# Review and Summary of the Epidemiological Literature on Children's Health Risks Associated with Environmental Exposures

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Paper prepared for the OECD Project on the "Valuation of Environment-Related Health Impacts, with a Particular Focus on Children" (VERHI).

# Valuation of Environment-Related Health Impacts with a Particular Focus on Children

**Background**
The lack of empirical surveys and associated lack of data in this area is a barrier to the provision of sound policy advice. Indeed, existing values used for monetisation of environment-related health impacts focus on adult populations and use scenarios that often do not match well with environmental scenarios. As such, there is concern that the continued use of existing estimates from unrelated contexts that do not take these factors into account may result in a misguided benefit-cost analyses, and in a possible misallocation of resources, especially when environmental policies with significant implications for children are under consideration.
In this context, the OECD Environment Directorate implemented in 2006 a project on the valuation of environmental health impacts, with a particular focus on children: the VERHI Project.

**Objectives**
This three-year project (2006-2008) funded by the European Commission under the 6th Framework Programme of Research (contract number SSPE-CT-2005-006529) seeks to improve the incorporation of environment-related health impacts in policy-making. An original survey instrument will be applied in three OECD countries (United Kingdom, Italy and the Czech Republic) that have disparities in terms of important factors, such as social insurance systems, health care systems, social concern about the environment, etc.
This survey will be developed so as to obtain methodologically comparable values for adults and children for similar risks, and will also seek to cast light on the context of the risk reduction, and on latency issues. Finally, the project will explore the potential for benefits transfer across countries with different socioeconomic characteristics.

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**For more information on the VERHI Project and to download documents, visit the website:** http://www.oecd.org/env/social/envhealth/verhi

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## 1. Introduction

The VERHI-Children project aims to improve benefits assessment of environmental policies, consequently allowing for the improvement of the allocation of resources in policy decisions. Within this project, the willingness to pay for immediate and latent environment-related risk reductions to adult and child populations in Italy, Czech Republic and the UK will be estimated. This report aims to review the epidemiological literature regarding environment-related health risks to children, summarising the characteristics of the main health outcomes associated with children's environmental exposures and thereby allowing us to inform the VERHI valuation team as to the choice of end-point characteristics to be valued. Since valuation of end-points depends on quantification of the risk we need to know for which end-points there is epidemiological evidence. The exercise also serves to highlight what gaps in the valuation literature exist and, additionally, may give an impression as to the perceived policy priorities.

An additional element of this task, with the purpose of providing context for environmental risk analysis, is to provide an understanding of the magnitude of the health risks involved in children's non-environmental related exposures.

The report is organised as follows: next section summarises the most relevant papers found and the main issues involved. We start with the mortality studies followed by the studies linking morbidity outcomes to environmental risks to children. Section 3 summarises the risks that children are exposed in non-environment-related activities and section 4 reviews previous analyses of environment-related policies. Conclusions and discussions are in section 5.

[1] Information given in this report reflects the author's views only. The Community is not liable for any use that may be made of the information contained therein.

## 2. Literature review of epidemiological studies and taxonomy of children's health risks related with environmental hazards

Section 2 provides a characterisation of the nature of the environmental risks identified to date in the epidemiological literature. As far as that literature allows, details relating to the cause of the risk, its health outcome and its size are presented along with information on the method and its limitations.

The search for epidemiological studies related to environmental risks and children observed two approaches. First, the references summarised in previous similar literature reviews were obtained, such as the epidemiological studies reviewed in OECD (2006), CAFE (2005) and CEC (2006). Second, a systematic search in the website of medical studies (PubMed) was undertaken in order to select papers and abstracts published between 2004 and 2006 relating environmental risks and children's health. This search was an attempt to update the list of epidemiological studies reviewed in the mentioned similar literature reviews. Key words used involved: child; infant; newborn; foetal; pollution; pesticide; diarrhoea; cancer; mortality; and morbidity, among others.

Some studies did not refer to children's direct exposure to environmental risk but children's health outcomes associated with parental exposure during gestation. For example, Sagiv *et al.* (2005) investigated the effect of ambient **outdoor air pollution** ($PM_{10}$ and $SO_2$) on risks for preterm delivery, which, in turn, can lead to **neonatal mortality** and an array of infant morbidities that range from **pulmonary to neurological outcomes**. Such studies were not the focus of our review since (i) the purpose in undertaking this literature review was to identify and characterize the main health endpoints associated with children's exposure to environmental hazards; and (ii) children's health endpoints associated with parental exposure to environmental risks represent a difficult endpoint to be valued since it is an ancillary effect of parent's own health effects associated with the environmental exposure.

Epidemiological studies in general provide risk measures that represent the risk of occurrence of a health endpoint for those exposed to the environmental factor compared to the risk for individuals not exposed, and are dependent on factors as the concentration level and the length of time of exposure. These risk measures are known as odds-ratios (OR). Another risk measure commonly used in epidemiological studies is the relative risk (RR), which represents the risk of occurrence of a health endpoint for those exposed to a certain level of environmental risk compared to the risk for individuals exposed to a different level of the same environmental hazard, also dependant on the concentration level and of time of exposure. Eventually, relative risks can approximate odds ratios, if the exposure-risk relationship is derived from case-control studies and the health endpoint is 'rare' (<10% prevalence - Desai *et al.*, 2004). We present the risk measures as they are given in the studies.

### *2.1 Mortality studies*

The findings of individual studies are reported in the following paragraphs and are summarised in Table 1. Note that for ease of use we use a cross-referencing system whereby the individual studies are numbered and these numbers are used in the summary tables. In these studies, as for those that address morbidity below, we highlight in bold the pollutant(s) considered, the health end-point and the country in which the study was undertaken.

*Air pollution*

Currie and Neidell (2005) examined the impact of **air pollutants** (**$PM_{10}$, CO and $O_3$**) on **infant all-cause death** in California, **U.S.**, between 1989 and 2000. Data on atmospheric pollution were obtained from the California EPA's monitoring stations, and data on infant deaths came from the states' birth cohort files for 1989 to 2000. The analysis was confined to deaths to infants with at least 26 weeks gestation so that pollution exposure could be observed during the first, second and third trimester of the pregnancy. The unit of time in the analysis was specified as one week since the sample constituted of newborns up to 52 weeks old. This procedure, however, may have introduced the potential problem observed in time-series analyses of mortality: the harvesting or mortality displacement problem. For example, children who died from exposure to high amounts of pollution in one week might have died anyway in the following week. In this case, the actual loss of life is only one week instead of the average life expectancy at birth.

The authors justify the adopted approach by claiming that if they had used one month as the time unit, as most similar studies do, children who have died in their first week of life would be incorrectly assigned average pollution levels for all the days in the month. Currie and Neidell (2005) concluded that **CO** had a significant effect on **infant mortality** in California, with the observed reductions in CO levels over the 1990s being responsible for approximately 1000 infant lives saved. Table 1 reports the main characteristics of this study (Study 16). Similar results were obtained by Chay and Greenstone (1999), who estimated the relationship between (all-cause) infant mortality and particulates air pollution at the county level in the US. The authors showed that a 1 $mg/m^3$ reduction in particulate levels results in about 4-8 fewer deaths per 100,000 live births.

