Emission Scenarios for Particulate Matter Research And Policy Assessment in Finland

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ABSTRACT

Particulate matter (PM) in air is one of the topical key air pollution problems. In Finland the observed annual levels of PM_{10} and $PM_{2.5}$ were roughly 30 and 10 mg/m^3, respectively, in urban areas in 1990s. The national air quality criteria were mainly exceeded in city centers and near heavily trafficked roads.

The Finnish Regional Emission Scenario (FRES) model was developed as part of the integrated PM model to assess the sectoral and spatial emissions and their future abatement potential. It is aggregated to about ten sectors, combustion fuels and industrial processes each in 1990, 2000 and 2010 with three energy scenarios and spatial emission source allocation.

The substantial decrease of 36, 70, 26, 13 and 29% for $PM_{2.5}$, SO_2, NO_x, NH_3 and VOC, respectively, in 1990s was due to the introduction of emission control measures in power plants, industry, traffic and the decline of animal husbandry. Future emissions are expected to hardly decrease. Traffic and small-scale wood combustion will continue to be the major contributors in primary PM emissions, especially in small size fractions.

NO_x was found to dominate in both absolute emissions and in aerosol formation potential, followed by SO_2 and $PM_{2.5}$. High emissions are mostly located in urban southwestern areas. The FRES model emissions compare well with national and international emission inventories. Biogenic VOC emissions are estimated to be twice the anthropogenic. Black and organic carbon emissions of 6.2 and 12 Gg/a, respectively, in primary PM in 2000 originate mainly from small-scale combustion and traffic.

INTRODUCTION

Air pollution due to particulate matter

One of the most important environmental issues is the air pollution and its effects on health. Several studies have demonstrated consistent associations between concentrations of particulate matter (PM) and adverse effects on human health (respiratory symptoms, morbidity and mortality) at concentrations commonly encountered in Europe and North America. Consequences for public health may be considerable[1].

Particulate matter in the atmosphere is a complex mixture of different chemical species and origins. Primary PM is emitted directly to the atmosphere by anthropogenic activities and natural processes. Secondary PM mostly originates from anthropogenic sources, and they are formed from precursor gases of sulfur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3) and non-methane volatile organic compounds (NMVOCs, hereafter referred to as VOCs).

Carbonaceous particles have received much attention lately because of the possible health and climatic effects. To estimate the climatic effect of black carbon, global inventories have been performed[2], however, more detailed studies on the regional or national level are needed[3, 4, 5].

Carbonaceous particles can be divided into two categories, black carbon (BC) or elemental carbon and organic carbon (OC). OC refers to the carbon content of the numerous organic compounds in the aerosol, but the terminology for BC is somewhat unclear. In the literature BC is often used as a synonym for e.g. elemental carbon, graphitic carbon or soot. The concepts can refer to different properties of the aerosol, measured with a variety of methods that concentrate on e.g. the molecular state, the light absorbing fraction or the fraction of the particles that does not oxidize below a certain temperature[6, 7, 8, 9].

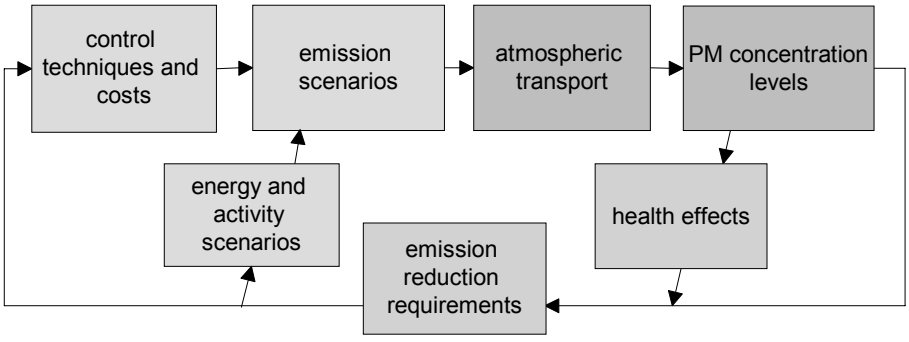
Effects oriented modeling approach

Integrated assessment models (IAMs) have been used to identify least-cost strategies to control multiple precursor emissions leading to acidification, eutrophication and ground-level ozone at international[10] and national level[11]. The European version of the RAINS (Regional Acidification INformation and Simulation) model has recently been extended to address control strategies for different size fractions of PM[12, 13]. This model framework, which has been and will be used as a tool in future negotiations on European emission reductions[14, 15], will utilize data on national emission characteristics provided by sources such as this study.

In Finland, IAMs have been used to assess changes in acidification, eutrophication, formation of tropospheric ozone, and primary PM emissions in various emission scenarios aiming to reduce air pollutant effects and to combat climate change[11, 16]. The development of the national integrated assessment model system for PM system in Finland is currently in progress[17].

