reduction in boilers	5010
All above measures	4730

Many modern wood stoves apply low-emission combustion technologies, e.g. enhanced combustion air supply. This leads to emission reductions along the renewal of combustion appliance stock, however, in a relatively slow rate. In this study, the effect of intensified renewal of appliance stock, e.g. by way of economical incentives, was estimated. If all conventional masonry heaters were replaced by modern ones by 2020, the emission would decrease by 280 Mg, i.e. 4% of total domestic wood combustion emissions.

Wood boilers are relatively sparse in numbers compared to stoves, however, they are typically used as a primary heating source, i.e. with high operation rate. Furthermore, some of the appliances are relatively simple and emissions high. Especially combustion of logs typically involves batch-wise combustion and manual fuel feeding, and in practice requires a proper sized accumulation tank to ensure efficient combustion. However, it has been estimated that roughly one third of log boilers are operated without a proper sized accumulation tank (pers. comm. S. Tuomi, Finnish Work Efficiency Institute, 28.8.2003). The effect of the ban on log boilers without accumulation tank was estimated at 1300 Mg, or 19% of total domestic wood combustion emissions.

End-of-pipe measures, e.g. electrostatic precipitators (ESPs), have also been developed for domestic combustion scale in recent years. They have been estimated to be relatively cost-efficient option for $PM_{2.5}$ reduction when used with high operation rate (Karvosenoja et al. 2007). In this study, it was estimated that the installation of ESPs for all domestic wood boilers in Finland would result in 2000 Mg (or 28% of total domestic wood combustion emissions) emission reduction compared to Baseline, or 640 Mg further reduction from the case of accumulation tank installations.

The maximum reduction in domestic wood combustion sector, i.e. if the measures for both stoves and boilers were taken into action, would be 2200 Mg or 32% of total domestic wood combustion emissions.

Emissions of non-exhaust $PM_{2.5}$ will be the future challenge in further reducing $PM_{2.5}$ emission from traffic. However, significant knowledge gaps exist about the efficiencies of possible abatement measures. Such information is needed to be able to cost-efficiently further reduce the harmful air quality effects of vehicular traffic. In this study the major source of non-exhaust traffic $PM_{2.5}$ emissions was estimated to be suspension of dust. Suspension can be reduced through minimizing the formation of dust during winter as well as suppressing and removing the dust deposit from the road surface before it is elevated into the air. Formation of PM can be reduced through e.g. material choices and finding alternatives for street sanding as well as tire choices. Optimized use of dust suppressants provides a way of reducing PM concentrations on dry days that are problematic for air quality, but the dust deposit should be removed efficiently later on. Currently used methods of street washing and vacuuming, that have been the traditional way of removing debris and dust from the street surface, seem not to be efficient in reducing suspension emissions of e.g. PM_{10} at least in the short term.

Street scrubbers may provide an interesting new method for mitigating suspension, but their efficiencies should be studied. It seems that reducing non-exhaust PM emissions is not an end-of-pipe solution but rather a combination of methods that mitigate several formation and emission pathways. For this purpose more information on formation, emissions and effects is needed.

Dispersion

To illustrate the dilution of the emission for different cases, some source-receptor matrices are given in figures 7 - 9. The effect of different meteorological conditions between calculation years is shown in figure 7, and meteorological differences between stations, e.g. the prevailing wind direction and speed, are depicted in figure 8. The differences between stations are more significant than the differences between calculation years. For some meteorological stations annual average matrices are quite similar for different years, but for some stations there are obvious differences as shown in Figure 7. The difference in dispersion for emission source categories is given in figure 9. The two categories of traffic emissions are assumed to have the same emission height, and therefore the differences are caused only by the varying seasonal variation. Also, for the two categories of wood combustion the differences are due to varying seasonal and diurnal variation of emissions. For traffic emissions, the concentrations in the centre of the calculation area are higher than for domestic wood combustion, due to lower release height. Further away from the source, the differences between the dispersion of traffic and wood combustion emissions are smaller.

The final result of the dispersion calculations was the spatial distribution of $PM_{2.5}$ concentration due to nearby emissions of wood combustion and traffic. These distributions for the years 2000 - 2003 are shown in figure 10 for wood combustion and in figure 11 for traffic. The overview of the distribution is similar for the years calculated, the differences reflecting mainly the difference in emissions. For the two source categories of wood combustion, concentration distributions differ as a result of smaller amount and different spatial distribution of emissions from recreational buildings, as compared to residential buildings. The concentrations caused by suspended emissions of traffic are slightly lower compared to direct emissions, but the spatial distributions are similar, high levels of $PM_{2.5}$ concentrated near the main roads.

Figure 7. An example of source-receptor matrices for different years. Matrices for direct traffic emissions for Kankaanpää for the years 2000–2002. Concentration of PM in µg/m^3 assuming a source of size 1 x 1 km^2 and strength of 1000 kg/a in the centre of the calculation area.

Kuva 7. Esimerkki lähde-kohde-matriiseista eri vuosille. Matriisit liikenteen suorille päästöille Kankaanpäälle vuosina 2000–2002. Hiukkaspitoisuus (µg/m^3). Alueen keskellä sijaitsevan lähteen koko 1 x 1 km^2 ja päästö 1000 kg/a.

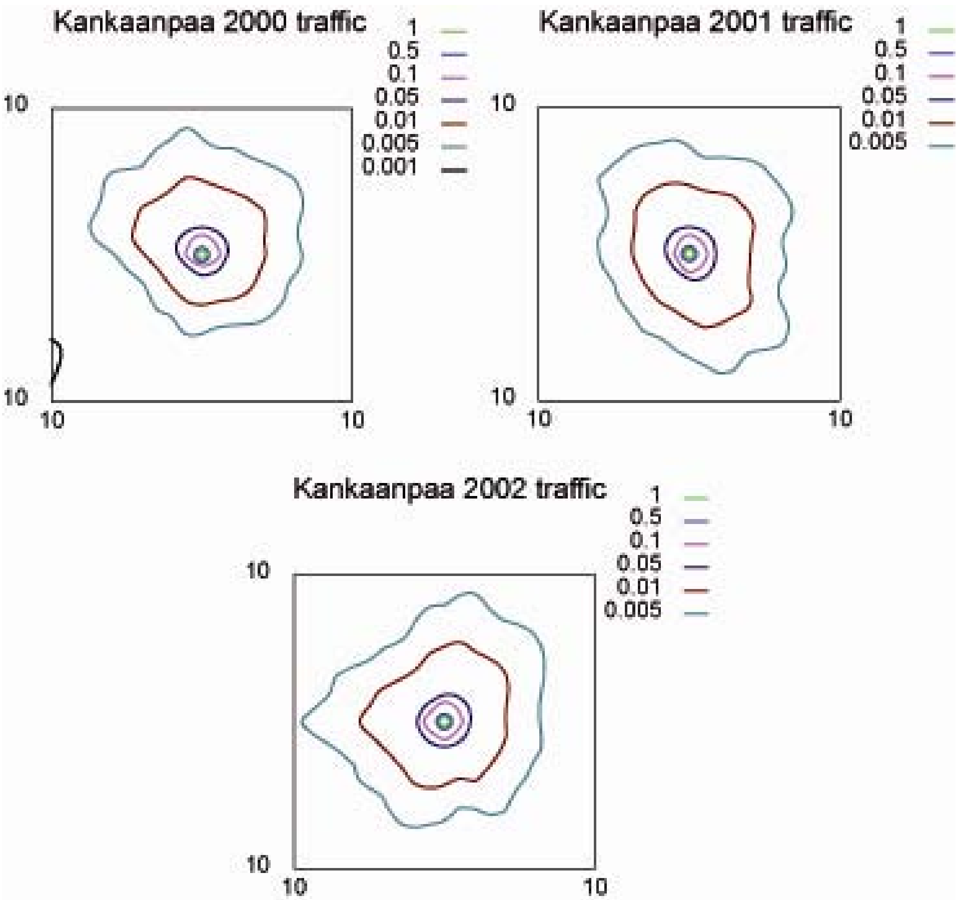


Figure 8. An example of source-receptor matrices for different stations. Matrices for suspended traffic emissions for Helsinki, Kuopio and Rovaniemi for the year 2000. Concentration of PM in µg/m^3 assuming a source of size 1 x 1 km^2 and strength of 1000 kg/a in the centre of the calculation area.

Kuva 8. Esimerkki lähde-kohde-matriiseista eri paikkakunnille. Matriisit liikenteen epäsuorille päästöille Helsingille, Kuopiolle ja Rovaniemelle vuonna 2000. Hiukkaspitoisuus (µg/m^3). Alueen keskellä sijaitsevan lähteen koko 1 x 1 km^2 ja päästö 1000 kg/a.

