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Comparative Risk Analysis of Dioxins in Fish and Fine Particles from Heavy-Duty Vehicles

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Dioxins and airborne fine particles are both environmental health problems that have been the subject of active public debate. Knowledge on fine particles has increased substantially during the last 10 years, and even the current, lowered levels in the Europe and in the United States appear to be a major public health problem. On the other hand, dioxins are ubiquitous persistent contaminants, some being carcinogens at high doses, and therefore of great concern. Our aim was to (a) quantitatively analyze the two pollutant health risks and (b) study the changes in risk in view of the current and forthcoming EU legislations on pollutants. We performed a comparative risk assessment for both pollutants in the Helsinki metropolitan area (Finland) and estimated the health effects with several scenarios. For primary fine particles: a comparison between the present emission situation for heavy-duty vehicles and the new fine particle emission standards set by the EU. For dioxins: an EU directive that regulates commercial fishing of Baltic salmon and herring that exceed the dioxin concentration limit set for fish meat, and a derogation (= exemption) from the directive for these two species. Both of these two decisions are very topical issues and this study estimates the expected changes in health effects due to these regulations. It was found that the estimated fine particle risk clearly outweighed the estimated dioxin risk. A substantial improvement to public health could be achieved by initiating reductions in emission standards; about 30 avoided premature deaths annually in the study area. In addition, the benefits of fish consumption due to omega-3 exposure were notably higher than the potential dioxin cancer risk. Both regulations were instigated as ways of promoting public health.

KEY WORDS: Dioxin; European Union legislation; fine particles; fish; risk assessment; risk comparison

1. INTRODUCTION

Exposures to dioxins and ambient fine particles are both ranked high as health hazards, but these pollutants display many important differences. Data for fine particle risk come mainly from epidemiological studies whereas most of the information on dioxin comes from toxicology. There are also differences in their biological half-lives. Furthermore, exposure to fine particles is rather uniform within a given area while exposure to dioxins varies according to food consumption habits. This leads to another difference between these two risks. Fine particle exposure is perceived as an unavoidable risk, whereas the risk from dioxin can be individually controlled, at least to some extent.

Dioxins are a group of highly toxic chemicals. The most potent dioxin congener is 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD). Due to their lipophilicity, dioxins are very slowly metabolized and excreted, thus they bioaccumulate and become biomagnified in wildlife and humans. We use the term "dioxin" in this study to refer to polychlorinated dibenzodioxins and dibenzofurans (PCDF) and

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polychlorinated biphenyls with dioxin-like toxicity (DL-PCB). Dioxins have been demonstrated to be animal carcinogens at high doses. The International Agency for Research of Cancer (IARC) of the World Health Organization (WHO) has classified TCDD as a group 1 human carcinogen.[1] They have been linked to many serious health effects, especially in animals and also in humans, including cancer, reproductive and developmental effects, altered immune function, and disruption of the endocrine system. Dioxins are believed to be a powerful cancer promoter, rather than an initiator.[2]

The ecosystem of the Baltic Sea has been badly polluted by dioxins. The EU has set the maximum dioxin concentration of 8 pg/g (WHO-TEQ in fresh weight) for fish products.[3] However, the dioxin concentrations of wild salmon and herring from the Baltic Sea frequently exceed 10 pg/g (WHO-PCDD/F-PCB-TEQ in fresh weight).[4] In comparison, wild salmon from north-east Europe display dioxin concentrations of approximately 2 to 3 pg/g (WHO-PCDD/F-PCB-TEQ in fresh weight) and salmon from South and North America have less than 2 pg/g (WHO-PCDD/F-PCB-TEQ in fresh weight).[5] In Finnish-farmed salmon, the concentrations of dioxins are lower since these fish are fed cleaner fish feed compared with the diet of wild salmon in the Baltic Sea.[4] In Finland, the principal human exposure from dioxins comes from fish, with fish from the Baltic Sea being the main source.[6]

In 2001, EU authorized a five-year transitional period for Finland and Sweden to allow Baltic herring and salmon to be sold on their domestic markets. During this five-year period, countries were obligated to study the health effects due to the consumption of these fish species. In the year 2006, Finland and Sweden were granted another transitional period, up till the end of the year 2011 (EC 199/2006).[3] Again, studies about health risks and benefits due to consumption of these fish will play an important role in the decision making concerning future regulation due in 2011.

Airborne ambient fine particles with aerodynamic diameter less than 2.5 μm ($PM_{2.5}$) are one of the major environmental health problems in modern Western societies. Fine particles have been linked to several adverse health effects. The adverse health effects have been seen in both short-term (daily variations)[7] and long-term (chronic)[8] studies. The strongest association has been found between ambient particulate matter (PM) and elevated cardiopulmonary mortality, lung cancer mortality, and reduced lung function.[9] The Clean Air for Europe (CAFE) program, funded by the European Commission, claimed that fine particles are responsible for over 300,000 premature deaths annually in Europe (EU25) and lower the average life-expectancy by 8.6 months.[10]

In Finland, traffic and domestic wood combustion are the main sources of primary fine particles.[11] Emissions of particles due to traffic were highest in the 1980s.[12] Changes to fuel composition, especially the decline in the levels of sulfur compounds, have lowered the particle emissions. A major decrease took place in 1994, when reformulated fuels entered general use.[12] At present, heavy-duty vehicles are responsible for 60% of the total fine particle emission of road traffic in the Helsinki metropolitan area, although the number of heavy-duty vehicles accounts for only 13% of total number of vehicles on the roads.[12] That is, heavy-duty vehicles emit more fine particle emissions than the automobiles powered by gasoline engines. For this reason heavy-duty vehicles are of particular interest in any attempt to reduce health effects of traffic-generated fine particles.

The aim of the study was to carry out a comparative risk assessment of these two pollutants and to compare health effects of the two regulations being initiated by the European Union.

2. MATERIALS AND METHODS

We chose the Helsinki metropolitan area as the geographical area. In this way, we could gain full access to the actual road traffic data measurements performed in the Helsinki metropolitan area and define the estimated risk of fine particles more accurately than elsewhere in Finland. To estimate the dioxin risks due to fish consumption, we calculated the risk for the Finnish population and scaled it down to the population of the Helsinki metropolitan area. We assumed that the citizens of the Helsinki metropolitan area would have similar fish consumption patterns as the rest of the Finnish population.

