Health effects of particulate matter air pollution
Policy paper for countries in Eastern Europe, Caucasus and Central Asia

This paper aims to summarize the evidence on the health effects of particulate matter (PM) air pollution and their policy implications for policy makers of various backgrounds. It should stimulate the development of more effective strategies to reduce air pollution and its health effects in the countries of the Eastern Europe, Caucasus and Central Asia (EECCA) region.

1. Introduction and context

In most countries of the United Nations Economic Commission for Europe (UN ECE) region, ambient air quality has improved considerably in the last few decades. This improvement was achieved by a range of measures to reduce harmful air emissions, including those stipulated by the various protocols under the Convention on Long-range Transboundary Air Pollution (LRTAP). However, there is convincing evidence that current levels of air pollution still pose a considerable risk to the environment and to human health.

Recently, the Executive Body for the LRTAP Convention has adopted amendments to the Convention's 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone. Following years of negotiations, the approved revised text of the Protocol now specifies national emission reduction commitments for main air pollutants to be achieved by the UN ECE Parties by 2020 and beyond. The revised Protocol includes, for the first time, emission reduction commitments for fine particulate matter ($PM_{2.5}$). Furthermore, black carbon (BC) or soot is now included in the revision as an important component of $PM_{2.5}$. BC is an air pollutant affecting health and at the same time contributes to climate change.

2. What is Particulate Matter (PM)?

- PM is a widespread air pollutant, consisting of a mixture of solid and liquid particles suspended in the air.
- Commonly used indicators describing PM which are relevant to health refer to the mass concentration of particles with a diameter less than 10 µm (PM_{10}) and particles with a diameter less than 2.5 µm ($PM_{2.5}$). $PM_{2.5}$, often called fine PM, also comprises ultrafine particles having a diameter of less than 0.1 µm. In most locations of Europe, $PM_{2.5}$ constitutes 50-70% of PM_{10}.
- PM between 0.1 and 1 µm in diameter can remain in the atmosphere for days or weeks and thus be subject to long-range transboundary transport in the air.
- PM is a mixture with physical and chemical characteristics varying by location. Common chemical constituents of PM include sulphates, nitrates, ammonium, other inorganic ions such as ions of sodium, potassium, calcium, magnesium, and chloride, organic and elemental carbon, crustal material, particle-bound water, metals (including cadmium, copper, nickel, vanadium, zinc), and polycyclic aromatic hydrocarbons. In addition, biological components such as allergens and microbial compounds are found in PM.

3. Where does PM come from?

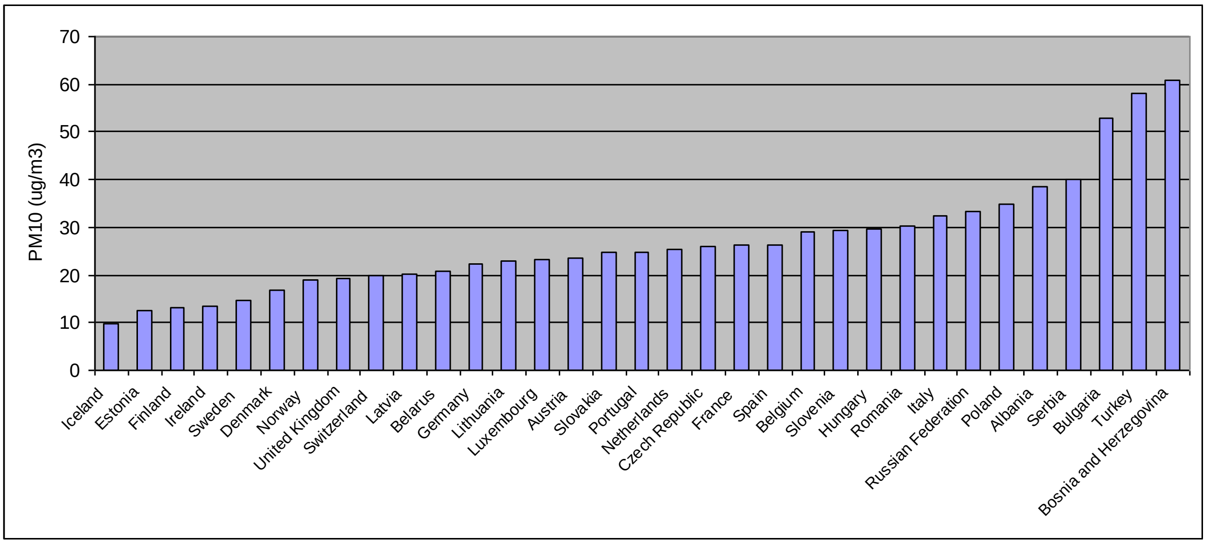
- Particles can be either directly emitted into the air (primary PM) or be formed in the atmosphere from gaseous precursors such as sulphur dioxide, oxides of nitrogen, ammonia and non-methane volatile organic compounds (secondary particles).