Lin *et al.*, (2004) assessed the impact of daily changes in **air pollutants ($NO_2$, $SO_2$, CO, $O_3$ and $PM_{10}$)** on total number of daily **neonatal deaths** (those that occur between the first and the $28^{th}$ days of life) in Sao Paulo, **Brazil**, from January 1998 to December 2000. The study used pollutant levels obtained at various stations, and the daily averages were considered to be indicative of the pollution level in the whole city. Information on daily minimum temperature and relative humidity was also obtained. Statistical modelling was done using Poisson regression techniques in generalized additive models, using a locally weighted smoothing process to control for time (long-term trend), temperature, humidity, and days of the week.

The effect of air pollutants was estimated using the air pollutant levels on the concurrent day and moving averages from two to seven days in single-pollutant models. Pollutants that presented a positive and statistically significant association with the outcome in single-pollutant models were analysed together – an index of air pollution was created with the pollutants included in the co-pollutant models. The authors concluded that primary pollutants correlated strongly with each other and $PM_{10}$ presented the highest correlations. Ozone presented a negative correlation with carbon monoxide but low and positive correlations with the other primary pollutants. Humidity was correlated inversely with all pollutants, while, as expected, minimum temperature was negatively correlated with primary pollutants but not with ozone. The study reported adverse health effects attributed to the exposure to the air pollutants. $PM_{10}$ and sulphur dioxide were found to have consistent associations with daily neonatal deaths in a short time lag (Study 31).

Conceicao *et al.* (2001) evaluated the association between child mortality and air pollution, also in Sao Paulo, **Brazil**, from January 1994 to December 1997. Daily records of mortality in children less than 5 years of age were obtained from the municipality information programme (PRO-AIM). Pollution data were obtained from the records of eleven monitoring stations, and weather data was also utilised. The authors used generalised additive models in the statistical analysis. According to the authors, such models consider non-parametric smooth functions of the explanatory variables, a Poisson distribution, and a log link. Several models for different sets of explanatory variables were used to evaluate the sensitivity of the pollutant concentration coefficients. The results suggest a significant association between **respiratory mortality in children** and daily levels of **CO, $SO_2$, and $PM_{10}$** in Sao Paulo (Study 15). The associations with these pollutants were significant even after terms for seasonal variation and weather were included or autocorrelation was considered. This conclusion was consistent with a previous study on child mortality in Sao Paulo (Saldiva *et al.*, 1994).

Gouveia and Fletcher (2000b) investigated the association between **outdoor air pollution** and **"all-cause", respiratory** (and **pneumonia**) **and cardiovascular mortality** in Sao Paulo, **Brazil**, and analysed the role of age and socio-economic status in modifying the association between air pollution and mortality. Daily mortality for age groups was explored during 1991 to 1993, but with an emphasis on children under five years and the elderly. Five socio-economic variables were used to generate a composite index of socio-economic status for each of the 58 administrative districts of Sao Paulo. For each of the socio-economic variables a value was assigned from zero to one in a comparative analysis – from the worst conditions to the best conditions. The composite index was estimated as the mean of these five values for each district. The socio-economic conditions of each subject were characterised based on their district of residence. The local environmental agency – CETESB – provided daily levels of **$SO_2$, $PM_{10}$, CO, $O_3$ and $NO_2$**. For each pollutant, daily levels were calculated by averaging all available data across all monitoring stations in the city of Sao Paulo.

Gouveia and Fletcher (2000b) used Poisson regression models to investigate the association between air pollution and mortality, adjusting for potential confounding factors, initially allowing for longer-term patterns in the data (time trend), then for seasonal and cyclical variations, for short-term systematic (calendar effects) and non-systematic (meteorological) effects. The effect of each pollutant was investigated on the same day and lagged by one and two days as these were the lags commonly used in similar studies in the literature. Poisson regressions were used to estimate the coefficients of the air pollution variables for different mortality outcomes and age groups. The authors estimated relative risks of death in relation to a change from the $10^{th}$ to the $90^{th}$ percentile in levels of each air pollutant.

The authors concluded that "all-cause" "all-age" mortality showed smaller associations with air pollution than mortality for specific causes and age groups. Associations between air pollutants and mortality in children under 5 years old, were not statistically significant (RR varied between 0.921 for $NO_2$ and respiratory mortality, and 1.141 for CO and pneumonia), whilst a significant increase in risk of death was more evident in individuals older than 65 (Study 25).

Woodruff *et al.* (1997) evaluated the relationship between post neonatal infant mortality and **$PM_{10}$** in the **U.S.** through the analysis of a cohort of approximately four million infants between 1989 and 1991. Data on infant mortality from the National Centre for Health Statistics were combined with air quality data from the EPA's aerometric database, and information on maternal and infant characteristics. Infant's exposure was considered to be the mean $PM_{10}$ levels for the first 2 months of life, and infants were categorised as having low ($<28\mu g/m^3$), medium (28.1 to $40\mu g/m^3$) or high ($>40\mu g/m^3$) level of exposure depending on their mean exposure being in the bottom one-third, middle one-third or top one-third of the range of exposures.

In order to focus the analysis on deaths that may plausibly be related to $PM_{10}$, the authors examined 4 infant death groups: **all-cause mortality; sudden infant death syndrome (SIDS) with normal birth weight (NBW); respiratory deaths with NBW and low birth weight (LBW)**. Mortality rates were estimated within each of the pollution categories for each of the 4 outcomes and logistic analysis was used to adjust for potential confounders. The odds-ratio for total (all-cause) mortality for the high exposure versus the low exposure group was 1.10; for sudden infant death syndrome the odds-ratio equalled 1.26; and for respiratory deaths (NBW) equalled 1.40, while for low birth weight infants high exposure was associated, but not significantly, withy mortality from respiratory diseases. Woodruff *et al.* (1997) concluded that particulate matter is associated with risk of post-neonatal mortality. Table 1 summarises the main findings (Study 60).

Pope *et al.* (2002) assessed the relationship between long-term exposure to fine particulate air pollution and "all-cause", lung cancer and cardiopulmonary mortality, using the American Cancer Society prospective mortality study. The risk factor data for approximately 500,000 **adults** were linked with air pollution data for several metropolitan areas throughout the United States and combined with socio-economic data, health status, and cause of death data. The authors concluded that **long-term exposure to** combustion-related **fine particulate air pollution** is an important environmental risk factor for cardiopulmonary and lung cancer mortality. Each 10-$\mu m/m^3$ elevation in fine particulate air pollution was associated with approximately a 4%, 6%, and 8% increased risk of **all-cause, cardiopulmonary, and lung cancer mortality**, respectively.

*Other environmental hazards*

No further studies were found associating children's mortality with other environmental risk factors, although, as described in section 0, some studies are available associating different environmental exposures to potential killer diseases such as cancer. We decided to restrict this section to studies focused on children's mortality associated with children's exposure to environmental risks.