The main characteristic of the Finnish economy relevant to air emissions is a large scale exploitation of forests, leading to both high energy needs because of energy-intensive forest industries, and the extensive use of different kinds of wood fuels. The most important primary energy carriers are fuel oils (27% of the total primary energy consumption of 1308 PJ in 2000), wood fuels (21%), nuclear (18%), natural gas (11%), coal (8%) and peat (5%)[18]. Black liquor combustion in the paper pulp industry is the most widely used wood fuel (53% of the total wood fuel use). The other sources are combustion of forest residues in industry and power plants (30%) and domestic small-scale wood combustion (17%).

Figure 1. Model diagram of the integrated assessment model for particulate matter in Finland.



Targets and concentrations of PM

Finland has contributed actively to the achievements and implementation of international conventions on air pollution control. The Ministry of the Environment is responsible for managing, directing and promoting the objectives of the Environmental Protection Act. National air quality guidelines, mainly based on health and ecosystem effects, express short and long-term targets as part of the administrative steering of air pollution prevention. The national guidelines and limits are currently based on the European Communities air quality directives [19, 20, 21] (Table 1).

Table 1. Legislation in Finland on PM. Notes: a) 98th percentile of daily means during the calendar year, b) second highest daily mean during the month, c) in temperature 293 K and pressure 101,3 kPa, and d) 95th percentile of daily means during the calendar year.

component	calculation period for mean value	limit $\mu g/m^3$	allowed exceedances	target time point for compliance
National guidelines				
TSP	24 h	120 [a)]		
TSP	calendar year	50		
PM10	month	70 [b)]		
National limits		[c)]		
PM10	24 h	50	35 times	1 Jan 2005
PM10	calendar year	40	-	1 Jan 2005
Transition period		[c)]		
TSP	24 h	300 [d)]		2001-2005
TSP	calendar year	150		2001-2005
EU directive				
PM10	24 h	50	35 times	1 Jan 2005
PM10	calendar year	40	-	1 Jan 2005
PM10	24 h	50	7 times	1 Jan 2010
PM10	calendar year	20	-	1 Jan 2010

The concentration levels of total suspended particles (TSP) and PM_{10} in Finland are in general high enough to be of concern. National daily and annual guidelines and limits for TSP and PM_{10} have been exceeded in many measurement stations, mainly in urban areas during the 1990s[22, 23]. Annual concentrations of PM_{10} in several downtown areas[23] have varied between 20 and 40 mg/m^3. The annual levels of PM_{10} and $PM_{2.5}$ have been about 20 mg/m^3 and 8–12 mg/m^3, respectively, in the Helsinki metropolitan area in late 1990s[24]. Experimental studies have helped to associate ambient air quality with personal exposures[25] and risks for health effects[26]. Inorganic secondary particles were found to be the major contributor of personal exposures on $PM_{2.5}$ in Helsinki[27].

PM concentrations in Finland are affected both by local and transboundary atmospheric transport. Particle concentrations in urban areas are typically dominated by local emissions, mainly from traffic. Many single-family houses in residential areas are equipped with wood-fired main or supplemental heating devices and sauna stoves with relatively low stack heights and no emission control devices. Thus primary particles from wood combustion may locally contribute to remarkable concentrations of fine particles, especially in cold winter days when heating devices are intensively used and atmospheric mixing is poor due to an inversion. Secondary particles, which are mainly of transboundary origin, are large contributors to fine PM concentrations in rural background areas[28].

Aims of this study

The Finnish Regional Emission Scenario (FRES) model was constructed to estimate the emissions of anthropogenic primary PM in several size classes (total, PM_{10}, $PM_{2.5}$ and PM_1), particulate BC and OC, and the precursor gases of secondary PM, including the status and potential of their control. The years include 1990, 2000 and 2010 with three energy scenarios. The emission components are compared based on their absolute mass emission values and on their aerosol formation potential. The sectoral division and spatial distribution of national total emissions are presented, and biogenic VOC emissions and first carbonaceous emission estimates are briefly discussed.

METHODS AND DATA

The Finnish Regional Emission Scenario (FRES) model

Main features of FRES model

The Finnish Regional Emission Scenario (FRES) model has been developed to work as a part of the integrated assessment model system of PM. Currently FRES calculates the annual emissions of primary total suspended particles (TSP) and finer size fractions (PM_{10}, $PM_{2.5}$ and PM_1), particulate BC and OC, and the main precursor gases of secondary PM, i.e., SO_2 and NO_x. The emissions of NH_3 and VOCs, as well as estimates of primary PM emissions from natural sources, are being added to the model and the national total emissions for these are already available. The emissions are calculated at point source and municipality level from all the anthropogenic emission sources, i.e., fuel combustion activities and industrial processes. In addition, primary PM emissions are calculated from several fugitive dust and other non-combustion PM sources. The main features of the model are described in this paper. The model structure and the data sources for PM, SO_2 and NO_x are reported in more detail in [29, 30, 31]. Recently particulate BC and OC emissions have been calculated in the FRES model. In this study the focus is on the light-absorbing fraction in the PM, therefore, the term black carbon (BC) was chosen. At this point it was not possible to take into account the variety measurement methodologies in choosing the sector specific emission characteristics, therefore BC stands as a synonym for the various terms. This may give rise to some uncertainty for the shares[32]. The calculations have been done partly in parallel with the European BC/OC inventory in the RAINS model[33]. Results from these studies have not yet been fully evaluated and reported. Therefore, in this paper the preliminary results of BC/OC emissions in Finland are given as country totals without sectoral division.