We had to use toxicological information to estimate the dioxin risk and epidemiological information to estimate the fine particle risk. When there was a discrepancy, we preferred to utilize assumptions exaggerating rather than understating the risk due to dioxins. This was because our prior hypothesis was that the estimated dioxin risk would be smaller and we wished to minimize the probability of encountering a false negative result for the dioxin risk.

Table I. Mortalities and Population Characteristics of the Helsinki Metropolitan Area in 2004

Helsinki Metropolitan Area Mortality Statistics	Value	ICD-10 codes
Population size	980,412	
Mortality rate	0.007454	
Total cancer mortality	1,727	C00-D48
Total mortality	7,308	A-Q
Lung cancer mortality	313	C34
Nonaccidental deaths	6,560	Total mortality-V01-Y98
Cardiopulmonary mortality	2,888	I11-I70 and J15-J47
Traffic-related fatalities in Helsinki	62	V01-V99
CHD mortality	1,488	I21,I22 and I20, I24, I25

For demographics statistics, we used the database from Statistics Finland[13] and for mortality data, data from Statistics Finland[13] combined with the WHO database.[14] The coronary heart disease mortality estimate consisted of acute myocardial infarction and other ischemic heart diseases.[15] Mortality statistics are summarized in Table I.

2.1. Scenarios

We estimated the health effects for the alternative scenarios. EU has set emission standards for the fine particle emissions of new heavy-duty vehicles. The fine particle emission standards scenarios are called EURO IV and EURO V, which have the same emission limit of 0.02 g/kWh[16] for particles. Therefore, we combined these two scenarios into one scenario, EURO IV and V. We compared this EURO IV and V scenario to the present situation "business as usual" (CURRENT PRACTICE PM). EURO standards represent total suspended particles, but we assumed that virtually all of the particles are $< 2.5\ \mu$m.

The two decision alternatives concerning dioxins were based on the commission regulation (EC) N:O 1881/2006,[3] setting maximum levels for certain contaminants in foodstuffs (see Table II). EU has set the directive for dioxins (scenario NO DEROGATION), which regulates the consumption of fish products exceeding dioxin concentration of 8 pg/g WHO-PCDD/F-PCB-TEQ. However, Finland and Sweden have been granted an exemption (scenario DEROGATION) for Baltic salmon and herring. These scenarios, based on the EU directives, are used in the model and are described in Table II. In the case of dioxins, we used premature cancer deaths as the endpoint; and for fine particles, we used cardiopulmonary, lung cancer, and other nonaccidental causes of death.[17]

2.2. Fish Consumption and Dioxins

The major part of Finnish dioxin exposure comes from fish. This is because the Baltic Sea is heavily contaminated with persistent organic pollutants such as dioxin and polychlorinated biphenyls (PCBs), while the environment is otherwise relatively clean of dioxins. Typical sources in other countries, such as dairy products or meat, make only a small contribution to the total dioxin exposure in Finland.[6] Therefore, it is very difficult to reduce Finnish dioxin intake without affecting fish intake. It is therefore necessary to study the collateral effects, that is, the detrimental effects on health, of reduced fish consumption when evaluating the overall risks of dioxin.

We selected the most common species available for consumers in Finland, including farmed salmon *(Salmo gairdneri)*, wild salmon (includes wild salmon *(Salmo salar),* wild rainbow trout *(Salmo gairdneri)* and wild trout *(Salmo trutta)*), herring *(Clupea harengus membras),* white fish *(Coregonus lavaretus),* sprat *(Sprattus sprattus),* perch *(Perca fluviatilis),* flounder *(Platiochthys flesus),* pike-perch *(Stizostedion lucioperca),* bream *(Abramis brama),* pike *(Esox lucius),* vendace *(Coregonus albula),* and burbot *(Lota lota).*

The fishery catch data were obtained from the Finnish Game and Fisheries Research Institute (RKTL). Recreational and commercial fishery catches were 40,952 metric tons and 109,025 metric tons, respectively, in 2002.[18] These values include both sea areas and fresh waters. Units were reported in fresh weight, that is, uncleaned, so filleting factors for the different species were used in order to obtain gutted weight. The filleting factor is a ratio of the gutted fish weight and whole fresh fish weight and this variable includes uncertainty estimated by the experts of the RKTL and varies between species. The herring species exhibits a strong correlation between size and dioxin concentration. Therefore, we included size distribution of the fishery catch for her-

Table II. The Fine Particle Emission Scenarios by the EU for New Heavy-Duty Diesel Engines and the Fish Consumption Scenarios

Pollutant	Endpoint	Scenario	Description
Particles	Cardiopulmonary and lung cancer mortality due to heavy-duty vehicles	**CURRENT PRACTICE**	Business as usual
		0.077 g/kWh	
		EURO IVand V	Commission regulation 98/69/EC and 99/96/EG
		0.02 g/kWh	
Dioxin	Total cancer	No derogation (salmon and herring must meet 8 pg/g)	Commission regulation EC 1881/2006
		Derogation (salmon and herring exempted)	Commission regulation EC 199/2006

ring. Finally, we estimated the proportion of fish (by species) that will actually be consumed by humans. The reminder of the catch is used as animal feed, waste, and for other purposes.[18] In this way, we obtained an estimate of consumption of Finnish fish.

The pollutant concentrations of fish were obtained from the National Food Agency of Finland.[4] Dioxin concentrations of the different species ranged from 0.2 to 14 pg/g (WHO-TEQ in fresh weight), large herring and wild salmon being the species with the highest concentrations and fresh water fish in general exhibiting the lowest concentrations. Samples included skin and ventral fat. This approach overestimates the concentration of dioxins in the edible part, as not everyone consumes these parts as food. In addition, we assumed a linear exposure-response relationship for excess cancers associated with dioxin intake as reported in the IRIS database[19] of the U.S. Environmental Protection Agency (EPA). The cancer slope factor (CSF) for TCDD is 156,000 per mg/kg/day. The estimated pollutant health risk was calculated assuming additivity between the pollutants. All cancer cases were assumed to be lethal.