*Main issues associated with mortality studies*

Since most studies associating short-term child mortality with environmental exposure refer to exposure to air pollutants, it is worth mentioning two relevant issues in the debate regarding air pollution and short-term mortality events; harvesting and potential confounders. It should be highlighted that these issues have been investigated principally in studies using adult populations only, and parallels with children may be limited.

Harvesting

Time-series studies in general analyse the mortality effect of air pollutants in the very short-run, within days of exposure (acute effect), while cohort studies in general deal with long-term (chronic) effects of air pollution. Zanobetti *et al.* (2003) analysed the effects of $PM_{10}$ on an intermediate time scale, and the potential for short-term mortality displacement or harvesting[2]. The authors assessed whether deaths associated with particulate air pollution are advanced by a few days or can be advanced by weeks. They argued that most studies reporting association between daily deaths and pollution concentrations analysed lags up to only two days. They found that the adverse response to pollution persists for a month or longer after exposure not only for total mortality but also for respiratory and cardiovascular mortality. Other studies which analysed this issue using different methodologies all also reported increased, rather than decreased, effects when longer lags were examined (*e.g.* Schwartz, 2001).

Confounding effects

Whilst confounding effects are taken into account as a matter of course in the statistical analysis of epidemiological linkages, the complexity of the interdependencies between variable is thought to threaten the robustness of the results of many studies. New confounding factors – and new ways of modelling them - are still being identified. For example, Braga *et al.* (2000) investigated the potential confounding effect of respiratory epidemics in the association between air pollution and daily deaths. The authors argued that previous studies that controlled for influenza epidemics using an indicator (dummy) variable for epidemic periods did not provide a systematic analysis to assess whether a control for epidemics changes the air pollution association with mortality in a meaningful way, and did not adequately control for respiratory

[2] The harvesting hypothesis refers to the death of those individuals who were likely to die anyway in a short period of time. "This could occur if air pollution hastened the deaths of persons who were extremely frail. If air pollution did not simultaneously increase the number of people who become frail, the size of the frail pool would decrease after an air pollution episode. On subsequent days, a smaller frail pool would result in a reduction in daily deaths" (Zanobetti *et al.*, 2003).

epidemics. Influenza is not the only pathogen that can produce pneumonia, which suggests that controlling for influenza outbreaks alone may miss some episodes. Braga *et al.* (2000) proposed to model the rise and fall of each respiratory epidemic separately, including those not due to influenza, and check if this changed the associations between air pollution and daily deaths.

The study concluded that, overall, the estimated effect of $PM_{10}$ concentration was reduced by 8% after controlling for respiratory epidemics, the decrease ranging from 3% in Minneapolis to 15% in Seattle. However, the authors argued that these decreases did not modify significantly the association previously observed between air pollution concentration and daily deaths, confirming the strength of the association and supporting causality in this relationship. The study showed that the association between air pollution and the number of daily deaths is robust enough to support controlling for respiratory epidemics, an issue that has been attracting attention among researchers.

*Discussion*

Some relevant points can be concluded from this literature review of studies associating environment-related mortality risks to children. First, only studies relating to exposure to air pollutants were found, which suggests perhaps that air pollution is regarded as more of a policy priority and/or that the epidemiological relationships between air pollutants and health end-points are more easily identified and therefore amenable to study. Second, all studies, apart from Woodruff (1997) reviewed were time-series analyses, which identify the short-term effect of air pollution on child mortality, in general in terms of number of deaths. For this reason, previous policy analysis (*e.g.* CAFE) has given greater weight to the results of the Woodruff study. Third, the validity of transferring results from other world regions to the EU, where absolute levels of ambient pollution and the burden of disease in the population are very different from the EU, is questionable and it may be justified to give the results of these studies less weight in subsequent discussions relating to choice of end-point to be valued.

From our stand-point of wishing to quantify a change in health status or health risk we would prefer that the study results are expressed in a form that is relatively easily communicated to a survey respondent recruited from the general population. The quantification of impacts presented in column 4 of Table 1 interprets the study finding as far as possible in this light. However, it is not always possible to present changes in annual terms; further working of the data in conjunction with the study authors may be required. At the same time, it is worth noting that the function used for current EC policy purposes is that reported by Woodruff *et al* (1997) for $PM_{10}$ (mean outdoor concentrations of $PM_{10}$ in the 1$^{st}$ two months of life) expressed as:

- Change in (all-cause) infant mortality of 4% per 10 $\mu g/m^3$ $PM_{10}$ (95% CI 2% - 7%).

One possibility would therefore be to include this into the valuation scenario.

Table 1: Taxonomy of mortality

| *Study* | *Physical impact (endpoint)* | *Impact source (environmental factor)* | *Quantification of impact (e.g. changes in life expectancy or mortality rate; relative risks)*[(a)] | *Age & Gender specificity* | *Comments (e.g. quality of study)* |
|---|---|---|---|---|---|
| 16<br>Currie and Niedell (2005) | All-cause mortality | Pre-natal and post-natal exposure to ambient air pollution ($PM_{10}$, CO, $O_3$). | Risk change given as the number of infant deaths per 100000 births averted by a one-unit decrease in pollutants = 18.1 (CO); -0.226 ($PM_{10}$); -0.288 ($O_3$). The observed 1.1 decrease in CO levels in 12 years corresponded to 991 infant lives saved, approximately 82.6 per year.<br>Baseline risk = 391/100000 (infant) and 358/100000 (foetal).<br>Immediate (acute) effect; time-lag between exposure and death is 9 months (pre-natal) plus number of weeks alive (up to 52). | Infants with at least 26 weeks gestation – 12 months; no gender specificity | Time-series analysis; 1989-2000, California, US. |
| 31<br>Lin et. al (2004) | Neonatal deaths | Exposure to ambient air pollution ($PM_{10}$, CO, $NO_2$, $SO_2$, $O_3$) | Risk change given as % increase in neonatal deaths (4% for $PM_{10}$; 6% for $SO_2$) due to inter quartile range increases in $PM_{10}$ (23.3 $mg/m^3$) and $SO_2$ (9.2 $mg/m^3$) on the concurrent day.<br>Baseline risk = 6.11 daily neonatal deaths (mean value in 1096 days).<br>Immediate (acute) effect; time-lag between exposure and death up to 7 days. | Deaths occurring between the first and the 28th day of life. | Time-series analysis; 1998-2000, Sao Paulo, Brazil. |
| 25<br>Gouveia and Fletcher (2000 a) | All-cause and respiratory mortality; pneumonia | Exposure to ambient air pollution ($PM_{10}$, CO, $NO_2$, $SO_2$, $O_3$) | Risk change given as:<br>• % increase in deaths: 9% ($SO_2$), 9% (CO), 6% ($O_3$) for respiratory disease, and 4% ($PM_{10}$), 11% ($SO_2$), 8% ($NO_2$), 14% (CO), 6% ($O_3$) for pneumonia;<br>• relative risks of death: 1.086 ($SO_2$), 1.086 (CO), 1.057 ($O_3$) for respiratory disease, and 1.041 ($PM_{10}$), 1.107 ($SO_2$), 1.08 ($NO_2$), 1.141 (CO), 1.061 ($O_3$) for pneumonia;<br>Results relate to a change from the 10th to the 90th centile in pollutants levels (64.2 $PM_{10}$, 20.2 $SO_2$, 180.9 $NO_2$, 106 $O_3$ and 5.1 CO), but are not statistically significant at the 5% level. | Under 5 years old | Time-series analysis; 1991-1993; Sao Paulo, Brazil. |