The basic structure of the FRES model is a combined general top-down approach of aggregated emission source sector description with more detailed bottom-up calculation of large point sources. The top-down feature makes a relatively light model structure possible, while the annual activity rate inputs of the source sectors are described in a relatively aggregated level. Large point sources and their emission control facilities are described in more technical detail, which enables the estimation of emissions more accurately both spatially and in the terms of emission quantities.

The main structure of the FRES model, describing the applicable main sectors and control technologies in it, is as follows:

- Fuel combustion sectors (11 fuels)
    - Power plants and combustion in industry (plants utilizing boilers with thermal capacity exceeding 50 MW_{th} as point sources
    - Domestic combustion
    - Traffic, off-road and machinery
- Industrial processes (plants with emissions >20 Mg(TSP, SO_2 or NO_x)/a as point sources)
- Other non-combustion sources for PM (fugitive dust, meat frying, tobacco smoking etc.)
- Emissions control technologies for PM, SO_2 and NO_x

The country-level emissions are calculated from the annual activity rates, the unabated emission factors (i.e., the emission factors before emission control devices) and the utilization and emission removal efficiency information of the emission control technologies. The activity data for 1990 and 2000 were determined using national statistics[18]. The source sector specific unabated emission factors of area sources and control technology removal efficiencies were estimated based on national and other literature[34, 35, 36, 37, 38, 39, 40, 41, 42]. The plant-specific emission factors of the point sources and the utilization rates of emission control technologies of the existing energy system were determined based on data of the register on air pollution permits of the Finnish environment administration VAHTI[43] containing technical, fuel use and emission information on the Finnish industrial and energy producing plants exceeding a thermal capacity of 5 MW_{th}.

The activity data in 2010 were based on three national energy scenarios of the Finnish climate strategy by the Ministry of Trade and Industry[44]. All scenarios assume an average annual economic growth of 2.4%. The first scenario "baseline" does not include any additional restrictions on energy production system, leading to a 16% increase in the total primary energy consumption in 2010 compared to 2000, met by a more extensive use of hard coal. The EU burden sharing agreement for Finland is the stabilization of emissions at the 1990 level. In the other two scenarios, "Kyoto-gas" (KIO1) and "Kyoto-nuclear" (KIO2), this agreement would be met. Both Kyoto-scenarios include greenhouse gas emission reduction measures, e.g., more emphasis on energy saving and fuel switching to low carbon content fuels in centralized heat and power production. "Kyoto-gas" includes a strong shift from coal to natural gas and biomass. In "Kyoto-nuclear", one new 1400 MW_e nuclear reactor would be introduced to the Finnish energy system, with a moderate shift from coal to biomass and gas. The utilization of emission controls in new capacities was estimated based on legislative requirements, e.g., the Large Combustion Plants Directive of the European Union[45].

Municipality level emissions

The country total emission in Finland is the sum of point source and area source emissions. The point source emissions are spatially directed to the geographical longitude-latitude locations of the respective plant stacks. The country level area emissions are directed to the population center locations of the 448 municipalities. The emission allocation is done using municipality level information of the activities in each of the emission source sectors, e.g. traffic intensities and fuel consumption, total population, animal numbers etc. At present, the area emissions from some sectors, e.g. domestic combustion, are currently evenly distributed to each of the municipalities. The distribution of the evenly distributed emissions will be reassessed in the future.

The emissions of ammonia have been estimated earlier in Finnish Environment Institute (SYKE)[46]. The emissions have not varied much in 1990s and drastic reductions are not expected in the near future. Anthropogenic VOC emissions have been estimated based on the inventories made in SYKE[47, 48]. Biogenic VOC emission estimates are based on model estimates for 1995–1997[49].

Pollutant contribution to aerosol formation

Particulate matter mass in the air consists of the directly emitted fraction, primary PM, and the fraction formed in the atmosphere from precursor gases, secondary PM. The main precursor gases for secondary inorganic PM are SO_2, NO_x and NH_3. Volatile organic compounds (VOCs) contribute to the organic secondary PM. The majority of long-range transported particulate mass is estimated to fall into the $PM_{2.5}$ size fraction[50].

The contribution of the above-mentioned pollutants to aerosol formation cannot be derived in a straightforward manner from conventional emission estimates. They can be made more commensurate with weight factors describing the fraction changing into aerosols and accounting for the molecular weight differences. Aerosol formation factors (AF) have been suggested for Europe[51] with respect to their potential effects on health. The AF value is defined as the product of Ms/Mp, Y and F. Ms/Mp denotes the ratio of the secondary aerosol molecule form to the gas emission component molecule. Y describes the fraction of emission yielding to potential aerosol formation, and it is unity for all components except for VOC. F denotes the fraction of emitted mass converted into secondary aerosols. F was derived with an atmospheric model, which considered the whole Europe as one modeling domain box, where advection and dispersion can be neglected and the atmospheric fate of the precursor depends only on gas deposition and conversion into aerosol. It takes into account only the deposition of the precursor gas (e.g. SO_2), not the total deposition as this includes also the secondary aerosol (e.g. SO_4) contribution. The values are shown in Table 2.