- Primary PM and the precursor gases can have both man-made (anthropogenic) and natural (non-anthropogenic) sources.
- Anthropogenic sources include combustion engines (both diesel and petrol); solid-fuel (coal, lignite, heavy oil and biomass) combustion for energy production in households and industry; other industrial activities (building, mining, manufacturing of cement, ceramic and bricks, and smelting); erosion of the pavement by road traffic and abrasion of brakes and tires. Agriculture is the main source of ammonium.
- Secondary particles are formed in the air through chemical reactions of gaseous pollutants. They are products of atmospheric transformation of nitrogen oxides (mainly emitted by traffic and some industrial processes), and sulfur dioxide resulting from the combustion of sulfur-containing fuels. Secondary particles are mostly found in the fine PM fraction.
- Soil and dust re-suspension is also a contributing source of PM, particularly in arid areas, or during the episodes of long range transport of dust, for example from Sahara to southern Europe.

4. What are the levels and trends of PM in the European Region[1]?

WHO Environment and Health Information System (ENHIS), based to a large extent on the data submitted by the Member States in the European Union (EU) to the European Environment Agency (EEA) AirBase, includes PM_{10} monitoring data from urban and suburban background locations. Figure 1 presents the annual mean concentration of PM_{10}, weighted by the total population in cities with data, in 357 cities in 33 Member States of the WHO European Region for the year 2009. In only 8 of the 33 Member States, PM_{10} levels in at least some cities are below the annual WHO Air Quality Guideline (AQG) level of 20 µg/m^3. Almost 83% of the population of the cities for which PM data exist, experience PM_{10} exceeding the guideline levels. Although this proportion remains high, there has been improvement compared to previous years, with average PM_{10} levels slowly decreasing in most countries in the last decade.

Figure 1. Population weighted annual mean PM_{10} in cities by Member State, 2009



Source: ENHIS Factsheet 3.3, WHO 2011

On the other hand, monitoring of PM_{10} and $PM_{2.5}$ is very limited in EECCA countries, with only a small number of monitoring stations in Belarus, Russian Federation (Moscow) and Uzbekistan (one location in Tashkent and one in Nukus). Initial data from the two Uzbek cities indicate that the PM_{10}