| | | | | | |
|---|---|---|---|---|---|
| | | | Baseline risk (daily mean deaths in 3 years) = 13.2 (all causes), 2.2 (respiratory) and 1.7 (pneumonia).<br><br>Immediate (acute) effect; time-lag between exposure and death up to 2 days. | | |
| 15<br><br>Conceicao *et al* (2001) | Respiratory mortality | Exposure to ambient air pollution ($PM_{10}$, CO, $SO_2$, $O_3$) | Risk change given as RR of mortality (15% CO; 13% $SO_2$ and 7% $PM_{10}$) for average pollutant concentration (4.4 ppm CO; 21.0 $mg/m^3$ $SO_2$ and 66.2 $mg/m^3$ $PM_{10}$).<br><br>Baseline risk (daily mean deaths in 4 years) = 13.1 (all causes), 2.4 (respiratory) and 10.7 (other causes).<br><br>Immediate (acute) effect; time-lag between exposure and death is 2 days. | Under 5 years old | Time-series analysis; 1994-1997; Sao Paulo, Brazil. |
| 14<br><br>Chay and Greenstone (1999) | All-cause mortality | Exposure to ambient air pollution (TSP) during the first 12 months of life. | Risk change given as number of deaths per 100,000 births (4 – 8) per 1 $mg/m^3$ reduction in TSP.<br><br>Immediate (acute) effect; time-lag between exposure and death is the number of days alive (up to 52 weeks). | 1-12 months of age. No gender specificity | Time-series analysis; 1978-1984; US. |
| 60<br><br>Woodruff *et al* (1997) | All-cause mortality | Exposure to ambient air pollution ($PM_{10}$) during the first 2 months of life. | Risk change given as relative risks between exposure groups: low-level (reference, 11.09 - 28 $mg/m^3$), medium-level (28.01 – 40 $mg/m^3$) and high-level (40.01 – 68.8 $mg/m^3$).<br><br>Baseline risk (deaths / 100000 births) = 311 (low), 350 (medium), 370 (high)<br><br>OR=1.05 (medium) and 1.10 (high) | 1-12 months of age<br><br>No gender specificity | Cohort study;<br><br>approximately 4 million infants;<br><br>1989-1991;<br><br>86 metropolitan areas, U.S. |
| | Sudden infant death syndrome (SIDS), normal weight birth | | Baseline risk (deaths / 100000 births) = 100 (low), 113 (medium), 126 (high)<br><br>OR=1.09 (medium) and 1.26 (high)<br><br>Immediate (acute) effect. Time-lag between exposure and death: initial 8 weeks until death (before 52 weeks). | | |

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|---|---|---|---|---|---|
| | Respiratory death, normal weight birth | | Baseline risk (deaths / 100000 births) = 11 (low), 13 (medium), 16 (high)<br><br>OR=1.08 (medium) and 1.40 (high) | | |
| | Respiratory death, low weight birth | | Baseline risk (deaths / 100000 births) = 124 (low), 126 (medium), 168 (high)<br><br>OR=0.93 (medium) and 1.18 (high) | | |

Notes: (a) Annual changes in risks are estimated according to our interpretation of the information available in the studies, when not stated in the study.

## *2.2 Morbidity studies*

As with our treatment of the mortality studies above, we outline the morbidity studies in general terms before presenting the quantitative results in Table 3.

*Air pollution*

Dugandzic *et al.* (2006) examined the association between **low birth weight** (LBW) among infants and **outdoor air pollution** in a region of low level of exposure (New Scotia, **Canada**). The cohort study consisted of live births (74,284) with more than 37 weeks of gestation observed between January 1988 and December 2000. Maternal exposure to $PM_{10}$, $SO_2$ and $O_3$ were assigned to women living within 25 km of a monitoring station at the time of birth. The results included an increased risk of delivering a LBW infant for first trimester exposures in the highest quartile for $SO_2$ and $PM_{10}$. The study's results suggest that exposure during the first trimester to relatively low levels of some air pollutants may be associated with a reduction in birth weight in born infants (Study 22). Djemek *et al.* (2000) obtained a similar result in **Czech Republic**: exposure to polycyclic aromatic hydrocarbons **(PAHs), $PM_{10}$, $PM_{2.5}$**, in early gestation may influence **foetal growth** (Study 20).

The results of the latter study complements the findings of Bobak and Leon (1999) who conducted a study to examine the association between air pollution in **Czech Republic** and **pregnancy outcomes** (LBW and stillbirth). Air pollution (**TSP, SO2 and NOx**) was monitored in 45 districts in Czech Republic during 1986 and 1988, and data on stillbirths and LBW (<2500 g) was routinely collected by the Czech Statistical Office. The authors concluded that stillbirth rate (4.2 / 1000 births) was not significantly associated with any pollutant, whereas the prevalence of LBW (5.5%) showed highly significant associations with socio-economic factors. After controlling for these socio economic factors, the odds-ratios per 50mg/m3 increase in pollutants were: OR=1.04 (TSP); 1.10 (SO2) and 1.07 (NOx). The authors, however, claim that the results should be interpreted cautiously since residual confounding by socio-economic factors cannot be ruled out.

Pierse *et al.* (2006) investigated the association between **primary $PM_{10}$** (particles directly emitted from local sources) and the prevalence and incidence of **respiratory symptoms** in Leicestershire, **UK**. A cohort of 4400 children aged 1-5 years was recruited in 1998 from a random sample of the local authority database, and a respiratory symptom questionnaire was sent to their parents. The same questionnaire was sent again in year 2001. Exposure assessment involved the use of a dispersion model to calculate spatial variations in total $PM_{10}$ levels. Exposure to primary $PM_{10}$ was consistently associated with the prevalence and incidence of cough without a cold, and the incidence of night time cough and current wheeze in young children in both 1998 and 2001 (Study 39).

Penard-Morand *et al.* (2005) analysed the associations between long-term exposure to air pollution and respiratory outcomes in a large population-based sample of schoolchildren in six cities in **France**. More than six thousand children aged 9-11 were recruited from 108 schools and were clinically examined, including skin prink tests to common allergens, exercise-induced bronchial reactivity and skin examination for flexural dermatitis. The prevalence of asthma, allergic rhinitis and dermatitis was assessed by standardised health questionnaires answered by the parents. The monitored air pollutants were **$PM_{10}$, $SO_2$, $NO_2$ and $O_3$**. The study concluded that a moderate increase in long-term exposure to ambient air pollutants was associated with an increased prevalence of asthma and atopic indicators in children (Study 38). Specifically, after adjusting for confounders, **asthma** and **allergic rhinitis** were found to be positively related to an increase in the exposure to $PM_{10}$, $SO_2$ and $O_3$. However, no consistent positive association was found with $NO_2$ (Penard-Morand *et al.*, 2005).