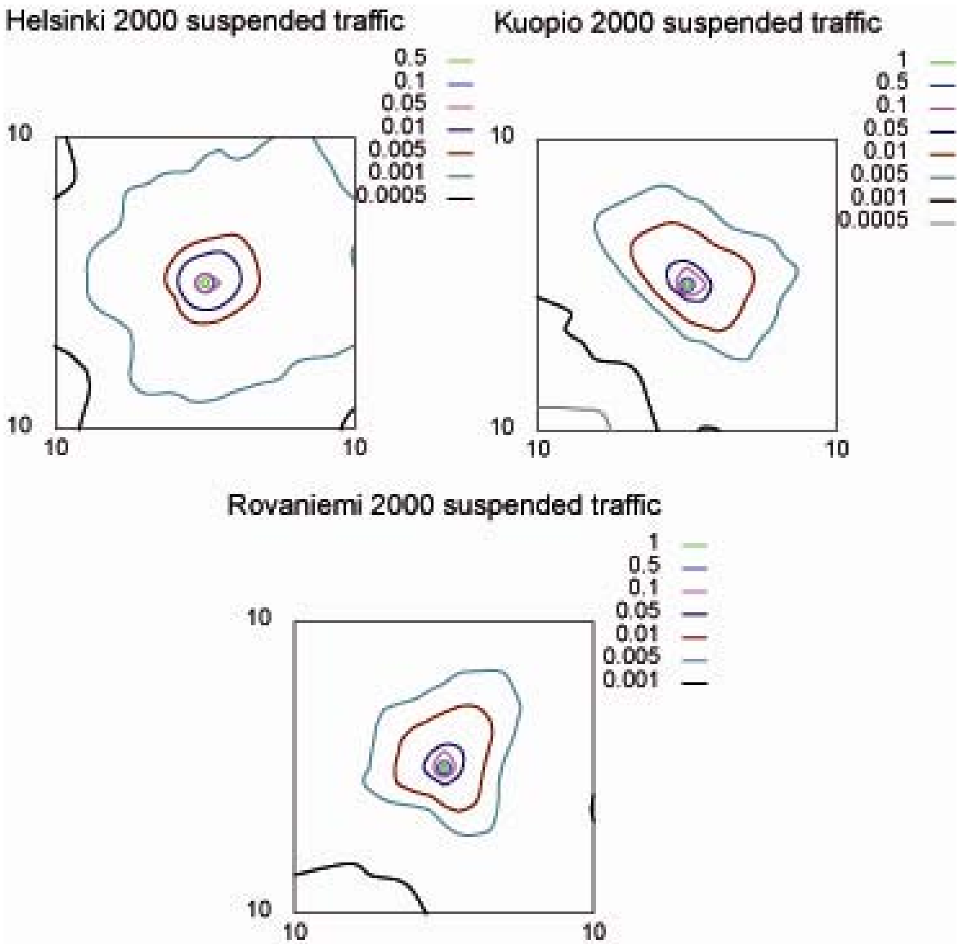


Figure 9. An example of source receptor matrices for different source categories. Matrices for different source categories for Helsinki for the year 2000. Concentration of PM in µg/m^3 assuming a source of size 1 x 1 km^2 and strength of 1000 kg/a in the centre of the calculation area.

Kuva 9. Esimerkki lähde-kohde-matriiseista eri päästöluokille. Matriisit Helsingille vuonna 2000. Hiukkaspitoisuus (µg/m^3). Alueen keskellä sijaitsevan lähteen koko 1 x 1 km^2 ja päästö 1000 kg/a.

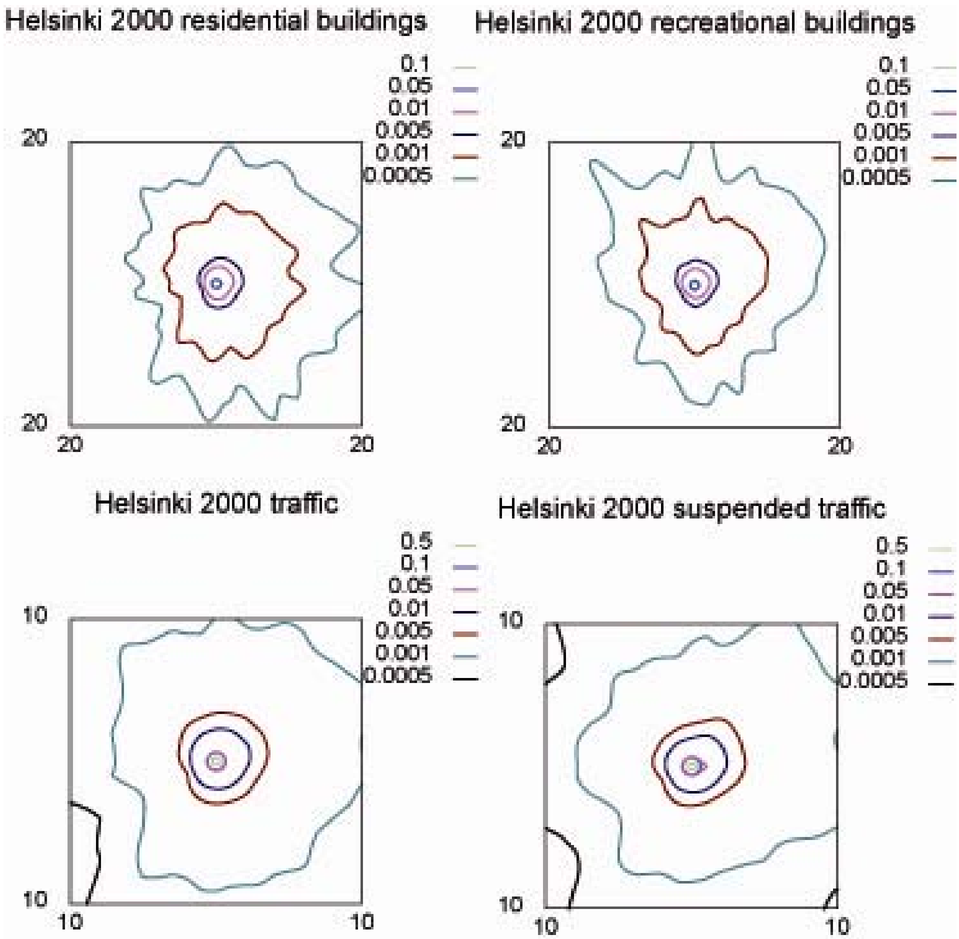


Figure 10a. Spatial distribution of annual mean concentration of $PM_{2.5}$ due to nearby emissions of wood combustion of residential buildings (left) and recreational buildings (right) in 2000 (ng/m^3).

Kuva 10a. Asuinrakennusten (vasen) ja vapaa-ajan rakennusten (oikea) päästöjen aiheuttama pitoisuus lähialueilla vuonna 2000 (ng/m^3).

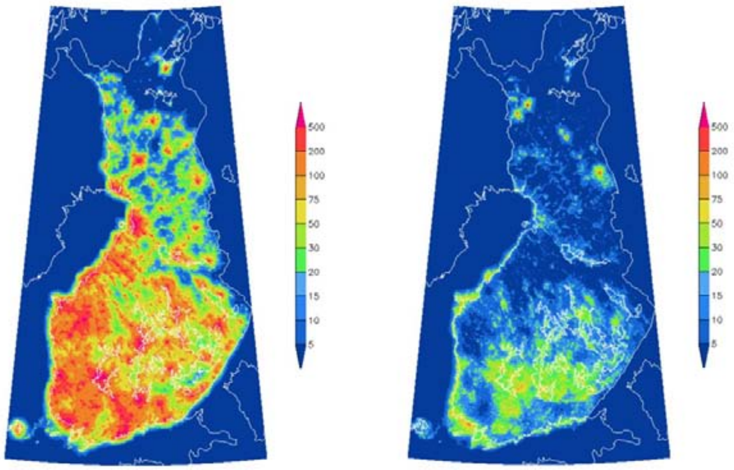


Figure 10b. Spatial distribution of annual mean concentration of $PM_{2.5}$ due to nearby emissions of wood combustion of residential buildings (left) and recreational buildings (right) in 2001 (ng/m^3).

Kuva 10b. Asuinrakennusten (vasen) ja vapaa-ajan rakennusten (oikea) päästöjen aiheuttama pitoisuus lähialueilla vuonna 2001 (ng/m^3).

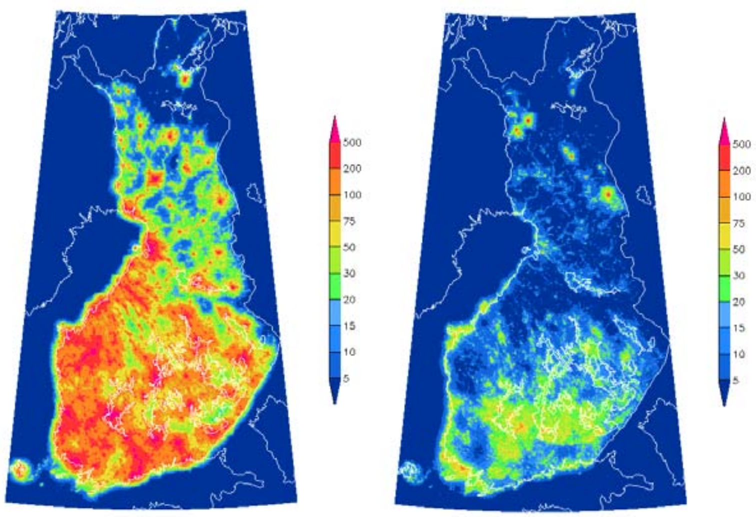


Figure 10c. Spatial distribution of annual mean concentration of $PM_{2.5}$ due to nearby emissions of wood combustion of residential buildings (left) and recreational buildings (right) in 2002 (ng/m^3).