Estimated risks from consuming Finnish fish were calculated in commensurable units, premature deaths, because this is readily comparable with both fine particles and consumption of fish. Nonlethal endpoints, for example, developmental effects, were not quantitatively taken into consideration in this study.

The exposure was calculated as the product of the pollutant concentration of fish and the fish consumption and the estimate of risk was the product of exposure-response, exposure, and background mortality.

A number of studies have shown the beneficial effects of omega-3 fatty acids in the reduction of coronary heart diseases (CHD).[20–24] CHD includes acute myocardial infarction and other ischemic heart diseases. In particular, fatty fish species, like salmon and herring, are rich in omega-3 fatty acids. For evaluating the concentrations of omega-3 fatty acids of fish species, we used the nutritional database Fineli,[25] maintained by the National Public Health Institute, Finland, and scientific articles as reference values.[22,23] Omega-3 fatty acids are also associated with some other beneficial endpoints, for example, risk reduction of stroke, improved cognitive development, prevention of depression, and decrease in hypertension.[26,27,28] These results are less definitive and the effects of these endpoints on public health would be smaller than that of CHD, so they were not taken into account in this study.

We were careful not to overestimate the beneficial effects of omega-3 fatty acids. A large proportion of the omega-3 benefit literature is based on studies of cardiac patients. We included a factor that reflected the uncertainty whether there was cardiac health benefit for everyone or only for CHD patients. According to Mozaffarian and Rimm,[29] modest consumption (250–500 mg/day) of omega-3 could reduce CHD deaths by 14.6% per each 100 mg/day of omega-3 exposure. After this limit, no extra benefit was assumed from omega-3 fatty acids in terms of reducing CHD incidence.

The estimate of the health effects was calculated as the product of omega-3 concentrations in the different fish species, consumption of fish by species, and background mortality.

2.3. Fine Particles Emitted by Heavy-Duty Vehicles

The estimated risks due to primary fine particle emissions were based on a recent study, which estimated emissions, exposure, and associated health effects of primary fine particles due to local bus traffic in the Helsinki metropolitan area.[30] Brief overviews for the exposure and health effect submodels are described in the following two paragraphs. The emission submodel was totally renewed for this study and it is described after the exposure and the health effect submodels.

Annual average population exposure to traffic-emitted primary $PM_{2.5}$ in the Helsinki metropolitan area was estimated using two alternative exposure models. The first model was based on the EXPOLIS-Helsinki study,[31] in which the observed average exposure to total $PM_{2.5}$ in this area was 10.7 μgm^{-3} in 1996–1997.[32] The average exposure was apportioned to source categories using elemental compositions. The exposure fraction attributable to the local traffic emissions was separated from the source-categorized results by comparing the emission rates of different emission sectors. In an alternative approach, exposure was calculated based on ULTRA study, in which the contribution of local traffic emissions was analyzed by using an absolute principal component analysis and multivariate linear regression, based on both particle and gaseous air pollutant concentrations.[33]

An exposure-response submodel described the slope of the exposure-response function and the plausibility of the $PM_{2.5}$ health effect. Only mortality due to long-term $PM_{2.5}$ exposure was considered. The exposure-response coefficient for three mortality outcomes (cardiopulmonary, lung cancer, and other nonaccidental) were estimated by using values with equal probability from the result distributions reported in Dockery *et al.*[34] and Pope *et al.*[17] They assumed that the exposure-response function was linear with no threshold. The plausibility of the estimated health effects was included in the exposure-response submodel using author judgment. Plausibility was defined as the probability that the observed exposure-response relationship actually represents a causal association. Background cardiopulmonary (International Classification of Disease (ICD-10) codes: I11-I70 and J15-J47), lung cancer (C34), and total mortality (A-Q) were 2,888, 313, and 7,308 deaths per year, respectively, in the Helsinki metropolitan area in 1996.[13] (see Table I).

An emission submodel was created for this study. Data for the emission submodel were received from the LIISA emission model maintained by the Technical Research Centre of Finland (VTT).[12] The emission model included annual fine particle emissions of all heavy-duty vehicles in the cities of Helsinki, Vantaa, Espoo, and Kauniainen. Emissions were calculated by data of road and street traffic volume in cases of the cities of Helsinki, Vantaa, and Espoo. Emissions of the municipality of Kauniainen were calculated by average Finnish road and street traffic data in proportion to the population of the city of Kauniainen. To calculate the present situation (CURRENT PRACTICE PM), we used also the data of VTT.[12]

2.4. Simulation

The variables and the uncertainty distributions included in the model are summarized in Table III. The whole model was implemented using the Analytica TM version 3.1.1 (Lumina Decision Systems, Inc., CA, USA) Monte Carlo simulation program. We used Latin hypercube sampling and the model was run with 20,000 iterations. An illustrative depiction of the graphical layout of the model is presented in Fig. 1. A more detailed description of this type of illustration can be found from an article and the model by Tuomisto and Tainio.[35,36] The complete model of this study is published on the *HEANDE* webpage. For a more detailed description of the variables and calculation, please see that model (URN:NBN:fi-fe20071159).[37]

Uncertainty analysis was performed by calculating absolute rank-order correlations between the uncertain input variables and the model outputs.