A similar result was obtained by Roemer *et al.* (2000), who assessed the relationship between short-term fluctuations in air pollution and short-term fluctuations in respiratory health in asthmatic children (aged 6 to 12) in **14 European cities**. Roemer *et al.* (2000) found that the association between peak expiratory flow (PEF) and combined air pollution was positive in asthmatic children using respiratory medication, while the associations tended to be negative in children selected on 'dry cough at night' who were not on medication.

A contrasting result was obtained by Rabinovitch *et al.* (2004), who investigated the association between **air pollution** and **asthma exacerbations**, in urban poor children (mostly African American) with moderate to severe asthma in Denver, **U.S**. The authors followed a school-based panel of children for 3 consecutive winters between 1999 and 2002. After controlling for time-varying factors, Rabinovitch *et al.* (2004) found a weak association between CO levels and bronchodilator use, but no association between daily air pollution concentrations and asthma exacerbations or other asthma indicators (Study 43).

However, Chauhan *et al.* (2003) found a positive association between high exposures to **$NO_2$** in the week before the start of a respiratory viral infection and the severity of a resulting **asthma exacerbation** in children aged 8-11 in Southampton, **UK** (Study 13).

Another issue regarding asthma and other respiratory symptoms related to exposure to air pollutants was discussed by Kuehni *et al.* (2006), who showed that parents of children with respiratory symptoms reported more road traffic exposure than parents of asymptomatic children (**exposure reporting bias**). Using a sample of 8700 pre-school children in Leicestershire, **UK**, the authors estimated the association between self-reported exposures to road traffic and respiratory symptoms. In order to investigate whether the effect could have been caused by reporting bias, the authors compared children with and without symptoms living at the same postcode area, which indicates the same level of exposure to road traffic. Kuehni *et al.* (2006) concluded that reporting bias could explain some or even all the association between reported exposure to road traffic and respiratory disease.

Yolton *et al.* (2005) investigated the relationship between **environmental tobacco smoke** (ETS) exposure and cognitive abilities among U.S. school children aged between 6 and 16. **Cognitive and academic abilities** were assessed using standardised reading (letter recognition, word reading and visual construction) and math (short-term and working memory) tests. Children were included in the sample if they denied using any tobacco product in the previous 5 days and their levels of serum cotinine, the biomarker of ETS exposure used, were higher than 15 ng/ml. The results suggested an inverse association between ETS exposure and cognitive deficits among children even at extremely low levels of exposure.

*Other environmental risks*

Neri *et al.* (2006) reviewed 178 studies published between 1980 and 2004 in order to evaluate and summarise the scientific evidence of the association between environmental exposure to genotoxic agents during the fetal, neonatal and infancy developmental periods, and the level of selected biomarkers of **genetic damage**. The environmental exposures investigated were **(i) urban air, (ii) soil and water pollution; (iii) cigarette smoke and environmental tobacco smoke (ETS).** The biomarkers included in the analysis were those related to the carcinogenesis process: DNA, haemoglobin and albumin adducts, chromosome aberrations (CA), sister chromatid exchanges (SCE), micronuclei (MN), DNA fragmentation by the Comet assay, the hypox-anthine-guanine phosphoribosyltransferase (HPRT) and the glycophorinA (GPA) mutation frequency assays.

For each study reviewed, the authors estimated the ratio of the mean levels (MR=mean ratio) of each biomarker detected in exposed and reference children, as a point estimate of the relative effect of exposure. The authors concluded that CA and MN were consistently increased in children exposed to environmental pollutants, both airborne pollutants and soil and drinking water contaminants; prenatal and postnatal exposure to tobacco smoke compounds were associated with increased frequencies of DNA and haemoglobin adducts and CA (Study 35). This latter result is consistent with the epidemiological evidence of **higher lung cancer risks** reported in adults who had never smoked and were exposed to ETS during childhood and with 7-15 times higher lung cancer risks reported in smokers than in non-smokers.

*Ozone layer depletion*

Gallagher and Lee (2006) reviewed the medical literature regarding evidences of the link between **ultraviolet radiation** (UVR) exposure and the main causes of morbidity and mortality attributable to UVR, namely chronic diseases of the skin – cutaneous malignant **melanoma** (CMM), basal (BCC) and squamous cell **carcinoma** (SCC) **of the skin** and **cancer of the lip** – and eye (cataract, uveal melanoma and macular degeneration). The authors concluded that there are convincing data for establishing a causal relationship between solar UVR and cutaneous melanoma, while the causal relationship between artificial UV and cutaneous melanoma is probable (Study 23). The same result was observed regarding basal and squamous cell carcinoma. In addition, it is observed that there is sufficient scientific evidence of causal relationship between solar UVR and cancer of the lip; and a probable relationship between ocular melanoma and URV, both solar and artificial. Cortical cataract is certainly related to URV exposure since there is convincing research evidence. The review, however, has no results specific to children.

*Noise*

Stansfeld *et al.* (2005) assessed the effect of exposure to **aircraft and road traffic noise** on **cognitive performance** and health of children aged 9-10 years. Between April and October 2002 the authors enrolled 2,844 children from primary schools close to major airports in the **Netherlands** (Schiphol, Amsterdam), **Spain** (Barajas, Madrid) and the **UK** (Heathrow, London). The children were selected by extent of exposure to external aircraft and road traffic noise at school as predicted from noise contour maps, modelling and on-site measurements, and schools were matched within countries for socioeconomic status. Cognitive and health outcomes were measured by using standardised tests and questionnaires administered in the classroom. The statistical analysis involved multilevel modelling of the pooled country data, controlling for potential confounding effects of socio-demographic aspects.

Stansfeld *et al.* (2005) concluded that there is a positive linear exposure-effect association between exposure to aircraft noise and impaired reading comprehension and recognition memory in children, and a negative linear association between exposure to road traffic noise and increased functioning of episodic memory, in terms of information and conceptual recall. In addition, the results show non-linear and linear exposure-response associations between aircraft and road traffic noise, respectively, and annoyance. However, neither aircraft noise nor road traffic noise affected children's sustained attention, self-reported health or mental health (Study 54).

*Lead and other chemicals*

The decrease in children's **cognitive performance**, measured as intelligence scores (**IQ**), has also been associated with **exposure to lead**. Lanphear *et al.* (2005) retrieved data of seven prospective lead (longitudinal) cohort studies conducted in Boston, Cincinnati, Cleveland (**U.S.**), **Mexico** City, Rochester, Port Pirie (**Australia**) and former **Yugoslavia**. The authors examined data collected from 1333 children followed from birth to age 5-10, aiming to examine the association of intelligence test cores and blood lead concentration focusing on children who had maximal measured blood lead levels below 10 μg/dL (low-level exposure). Lanphear *et al.* (2005) observed, after adjusting for covariates, an inverse relationship between blood lead concentration and IQ scores (intellectual deficits) (Study 30). A similar study was undertaken by Needleman and Gatsonis (1990), who identified 24 studies associating lead exposure to **children's IQ** and carried out a quantitative analysis (meta-analysis). The authors concluded that the hypothesis that lead impairs children's IQ at low dose is strongly supported by their results (Study 33).