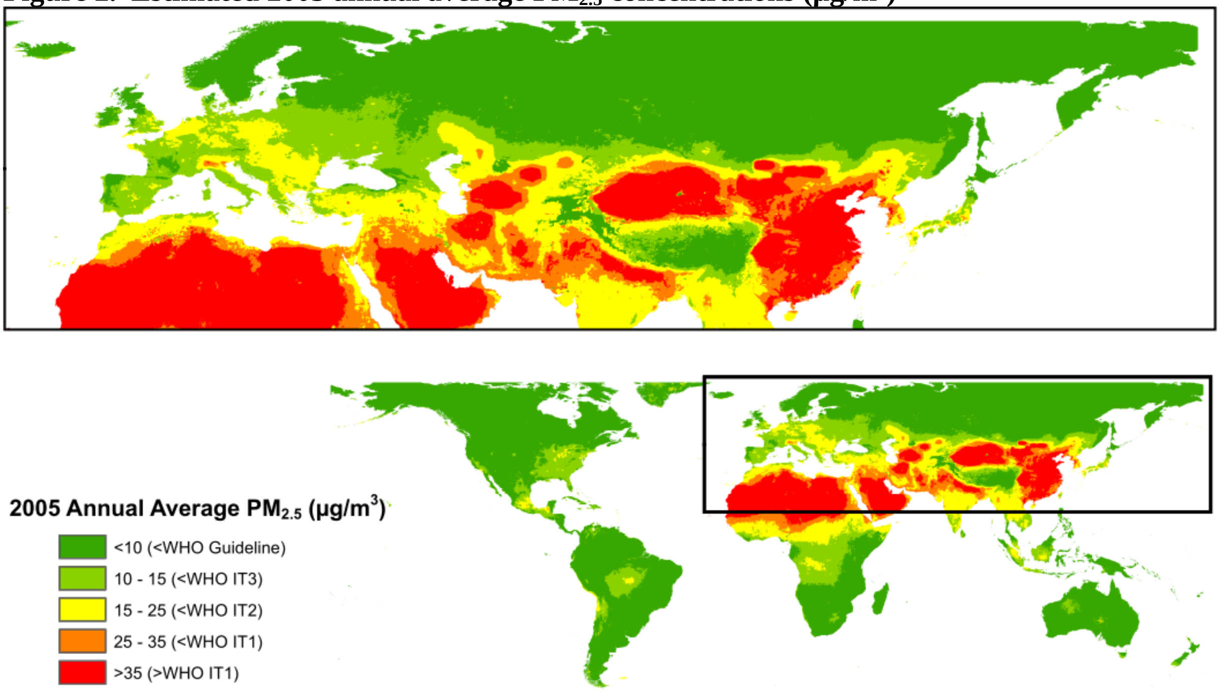
[1] The WHO European Region includes 53 countries stretching from the Atlantic Ocean to the Pacific, with a population of almost 900 million.

and $PM_{2.5}$ levels are high in comparison with most of the other cities with available PM monitoring in the Region. While the levels in Nukus might be affected by dust storms, frequent in that area, various combustion sources might dominate in Tashkent.

Proper assessment of levels and trends of PM in EECCA countries requires introduction of PM_{10} and/or $PM_{2.5}$ monitoring in more locations in EECCA. Assessment of PM concentrations requires continuous monitoring (conducted for 24 hours daily, throughout a year, with standardized methods or methods equivalent to the standard). Quantitative knowledge about sources, levels and trends of emissions of primary particles and precursor gases plays an important role in finding the best control strategy for reducing risks.

In the scarcity of ground-level data for PM, remote (satellite) sensing combined with modeling and existing surface measurements has been recently used for the assessment of the population exposure at country level. Recent estimates have been published for $PM_{2.5}$ concentrations using this technology as part of the Global Burden of Diseases, Injuries and Risk Factors Project (see Figure 2). Further development of these methods and their precision depends to a large extent on the availability of surface measurements in all regions of the world.

Figure 2. Estimated 2005 annual average $PM_{2.5}$ concentrations (µg/m^3)



Source: Michael Brauer, personal communication based on Brauer et al., 2012

5. What are the health effects of PM?

PM_{10} and $PM_{2.5}$ size fractions include those inhalable particles which are small enough to penetrate in the thoracic region of the respiratory system. Health effects of inhalable PM are well documented. They are due to both short-term (hours, days) and long-term (months, years) exposures and include:

- Respiratory and cardiovascular morbidity, such as aggravation of asthma, respiratory symptoms, increase in hospital admissions;
- Mortality from cardiovascular and respiratory diseases and from lung cancer.