3. RESULTS

The estimated health risk due to dioxins from Finnish fish was 1.2 cancer deaths (90% confidence interval 1.1–1.4) per year in the Helsinki metropolitan area population (980,412 inhabitants, year 2004). Most of the estimated total cancer risk was due to PCDD/F; PCBs were responsible for only 13% (0.16 cancer death) of the total pollutant risk. Over 50% of the total risks of dioxins was attributable to large (size over 17 cm) Baltic herring. The extent of Finnish herring consumption has been declining in recent years. According to RKTL, in 2005, it was approximately 20% of the total fish consumption.[38]

In the NO DEROGATION scenario, the cancer deaths would be decreased by 0.7 per year due to reduced dioxin exposure. At the same time, there would be almost 40 more CHD deaths due to diminished omega-3 intake (see Table IV and Fig. 2). The net health effect, annual avoided CHD deaths, of consuming Finnish fish are 170 (90% CI 50–350) and 140 (90% CI 40–270) in scenarios DEROGA-

Table III. Key Variables with Uncertainty; Distributions with Parameters and References

Variable	Distribution	Parameters	Reference
Exposure to road traffic fine particles	Bernoulli[a]	$p = 0.7$ for 1.8 μg/m^3 $p = 0.3$ for 2.4 μg/m^3	Jantunen *et al.*,[31] Vallius *et al.*[33] Probabilities [30]
Concentration of combustion-based long-range transported fine particles	Triangular	1.0,2.0,2.5 (min, mode, max) (μg/m^3)	Tainio *et al.* 2004[30]
Relative weight factor for road traffic emissions	Triangular	1.0,2.0,3.0 (min, mode, max)	Tainio *et al.* 2004[30]
Plausibility[b] of	Bernoulli		Tainio *et al.* 2004[30]
- Cardiopulmonary mortality		$p = 0.7$ yes, $p = 0.3$ no	
- Lung cancer mortality		$p = 0.9$ yes, $p = 0.1$ no	
- All other mortality		$p = 0.1$ yes, $p = 0.9$ no	
Crude mortality rate random	Bernoulli	$p = 0.5$ yes, $p = 0.5$ no	Tainio *et al.* 2004[30]
Does omega-3 help CHD patients only	Bernoulli	$p = 0.5$ yes, $p = 0.5$ no	AJ[d]
Exposure-response of health benefit	Mixed	Relative risk of CHD death: 36 % (95 % CI 20–50) at intake 250 mg	Mozaffarian, D., Rimm, E.B. 2006[29]
Highest omega-3 dose with health benefit	Uniform	0.25,0.5 (min, max) (g/d)	Mozaffarian, D., Rimm, E.B. 2006[29]
Omega-3 content in fish	Mixed	Vary by fish species[c]: Mean 1.0 % *SD* (0.68) (%)	Database of Fineli, [25] Distributions by AJ[d]
RR			Tainio *et al.* 2005[30]
- Cardiopulmonary mortality	Mixed[e]	1.013 (1.000–1.023) (μg/m^3)	
- Lung cancer mortality	Mixed	1.009 (0.994–1.033) (μg/m^3)	
- All other mortality	Mixed	1.000 (1.000–1.001) (μg/m^3)	

[a]Bernoulli (binomial) binary probability distribution with probabilities (p,1-p).
[b]Plausibility = probability that the observed effect is due to true causal connection.
[c] Includes 12 fish species.
[d]AJ = Author judgment.
[e]Combination of several distribution means (95% confidence intervals in parentheses).

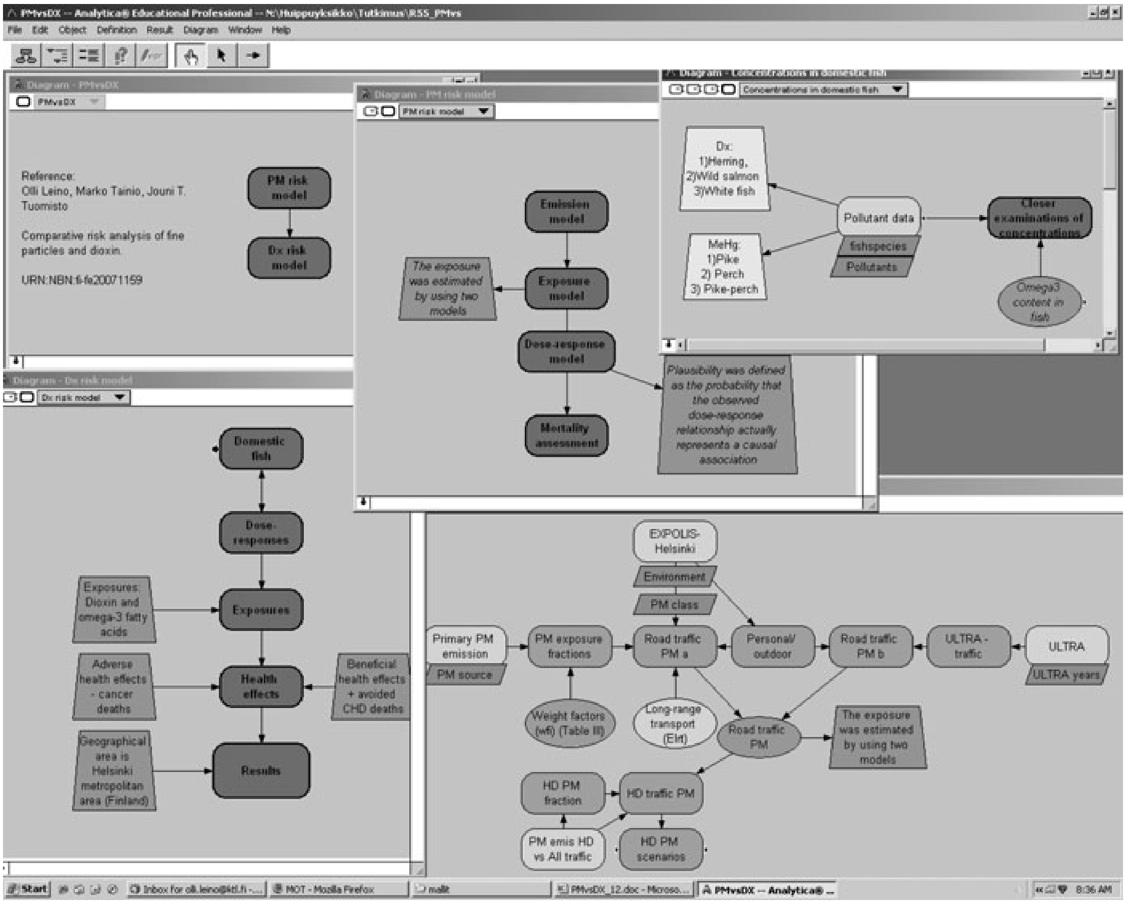

Fig. 1. Illustrative figure of the graphical layout of the model. Trapezoid-shaped, larger boxes state an argument or a conclusion related to an object. Flat parallelograms are indexes of a table. Round-cornered, darker-colored rectangles with thicker black border lines are submodels and the other round-cornered and oval-shaped objects are variables. See the models in References 30 and 37 for more detailed description.