*Pesticides*

Zahm and Ward (1998) reviewed the epidemiological studies linking **parental and children exposure to pesticides** with several types of **cancer**, such as leukaemia, neuroblastoma and cancer of the brain and colorectal. Most of the results reviewed by Zahm and Ward regard parental exposure to pesticides through agricultural use or children's exposure in gardens or dealing with animals (Table 2). The authors summarised the results of cross-sectional, case-control and cohort studies to conclude that although these studies have been limited by non-specific pesticide exposure information, small numbers of exposed subjects, and the potential for case-response bias, many of the reported increased risks are of greater magnitude than those observed in studies of pesticide-exposed adults. It suggests that children may be particularly sensitive to the carcinogenic effects of pesticides (greater susceptibility). Recently, studies have observed that the **consumption of organic** fruits, vegetables and juice can significantly help to **reduce children's exposure to** (organophosphorus) **pesticides** (*e.g.* Curl *et al*., 2003).

Table 2: Selected studies on health effects of pesticides on children

| Health effect | exposure | Timing of exposure | Relative risk estimate - case-control studies |
|---|---|---|---|
| Leukemia | Household pesticide exposure - Maternal | < 1 / week | 1.4 (0.8 – 2.2) |
| | | 1 – 2 / week | 0.9 (0.4 – 2.1) |
| | | Most of days | -- |
| | Household pesticide exposure - Child | < 1 / week | 1.8 (0.0 – 3.0) |
| | | 1 – 2 / week | 2.0 (0.8 – 5.0) |
| | | Most of days | 3.5 (0.9 – 13.8) |
| Brain cancer | Child exposed to herbicides or insecticides | Childhood | 0.9 (0.5 – 5.19) |
| Lymphoma | Pesticide exposure - child | Ever | 1.3 (0.1 – 11.4) |
| | | > 3 hours/week | 6.0 (0.3 – 36.3) |
| | Pesticide exposure - paternal | Ever | 1.0 (0.2 – 6.1) |
| | | > 3 hours/week | 2.1 (0.4 – 12.5) |
| Wilm's tumor | Household insecticide extermination - childhood | Ever | 2.2 (0.2 – 3.8) |
| | | Once/year | 2.4 (0.1 – 5.1) |
| | | Twice or more/year | 2.2 (0.9 – 5.1) |
| Ewing's sarcoma | Paternal occupation as farmer | Pregnancy | 2.2 (0.7 – 6.5) |
| | | Usual occupation | 3.1 (0.9 – 9.5) |
| | Lived on farm or ranch | Childhood | 1.4 (0.8 – 2.4) |
| | Pets | Childhood | 1.5 (0.9 – 2.4) |
| | Household extermination | Pregnancy | 1.3 (0.8 – 2.1) |

Source: Adapted from Zahm and Ward 1998. For a complete summary of the epidemiologic literature on pesticides and child health the reader can refer to Zahm and Ward (1998).

*Discussion*

The findings of the review of morbidity studies can be summarised in the following bullet points:

- There are more recent epidemiological studies that investigated the morbidity impacts on children of exposure to different environmental risks than there are for mortality and many of these studies have been undertaken in EU countries. Air pollution is still the environment-related risk attracting the highest number of epidemiological studies, and this is primarily associated with transport and energy sources.
- Several studies associate exposure to air pollutants to a number of children's health effects: decrease in cognitive and academic abilities; low birth weight among infants; asthma exacerbation and other respiratory symptoms, although some results are conflicting for specific social groups of children (*e.g.* Afro-American children).
- The results seem not to be consistent regarding exposure to $NO_2$, while exposure to $PM_{10}$, $O_3$ and CO seems to affect children's health in different ways.
- Genetic damage has been associated with exposure to various environmental risks during the foetal period and infanthood, which in turn is associated with higher risks of lung cancer in adulthood.
- A review of studies associating exposure to ultraviolet radiation (not specifically during childhood) with different types of cancer may not be transferred to children, although it is likely that exposure to ultraviolet radiation in early years of life may cause similar health consequences.
- Children's cognitive performance and reduction in children's IQ have also been associated with exposure to high levels of noise and exposure to lead, as to environmental tobacco smoke.
- Results associating exposure to pesticides with different types of cancer refer mainly to parental exposure or children's exposure in gardens or via pets. The study providing evidence of higher risks of contamination via the food chain, however, fails to associate these higher levels of contaminants with specific health outcomes or diseases.

Table 3: Taxonomy of morbidity endpoints

| *Study* | *Physical impact (endpoint)* | *Characteristics of impact or endpoint* | *Impact source (environmental factor)* | *Quantification of impact (e.g. change in incidence, prevalence or quality of life; relative risks)* | *Age & Gender specificity* | *Comments (e.g. quality of study)* |
|---|---|---|---|---|---|---|
| 35 Neri *et al* (2006) | Genetic damage | Cytogenetic biomarkers are related to lung cancer in adulthood | Airborne pollutants; soil and drinking water contaminants; and tobacco smoke during infanthood. | Variations in chromosome aberrations, micronuclei, sister chromatid exchanges (MR=1.02), DNA, albumin and haemoglobin adducts (MR=1.38; 6.65) | Prenatal; postnatal; no gender specificity | Meta-analysis of medical literature; various places; 1980-2004 |
| 23 Gallagher and Lee (2006) | Skin cancer; lip cancer and cataract | | Ultraviolet exposure, solar and artificial | Increase the incidence of skin cancer (OR=1.61) and lip cancer, and cataract | Adults; no gender specificity | Review of medical literature; various places |
| 54 Stansfeld *et al* (2005) | Cognitive performance | Reading impairment and recognition memory | Aircraft and road noise | Decrease in cognitive performance of school children (quality of life) | 9-10 years old | Multilevel analysis of pooled data obtained with standardised tests and questionnaires, and in-situ noise level measurement; Spain, UK and Holland; 2002 |
| 61 Yoltan *et al* (2005) | Cognitive performance | Letter recognition and word reading; visual construction abilities | ETS | Decrease in cognitive performance of school children (quality of life) | 6-16 years | Log-linear multiple regression analysis with data obtained with standardised tests and questionnaires; 1988-1994; US |