The AF for primary PM is unity, since all emitted mass is transmitted to the atmosphere where it may potentially have adverse health effects. Comprehensive emission inventories and time series of PM_{10} for Europe were not available until recently, and were not considered[51].

The values for F can vary depending on the atmospheric model application. Results from other studies are cited[51], which yielded F=0.50 for SO_2 and NH_3. Since no additional values for NO_2 were reported, an assumption of the same value for NO_2 was made here for the variability assessment. The values for the variability estimate are in parenthesis in Table 2.

The conversion yield of VOCs to secondary organic aerosols depends on its chemical structure and meteorological conditions. The share of long carbon chain VOCs, which tend to have a relatively high aerosol formation yield, is small in anthropogenic emissions. A rough estimate was made[51] by assuming that one quarter of VOCs have long carbon chains of more than six carbon atoms (Y=0.25), assigning F=5% for aerosol yield and Ms/Mp=1.5 to account for additional oxygen atoms in secondary aerosol form, leading to AF of 0.02. For PM_{10} this would lead to a minimal contribution of VOCs, which is in contrast to observations with a significant organic component of 25-50%. The variability is explored by assuming high values for these parameters: Y=0.5, F=0.20 and Ms/Mp=2, which lead to AF=0.20.

Table 2. Aerosol formation factors (AF) for primary PM and the precursor gases of secondary PM in Europe[51]. Secondary molecule represents the aerosol form molecular mass Ms of the precursor gas component of mass Mp. Y describes the fraction of emission potentially leading to aerosol formation. F denotes the fraction of emitted mass converted into secondary aerosols. AF is the product of Ms/Mp, Y and F. Values in parentheses were used to explore the potential variability.

emission component	secondary molecule	Ms/Mp	Y	F	AF
primary PM	same	1	1	1	1
SO_2	SO_4	1.55	1	0.35 (0.50)	0.54 (0.78)
NO_2	NO3	1.35	1	0.65 (0.50)	0.88 (0.68)
NH_3	NH_4	1.06	1	0.60 (0.50)	0.64 (0.53)
VOC	O_xC_y	1.5 (2)	0.25 (0.5)	0.05 (0.20)	0.02 (0.20)

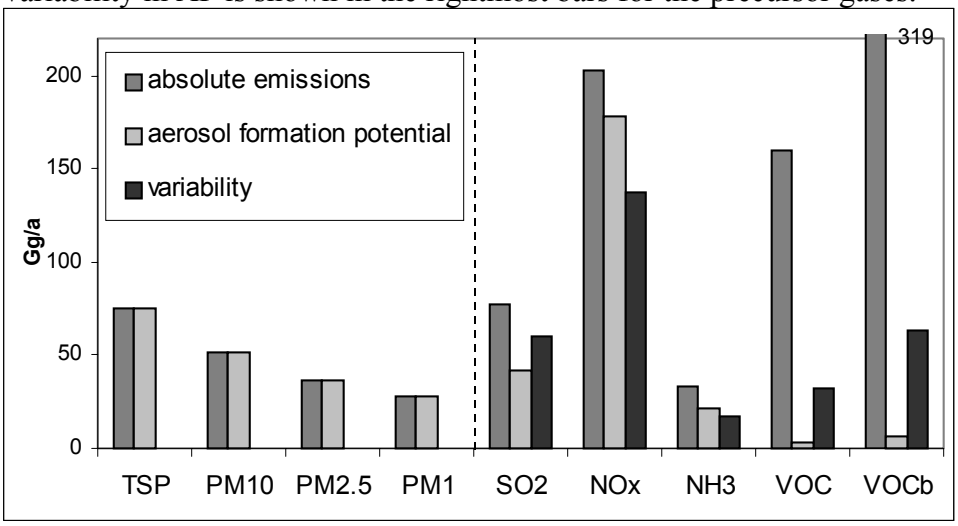
RESULTS

Total emissions in 2000

The national total anthropogenic emissions of primary PM and the precursor gases for secondary PM were calculated for the year 2000 and are shown in Figure 2. In addition, the biogenic VOC emissions, denoted as VOC_b, are presented. The most dominant emissions are VOCs. Next, SO_2 and NO_x emissions are relatively large, and $PM_{2.5}$ is slightly more that NH_3. Studies[24] using results from atmospheric model, which also include the long-range transported fraction, support the dominance of secondary organic compounds in PM concentrations.

The figure includes the emissions weighted with the aerosol formation factor AF. AF is unity for primary PM. The weighted contribution of SO_2 is greatly reduced to half, and somewhat less for NO_x and NH_3. Nitrogen oxides are clearly the most important compounds. The basic assumption for VOCs is that they hardly convert into secondary organic aerosols. This can be true in general at European level, however, studies with atmospheric models suggest, that the contribution can be of importance in certain regions such as the boreal forest zone[52]. The variability estimate would change the order of compound importance only for VOCs. However, the assumptions made may be unrealistic and were chosen only for illustrative purposes at this stage.