TION and NO DEROGATION, respectively. The benefits of consuming fish due to the reduced CHD mortality are clearly larger than the estimated cancer risks due to dioxins. The uncertainties of the health benefits are remarkably large.

In case of the estimated fine particle risk, cardiopulmonary death was clearly the predominant endpoint, accounting for over 85% of the total fine particle risk. A further 12% of the risk was attributable to lung cancer whereas other nonaccidental causes of death contributed only a small percentage of the total risk. The estimated total mortality due to the fine particle exposure emitted by heavy-duty vehicles was 34 (90% CI 0–93) and 9.3 (90% CI 0–27) deaths per year in scenarios CURRENT PRACTICE and EURO IV and V, respectively (Table IV). The uncertainties are large, including a zero value for the lowest percentile.

3.1. Uncertainty Analysis of Uncertain Variables

Key input variables with uncertainty are summarized in Table III. The uncertainty analysis of the benefits of consuming domestic fish revealed that the variables "does omega-3 help only CHD patients or everyone" and "dose-response of health benefits" were clearly the most important sources of uncertainty (Fig. 3). The former variable was our own judgment and the assumptions are indicative. Contributions of the other risk variables were lower (below 0.3) than the two key variables.

The uncertainty analysis of the fine particle risk reveals one variable that had a high level of uncertainty. Plausibility of cardiopulmonary effects contributes clearly most to uncertainty (Figs. 4A and 4B). The ranking of the variables is rather similar in the two scenarios. The variable "Emission

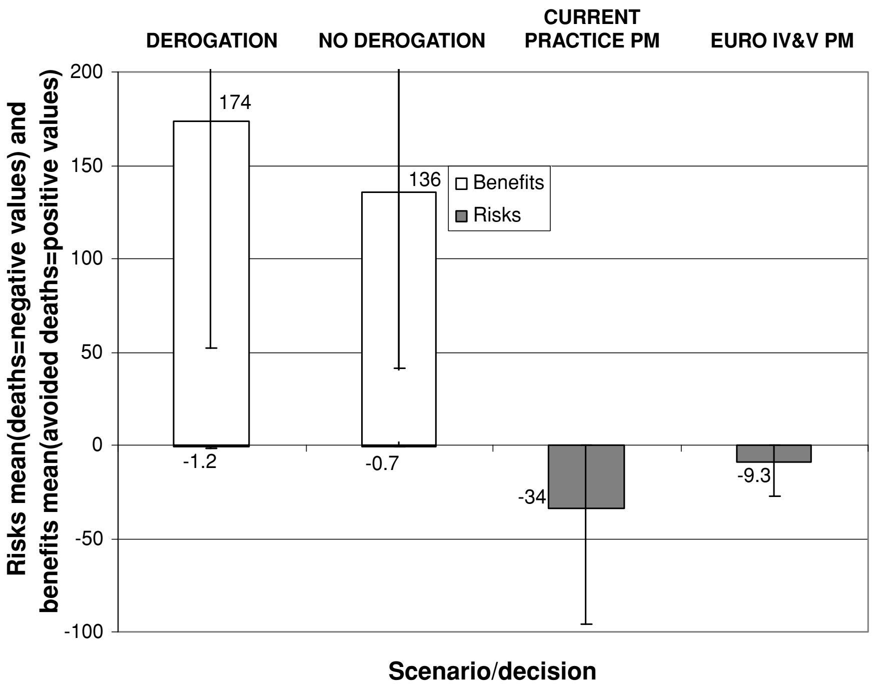

Fig. 2. Mean value of health risk (annual mortality) in the Helsinki metropolitan area according to whether the two pieces of legislation are implemented in decision situations. Mean values and 90% confidence intervals.

factor current to EURO IV&V" is significantly larger in the scenario EURO IV and V than in CURRENT PRACTICE because it is used only in the calculations of the latter scenario.

4. DISCUSSION

Our goal was to compare the effects of the EU regulations for two environmental pollutants. There are topical EU regulations set for Baltic salmon and herring consumption and fine particle exposure from the exhaust gases of heavy-duty vehicles. We compared estimated dioxin risk due to fish consumption with estimated fine particle risk due to heavy-duty vehicles and found that the risk of fine particles was much higher than the risk of dioxins when death was considered as the endpoint of the health effects. In addition, the beneficial health effects of fish consumption outweigh the cancer risk. The uncertainties were large and therefore the results must be considered with caution.

4.1. Dioxins

Omega-3 is believed to reduce the tendency toward arrhythmias and formation of atherosclerotic plaques.[23] We were careful not to overestimate the beneficial effects of omega-3 fatty acids by assuming maximum beneficial intake and uncertainty of whether omega-3 helps only CHD patients or everyone (Table III). In addition, we used a linear model instead of a threshold concentration in order not to underestimate the cancer risk of dioxins. Uncertainty in the cancer slope factor (CSF) offsets the three major factors—(a) interspecies extrapolation, (b) high-to-low exposure extrapolation, and (c) data analysis techniques—designed to provide upper-bound values.[39] We also assumed that every cancer case due to dioxin exposure would be fatal. Therefore, it is unlikely that the dioxin risks have been underestimated or the benefits of omega-3 overestimated.