There is good evidence on effects of short term exposure to PM_{10} on respiratory health, but for mortality, and especially as a consequence of long term exposure, $PM_{2.5}$ is a stronger risk factor than the coarse fraction of PM_{10} (i.e. the particles in 2.5 – 10 µm size range). All-cause daily mortality is estimated to increase by 0.2-0.6% per 10 µg/m^3 of PM_{10} (WHO, 2005; Samoli et al., 2008). Long term exposure to $PM_{2.5}$ is associated with the increase in long term risk of cardiopulmonary mortality by 6-13% per 10 µg/m^3 of $PM_{2.5}$ (Pope et al., 2002; Krewski et al., 2009; Beelen et al., 2008).

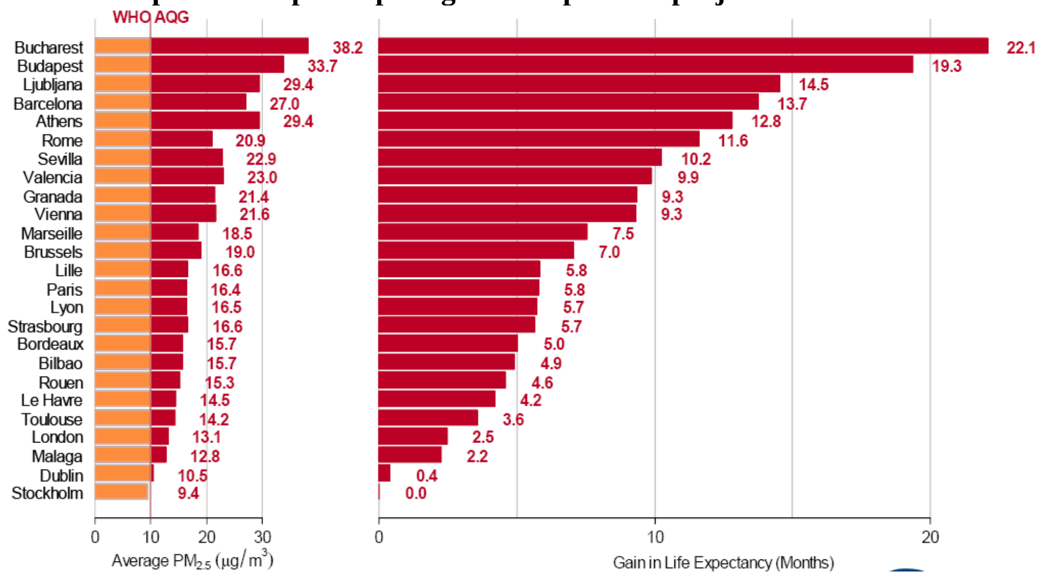
Susceptible groups with pre-existing lung or heart disease, as well as the elderly and children, are particularly vulnerable. For example, PM exposure affects lung development in children, including reversible deficits in lung function as well as chronically reduced lung growth rate and long-term lung function deficit (WHO, 2011). There is no evidence of a safe level of exposure or a threshold below which no adverse health effects occur. The exposure is ubiquitous and involuntary, increasing significance of this determinant of health.

At present, at the population level, evidence is not sufficient to identify differences in the effects of particles with different chemical composition or coming from various sources (Stanek et al., 2011). It should be noted, however, that the evidence on health effects of PM originating from combustion is relatively better established. The BC fraction of $PM_{2.5}$, resulting from incomplete combustion, has attracted attention of the air quality community due to the evidence of its contribution to detrimental effects on health as well as on climate. Many components of PM attached to BC are currently seen as responsible for the health effects, for instance organics such as polycyclic aromatic hydrocarbons (PAHs) that are known carcinogens and directly toxic to the cells, as well as metals and inorganic salts. Recently, the exhaust from diesel engines (consisting mostly of particles) was classified by the International Agency for Research on Cancer (IARC) as carcinogenic (Group 1) to humans.

