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Human exposure to carcinogens in ambient air in Denmark, Finland and Sweden

P. Fauser [a, *], M. Ketzel [a], T. Becker [a], M.S. Plejdrup [a], J. Brandt [a], L. Gidhagen [b], G. Omstedt [b], T. Skårman [c], A. Bartonova [d], P. Schwarze [e], N. Karvosenoja [f], V.-V. Paunu [f], J. Kukkonen [g], A. Karppinen [g]

[a] Department of Environmental Science, Aarhus University (AU), Denmark
[b] Swedish Meteorological and Hydrological Institute (SMHI), Sweden
[c] Swedish Environmental Research Institute (IVL), Sweden
[d] Norwegian Institute for Air Research (NILU), Norway
[e] Norwegian Institute of Public Health (FHI), Norway
[f] Finnish Environment Institute (SYKE), Finland
[g] Finnish Meteorological Institute (FMI), Finland

HIGHLIGHTS

- A risk screening of 17 carcinogenics in air is performed at a resolution of 1 × 1 km^2.
- No exceedances of the EU air quality limit, guideline or target values are found.
- B(a)P exceeds its US-EPA 1:100,000 cancer risk conc. for approx. 80% of the Danish population.
- B(a)P commonly originates mostly from local residential wood combustion.
- National and regional background contributions to air concentrations are estimated.

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ABSTRACT

The concentrations of seventeen pollutants (particulate mass fractions $PM_{2.5}$ and PM_{10}, a range of metals, inorganic gases and organic compounds) are for the first time analyzed in a screening of the carcinogenic risk at a resolution of 1 × 1 km^2 in ambient air in three Nordic countries. Modelled annual mean air concentrations in 2010 show no exceedances of the EU air quality limit, guideline or target values. The only modelled exceedance of US-EPA 1:100,000 cancer risk concentrations (0.12 ng/m^3, US-EPA IRIS, 2015) occurs for B(a)P in Denmark, for approximately 80% of the Danish population. However, the EU target value threshold of 1 ng/m^3 for B(a)P is not exceeded in the modelled values in any parts of Denmark. No emission data for B(a)P were available for the whole domain of the other two considered Nordic countries and important uncertainties are still related to the emissions. Long-range transport is significant for the concentrations of all of the considered pollutants, except for B(a)P that commonly originates mostly from local residential wood combustion. The ambient air concentrations of NO_x, SO_2, Cd, Cr and Pb also have significant contributions from national sources; 45–65% for NO_x and SO_2, and for the metals from 15 to 60% in urban areas and from 1 to 20% in rural areas, within the considered Nordic area. High national contributions occur especially in urban air, due to primarily road traffic, residential wood combustion, energy production and industrial point sources. It is recommended to monitor the influence from residential wood combustion more extensively, and to analyze longer time trends for long-term human exposure.

1. Introduction

It is well known that the exposure to air pollution is associated with adverse health effects in the population (EU Environment

* Corresponding author.
E-mail address: paf@envs.au.dk (P. Fauser).

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Health Action Plans; EU Parma Declaration on Environment and Health; Forouzanfar et al., 2015; Brauer et al., 2016). It is also commonly known that carcinogenetic environmental exposures play an important role in the cancer aetiology in western societies. However, the environmental exposure-health associations remain relatively uncertain due to lack of information integration. The 2010–2011 report by the U.S. Presidential Cancer Panel concluded that the estimated environmentally related cancer burden of 4–6% (WHO) is most likely a significant underestimation (US PCP, 2012). Moreover the report concluded that some 40% of the total cancer burden is still unaccounted for when life-style, heredity, etc. have been uncovered. How much of these 40% that can be ascribed to environmental exposures is unknown.

Cancer development is complex and per definition multi-causal and often displays delayed and non-linear responses, which needs to be reflected in the risk appraisal (Hanahan and Weinberg, 2000). Hence, ascribing causal relationships is often very difficult. Epidemiological studies show that life-style such as smoking is the predominant source to important cancers such as lung cancer, which is one of the most frequent cancers (US PCP, 2012; http://globocan.iarc.fr/). However, previous studies also show significant correlation between chemical exposures via environment and cancers; e.g. in Denmark and in 17 European cohorts (Raaschou-Nielsen et al., 2010, 2013) and urban air pollution in Stockholm (Nyberg et al., 2001). A 16-year cohort study of 500,000 Americans living in different cities found association between $PM_{2.5}$ and lung cancer mortality (Pope et al., 2002). Furthermore ambient air quality is a typical primary exposure route of carcinogens to humans in urban environments (Danaei et al., 2005). Although the focus on the health effects has been on a limited number of pollutants such as particles, SO_2 and NO_x, often as indicators for specific sources such as traffic (Davidson et al., 2005) also other gaseous pollutants have significant negative health effects (Maynard, 2004). Emission inventories, air modelling and monitoring show that there are a number of sources that emit carcinogens, all contributing possibly in a synergistic way, to the overall cancer risk.