Figure 2. Total national emissions in Gg/a of primary PM (left) and the precursor gases for secondary PM (right) in 2000 in absolute mass and weighted with aerosol formation factor (AF). The potential variability in AF is shown in the rightmost bars for the precursor gases.

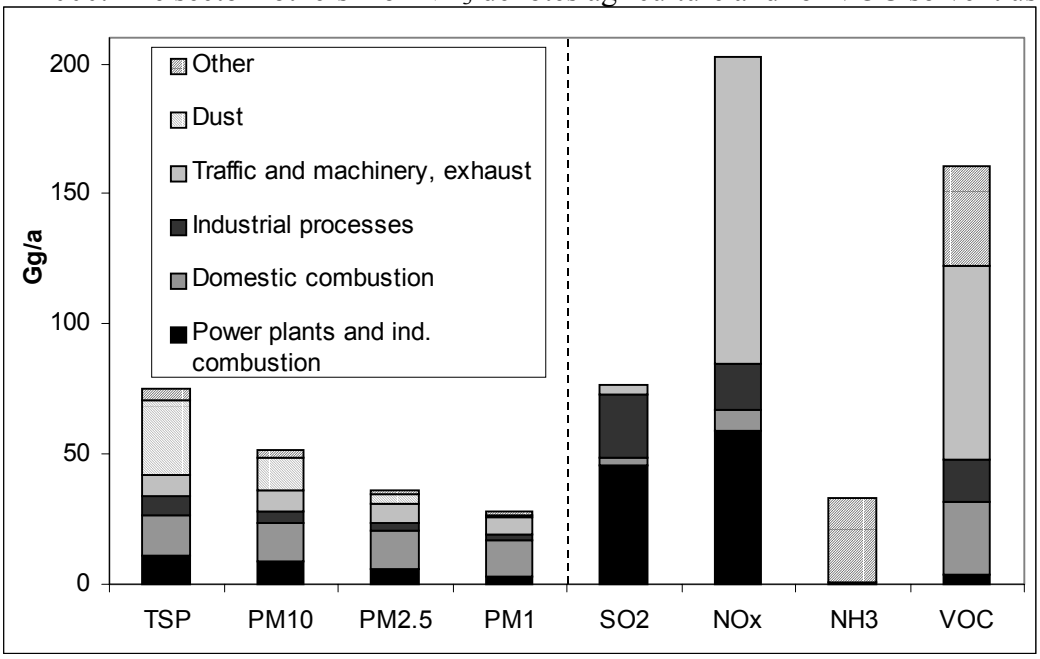


Sectoral division in 2000

The major sectors contributing to primary PM are domestic wood combustion and traffic (Figure 3). The PM emissions from non-combustion sources account for a considerable share of the total emissions: 54, 39, 23 and 16% for TSP, PM_{10}, $PM_{2.5}$ and PM_1, respectively. However, the uncertainties in emission estimates for non-combustion sources other than industrial processes are large, especially in fugitive dust and domestic wood combustion[53].

Stationary industrial activities, i.e. power plants, and combustion and processes in industry, caused 90% of the total SO2 emissions in Finland. Traffic contributed to more than half of the total NO_x emissions. Ammonia emissions originated almost entirely from agriculture, predominately from animal husbandry. Roughly half of the VOC emissions was from traffic. The next major sectors were solvents use and domestic wood combustion.

Figure 3. Absolute anthropogenic sectoral emissions in Gg/a of primary particulate matter (TSP, PM10, PM2.5 and PM1) and of precursor gases of secondary PM (SO_2, NO_x as NO_2, NH_3 and VOC) in Finland in 2000. The sector "others" for NH_3 denotes agriculture and for VOC solvent use.



Temporal development of emissions

All emissions have clearly decreased during the 1990s (Figure 4). For $PM_{2.5}$, SO_2, NO_x and VOC (36, 70, 26 and 29% decrease, respectively) it was mainly due to the introduction of emission control measures in power plants, industry and traffic sectors. NH_3 emissions have decreased 13% due to the decline of animal husbandry. Note, that all dust emissions, which were calculated for PM2.5 in 2000, are assumed the same for the years 1990 and 2010, which causes only a marginal error in the total emission values. The most efficient emission reduction measures in power plants and industry are already in use, and the future emissions will remain roughly at the current level in 2010 for all scenarios. Extensive use of hard coal in the baseline scenario would result in slight increase in SO_2 and NO_x emissions. PM emissions in new large power plants are efficiently controlled, and primary energy choices for electricity production do not affect PM emissions significantly. Traffic emissions will continue to decline along the renewal of vehicle fleet in all scenarios.

Figure 5, on the left, shows the component shares from the total absolute emitted mass, and on the right, weighted with the aerosol formation factors (AF). In both cases NO_x is the dominant component. Next largest are SO_2 and $PM_{2.5}$, while ammonia seems to have minor importance. The contribution of VOCs in secondary aerosol formation is presumably very small.