6. What is the burden of disease related to PM exposure?

- It is estimated that ca. 3% of cardiopulmonary and 5% of lung cancer deaths are attributable to particulate matter globally. In the European Region of WHO, this proportion is 1-3% and 2-5%, respectively, in various WHO/Euro sub-regions (CRA 2004).
- Exposure to $PM_{2.5}$ reduces the life expectancy of inhabitants of the European Region by about 8.6 months on average. Results from the scientific project "Aphekom", using traditional health impact assessment methods, indicate that the average life expectancy in the most polluted cities could be increased by ca. 20 months if the long-term $PM_{2.5}$ concentration was reduced down to the WHO AQG annual level (see Figure 3).

Figure 3. Predicted average gain in life expectancy (months) for persons 30 years of age for a reduction in average annual levels of $PM_{2.5}$ down to the WHO AQG annual mean level of 10µg/m^3 in 25 European cities participating in the Aphekom project



Source: Aphekom Summary Report (2011)

7. WHO Air Quality Guidelines

WHO last revised its Air Quality Guidelines (AQG) for PM in 2005:

- For $PM_{2.5}$, the AQG values are 10 µg/m^3 for the annual average and 25 µg/m^{3}for the 24-hour mean (not to be exceeded for more than 3 days/year);
- For PM_{10}, the AQG values were set at 20 µg/m^3 for the annual average and 50 µg/m^3 for the 24-hour mean.

In addition to these guideline values, the AQGs provide interim targets for each air pollutant, aimed at promoting a gradual shift to lower concentrations in highly polluted locations. If these targets were to be achieved, significant reductions in risks for acute and chronic health effects from air pollution can be expected. Progress towards the guideline values, however, should be the ultimate objective. As no threshold for PM has been identified below which no damage to health is observed, the recommended values should be regarded as representing acceptable and achievable objectives to minimize health effects in the context of local constraints, capabilities and public health priorities.

Furthermore, WHO is currently developing indoor air guidelines for household combustion of fuels for cooking, heating and lighting. These will provide recommendations for household fuels and technology use that will enable a move towards the AQGs.

8. Evidence on effects of air quality improvements

There is consistent evidence that decreased air pollution levels following a sustained, long-term intervention results in health benefits for the population, with improvements in population health occurring soon (a few years) after the pollution reduction. Several successful interventions and accountability studies have been evaluated (Henschel et al., 2012; van Erp et al., 2012). A few examples are selected and summarized below:

a) **Follow-up to the Harvard Six Cities Study, USA**. A group of adults living in six cities in the United States of America was followed over time from 1974 to 2009 in order to estimate the effects of air pollution on mortality. Overall, $PM_{2.5}$ concentrations had decreased below 15 µg/m^3 by 2000 (except in one city where levels were below 18 µg/m^3). The main finding was that a 2.5 µg/m^3 decrease in annual average $PM_{2.5}$ was associated with a 3.5% reduction in all-cause mortality (Dockery et al., 1993; Laden et al., 2006; Lepeule et al., 2012). Results show associations between chronic $PM_{2.5}$ exposure and all-cause, cardiovascular, and lung-cancer mortality, with health effects seen at any PM concentration. Results indicate that the critical period of $PM_{2.5}$ exposure for the associated health effects is one year for all-cause mortality,suggesting that health improvements can be expected to start almost immediately after a reduction in air pollution. In a related study, but using different data, it was demonstrated that the reduction in air pollution in the USA in the 1980s and 1990s accounted for as much as 15% of the overall increase in life expectancy observed in the study areas (Pope et al. 2009).