Kuva10c. Asuinrakennusten (vasen) ja vapaa-ajan rakennusten (oikea) päästöjen aiheuttama pitoisuus lähialueilla vuonna 2002 (ng/m^3).

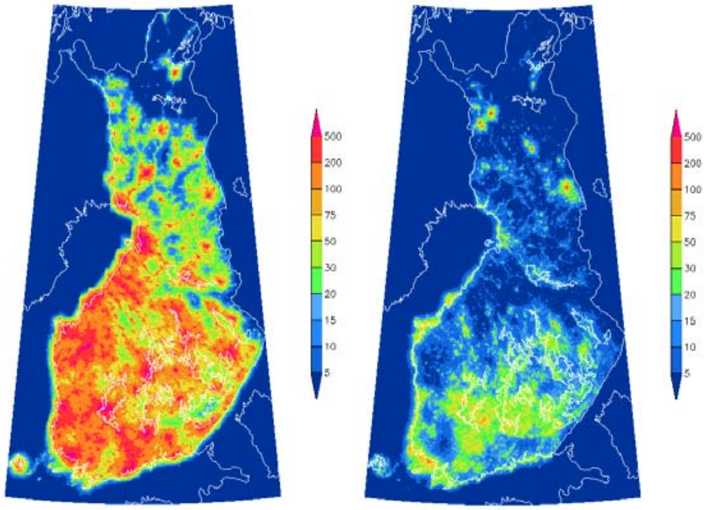


Figure 10d. Spatial distribution of annual mean concentration of $PM_{2.5}$ due to nearby emissions of wood combustion of residential buildings (left) and recreational buildings (right) in 2003 (ng/m^3).

Kuva 10d. Asuinrakennusten (vasen) ja vapaa-ajan rakennusten (oikea) päästöjen aiheuttama pitoisuus lähialueilla vuonna 2003 (ng/m^3).

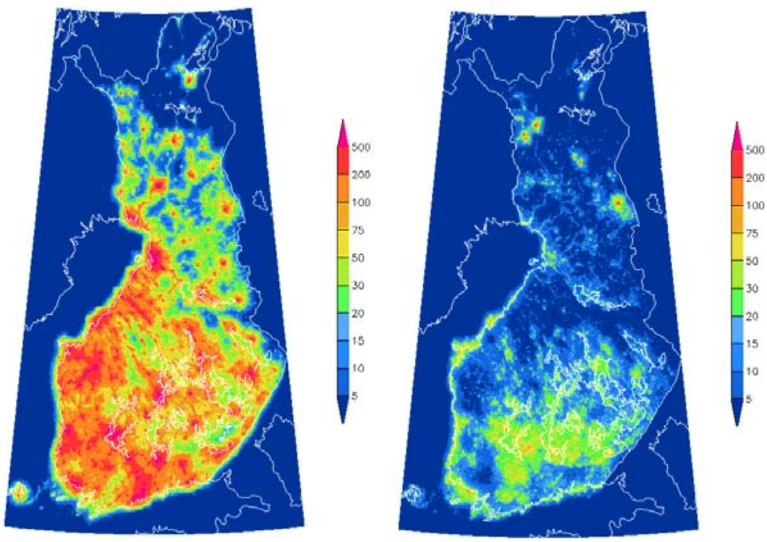


Figure 11a. Spatial distribution of annual mean concentration of $PM_{2.5}$ due to nearby direct (left) and suspended (right) emissions of traffic in 2000 (ng/m^3).

Kuva 11a. Tieliikenteen suorien päästöjen (vasen) ja suspensiopäästöjen (oikea) aiheuttama pitoisuus lähialueilla vuonna 2000 (ng/m^3).

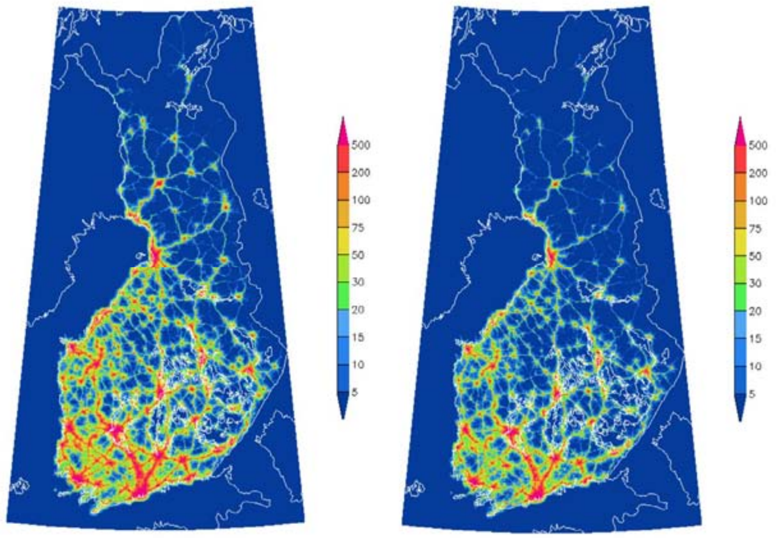


Figure 11b. Spatial distribution of annual mean concentration of $PM_{2.5}$ due to nearby direct (left) and suspended (right) emissions of traffic in 2001 (ng/m^3).

Kuva 11b. Tieliikenteen suorien päästöjen (vasen) ja suspensiopäästöjen (oikea) aiheuttama pitoisuus lähialueilla vuonna 2001 (ng/m^3).

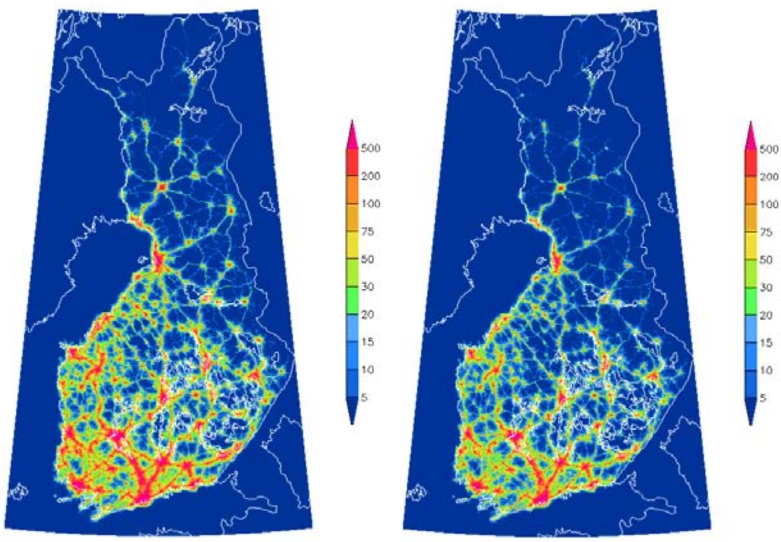


Figure 11c. Spatial distribution of annual mean concentration of $PM_{2.5}$ due to nearby direct (left) and suspended (right) emissions of traffic in 2002 (ng/m^3).

Kuva 11c. Tieliikenteen suorien päästöjen (vasen) ja suspensiopäästöjen (oikea) aiheuttama pitoisuus lähialueilla vuonna 2002 (ng/m^3).

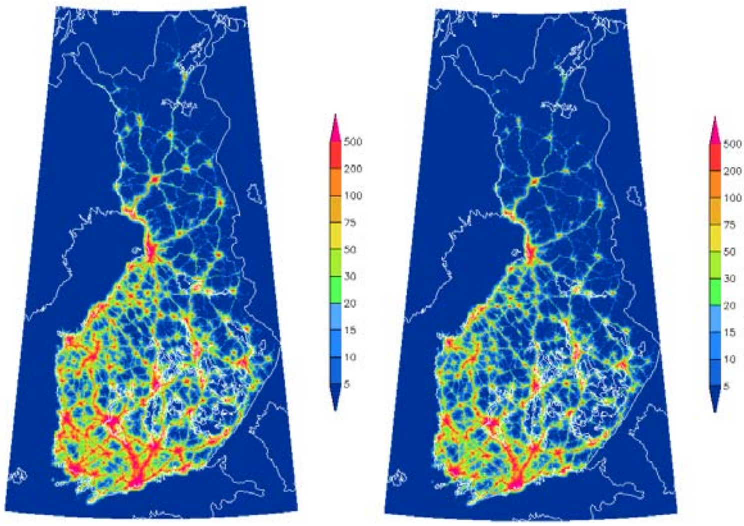
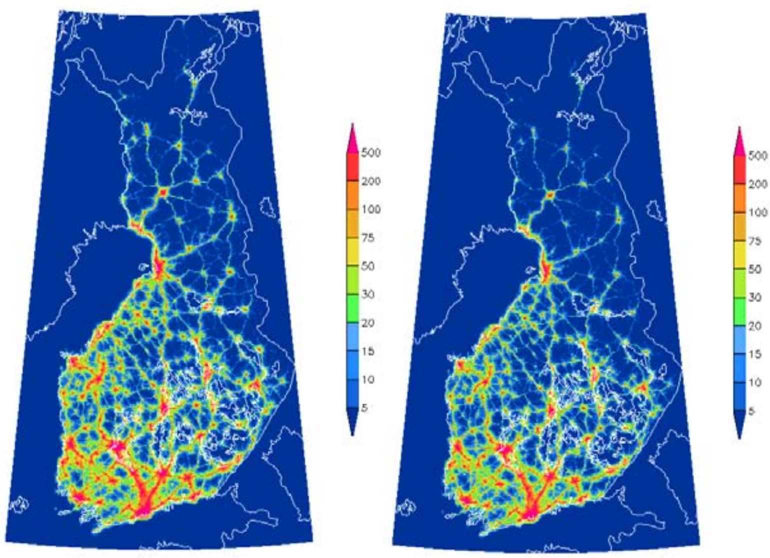


Figure 11d. Spatial distribution of annual mean concentration of $PM_{2.5}$ due to nearby direct (left) and suspended (right) emissions of traffic in 2003 (ng/m^3).