Figure 4. Emissions of $PM_{2.5}$, SO_2, NO_x, NH_3 and VOC in Gg/a in 1990, 2000 and 2010 with three energy scenarios: baseline, "Kyoto-gas" (KIO1) and "Kyoto-nuclear" (KIO2).

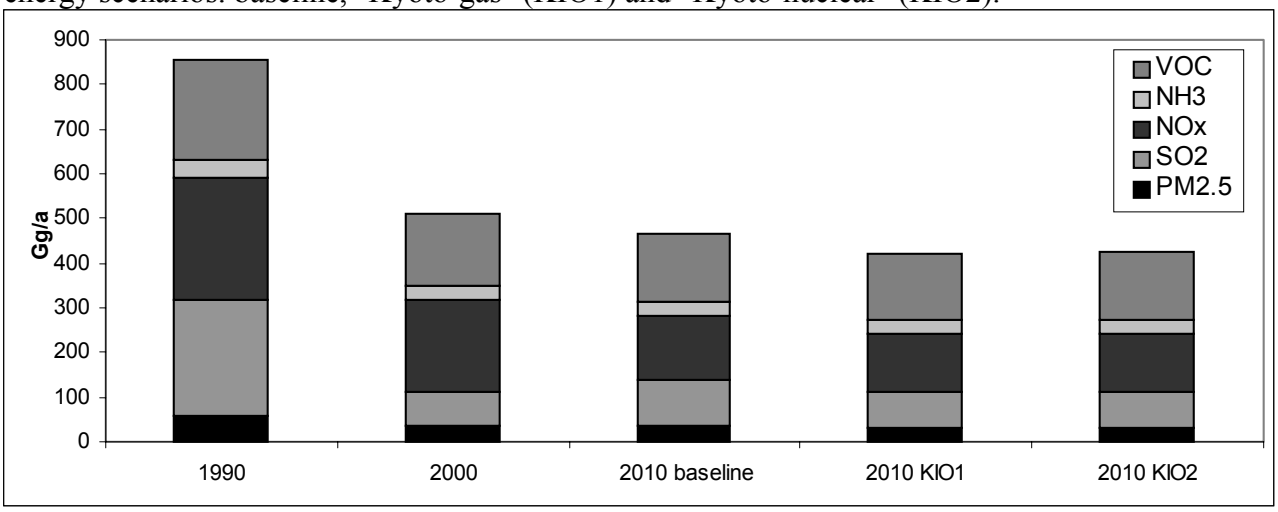
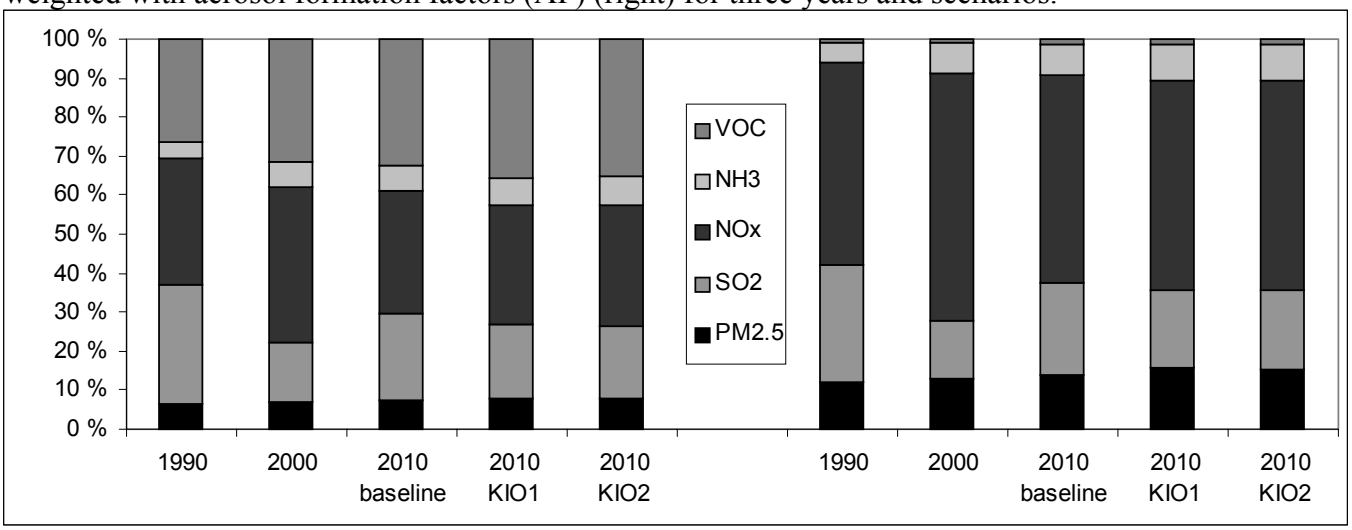


Figure 5. Emissions shares of $PM_{2.5}$, SO_2, NO_x, NH_3 and VOC from absolute mass (left) and from mass weighted with aerosol formation factors (AF) (right) for three years and scenarios.