We limited this study to cover only Finnish fish consumption because accurate geographical and concentration data for imported fish products are usually unavailable or they would be crude approximations. Also the Baltic Sea, the main source of domestic fish, is a problematic area with respect to dioxins and we can assume that concentrations of these pollutants are significantly lower elsewhere.[4] According to RKTL, domestic fish consumption represents approximately one-half of the total fish consumption in Finland. Therefore, we can assume that the consumption of domestic fish is the most relevant

Table IV. Health Risk (Annual Excess Mortality) of Helsinki Metropolitan Area in Decision Situations; Mean (90% Confidence Interval)

Hazard	Decision/Action	Number of Premature Deaths per Year	Net Effect Including Benefits
Fine particle exposure caused by heavy-duty vehicles	**CURRENT PRACTICE**	34 (0–93)	
	EURO IVand V	9.3 (0–27)	
Background cardiopulmonary and lung cancer mortality in the study area	**ICD 10** (I11-I70, J15-J47, and C34)	3,201	
Exposure from dioxin and PCB from Finnish fish	**DEROGATION** for commercial fishery of salmon and herring	1.2 (1.0–1.4)	170 (50–360)
	NO DEROGATION for commercial fishery of salmon and herring	0.6 (0.46–0.65)	130 (40–280)
Background total cancer mortality in the study area	**ICD 10** (C00-D48)	1,727	
	ICD 10 (C00-D48)	1,727	

dioxin risk with respect to fish consumption in Finland. The amount of imported fish consumed has, however, an impact on the calculations of health benefits as the maximum beneficial omega-3 intake for the reduction of CHD has been proposed to be 250–500 mg/day.[29] We deducted the omega-3 exposure of the imported fish from the maximum beneficial intake. Thus omega-3 exposure from imported fish was 70 mg/day with 130 mg/day from domestic fish. Inclusion of omega-3 consumption from imported fish has a mitigating effect on the health benefits of domestic fish source.

The use of a linear exposure-response for the cancer slope factor for dioxin provides a high estimate for risk when compared to an approach using threshold assumption and safety margin. The latter approach, using developmental effects as the most sensitive endpoint, was used by the WHO. It concluded that weekly intake of 7 pg/kg bw dioxin in toxic equivalents (WHO-TEQ) would lead to a negligible risk. The current average intake of young women in Finland is estimated at 10.5 pg/kg bw/week.[6] However, it is not clear how large the risk is if the exposure is 50% more than "negligible," as is the case in Finland.

There has been much discussion about the recommendation that risk groups, for example, pregnant women and young children, should only consume fish species with low concentrations of pollutants. Also, the use of fish oil supplements instead of consuming fish has been debated. Cohen *et al.*[40] conducted a study to evaluate fish consumption after the hypothetical consumption recommendation. They found that increased fish consumption increased the health benefits more than the health risks. Even special population risk groups, like women of childbearing age, seemed to benefit from increased consumption of fish. The conclusion was that the recommendations may well have negative impacts on the health of other subpopulations. In addition, fish consumption appears to be even more vital to developing children as omega-3 fatty acids seem to play an important role in the cognitive development of children.[26] Thus, by restricting fish use, we might have a negative effect on the health of the general public by ignoring the health benefits of fish.

We took into account the benefits of omega-3 fatty acids only in the reduction of CHD. This seems to be the most important health attribute of omega-3 fatty acids although there might well be some other beneficial health effects, like reduced risk of sudden death, decrease of mild hypertension, prevention of cardiac arrhythmias, lowering incidence of diabetes, relieving symptoms of rheumatoid arthritis, fighting against some types of cancers, and promoting the development of nervous system, to name but a few.[27,28,41,42]However, these benefits have a less solid foundation and are more or less controversial.

The beneficial effects of consuming fish were two orders of magnitude higher than their estimated risks. If the exemption was no longer available, there would be an almost total cessation of commercial

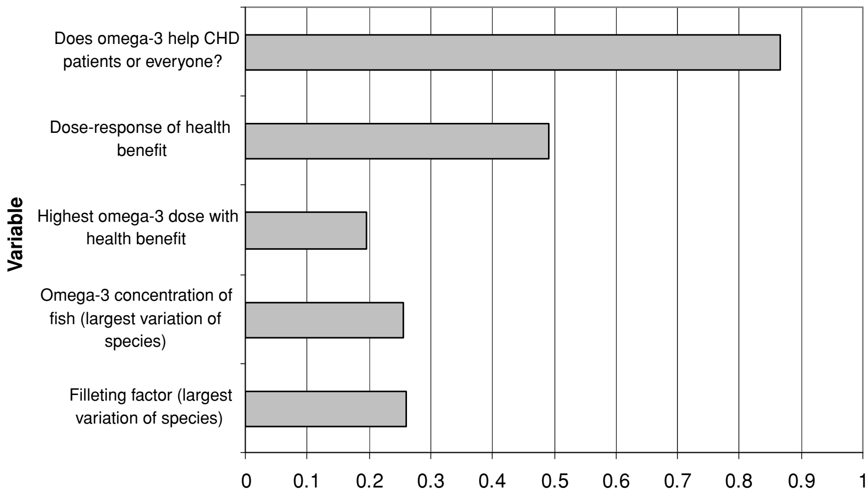

Fig. 3. Uncertainty analysis of omega-3 exposure due to Finnish fish consumption.

fishing in the Baltic and this would impact on some of the most nutritionally beneficial fish species, salmon and herring. This could cause tens of deaths more in the form of increased CHD mortality in the Helsinki metropolitan area alone. The beneficial effects of omega-3 fatty acids dramatically outweigh the estimated risk of consuming fish.

We estimated the dioxin risk of the Helsinki metropolitan area assuming a similar consumption pattern of fish consumption as in the general Finnish population. This is probably an underestimate, since the city of Helsinki lies on the coast and its citizens may consume more fish from the sea-areas than from elsewhere in Finland. However, this difference is not very large because consumers most often purchase their fish from large grocery chains, which sell fish caught and transported from a variety of locations. Traditional marketplaces with locally caught fish account for only a small proportion of the total sale of domestic fish.

The current EU legislation allows the domestic trading of Baltic salmon and herring. The net benefits of this present scenario (NO DEROGATION) seem to promote public health as was the purpose, despite the marginal risk from dioxins.