Kuva 11d. Tieliikenteen suorien päästöjen (vasen) ja suspensiopäästöjen (oikea) aiheuttama pitoisuus lähialueilla vuonna 2003 (ng/m^3).



Exposure and health effects in 2000

The intake fractions for primary fine particle emissions due to domestic wood combustion and traffic in Finland year 2000 varied over an order of magnitude. The iF's were 9.7 and 9.5 per million for direct (tailpipe) traffic emissions and suspended traffic emissions, respectively. The difference in iF between these two emission sub-sectors was small suggesting correlation in emission location and concentrations. The iF's for domestic wood combustion for residential building and domestic wood combustion for recreational buildings were 3.4 and 0.6 per million, respectively. Such a large difference in iF shows that the potency of these two sub-sectors to expose people differ significantly and that emission reductions in domestic wood combustion for residential building emissions has much smaller an import on exposure.

The population average exposure for these four emissions sectors was 2.46 $\mu g/m^3$ (Figure 12). Most of this was due to traffic-related primary fine particle emissions (Figure 12). Exposure to emissions from residential and recreational combustion was less than 1 $\mu g/m^3$.

Exposure to fine particles from domestic wood combustion and traffic was estimated to cause 1089 (95% CI 33-5100) premature deaths annually in Finland (Figure 13). The direct emissions and emissions from road, tyres, and breaks with suspended emissions from traffic contributed most to the health effects (in total 831; 95% CI 25-3900). The main reasons for this result are that the PM emissions from traffic are relatively high, and the emission-exposure relationship is effective.

The average exposure of the different population subgroups for primary $PM_{2.5}$ emissions from domestic wood combustion and traffic are presented in Figure 14a-c. The population average exposure for primary $PM_{2.5}$ emissions from wood combustion and traffic did not have significant relative differences in the various selected gender and age groups. In different education subpopulations, the exposure varied between 1.1-1.7 $\mu g/m^3$ and 0.7-1.0 $\mu g/m^3$ for traffic exhaust and wear, and traffic suspended emissions, respectively, so that people with higher education were exposed more than people with lower education (Figure 14c). There were no significant differences in exposures to domestic wood combustion emissions between different education subpopulations.

Figure 12. Exposure (µg/m^3) for entire Finnish population for domestic wood combustion and traffic emissions of Finland in year 2000.

Kuva 12. Keskimääräinen väestöpainotettu altistuminen Suomessa puun pienpolton ja liikenteen pienhiukkaspäästöille vuonna 2000.

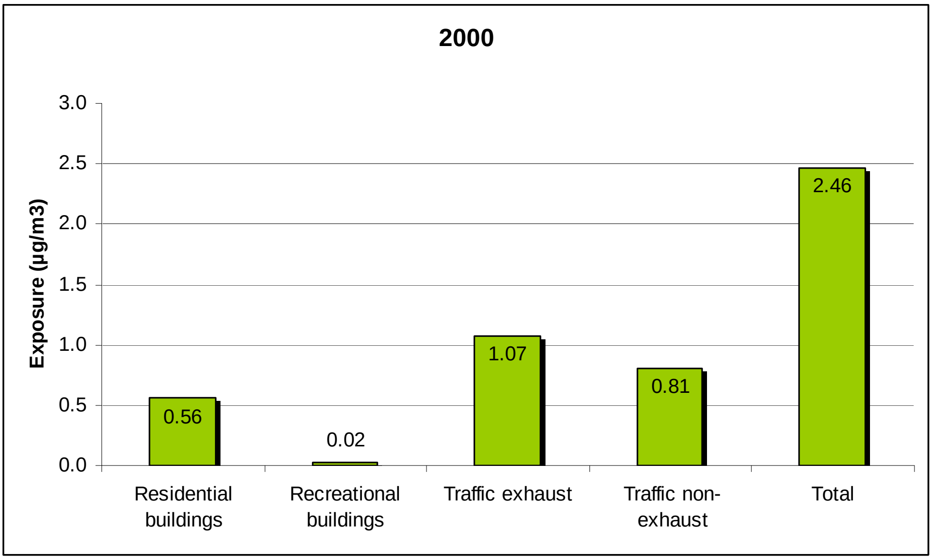


Figure 13. Health effects for Finnish population as premature mortality resulted by traffic and domestic wood combustion emissions of Finland in year 2000.

Kuva 13. Pienhiukkasten aiheuttamat ennenaikaiset kuolemantapaukset Suomessa vuonna 2000.

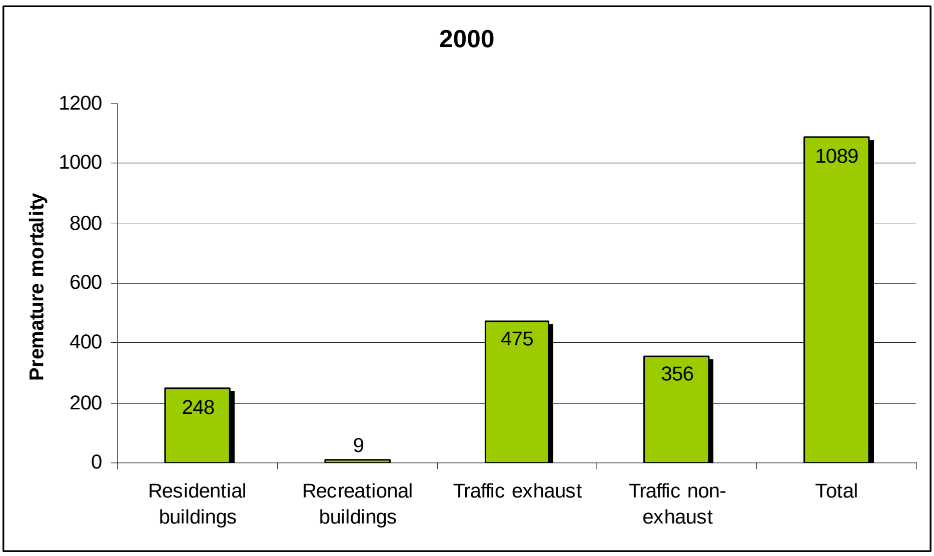
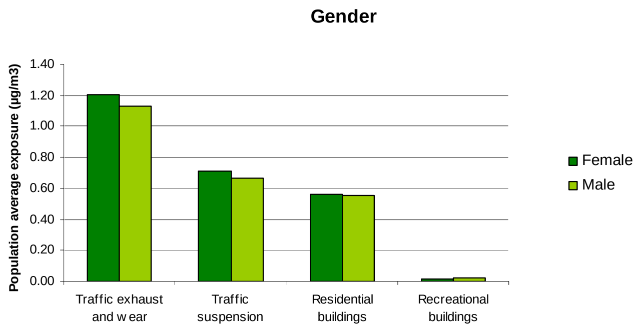
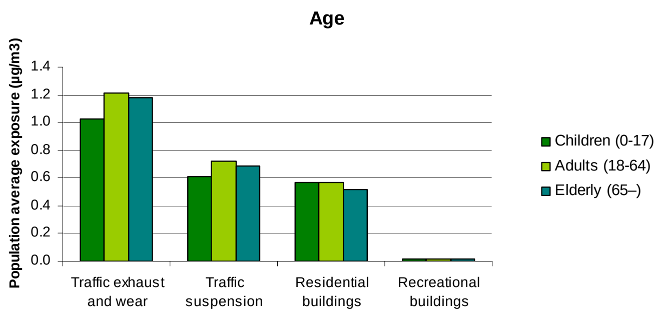


Figure 14a-c. Population average exposure (µg/m³) of different subpopulations for primary $PM_{2.5}$ emissions from domestic wood combustion and traffic in Finland in 2000.

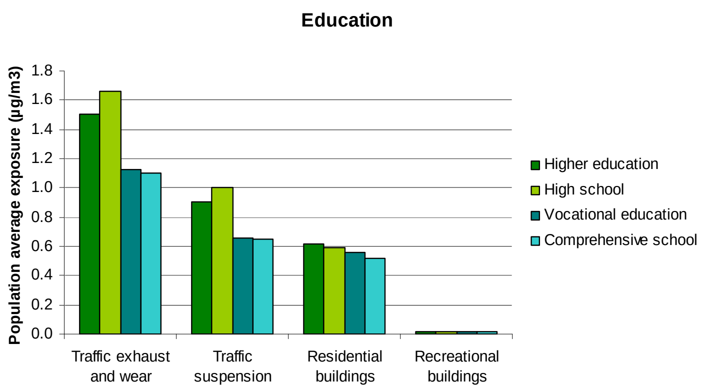
Kuva 14a-c. Eri väestöryhmien keskimääräinen altistuminen (µg/m³) puun polton ja liikenteen pienhiukkasille Suomessa vuonna 2000.



a)



b)



c)

Exposure and health effects in 2020

Exposure and health effect scenarios for Finnish population due to total fine particle emissions from domestic wood combustion and traffic for year 2020 are presented in Figures 14 and 15. The population average exposure to fine particles due wood combustion in buildings and traffic was estimated to be 1.62 $\mu g/m^3$ in year 2020. Most exposure to fine particles was assessed to be caused by traffic non-exhaust emissions (1.03 $\mu g/m^3$) and domestic wood combustion emissions (0.50 $\mu g/m^3$), respectively. Exposure to fine particles from Finnish direct traffic emissions in 2020 was evaluated to be less than 0.1 $\mu g/m^3$. Exposure to fine particles from domestic and traffic emissions was estimated to cause 453 premature deaths in Finland in year 2020. Most deaths were evaluated to be caused by domestic wood combustion and traffic non-exhaust emissions. Road traffic exhaust emissions were assessed to induce 26 premature deaths in Finland in year 2020.