| *Study* | *Physical impact (endpoint)* | *Characteristics of impact or endpoint* | *Impact source (environmental factor)* | *Quantification of impact (e.g. change in incidence, prevalence or quality of life; relative risks)* | *Age & Gender specificity* | *Comments (e.g. quality of study)* |
|---|---|---|---|---|---|---|
| 30 Lanphear *et al* (2005); 33 Needleman and Gatsonis | Cognitive performance | Lower IQ score, which is a composite score of verbal and performance tests | Exposure to lead | Decrease in IQ scores = 6.9 for an increase in blood lead levels from 2.4 to 30 μg/dL (OR= 2.4, 3.9, 1.9, 1.1); | 0-10 years | Pooled analysis of 7 cohort studies (U.S.; Mexico; Australia and Yugoslavia); 1333 children; 1995 |
| 27 Jain *et al* (2005) | Anaemia | Haemoglobin level < 11g/dl | Exposure to lead | Increase in incidence and prevalence of anaemia (OR=1.3 and 1.7) | 0-3 years | Abstract only; no details on methods; India |
| 20 Djemek *et al* (2000) | LBW (Intrauterine growth retardation) | Weight at birth below the 10th percentile, by sex and gestational week, in the general population | Exposure to ambient $PM_{10}$, $PM_{2.5}$, and PAHs | Decrease in foetuses' weight from mothers exposed to medium levels of PAH (OR=1.60) and high levels of PAH (OR=2.15) | Newborns | Cohort study of 4883 live births; southern Bohemia, Czech Republic; 1994-1998. |
| 22 Dugandzic *et al* (2006) | Low birth weight (LBW) | Weight at birth lower than 2,500 grams | Maternal exposure to ambient $PM_{10}$, $SO_2$ and $O_3$ | Increase in incidence of LBW when mothers are exposed (RR=1.36 for $SO_2$; RR=1.33 for $PM_{10}$) | Newborns – 1 year | Cohort study; Nova Scotia, Canada; 1988-2000 |
| 46 Rogers *et al* (2000) | Very low birth weight | Weight at birth lower than 1,500 grams | Maternal exposure to ambient TSP and $SO_2$ | Increase in incidence of VLBW (OR=2.88 and 1.27) | Newborns | Case-control study; Georgia, U.S.;1986-1988 |

| *Study* | *Physical impact (endpoint)* | *Characteristics of impact or endpoint* | *Impact source (environmental factor)* | *Quantification of impact (e.g. change in incidence, prevalence or quality of life; relative risks)* | *Age & Gender specificity* | *Comments (e.g. quality of study)* |
|---|---|---|---|---|---|---|
| 38 Penard-Morand *et al* (2005) | Asthma, allergic rhinitis (AR) and dermatitis | EIB = decrease in peak expiratory flow (PEF) exceeding 10%; Others were identified through questions: "Have your children ever had asthma, hayfever, other types of AR or eczema? | Exposure to ambient $PM_{10}$, $SO_2$, $NO_2$ and $O_3$ | Skin prick test (SPT) to common allergens, exercise induced bronchial reactivity (EIB) and skin examination used to characterise the endpoints. Increase in prevalence of asthma (OD=1.39 and 1.19) and AR (OD=1.32) | 9-11 years old | Cross-sectional study, 6,672 children in 6 cities in France; 1999-2000 |
| 43 Rabinovitch *et al* (2004) | Asthma exacerbation | Asthma episodes severe enough to require oral prednisone use, visits to urgent care facilities, emergency departments, or hospitalisation. | Exposure to ambient $PM_{10}$, $PM_{2.5}$, $SO_2$, CO, $NO_2$ and $O_3$ | Exacerbation of asthma (OR=0.97 for $PM_{2.5}$; 1.016 for $PM_{10}$; 1.012 for CO; 1.1 for $NO_2$; 1.048 for $SO_2$ and 0.91 for $O_3$). | 6-12 years | Panel study (45 children, approximately); 1999-2000; Denver, U.S. |
| 13 Chauhan *et al* (2003) | Asthma exacerbation | Daily lower (cough or wheezing on waking or during the day; shortness of breath) and upper respiratory symptoms (runny nose, sneezing, sore throat, hoarse voice, fever ) | Exposure to $NO_2$ | Increase in the severity of lower respiratory-tract symptom scores. | 8-11 years | Cohort study (114 asthmatic children); Southampton, UK, 1994 |

| *Study* | *Physical impact (endpoint)* | *Characteristics of impact or endpoint* | *Impact source (environmental factor)* | *Quantification of impact (e.g. change in incidence, prevalence or quality of life; relative risks)* | *Age & Gender specificity* | *Comments (e.g. quality of study)* |
|---|---|---|---|---|---|---|
| 32 Millstein *et al* (2004) | Asthma | Asthma medication use and wheeze | Exposure to ambient $PM_{10}$ and $O_3$ | Increase in asthma medication use (OR=1.80 and 1.57) and wheeze (OR=2.91) | Not specified (abstract only) | 2034 school children in 12 Southern California communities, U.S. |
| 39 Pierse *et al* (2006) | Respiratory symptoms (cough, wheezing, phlegm) | Cough without a cold; night-time cough; and current wheeze | Exposure to ambient $PM_{10}$ | Increase in incidence and prevalence of cough without cold (OR=1.21 and 1.56); night-time cough (OR=1.06 and 1.25); current wheeze (OR=0.99 and 1.28) | 1-5 years | Cohort study (4400 children) 1998 and 2001; Leicestershire, UK. |
| 44 Ribeiro *et al* (2003) | Respiratory symptoms | Cough, phlegm, wheezing | Exposure to ambient $PM_{10}$, $SO_2$ | Increase in incidence and prevalence of respiratory symptoms (comparison of % in different regions) | 11-13 years | Comparative study (different metropolitan regions); 1986 and 1998, Sao Paulo, Brazil |

## 3. Risks associated with non-environmental factors

Table 4 presents WHO data on mortality per 100,000 inhabitants, per age groups and selected European countries. It shows the mortality rates observed in 2004 for all-causes mortality, diseases that may be associated with environmental exposures such as cancer, circulatory and respiratory diseases, and deaths caused by accidents or not related to diseases. As can be seen in Table 4, for infants (newborns younger than 12 months of age) deaths attributed to respiratory diseases, part of which may be attributed to exposure to air pollutants, in some countries account for a bigger share of total mortality than deaths per accidents, which are certainly not related to any environmental risk exposure. The same result can not be observed for children and adolescents, which suggests that deaths associated with exposure to environmental risks have higher relative importance for infants than for older children in European countries. The literature review of epidemiological studies confirmed the association of infants' exposure to air pollution and all-cause and respiratory mortality.

In addition, deaths attributed to different types of cancer represent lower risks to infant and older children than general accidents, in particular transport-related accidents that account for the higher share of accident deaths. The figures in Table 4 seem to suggest that exposure to air pollution has a higher impact than other environmental exposures for children in European countries; and that infants are likely to be more susceptible than older children.

The European Mortality Database (MDB) does not provide detailed information per different age groups of children, only for children aged between 1 and 19 years. We acknowledge that there might be different leading causes of deaths for different age groups and sub-regions, but such data was not available at the MDB. However, the World Health Report 2005 (**http://www.who.int/whr/2005/annexes-en.pdf**) shows some child mortality figures for the EU for children aged 5 or less and neonates (Table 5).