b) **Short-term decrease in industrial emissions, USA.** A copper smelter strike in 1967-1968 in four states, as well as the closure and reopening of a steel mill in Utah Valley in 1986-1987 are two examples of unplanned events which positively impacted on health by decreasing air pollution concentrations in specific areas. The copper smelter strike in the late 1960s led to a 60 % drop in regional sulphur dioxide (SO_2) concentrations over 8 months and was associated with a 2.5 % decrease in mortality (Pope et al. 2007). In the Utah Valley, the closure of the steel mill, which was the primary source of PM_{10} in the area, lasted for 13 months and lead to a decrease in PM_{10} levels of approximately 50% during the closure in winter, compared to the previous winter when the mill was operating. As a result, hospital admissions for children were approximately three times lower and bronchitis and asthma admissions were halved when the mill was closed (Pope et al., 1989). Furthermore, the reported 3.2 % drop in daily number of deaths was associated with a simultaneous decrease of PM_{10} levels of approximately 15 μg/m^3 during the steel mill closure, with the strongest association being for respiratory deaths (Pope et al., 1992).

c) **Respiratory health studies and air pollution abatement measures, Switzerland.** The Swiss study on air pollution and lung diseases in adults (SAPALDIA) assessed lung diseases in adults from eight Swiss communities in 1991 and again in 2002. Overall exposure to outdoor PM_{10} estimated at each individual's residence declined by an average 6.2 μg/m^3 over the study period, to reach a range of between approximately 5 and 35 μg/m^3 in 2002, depending on the community. This reduction in particle levels was associated with attenuated age-related annual declines in various lung function parameters. The declining PM_{10} levels were also associated with fewer reports of respiratory symptoms such as regular cough, chronic cough or phlegm, and wheezing and breathlessness (Downs et al., 2007; Schindler et al., 2009). As part of a separate investigation, children from nine Swiss communities were followed between 1992 and 2001 as part of the Swiss study on childhood allergy and respiratory symptoms with respect to air pollution, climate and pollen (SCARPOL). Declining levels of regional PM_{10} were associated with declining prevalence of various respiratory symptoms, including chronic cough, bronchitis, common cold, nocturnal dry cough, and conjunctivitis symptoms (Bayer-Oglesby et al., 2005). These findings suggest that not only drastic, but also modest improvements in ambient air quality are beneficial for respiratory health, in both children and adults.

These examples of successful interventions show that decreased levels of particulate air pollution can substantially diminish total, respiratory and cardiovascular death rates. Benefits can be expected practically at any level of air pollution, and suggest that further policy efforts that reduce fine particulate matter air pollution are likely to have continuing favourable effects on public health.

9. Air quality management and policy

Up to 80% of the particulate air pollution in EECCA countries can be reduced using currently available technologies (WHO, 2006). Reduction of outdoor air pollutants in general and PM in particular, requires concerted action by public authorities, industry and individuals at the national, regional and even international levels. Responsible authorities with a vested interest in air pollution management include environment, transport, land planning, public health, housing and energy sectors. Since even at relatively low concentrations, the burden of air pollution to health is significant, effective management of air quality is necessary to reduce health risks to a minimum.

Development and exchange of information on policies, strategies and technical measures to reduce emissions belong to the fundamental principles of the Convention on LRTAP. The Working Group on Strategies and Reviews of the Convention, and in particular its Expert Group on Techno-economic Issues[2] maintains the database of information on control technologies for air pollution abatement and their costs. An example of its work is provided by the 2010 report of the Expert Group, summarizing the progress in the work on reducing dust emissions from small combustion installations (UNECE 2010).

There are co-benefits to addressing particulate air pollution that go beyond the sole positive impact on health. For example, reductions in BC emissions from the strategic mitigation of combustion sources will also simultaneously reduce global warming (Schindell et al., 2012).

Finally, integrated policies on urban planning and transport can encourage the use of cleaner transportation modes and lead to changes in individual behaviours, by promoting walking, cycling and increased commuting by public transportation. These policies contribute to cleaner air while also promoting physical activity and largely benefiting public health.