Potential for wood combustion emission reductions with technical measures affected exposure and health effect scenarios for Finnish population due to fine particle emissions from domestic wood combustion in year 2020. Exposure and health effect comparison between different reduction scenarios is presented in Figures 16 and 17. The population average exposure to fine particles due to wood combustion in buildings was estimated to vary from 0.36 to 0.53 $\mu g/m^3$ in year 2020. Exposure to fine particles for domestic wood combustion emissions was estimated to cause 160 to 236 premature deaths in Finland in year 2020 depending on the reduction potential scenario.

Figure 14. Population average exposure (µg/m^3) of Finnish population for total traffic and domestic wood combustion primary $PM_{2.5}$ emissions of Finland in year 2020.

Kuva 14. Suomen väestön altistuminen liikenteen ja puun pienpolton (µg/m^3) kokonaispienhiukkaspäästöille vuonna 2020.

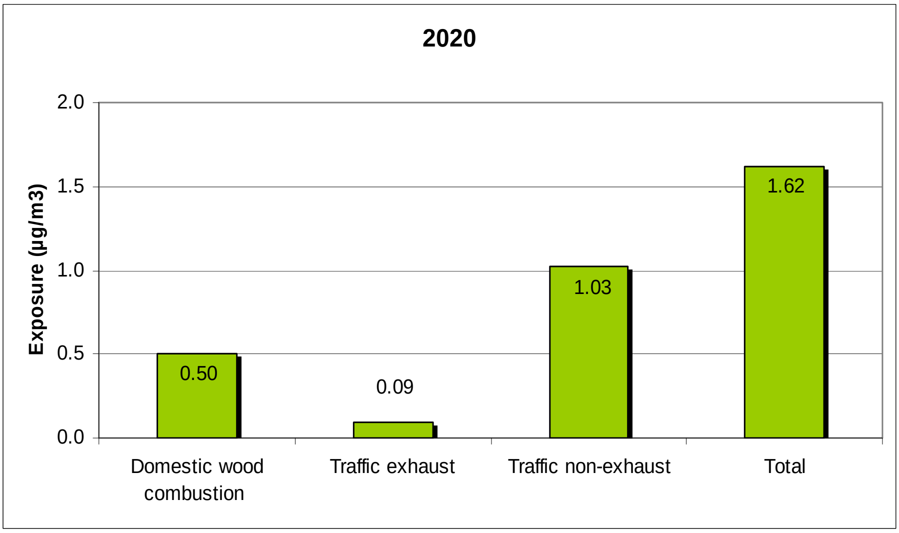


Figure 15. Premature deaths of Finnish population for traffic and domestic wood combustion primary $PM_{2.5}$ emissions in Finland in year 2020.

Kuva 15. Liikenteen ja puun pienpolton kokonaispienhiukkaspäästöjen aiheuttamat ennenaikaiset kuolemantapaukset Suomen väestölle vuonna 2020.

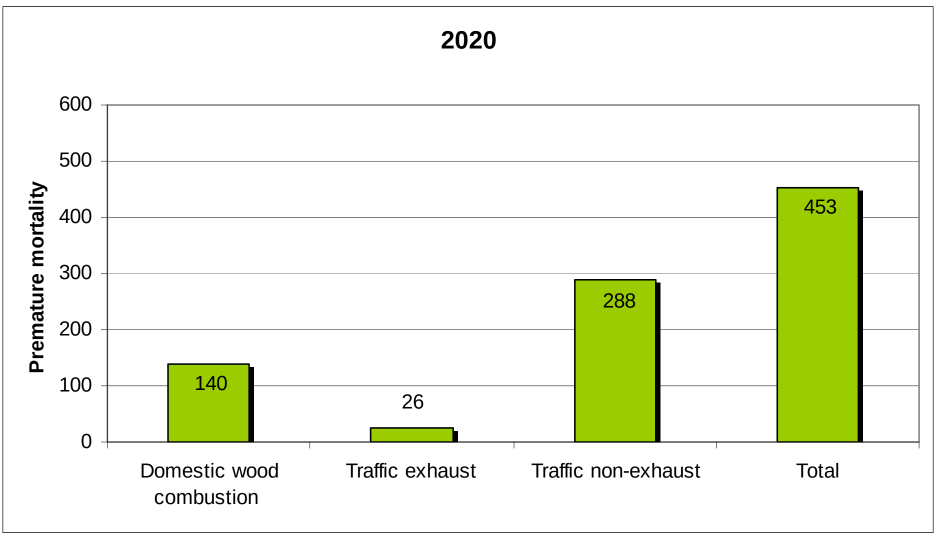


Figure 16. Comparison of population average exposure (µg/m[3]) of Finnish population between different domestic wood combustion emission reduction scenarios in Finland in year 2020.

Kuva 16. Suomen väestön altistuminen puun pienpolton (µg/m[3]) pienhiukkaspäästöille vuonna 2020. Eri vähennysskenaarioiden vertailu.

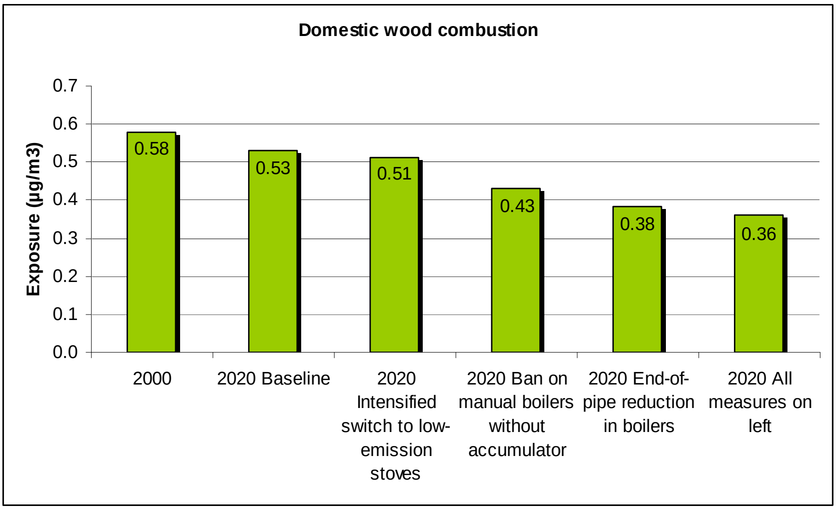
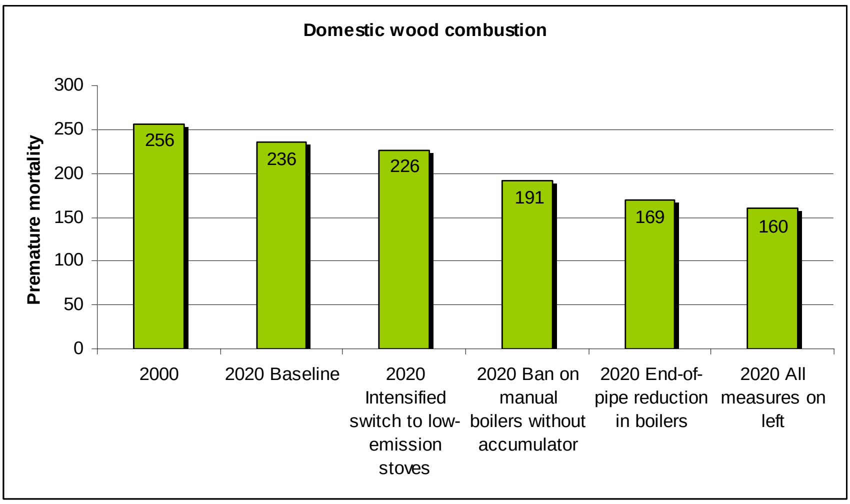


Figure 17. Premature death for Finnish population for domestic wood combustion primary $PM_{2.5}$ emissions in Finland in year 2020. Comparison between different reduction scenarios.

Kuva 17. Puun pienpolton pienhiukkaspäästöjen aiheuttamat ennenaikaiset kuolemantapaukset Suomen väestölle vuonna 2020. Eri vähennysskenaarioiden vertailu.



4 Discussion

We have evaluated in the PILTTI project the primary fine particle emissions from domestic wood combustion and traffic sources in Finland. The fine particle emissions from these sources were estimated to cause annually over 1000 premature deaths in Finland in 2000. The exposures for these emissions were evaluated only in the vicinity of emission sources (a few kilometres away from sources).