Comparison with other emission inventories

The FRES model results are compared against three other sources of national total PM emissions for Finland in Table 3. The national statistics are computed at Statistics Finland on a plant-by-plant basis from about 2200 combustion and industrial processes[18, 54]. The PM inventory was done in SYKE for the year 2000 using official European guidelines. The emissions are based on reported plant-by-plant basis emissions from several thousands of point sources of the VAHTI database[43]. The FRES model results are mainly based on same activity data as the inventory, but it includes more dust sources and updated emission factors. The RAINS model calculates emissions for all European countries, however, it current results are based on an outdated energy scenario for Finland.

There is a good agreement between FRES and the SYKE inventory, which is not surprising since they are based mainly on same data. RAINS tends to underestimate the Finnish emissions for all the years and size classes, partly because it does not include all dust sources.

Table 3. The comparison of PM emissions from different sources: a) national statistics (TSP only), b) the official inventory made in Finnish Environment Institute (SYKE), c) the FRES model results, and d) the RAINS model results (based on an outdated baseline energy scenario for Finland in 2010), which does not include estimates on traffic dust resuspension. The values either include or exclude the non-combustion non-industrial dust emissions, which are calculated separately in the FRES model for the year 2000 and are assumed to be the same in 1990 and 2010.

		1990		2000		2010 baseline	
		excl. dust	incl. dust	excl. dust	incl. dust	excl. dust	incl. dust
TSP	Statistics Finland	84	-	45	-	-	-
	SYKE inventory	-	-	-	74	-	-
	FRES	74	108	42	75	40	73
	RAINS	-	59	-	49	-	44
PM10	SYKE inventory	-	-	-	48	-	-
	FRES	64	79	36	52	35	50
	RAINS	-	38	-	29	-	24
PM2.5	SYKE inventory	-	-	-	38	-	-
	FRES	51	56	31	36	29	34
	RAINS	-	29	-	23	-	17

Spatial distribution in 2000

The spatial distributions of primary PM, SO_2, NO_x, NH_3 and anthropogenic VOC emissions are shown in Figure 6 in the 50 km × 50 km grid system of EMEP/MSC-W. The emissions of traffic exhaust and road dust dominate primary $PM_{2.5}$ emissions in urban areas. Industrial processes and black liquor combustion emissions from point sources dominate in some industrial municipalities. The emissions from domestic wood combustion sector, the major contributor to $PM_{2.5}$ at country level, are currently evenly distributed to the municipalities, and thus no conclusions on spatial distribution can be drawn. The $PM_{2.5}$ emissions calculated as point sources, 7.1 Gg/a, contributed to 19% of the total primary $PM_{2.5}$ emissions in Finland in 2000.

Traffic is the predominant source for NO_x emissions, especially in urban areas. Point sources of energy production in power plants and industry also cause relatively high emissions. The highest municipality level emissions of SO_2 are caused by large industrial and power plants. The point sources caused 60 and 29% of the country total emissions of SO_2 and NO_x, respectively. Ammonia emissions concentrate in the southwestern and western coastal areas of Finland, where intensive farming is practiced. Anthropogenic VOC emissions originate mostly from traffic and solvent use, which concentrate in urban areas.

Domestic combustion of wood is an important source for PM in general. The national total emission from these sources is currently distributed evenly to each municipality. In the future, a reallocation will be done using the number of buildings, which have wood heating as the primary heating system, as a surrogate indicator. The data is taken from the national building and dwelling register, which includes building-specific technical and other information. The spatial distribution of this surrogate indicator is shown in Figure 7.

Figure 6. The spatial distribution of the emissions in Finland in 2000 in Mg/a of a) TSP, b) PM_{10}, c) $PM_{2.5}$, d) PM_1, e) SO_2, f) NO_x (as NO_2), g) NH_3, and h) anthropogenic VOC.