[2] http://citepaax.alias.domicile.fr/forums/egtei/egtei_index.htm

10. Conclusions

- PM is an air pollutant that is widespread, and present wherever people live.
- Health effects of PM_{10} and $PM_{2.5}$ are well documented. There is no evidence of a safe level of exposure or a threshold below which no adverse health effects occur.
- Since even at relatively low concentrations the burden of air pollution to health is significant, effective management of air quality aiming to achieve WHO Air Quality Guidelines levels is necessary to reduce health risks to a minimum.
- Monitoring of PM_{10} and/or $PM_{2.5}$ needs to be improved in many countries to assess population exposure and to assist local authorities in establishing plans for improving air quality.
- There is consistent evidence that decreased levels of particulate air pollution following a sustainable intervention result in health benefits for the assessed population. These benefits can be seen practically at any levels of PM. The health and economic impacts of "inaction" should be assessed.
- Particulate air pollution can be reduced using currently available technologies.
- Interventions resulting in reduction of health effects of air pollution range from regulatory measures (stricter air quality standards, limits for emissions from various sources), structural changes (such as reducing energy consumption especially that based on combustion sources, or changing transport modes, land use planning) as well as behavioral changes of people, e.g. by using cleaner modes of transport or household energy sources.
- There are clear co-benefits of integrating climate change and air pollution management strategies, as evidenced by the importance of the PM indicator and climate change contributor black carbon (BC).

11. References and selected bibliography

Air Quality Guidelines: Global Update 2005. Particulate matter, ozone, nitrogen dioxide and sulphur dioxide. Copenhagen, WHO Regional Office for Europe, 2006 (http://www.euro.who.int/en/what-we-do/health-topics/environment-and-health/air-quality/publications/pre2009/air-quality-guidelines.-global-update-2005.-particulate-matter,-ozone,-nitrogen-dioxide-and-sulfur-dioxide, accessed 26 July 2012).

Bayer-Oglesby L et al (2005). Decline of Ambient Air Pollution Levels and improved Respiratory Health in Swiss Children. *Environmental Health Perspectives* 113:1632-1637.

Beelen R et al (2008). Long-Term Effects of Traffic-Related Air Pollution on Mortality in a Dutch Cohort (NLCS-AIR Study). *Environmental Health Perspectives*. 116(2):196-202.

Brauer M et al. (2012). Exposure Assessment for Estimation of the Global Burden of Disease Attributable to Outdoor Air Pollution. *Environmental Science and Technology* 46:652-660.

Dockery DW et al. (1993). An association between air pollution and mortality in six U.S. cities. *The New England Journal of Medecine* 329(24):1753–1759.

Downs SH et al (2007). Reduced Exposure to PM_{10} and Attenuated Age-Related Decline in Ling Function. *The New England Journal of Medecine* 357:2338-47.

European Environment Agency (EEA) Airbase [online database]. (http://www.eea.europa.eu/themes/air/airbase, accessed 31 August 2012).

ENHIS Factsheet 3.3 Exposure to air pollution (particulate matter) in outdoor air. Copenhagen, WHO Regional Office for Europe, 2011 (http://www.euro.who.int/en/what-we-do/data-and-evidence/environment-and-health-information-system-enhis/publications/2009/enhis-fact-sheets/3.3-exposure-to-air-pollution-particulate-matter-in-outdoor-air, accessed 26 July 2012).

Health risks of particulate matter from long-range transboundary air pollution. Joint WHO/Convention Task Force on the Health Aspects of Air Pollution. Copenhagen, WHO Regional Office for Europe, 2006 (www.euro.who.int/document/e88189.pdf, accessed 26 July 2012).

Henschel S et al. (2012). Air pollution interventions and their impact on public health. *International Journal of Public Health* DOI 10.1007/s00038-012-0369-6.

Janssen NAH et al. (2012). Health effects of black carbon. Copenhagen: WHO Regional Office for Europe. Report for the UNECE Convention on Long-range Transboundary Air Pollution, Task Force for Health, (http://www.euro.who.int/en/what-we-do/health-topics/environment-and-health/air-quality/publications/2012/health-effects-of-black-carbon)

International Agency on Research on Cancer (2012). Press Release 213. IARC: Diesel Engine Exhaust Carcinogenic (http://www.iarc.fr/en/media-centre/iarcnews/2012/mono105-info.php, accessed 26 July 2012).