Comparison of the model predictions in the KOPRA and PILTTI projects

This study followed the previous KOPRA-project that evaluated the emissions, dispersion and health effects of Finnish primary fine particles in Finland and elsewhere in Europe. The projects have several linkages in the methodology and data.

Emission estimates of the KOPRA project were reviewed, and emission calculation procedure for traffic non-exhaust emissions were updated in this project. The new method takes into account differences between highway and urban road characteristics, as well as effect of meteorology on dust suspension. Furthermore, emission reduction potential for domestic wood combustion sector was evaluated in PILTTI.

The source-receptor matrices calculated in this study were compared with regional scale source-receptor matrices computed within KOPRA project. The comparison was made for the matrices for the year 2001. For PILTTI matrices with higher resolution than KOPRA, average concentrations were calculated corresponding to the size of the grid square of KOPRA matrices (approximately 10 x 10 km^2). These average concentrations computed in the PILTTI project were higher than those evaluated in KOPRA throughout the country. For wood combustion, the predicted concentrations were 10- to 20-fold in southern and central Finland, and 20- to 30-fold in northern Finland. For traffic the difference was slightly higher. This result was expected, as the KOPRA results are based on calculations with the Lagrangian version of the SILAM model, in which the initial dilution of emissions is stronger due to a coarser model resolution both horizontally and vertically. The vertical injection for area sources in KOPRA calculations was assumed to be within the lowest 100m (Sofiev et al., 2006). The comparison was, however, performed only for the source-receptor matrices. For the actual $PM_{2.5}$ concentrations, the difference is smaller, because in PILTTI project, only traffic and wood combustion emissions were considered, and furthermore, high concentrations occur only in the immediate vicinity of the sources.

The iF's for traffic were over an order of magnitude higher in the present study, 9.7 and 9.5 per million for direct (tailpipe) traffic emissions and suspended traffic emissions, respectively, than in KOPRA project (0.68 per million for all traffic emissions) (Tainio et al. 2009). The exposures presented in the KOPRA project for shorter than regional scale dispersion are probably significantly underestimated, especially for traffic emissions. The results also indicate that the health effects of traffic related primary fine particles are mostly caused near the emission source categories (up to, say, 10 km).

For the domestic wood combustion, the differences between KOPRA and PILTTI results are smaller but still significant. The iF for domestic wood combustion for residential building emissions was in the present study 3.4 per million. This is almost an order of magnitude higher than the iF for domestic wood combustion in the KOPRA project (0.54 per million). However, the iF for recreational building emissions was 0.6 in the present study. These results show how different domestic wood combustion sub-sectors have varying potential to expose people. This difference is mainly caused by the much lower density of populations near recreational buildings, compared with that near other buildings with domestic heating. This difference is important when planning of mitigation actions for the fine particle emissions from domestic combustion.

All traffic emissions contributed to 54 premature deaths in KOPRA. This is over fifteen times less than the health effects of the combined exhaust and non-exhaust traffic emissions in PILTTI (Figure 12). Domestic sources of fine particles were estimated to cause 29 premature deaths in KOPRA but 257 premature deaths in PILTTI. Because the concentration-response functions and population background mortality were the same in these two studies, the difference is due to differences in emissions and especially in exposure (predicted with different dispersion models).

Comparison to other studies

Emissions estimates of the FRES model have been earlier compared to other studies (Karvosenoja 2008). The calculation for domestic wood combustion emissions have been developed mainly during KOPRA project based on a review study on emission estimates in different countries (Sternhufvud et al. 2004), and later refined based on recent national data (e.g. Tissari 2008). Traffic exhaust emission factors were based on several measurement studies that are also used in the international RAINS model as country-specific data, and documented in Klimont (2002) and the on-line version of the model (http://www.gains.iiasa.ac.at). Emission factors represent the emission levels of vehicles of different ages defined by European legislation according to EURO standards. As for non-exhaust emissions, a literature review have been earlier conducted by Karvosenoja et al. (2008). Based on the review, national measurements (review in Kupiainen 2007) and the traffic suspension model by Omstedt et al. (2005), the calculation procedure in FRES have been renewed in this project.

The verification of UDM-FMI modelling system is discussed e.g. in Karppinen (2001).

Several studies have evaluated intake fractions for traffic emissions in the US using different methods (Table 7). For example Greco et al. (2007) estimated iF for mobile sources across the US and found emissions-weighted iF of 2.5 per million. Greco et al. estimates were based on source-receptor matrixes and evaluated exposure due to long-range transport of primary fine particles. Marshall et al. (2005) have estimated iF for urban diesel particles and found an intake fraction of 4 per million. These results are in same order of magnitude as the one estimated in the present study and one order of magnitude higher than the iF's estimated in the KOPRA study. For comparison to other studies see Table 7.

The European CAFE program estimated that fine particles cause in Finland approximately 1300 premature deaths in 2000. In the present study we estimated that local domestic wood combustion and traffic primary fine particle emissions contribute together over 1000 premature deaths in 2000. The result proposes that the European CAFE evaluation has underestimated the health impacts in Finland. This is probably due to underestimated exposure near the emissions sources since the CAFE analysis is regional-scale and the exposure model therefore resembles the KOPRA exposure model.

Table 7. Domestic wood combustion and traffic $PM_{2.5}$ source intake fractions from selected studies. The studies have been ordered primary between traffic and then domestic wood combustion studies and secondary from highest iF to lowest. Results from present study are in bold.

Taulukko 7. Eri tutkimusten saantiosuuksia puunpienpolton ja liikenteen pienhiukkaspäästöille. Tutkimukset on jaoteltu erikseen liikenteelle ja puun pienpoltolle sekä saantiosuuksien mukaan suurimmasta pienimpään.

Source	iF (per million)	Geog. location	Time scale	Indoor exposure ass. included	BR (m^3/day) (Scaled)	BR (m^3/day) (Original)	Pop. Characer	Ref.
Traffic	120	Mexico City	-	No	20	20	Urban	Stevens et al. 2007
Traffic	26	Mexico City	-	No	20	20	Urban	Stevens et al. 2007
Traffic	15.4[a)]	U.S.	Year	No	20	12.2	Urban	Evans et al. 2002
Traffic	14.4[a)]	U.S.	Year	No	20	12.2	Rural	Evans et al. 2002
Traffic (exhaust and wear)	**9.7**	**Finland**	**Year**	**No**	**20**	**20**	**People in country average**	**The present study**
Traffic (suspended)	**9.5**	**Finland**	**Year**	**No**	**20**	**20**	**People in country average**	**The present study**
Traffic	9.1	U.S.	Year	No	20	20	Rural & urban	Levy et al. 2002a
Traffic	7.2[a)]	U.S.	Year	No	20	12.2	Urban	Marshall et al. 2005
Traffic	1.2	U.S.	Year	No	20	20	County-level population	Greco et al. 2007
Traffic	0.7	Northern European	Year	No	20	20	People in country average	Tainio et al. 2009
Wood smoke levoglucosan	20.7[a)]	Canada	Winter	Yes	20	14.5	Urban	Ries et al. 2009
Wood smoke	17.9[a)]	Canada	Winter	Yes	20	14.5	Urban	Ries et al. 2009
Wood smoke (residential buildings)	**3.4**	**Finland**	**Year**	**No**	**20**	**20**	**People in country average**	**The present study**
Wood smoke (recreational buildings)	**0.6**	**Finland**	**Year**	**No**	**20**	**20**	**People in country average**	**The present study**
Wood smoke (domestic combustion)	0.5	Northern European	Year	No	20	20	People in country average	Tainio et al. 2009

a) iF is scaled to breathing rate of 20 m^3/day with the calculation of (iF/BR)*20.
a) iF on skaalattu vastaamaan 20 m^3/päivä hengitystiheyttä.

5 Conclusions

The PILTTI project has evaluated the emissions, dispersion, exposure and resulting health effects due to Finnish primary fine particle emissions from domestic wood combustion and traffic. The primary fine particle emissions for these two emission sectors were 7420 Mg/a and 7580 Mg/a, respectively, in 2000. The emission uncertainties were recognized to be high especially for domestic wood combustion emissions.

The dispersion of primary fine particles were estimated with the urban dispersion model up to 10 and 20 km from source for traffic and domestic wood combustion, respectively. The concentrations near the source were higher for traffic emissions due to lower emission height. Source-receptor matrices computed within PILTTI project improve the regional dispersion estimates of KOPRA matrices by giving a refined estimate for the dispersion near the emission source categories for domestic wood combustion and traffic emissions. Compared to KOPRA, PILTTI calculations give higher concentrations near the emission source categories. Direct comparison with the total concentration levels originated from all sources computed in KOPRA was not performed because PILTTI calculations do not include all source categories, and furthermore they only describe the dispersion near the source. The calculations, however, show that the calculation area used in PILTTI project is sufficient to cover at least 85% of the concentrations at calculation level for wood combustion, and for traffic at least 90–95%.

The emission-exposure relationship, expressed as intake fraction, showed that the traffic emissions have higher potential to expose people than domestic wood combustion emissions. The differences between different domestic wood combustion sub-sectors were also significant.