4.2. Fine Particles

Estimation of vehicle-related emissions may often cause some problems. The Helsinki metropolitan area was selected as the geographical area of this study since then it was possible to use the best available road traffic data and in this way reduce the bias due to inaccurate estimations of emissions and road traffic volumes. The traffic volume prediction was based on calculations performed by VTT.[12]

Vans and six-wheeler trucks were estimated to be responsible each for about 40% (14 deaths [0–38 90% CI] and 13 deaths [0–35 90% CI], respectively) of the premature mortality. With the implementation of EURO IV and V, it was estimated that these numbers would be reduced to 4.3 (0–11 90% CI) and 3.9 (0–10 90% CI), respectively. Tractor trailers and buses accounted for only 20% of the estimated total premature deaths. It is important to note the large uncertainties associated with the fine particle risk estimates. The uncertain variables used in the model are listed in Table III.

The calculation of the risk estimates for fine particles is based on epidemiological data. This means that confidence intervals in this study only reflect the particular conditions in the study and the estimation methods used. If a confounding or exposure measurement error exists, then the confidence intervals calculated in this study may not reflect the true uncertainty.

Another source for uncertainty comes from an assumption that all fine particles are the same in terms of toxicity. This may not be true and it must be accounted as a potential source of uncertainty.

The emissions from light-fleet vehicles have declined significantly, but the problem remains for the heavy-duty vehicles, that is, these powered by diesel engines that emit a constant stream of fine particles. Thus, tightening of EURO emission standards

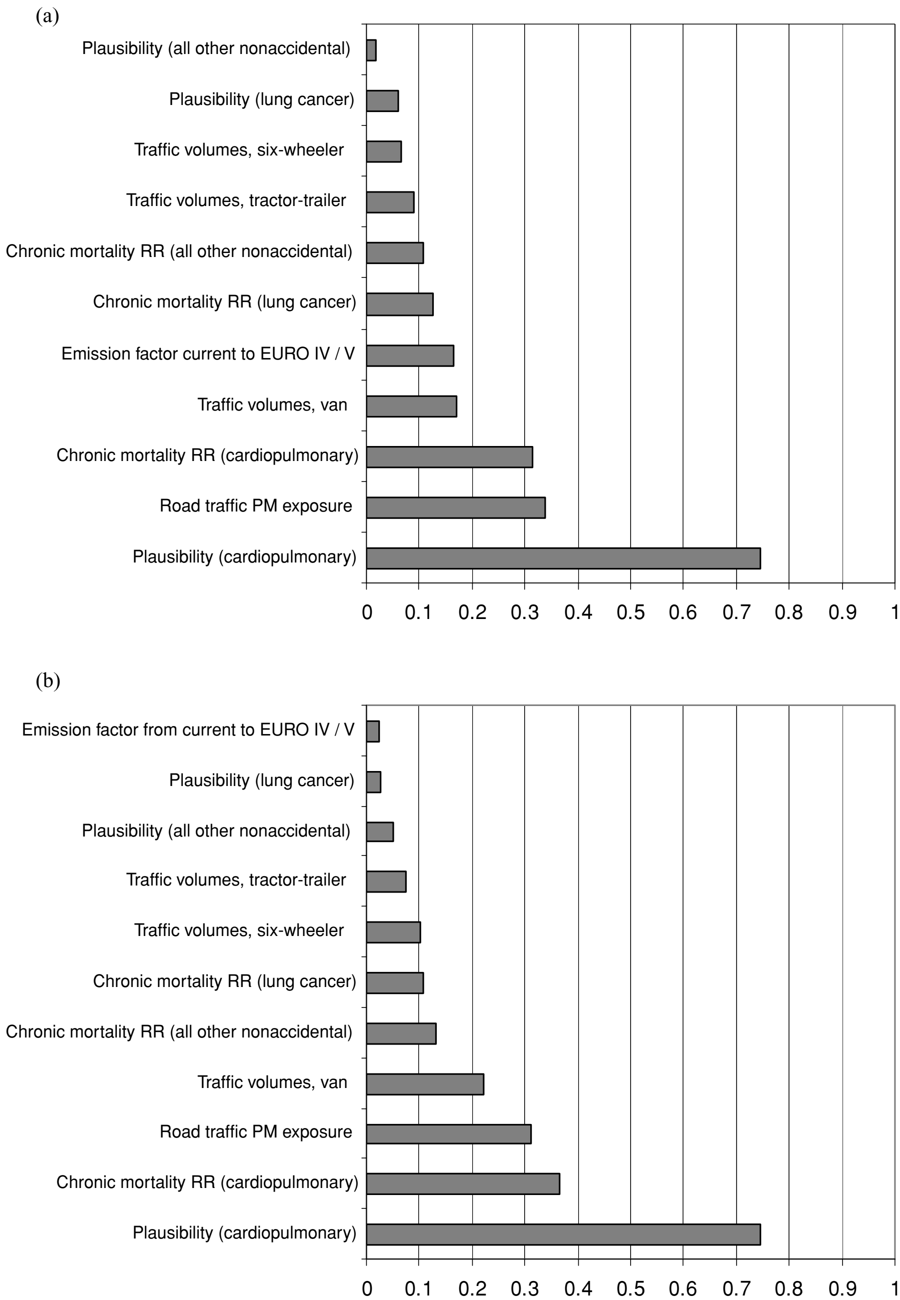

Fig. 4 (a) Uncertainty analysis of fine particle emissions of heavy-duty vehicles in scenario EURO IV. (b) Uncertainty analysis of fine particle emissions of heavy-duty vehicles in scenario CURRENT PRACTICE.

for the heavy-duty fleet should achieve the greatest health benefits related to traffic-related fine particles. There are still vehicles that do not meet the EURO IV or even EURO III standards, but their number is decreasing. The difference between EURO IV and EURO V emission standards relates only to NO_x emissions. All other emission limits (carbon monoxide, hydrocarbons, fine particles, and smoke) are the same in these two standards.

There are two possible ways to reduce fine particle emissions from vehicles. First, improving the technology and design of motor engines and second by installing particle traps. It appears to be easier for automobile manufacturers to decrease only

NO_x emissions. There are technical challenges in reducing both fine particles and NO_x emissions at the same time. However, there is already one known way to achieve this goal by using a process called cooled reuse of exhaust gas.[43] Also, some major changes are taking place in diesel technology, such as exhaust after-treatment and the introduction of ultra low sulfur fuels. These solutions are being tested currently by several manufacturers and in the future they may have a substantial impact in reducing the fine particle emissions.