The Nordic countries, and Denmark in particular, have according to the WHO relatively high female total cancer and female lung cancer incidence rates among the 27 EU member states. This warrants an investigation of the influence of environmental quality and answers to the questions: What is the exposure of carcinogens and co-carcinogens from inhalation of ambient air in the Nordic countries? What are the exceedances of the EU air quality and cancer risk values with respect to population number and location? Which pollutants are the most critical with respect to exceeding these values? Are the exceedances related to specific activities (e.g. residential wood burning) or locations? What are the most important needs in terms of emission and air concentration data to give a more accurate and complete understanding of the cancer risk from exposure of atmospheric pollutants? In this study these questions are investigated for pollutants that exhibit carcinogenic or co-carcinogenic properties and that have high quality emission estimates that can be used in urban and regional scale modelling of concentrations in ambient air in the Nordic countries.

2. Methodology and data

2.1. Carcinogens, co-carcinogens and national emission data

Ambient air pollution consists of a highly variable and complex mixture of different substances, which may occur in the gas, liquid or solid phase. Several hundred different components have been found in the troposphere, and a set of indicator and criteria pollutants have been widely used to characterize air quality (WHO, 2005). Some of these pollutants are carcinogens and co-carcinogens, where carcinogens are defined according to the principles, procedures, and scientific criteria that guide the evaluations that a pollutant can increase the risk of cancer. These are described in the preamble to the IARC Monographs (http://monographs.iarc.fr/). Co-carcinogens are chemical substances that cannot induce cancer when they are administered alone, but can enhance the carcinogenic effect of other substances. In general, co-carcinogens act as promoters in tissues in which the initiation stage has appeared (Haverkos, 2004).

Relevant airborne carcinogens and co-carcinogens, together denoted (co-)carcinogens, originating from anthropogenic sources are identified from a literature review of available official and scientific environmental emission studies, see supplementary material Table s1. Among these the following pollutants are covered by the national emission reporting to the United Nations Economic Commission for Europe - Convention on Long-Range Transboundary Air Pollution (CLRTAP) (http://www.unece.org/env/lrtap/welcome.html):

- Co-carcinogenic inorganic gases and particles; sulphur dioxide (SO_2), nitrogen dioxide and -oxides (NO_2/NO_x), total suspended particulates (TSP), coarse particulates (PM_{10}), fine particulates ($PM_{2.5}$).
- Carcinogenic metals; arsenic (As), cadmium (Cd), chromium (Cr), mercury (Hg), nickel (Ni), lead (Pb).
- Organic compounds; non-methane volatile organic compounds (NMVOC), dioxins and furans (PCDD/F), hexachlorobenzene (HCB) and the polycyclic aromatic hydrocarbons (PAHs): benzo(b)flouranthene, benzo(k)flouranthene, benzo(a)pyrene and indeno(1,2,3-*c*,*d*)pyrene.

The emissions are reported to CLRTAP as national totals for a number of sectors and sub-sectors as defined by the Nomenclature For Reporting (NFR), i.e. large point sources, stationary combustion for point sources, stationary combustion for area sources, residential heating, mobile sources, aviation, fugitive emissions, industry, F-gases, solvents, waste and a number of sub-sectors for the agricultural sector. There is a mandatory reporting every five years of gridded emissions (50×50 km^2 EMEP grid and $0.1 \times 0.1^\circ$ EMEP grid from 2017).

To assess the contribution from national anthropogenic sources this study uses annual mean 2010 emission data available on a 1×1 km^2 grid covering the entire countries. Denmark and Sweden have developed national emission gridding of their CLRTAP emissions down to 1×1 km^2 resolution. These data include 14 pollutants (11 carcinogens, 3 co-carcinogens) for Denmark and 11 pollutants (7 carcinogens, 4 co-carcinogens) for Sweden. For Finland, only having CLRTAP emissions available on a 50×50 km^2 EMEP grid, emission data from the Finnish Regional Emission Scenario model (FRES) (Karvosenoja, 2008) at 1×1 km^2 resolution are used, which includes 4 pollutants (co-carcinogens).

2.2. Modelling air pollution concentrations for exposure assessment

The contribution from the above national sources to the selected pollutants air concentrations is calculated on a 1×1 km^2 resolution using the Urban Background Model (UBM) (Brandt et al., 2001a, b, c; 2003) for the three addressed Nordic countries. In UBM inert pollutants are assumed, i.e. degradation, volatilization, transformation etc., are not taken into account, except for NO_x/O_3 chemistry.

The UBM model also calculates concentrations from point sources, using a Gaussian approach, such as industrial facilities, on a 1×1 km^2 resolution, and includes the dispersion up to 30 km from