The effects caused by primary fine particle emissions from domestic wood combustion and traffic were estimated to be over 1000 premature deaths annually. This is much higher than the estimates from the previous KOPRA project and also indicates higher health impact than the values evaluated in the European CAFE-project. This result highlights the importance of low-emission height sources in comparison to other sources when estimating the population exposure and health effects for primary fine particles. This will have an impact on both methods used to estimate risks caused by fine particles and on legislation.

Steering group of PILTTI project

Supervisors from the Ministry of the Environment

- Seppo Sarkkinen (Ministry of the Environment)
- Pekka Kalliomäki (Ministry of the Environment)

External members in the steering group

- Tarja Lahtinen (Ministry of the Environment)
- Pekka Järvinen (Enprima, ÅF-Enprima Oy)
- Mikko Moisio (Tekes)
- Anu Kousa (Helsinki Metropolitan Area Council, YTV)
- Matti Johansson (UNECE)
- Raimo Salonen (National Institute for Health and Welfare, THL),
- Eija Alakangas (Technical Research Centre of Finland, VTT)
- Harri Pietarila (Finnish Meteorological Institute, FMI)

Project members in the steering group

- Jouni Tuomisto (National Institute for Health and Welfare, THL)
- Marko Tainio (National Institute for Health and Welfare, THL)
- Pauliina Ahtoniemi (National Institute for Health and Welfare, THL)
- Juha Pekkanen (National Institute for Health and Welfare, THL)
- Niko Karvosenoja (Finnish Environment Institute, SYKE)
- Kaarle Kupiainen (Finnish Environment Institute, SYKE)
- Petri Porvari (Finnish Environment Institute, SYKE)
- Jaakko Kukkonen (Finnish Meteorological Institute, FMI)
- Ari Karppinen (Finnish Meteorological Institute, FMI)
- Mikhail Sofiev (Finnish Meteorological Institute, FMI)
- Leena Kangas (Finnish Meteorological Institute, FMI)

Publication of PILTTI results in scientific journals and abstracts

Articles in refereed scientific journals

Ahtoniemi P., Tainio M., Karvosenoja N., Kupiainen K., Porvari P., Karppinen A., Kangas L., Kukkonen J., Tuomisto J.T. Evaluation of intake fractions for different subpopulations due to primary fine particulate matter (PM2.5) emitted from domestic wood combustion and traffic. Air Quality, Atmosphere and Health. Submitted

Hänninen O., Kauhaniemi M., Karppinen A., Kukkonen J., Kousa A., Jantunen M. 2008. Inter-comparison of predicted population exposure distributions during four selected episodes in Helsinki and evaluation against measured data. International Journal of Environment and Pollution. 19 p., in press.

Karvosenoja N., Kangas L., Kupiainen K., Kukkonen J., Karppinen A., Sofiev M., Tainio M., Paunu V.V., Ahtoniemi P., Tuomisto J.T., Porvari P. (Submitted). Integrated modeling assessments of the population exposure in Finland to primary PM2.5 from traffic and domestic wood combustion on the resolutions of 1 and 10 km. Air Quality, Atmosphere & Health.

Karvosenoja N., Tainio M., Kupiainen K., Tuomisto J. T., Kukkonen J. and Johansson M. 2008. Evaluation of the emissions and uncertainties of PM2.5 originated from vehicular traffic and domestic wood combustion in Finland. Boreal Environ. Res. 13:465-474.

Karvosenoja N., Klimont Z., Tohka A., Johansson M. 2007. Fine primary particle emission reduction potential and cost efficiency in Finland. Environ. Res. Lett. 2 (2007) 044002.

Kauhaniemi M., Karppinen A., Härkönen J., Kousa A., Alaviippola B., Koskentalo T., Aarnio P., Elolähde T. and Kukkonen J. 2008. Evaluation of a modelling system for predicting the concentrations of PM2.5 in an urban area. Atmos. Environ. Vol 42/19 pp 4517-4529, doi:10.1016/j.atmosenv.2008.01.071.

Loh M., Soares J., Karppinen A., Kukkonen J., Kangas L., Riikonen K., Kousa A., Asikainen A. and Jantunen M. 2008. Intake Fraction Distributions for Benzene from Vehicles in the Helsinki Metropolitan Area. Atmos. Environ. Vol. 43, pp. 301-310.

Tainio T., Tuomisto J.T., Hänninen O., Ruuskanen J., Jantunen M.J., Pekkanen J. 2007. Parameter and model uncertainty in a life-table model for fine particles (PM2.5): a statistical modeling study. Environmental Health 6: 24 http://www.ehjournal.net/content/6/1/24.

Tainio M., Karvosenoja N., Porvari P., Raateland A., Tuomisto JT., Johansson M., Kukkonen J., Kupiainen K. 2009. A simple concept for GIS-based estimation of population exposure to primary fine particles from vehicular traffic and domestic wood combustion. Boreal Environment Research.14: 850-860.

Articles in refereed scientific edited volumes and conference proceedings

Ahtoniemi P., Tainio M., Karvosenoja N., Kupiainen K., Porvari P., Karppinen A., Kangas L., Kukkonen J., Pohjola M., Tuomisto J.T. 2009. Exposure of Finnish subpopulations to fine particles due to domestic wood combustion. Proceedings of the 1st Joint Annual Meeting of EnSTe and SYTYKE Graduate Schools on 7th -8th December 2009.

Karvosenoja N., Kupiainen K., Kangas L., Karppinen A.., Sofiev M.,, Tainio M., Porvari P., Kukkonen J., Tuomisto J.T. 2009. Integrated modeling assessments of the population exposure in Finland to primary PM2.5 from traffic and domestic wood combustion on the resolutions of 1 and 10 km. Air Quality 2009 Conference Proceedings.

Karvosenoja N. and Johansson M. 2007. FINNISH REGIONAL EMISSION MODEL IN POLICY-SUPPORT. In: Doley D. (ed.) Proceedings of the 14th World Congress of IUAPPA, 9-14 Sept 2007. 6 pp.

Kauhaniemi, M., Karppinen, A., Härkönen, J., Kousa, A ., Koskentalo, T.,Aarnio,P. and Kukkonen, J., 2007. Refinement And Statistical Evaluation Of A Modelling System For Predicting Fine Particle Concentrations In Urban Areas. In: Ranjeet S. Sokhi and Marina Neophytou (eds): Proceedings of the 6th International Conference on Urban Air Quality, Limassol, Cyprus, 27-29 March 2007, CD-disk: ISBN 978-1-905313-46-4, University of Hertfordshire and University of Cyprus (pp. 68-71).

Kupiainen K., Karvosenoja N. and Porvari P. 2007. NON-EXHAUST PARTICLE EMISSIONS FROM TRAFFIC SOURCES IN FINLAND In: Doley D. (ed.) Proceedings of the 14th World Congress of IUAPPA, Brisbane, Australia 9-14 Sept 2007. CD-ROM. 6 pp.

Kukkonen, J., Karppinen, A., Kauhaniemi, M., Härkönen, J., Nikmo, J., Kousa, A., Alaviippola, B., Koskentalo, T., Aarnio, P. (2006). A model for evaluationg the urban and regional scale concentrations of PM2.5, and its application in Helsinki, In: Vehkamäki, H. et al. (eds.): Report Series in Aerosol Science, No 83, NOSA 2006 Aerosol Symposium, combined with the X Finnish National Aerosol Symposium, Finnish-Czech Aerosol Symposium and BACCI workshop, Helsinki 8.-10.11.2006, pp. 167-170, Yliopistopaino, Helsinki.

Soares J, Karppinen A, Kangas L., Jantunen M., Kukkonen J. 2007. Intake fraction for benzene traffic emissions in , In: Miranda, A. I., Borrego, C. (Eds.), 29th NATO/SPS International Technical Meeting on Air Pollution Modelling and its Application, Aveiro, Portugal, September 24-28.University of Aveiro, 2007.

Sofiev, M., Jourden, E., Kangas, L., Karvosenoja, N., Karppinen, A. and Kukkonen, J. (2006). Numerical Modelling of Spatial Distribution of Fine Particulate Matter in Europe and Finland. In: Vehkamäki, H. et al. (eds.): Report Series in Aerosol Science, No 83, NOSA 2006 Aerosol Symposium, combined with the X Finnish National Aerosol Symposium, Finnish-Czech Aerosol Symposium and BACCI workshop, Helsinki 8.-10.11.2006, pp. 348-352, University press, Helsinki.

Sofiev, M., Jourden, E., Kangas, L., Karvosenoja, N., Karppinen, A., Kukkonen, J. (2006). <Numerical modelling of the spatial distribution of fine particulate matter in Europe and Finland. Report series in aerosol science, Finnish Association for Aerosol Research, 83, 348-353.

Sofiev, M., Jourden, E., Kangas, L., Karvosenoja, N., Karppinen, A. and Kukkonen, J., 2007. The spatial distribution and temporal variations of fine particulate matter in Europe. In: Ranjeet S. Sokhi and Marina Neophytou (eds): Proceedings of the 6th International Conference on Urban Air Quality, Limassol, Cyprus, 27-29 March 2007, CD-disk: ISBN 978-1-905313-46-4, University of Hertfordshire and University of Cyprus(4p).

Sofiev, M., Jourden, E., Pirjola, L., Kangas, L., Karvosenoja, N., Karppinen, A., and Kukkonen, J., 2007. Dispersion modelling of the concentrations of fine particulate matter in Europe. In: C. Borrego & E. Renner (eds.). Developments in Environmental Science, 6. DOI: 10.1016/S1474-8177(07)0621-0. Air Pollution Modelling and its Applications XVIII, 189-199.