It is clear that the estimated cardiovascular health effects of this study are substantially smaller than cardiovascular health effects of smoking. In other words, reducing smoking obviously promotes public health much more effectively than the implementation of EURO IV and V emission standards. Fig. 5 illustrates the decreasing trend of cardiopulmonary mortality (ICD10: I20, I21, I22, I24, and I25) in the study area over the last 10 years. The trend of total mortality is very similar. These trends might be attributable to reduced smoking among males.[44]

There are 62 traffic-related fatalities per year in the study area (see Table I). Estimated fine particle health risk is 34 death per year. Traffic-related fatalities also include the fatalities caused by the light-duty fleet. Thus, fine particles pose a significant risk when considering the risks of traffic as a whole.

The comparison between the results of this study and the study performed by Tainio *et al.*[30] is not straightforward. First, they use bus engine technologies as scenarios whereas in this study we use the emission standards. Second, the results of the Tainio *et al.* article are presented at the level of year 2020 whereas in this study the results are presented in present time. By selecting technology (scenario DIESEL WITH PARTICLE TRAP) that best corresponds to EURO IV and taking into account the 60% increase in traffic intensity proposed by Tainio *et al.,*[30] we get 2.8 (0–8.8 90% CI) deaths/year. The comparable estimate of this study (scenario EURO IVand V) gives 0.8 deaths/year (0–8.1 90% CI). The estimates are on the same level and the range is similar.

4.3. Comparing Risks

The risks of dioxins are a matter of wide public interest and their risks are often considered as unacceptable. At the same time, the health benefits of fish consumption may appear ambiguous. Nonetheless, the fine particles emitted by road traffic represent a health risk that is more than an order of magnitude higher than the risk of dioxins present in Baltic fish. The fine particle risk is generally accepted by the population because of readily comprehensible benefits, that is,, necessity of transportation. These benefits are difficult to take into account quantitatively and to some extent fine particle health risks of road traffic may be considered by the general population as unavoidable phenomena of the urban world. However, we can reduce the risk substantially by implementing EU-regulated emission standards, as pointed out in this study (Fig. 2). The public health outcomes of these two pieces of EU legislations may differ greatly; perversely, the outcome with the smaller risk seems to attract greater public attention.

The half-lives of dioxins are very long, in both the environment and in humans, and they will cause a risk of similar order of magnitude for many years to come. This means that the situation concerning the risk of dioxins is more stable whereas the risk of fine particles could be reduced rapidly.

When comparing the estimated fine particle risks and the estimated risk of fish consumption, we find that the risk of fish consumption is much lower. Even after including pessimistic assumptions in the estimation of the risk of fish consumption, we can be quite confident in our conclusion of ranking fine particles as a more relevant risk from the public health point of view. However, the dioxin question also requires scrutiny, as the collateral effects of possible policies are even greater than the risks posed by fine particles.

It is useful to perform comparative risk assessments. This study illustrates a case where the magnitudes of two well-known risks actually lie on different levels. The EU decisionmakers have to deal with risks of very different magnitudes and often considerations outweigh scientific data. Many Baltic Sea fishermen obtain much of their income from salmon fishery and their boats are often equipped for herring fishing. To this extent, the entire professional fishing community is largely dependent on the exemption.

In this study, we did not describe new major risks; we simply compared two well-known risks and quantified how these EU regulations have an impact on the health problems associated with these risks.

5. CONCLUSION

We found that the estimated risks of fine particles emitted by heavy-duty vehicles are much greater than the estimated risks of dioxin associated with the consumption of Finnish fish. The estimated fine

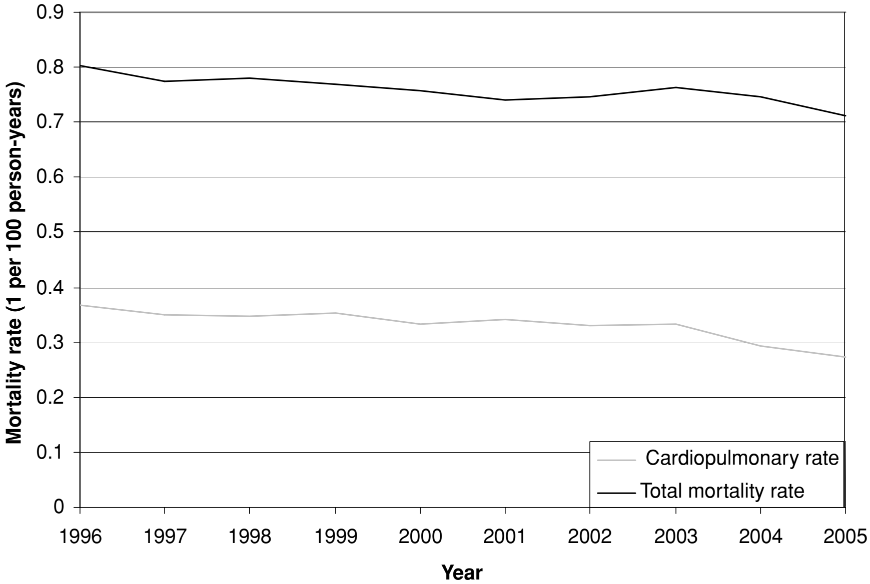

Fig. 5. Mortality rates in Helsinki metropolitan area 1996–2005.

particle risk appeared to be tens of times higher than the estimated dioxin risk. According to our model, the annual cardiopulmonary mortality attributable to heavy-duty vehicles could be reduced by approximately 30 deaths by moving from the present situation to EURO IV and V. The estimates are somewhat uncertain and both risks need to be considered independently. When estimating risks due to fish consumption, the analysis needs to consider not only risks but also benefits.

Based on our results, two recent EU directives, that is, exemption allowing domestic consumption of Baltic fish and imposing strict standards of PM emission, both achieve their intention of protecting public health.

Mortality could be reduced much more effectively in the case of fine particles compared with dioxins. However, the net benefit would be higher in the case of sanctioning salmon and herring consumption rather than with restricting their consumption, thanks to their omega-3 fatty acids.

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