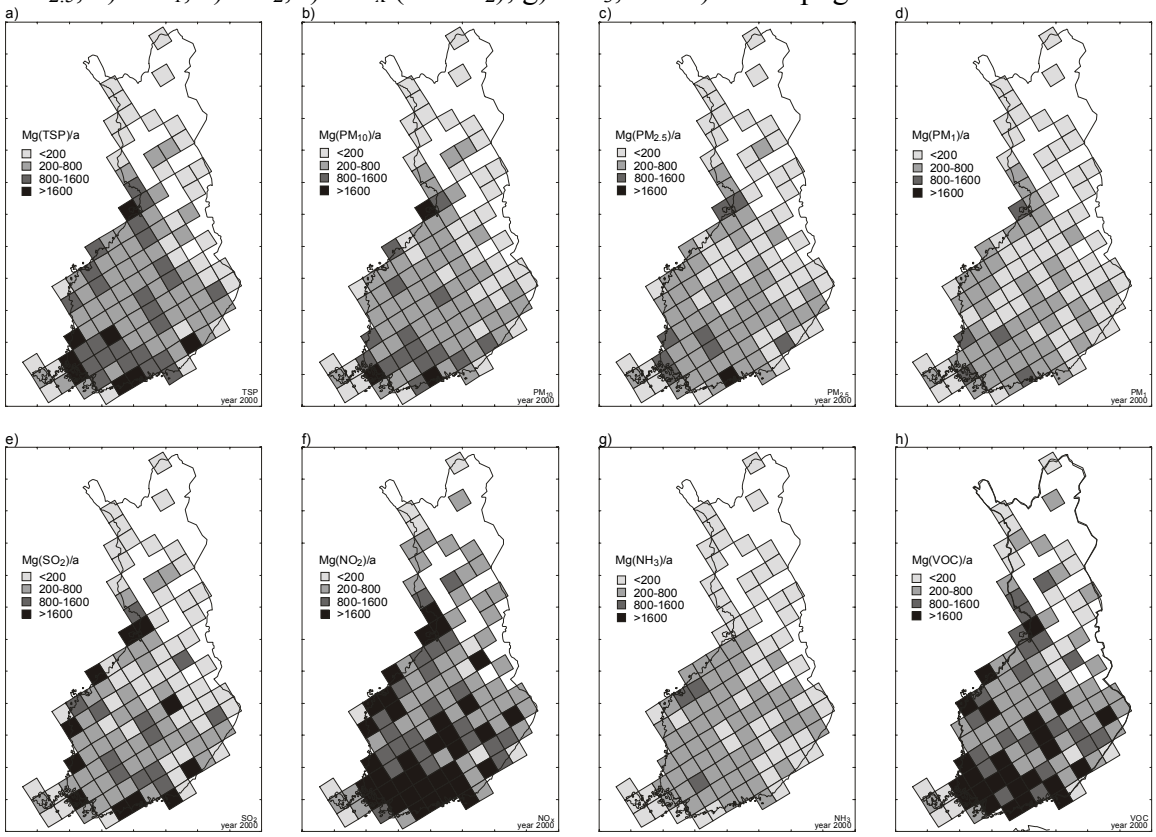
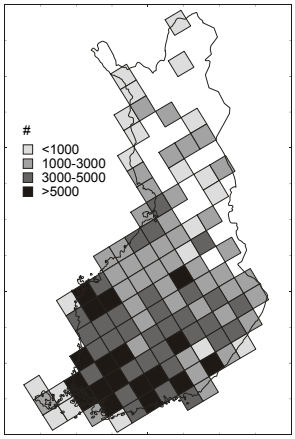


Figure 8. The number of buildings with wood heating as primary heating device.



Biogenic VOC emissions

Although this study concentrates on anthropogenic emissions only, the amount of biogenic VOCs is described in some detail here. The reason is the high natural emissions compared to anthropogenic ones in Finland. At the moment, the biogenic VOC emissions in Finland are estimated to be 319 Gg/a in

mid-1990s[49]. This inventory included forests and the calculated emissions were for three years were 320, 291 and 347 Gg/a in 1995, 1996 and 1997, respectively. In comparison with the national estimate, the latest European inventory by EMEP/MSC-W estimates 341 Gg/a for Finland[55 cited in 49].

In the above calculation, the majority of emissions originates from coniferous trees (80-90%) and consists mainly of monoterpenes (45%). The emission density in Northern Finland is approximately half of the emissions in the southern parts of the country, mainly reflecting the forested area and climatological conditions. The majority of biogenic VOC emissions in Finland originates from forests, approximately 85–95%[56]. The national calculation takes into account forested swamp areas and partly the forest underbrush. Some emissions arise from fields, depending on the vegetation and snow cover, and they are not included in the national estimate.

Emissions of black and organic carbon

The Finnish national total emissions for BC and OC were calculated for the year 2000. The calculation is based on a literature study about the shares of BC and OC in PM from different emission sources. Total emissions for Finland in 2000 were 6.2 Gg/a BC and 12 Gg/a OC. For BC the main sources were diesel engines in traffic and machinery and domestic combustion. For OC domestic combustion was the biggest contributor. Both diesel and gasoline engines in traffic caused significant OC emissions. The results are very preliminary at this stage. Further work will include a review of the shares, a comparison of emission factors in the model with RAINS and original studies, and an uncertainty analysis.

CONCLUDING REMARKS

The paper presented the basic structure of the Finnish Regional Emission Scenario (FRES) model. It was designed to be used as a part of the Finnish particulate matter integrated assessment modeling system. The relatively aggregated model structure on activity rate input categories supports a straightforward conversion of energy and activity scenarios on the FRES aggregation.

The model enables an operative calculation of all anthropogenic emissions of primary particles of different size classes, sulfur dioxide, nitrogen oxides, ammonia and anthropogenic VOCs. The results for the base year 2000 are well convergent with the values in national statistics for all pollutants. The largest uncertainties in PM estimates are identified in fugitive dust and domestic wood combustion. The model gives a sectoral division and spatial distribution of emissions detailed enough for extensive scenario analyses.

The emissions were weighted with an aerosol formation factor to compare the emission component contribution to health related aerosol effects. NO_x was the major contributor, while NH_3 and VOC were relatively minor. First results on natural emissions (VOCs) and carbonaceous particles extend the possibilities for model application in, e.g., climate change studies.

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