Tainio, M., Hujo, M., Sofiev, M., Kukkonen, J., Karppinen, A., Karvosenoja, N., Tuomisto. J.T., 2006. Evaluation of the seasonal variation of Intake Fractions (iF) for the Primary Fine Particle (PM2.5) Emissions in Finland for Various Source Sectors. In: Proceedings of the International Conference on Environmental Epidemiology & Exposure, Paris. 2-6 September. pp. 17.

Tainio M.(1,2), Ahtoniemi P.(1), Karvosenoja N.(3), Kupiainen K.(3), Porvari P.(3), Karppinen A.(4), Kangas L.(4), Kukkonen J.(4) and Tuomisto J.T.(1). Exposure of different subpopulations to primary fine particulate matter (PM2.5) air pollution due to traffic and domestic wood combustion in Finland. In: Proceedins of the SRA 2009 annual Meeting, Baltimore. 6-9 December. pp. 187.

Monographs

Karvosenoja N. 2008. Emission scenario model for regional air pollution. Monographs Boreal Environ. Res. 32.

Kupiainen K. 2007. Road Dust from Pavement Wear and Traction Sanding. Boreal Environ. Res. 26.

Tainio M. (2009). Methods and Uncertainties in the Assessment of the Health Effects of Fine Particulate Matter (PM2.5) Air Pollution. National Institute for Health and Welfare (THL), Research 18. 165 pages. Helsinki, Finland 2009. ISBN 978-952-245-101-9 (printed), ISBN 978-952-245-102-6 (pdf). PhD thesis.

References

Bennet, D.H., McKone, T.E., Evans, J.S., Nazaroff, W.W., Margni, M.D., Jolliet, O., Smith, K.R. 2002. Defining intake fraction. Environmental Science & Technology 36 (9): 206A-211A.

Cooke R.M., Wilson A., Tuomisto J.T., Morales O., Tainio M., Evans J.S.. (2007). A Probabilistic characterization of the relationship between fine particulate matter and mortality: Elicitation of European experts. Environmental Science & Technology 41(18): 6598-6605

EC (European Commission) 1998.Directive 98/69/EC of the European Parliament and of the Council relating to measures to be taken against air pollution by emissions from motor vehicles. Official Journal of the European Communities L 121/13, 11 May 1999.

Greco, S.L., Wilson, A.M., Spengler, J.D., Levy, J.I., 2007. Spatial patterns of mobile source particulate matter emissions-to-exposure relationships across the United States. Atmospheric Environment 41 (5), 1011-1025.

Hildén M., Karvosenoja N., Kankaanpää S., Ratinen M., Liski J. and Hämekoski K. 2005. Ympäristöarviointi kansallisesta strategiasta Kioton pöytäkirjan toimeenpanemiseksi (Environmental assessment of the National strategy for the implementation of the Kyoto protocol). The Finnish Environment 802, Helsinki, Finland. (In Finnish with English abstract.)

Karasmaa, N., Kurri, J., Voltti, V., Rinta-Piirto, J., Elolähde, T. and Valtanen, R. 2003. Helsinki metropolitan area travel forecasting models 2000. Helsinki Metropolitan Area Publication Series B2003:9. Helsinki, Finland. 198 pp. (In Finnish with English abstract.)

Karppinen, A., Joffre, S.M. and Vaajama, P., 1997. Boundary layer parameterization for Finnish regulatory dispersion models. International Journal of Environment and Pollution 8, pp. 557-564.

Karppinen, A., Kukkonen, J., Nordlund, G., Rantakrans, E., Valkama, I., 1998. A dispersion modelling system for urban pollution. Finnish Meteorological Institute, Publications on Air Quality 28. Helsinki, 58 p.

Karppinen, A., 2001. Meteorological pre-processing and atmospheric dispersion modelling of urban air quality and applications in the Helsinki metropolitan area. Finnish Meteorological Institute Contributions No.33, FMI-CONT-33, 94 p.

Karvosenoja N. 2008. Emission scenario model for regional air pollution. Monographs Boreal Environ. Res. 32.

Karvosenoja N., Tainio M., Kupiainen K., Tuomisto J. T., Kukkonen J. and Johansson M. 2008. Evaluation of the emissions and uncertainties of PM2.5 originated from vehicular traffic and domestic wood combustion in Finland. Boreal Environ. Res. 13:465-474.

Karvosenoja N., PorvariP., Raateland A., tuomisto J.T., Tainio M., Johansson M. and Kousa A. 2005a. Emission modeling in the assessment of PM2.5 from traffic and residentia wood combustion . Proceedings of the 3rd Air Quality management Conference, Istanbul 26-30 September. pp. 581-590.

Karvosenoja N., Porvari P., Raateland A., Kupiainen K., Johansson M. 2005. The spatial allocation of air pollutants in Finnish regional emission model. Proceedings of the 3rd Air Quality Management Conference, Istanbul 26-30 September. pp. 571-580.

Kukkonen, J., Karppinen, A., Sofiev, M., Kangas, L., Karvosenoja, M., Johansson, M., Porvari, P., Tuomisto, J., Tainio, M., Koskentalo, T., Aarnio, P., Kousa, A., Pirjola, L., Kupiainen, K., 2007. Kokonaismalli pienhiukkasten päästöjen, leviämisen ja riskin arviointiin – KOPRA. Finnish Meteorological Institute, Studies, 1, Helsinki, ISBN 978-951-697-635-1. (In Finnish with English abstract)

Kupiainen K. 2007. Road Dust from Pavement Wear and Traction Sanding. Boreal Environ. Res. 26.

Marshall, J.D., Teoh, S.K., Nazaroff, W.W., 2005. Intake fraction of nonreactive vehicle emissions in US urban areas. Atmospheric Environment 39 (7), 1363-1371.

Mikkola A., Jaakkola O., Sucksdorff Y. 1999. The Slices project: National classification of land use, land cover and soil, and the production of databases. Finnish Environment 342. Helsinki, Finland.

Mäkelä K., Laurikko J. and Kanner H. 2002. Road traffic exhaust gas emissions in Finland. LIISA 2001.1 calculation model. VTT Research Notes 2177. Finland.

Nieminen M. 2004. Kesämökkibarometri 2003. Tilastokeskus. http://www.intermin.fi/intermin/images.nsf/files/5d0d5cd4a9a81e43c2257005002fc699/$file/lopullinen%20raportti.pdf

Omstedt G., Bringfelt B., and Johansson C., 2005. A Model for Vehicle-induced Nontailpipe Emissions of Particles along Swedish Roads. Atmospheric Environment 39, 6088-6097.

Sofiev, M., Jourden, E., Kangas, L., Karvosenoja, N., Karppinen, A. and Kukkonen, J. (2006). Numerical Modelling of Spatial Distribution of Fine Particulate Matter in Europe and Finland. In: Vehkamäki, H. et al. (eds.): Report Series in Aerosol Science, No 83, NOSA 2006 Aerosol Symposium, combined with the X Finnish National Aerosol Symposium, Finnish-Czech Aerosol Symposium and BACCI workshop, Helsinki 8.-10.11.2006, pp. 348-352, University press, Helsinki.

Statistics Finland 2008. Energy Statistics Yearbook 2008. Energy 2008. Helsinki, Finland.

Tainio M., Karvosenoja N., Porvari P, Raateland A., Tuomisto J.T.1, Johansson M., Kukkonen J., Kupiainen K. A simple concept for GIS-based estimation of population exposure to primary fine particles from vehicular traffic and domestic wood combustion. Boreal Environment Research. In press.

Tainio M., Sofiev M., Hujo M., Tuomisto J.T., Loh M., Jantunen M.J., Karppinen A., Kangas L., Karvosenoja N., Kupiainen K., Porvari P., Kukkonen J. Evaluation of the intake fractions of primary fine particulate matter originated from various source categories. Manuscript.

Tainio M., Tuomisto J.T., Pekkanen J, Karvosenoja N., Kupiainen K., Porvari P., Sofiev M., Karppinen A., Kangas L., Kukkonen J. Finnish anthropogenic primary fine particle (PM2.5) emissions and their health effects: health impact assessment. Manuscript.

Tissari J. 2008.Fine particle emissions from residential wood combustion.

Tissari, J., Salonen, R.O., Vesterinen, R. & Jokiniemi, J. (toim). 2007. Puun pienpolton päästöt, ilmanlaatu ja terveys. Kuopion yliopiston ympäristötieteen laitoksen monistesarja 2/2007. Kuopion yliopisto, Pienhiukkas- ja aerosolitekniikan laboratorio.

Tuomisto J.T., Wilson A., Evans J.S., Tainio M. Reliability Engineering and System Safety 93: 732–744. (2008). Uncertainty in mortality response to airborne fine particulate matter: Combining European air pollution experts.

Watkiss, P., Pye S., Holland M., 2005. Baseline Scenarios for Service Contract for carrying out cost-benefit analysis of air quality related issues, in particular in the clean air for Europe (CAFE) programme. AEAT/ED51014/ Baseline Issue 5.

WHO (World Health Organization), 2003. Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide. Report on a WHO Working Group. Bonn, Germany 13–15 January 2003. < http://www.euro.who.int/document/e79097.pdf >