Krewski D et al. (2009). Extended Follow-Up and Spatial Analysis of the American Cancer Society Linking Particulate Air Pollution and Mortality. HEI Research Report 140. Health Effects Institute, Boston, Massachusetts, USA.

Laden F et al. (2006). Reduction in fine particulate air pollution and mortality: Extended follow-up of the Harvard Six Cities study. *American Journal for Respiratory Critical Care Medecine* 173(6):667–672.

Lepeule J et al. (2012). Chronic Exposure to Fine Particles and Mortality: An Extended Follow-up of the Harvard Six Cities Study from 1974 to 2009. *Environmental Health Perspectives* 120:965-970.

Medina S. (2012) *Summary report of the APHEKOM project 2008-2011*. (www.endseurope.com/docs/110302b.pdf, accessed 26 July 2012).

Pope CA III (1989). Respiratory Disease Associated with Community Air pollution and a Steel Mill, Utah Valley. *American Journal of Public Health* 79(5):623-628.

Pope CA III et al, (1992). Daily Mortality and PM_{10} pollution in Utah Valley. *Archives of Environmental Health* 47(3):211-7.

Pope CA III et al. (2002). Lung cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution. *Journal of the American Medical Association* 287(9):1132-1141.

Pope CA III et al. (2007). Mortality Effects of a Copper Smelter Strike and Reduced Ambient Sulfate Particulate Matter Air Pollution. *Environmental Health Perspectives* 115(5):679-683.

Pope CA III et al. (2009). Fine-Particulate Air pollution and Life Expectancy in the United States. *The New England Journal of Medecine* 360:376-386.

Samoli E et al. (2008). Acute Effects of Ambient Particulate Matter on Mortality in Europe and North America: Results from the APHENA Study. *Environmental Health Perspectives* 116(11):1480-1486.

Schindell D et al. (2012). Simultaneously Mitigating Near-Term Climate Change and Improving Human Health and Food Security. *Science* 335(6065):183-189.

Schindler C et al. (2009). Improvements in PM_{10} Exposure and Reduced Rates of Respiratory Symptoms in a Cohort of Swiss Adults (SAPALDIA). *American Journal for Respiratory and Critical Care Medecine* 179:1-9.

Stanek LW, Sacks JD, Dutton SJ, Dubois JJB (2011). Attributing health effects to apportioned components and sources of particulate matter: An evaluation of collective results. *Atmospheric Environment* 45:5655-5663.

UNECE. *Convention on Long-range Transboundary Air Pollution*. (http://www.unece.org/env/lrtap/, accessed 26 July 2012).

UNECE (2010) Techno-Economic Issues. Report by the Co-Chairs of the Expert Group on Techno-economic Issues. Forty-seventh session of the Working Group of Strategies and Review, Genevam 30.08-2.09.2010. ECE/EB.AIR/WG.5/2010/15 (http://www.unece.org/fileadmin/DAM/env/documents/2010/eb/wg5/wg47/ECE.EB.AIR.WG.5.2010.15_e.pdf, accessed 10 Aug 2012)

Van Erp AM, Kelly FJ, Demerjian KL, Pope CA III (2012). Progress in research to assess the effectiveness of air quality interventions towards improving public health. *Air Quality and Atmospheric Health* 5:217-230.

Acknowledgements

This brochure was prepared by the Joint World Health Organization (WHO)/Convention Task Force on Health Aspects of Air Pollution according to the Memorandum of Understanding between the United Nations Economic Commission for Europe and the WHO Regional Office for Europe. The Regional Office thanks the Swiss Federal Office for the Environment for its financial support of the work of the Task Force. The Task Force on Health work is coordinated by the WHO European Centre for Environment and Health, Bonn.