Table 4: Infant and children mortality per 100000, per European country, 2004

| Country | *Infants* | | | | | | | *1 – 19 years* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | All-causes | Malignant neoplasms | Diseases of the circulatory system | Diseases of the respiratory system | Pneumonia | Accidents | Transport accidents | All-causes | Malignant neoplasms | Diseases of the circulatory system | Diseases of the respiratory system | Accidents | Transport accidents |
| Austria | 453.69 | 2.57 | 3.86 | 10.28 | 3.86 | 2.57 | 0 | 24.74 | 3.13 | 0.49 | 0.37 | 8.42 | 6.05 |
| Bulgaria | 1266.55 | 9.04 | 97.94 | 198.90 | 167.26 | 51.23 | 0 | 42.51 | 4.71 | 6.47 | 4.54 | 12.73 | 6.25 |
| Croatia | 625.00 | 7.65 | 5.10 | 12.76 | 5.10 | 20.41 | 7.65 | 24.60 | 4.47 | 0.84 | 0.47 | 12.65 | 9.61 |
| Cyprus | 306.71 | 0 | 0 | 0 | 0 | 0 | 0 | 23.40 | 3.94 | 1.65 | 0 | 7.42 | 5.04 |
| Czech Republic | 382.89 | 6.28 | 4.18 | 9.42 | 5.23 | 19.88 | 2.09 | 23.36 | 3.24 | 1.18 | 0.85 | 8.52 | 5.29 |
| Estonia | 669.69 | 0 | 0 | 22.32 | 14.88 | 29.76 | 0 | 35.95 | 3.44 | 1.59 | 0.76 | 17.56 | 6.29 |
| Finland | 338.47 | 1.75 | 3.51 | 0 | 0 | 5.26 | 1.75 | 26.43 | 3.13 | 0.74 | 0.45 | 11.83 | 4.70 |
| Germany | 413.59 | 3.40 | 4.54 | 4.25 | 2.41 | 4.54 | 0.71 | 19.10 | 2.70 | 1.24 | 0.62 | 6.47 | 4.84 |
| Greece | 409.09 | 4.77 | 0 | 22.89 | 14.30 | 4.77 | 1.91 | 23.57 | 4.08 | 0.46 | 1.49 | 11.14 | 8.62 |
| Latvia | 926.64 | 14.55 | 4.85 | 9.70 | 9.70 | 29.11 | 0 | 46.23 | 4.45 | 1.20 | 1.86 | 21.73 | 7.70 |
| Lithuania | 791.82 | 6.60 | 6.60 | 42.89 | 29.69 | 39.59 | 3.30 | 41.96 | 5.18 | 1.63 | 1.36 | 18.59 | 8.64 |
| Luxembourg | 354.02 | 0 | 0 | 0 | 0 | 0 | 0 | 15.71 | 3.00 | 2.94 | 0 | 7.81 | 4.90 |
| Malta | 582.28 | 0 | 0 | 0 | 0 | 25.32 | 0 | 26.97 | 6.69 | 0.93 | 0 | 5.02 | 1.80 |
| Netherlands | 431.89 | 2.03 | 8.11 | 4.56 | 1.01 | 3.55 | 0 | 18.31 | 3.11 | 1.21 | 0.83 | 4.97 | 3.30 |
| Poland | 687.25 | 5.11 | 6.52 | 17.30 | 13.33 | 12.48 | 0.85 | 25.89 | 3.45 | 1.26 | 1.07 | 9.32 | 6.16 |
| Romania | 1731.70 | 5.23 | 5.23 | 489.88 | 478.46 | 72.77 | 1.43 | 49.08 | 5.62 | 1.43 | 6.83 | 18.52 | 7.1 |
| Slovenia | 375.13 | 11.37 | 0 | 5.68 | 0 | 0 | 0 | 25.20 | 2.82 | 0.95 | 0.60 | 9.59 | 7.33 |
| Spain | 406.53 | 2.47 | 3.81 | 7.18 | 0.90 | 7.85 | 1.57 | 21.95 | 3.03 | 1.08 | 0.68 | 9.05 | 6.30 |
| UK | 515.16 | 2.84 | 7.52 | 9.65 | 3.55 | 6.10 | 0.85 | 20.68 | 3.15 | 1.07 | 1.19 | 5.43 | 3.89 |
| **EU** | **472.99** | **2.80** | **6.28** | **9.12** | **4.54** | **8.40** | **1.46** | **22.76** | **3.28** | **1.17** | **0.81** | **8.22** | **5.67** |

Source: WHO/Europe, European mortality database (MDB)

Table 5: Annual number of deaths in WHO region (Europe) – 2000-2003

| | All | | Member states with low mortality[(a)] | | Others | |
|---|---|---|---|---|---|---|
| | (000) | % | (000) | % | (000) | % |
| | *Children under 5 years of age* | | | | | |
| Total deaths | 263 | 100 | 25 | 100 | 238 | 100 |
| HIV/AIDS | 1 | 0 | 0 | 0 | 1 | 0 |
| Diarrhoeal diseases | 35 | 13 | 0 | 0 | 35 | 15 |
| Measles | 2 | 1 | 0 | 0 | 1 | 1 |
| Malaria | 0 | 0 | 0 | 0 | 0 | 0 |
| Acute respiratory infections | 32 | 12 | 0 | 2 | 31 | 13 |
| Neonatal causes | 116 | 44 | 14 | 55 | 102 | 43 |
| Injuries | 17 | 7 | 2 | 7 | 16 | 7 |
| Others | 61 | 23 | 9 | 36 | 52 | 22 |
| | *Neonates* | | | | | |
| Total deaths | 116 | 100 | 14 | 100 | 102 | 100 |
| Neonatal tetanus | 1 | 1 | 0 | 0 | 1 | 1 |
| Severe infection [(b)] | 21 | 18 | 1 | 6 | 20 | 20 |
| Birth asphyxia | 21 | 18 | 2 | 15 | 19 | 18 |
| Diarrhoeal diseases | 1 | 1 | 0 | 0 | 1 | 1 |
| Congenital anomalies | 21 | 19 | 4 | 32 | 17 | 17 |
| Preterm birth | 44 | 38 | 6 | 41 | 38 | 37 |
| Others | 7 | 6 | 1 | 6 | 6 | 6 |

Notes: Adapted from the World Health Report 2005 – Annex Tables 3 and 4;

(a) Andorra, Austria, Belgium, Croatia, Cyprus, Czech Rep., Denmark, Finland, France, Germany, Greece, Iceland, Israel, Italy, Luxembourg, Malta, Monaco, Netherlands, Norway, Portugal, San Marino, Slovenia, Spain, Sweden, Switzerland and United Kingdom.
(b) Includes deaths from pneumonia, meningitis, sepsis/septicaemia and other infections during the neonatal period.

**4. Previous analyses of specific environmental policies**

CAFE (2005)[3] evaluated the **Clean Air for Europe** programme in terms of potential costs and benefits associated with air pollution reduction in EU until 2020. Health effects of air quality regulation in Europe were estimated following WHO's "Systematic Review of Health Effects of Air Quality in Europe" and advice of UNECE WHO joint task force on health. The methodology used was peer reviewed by leading experts and followed extensive stakeholder dialogue. Mortality and morbidity effects of exposure to $PM_{10}$ and $O_3$ were split into acute and chronic effects. In order to estimate the mortality impact of the programme, the study used two alternative metrics: the number of years of life lost and the number of deaths. The infant mortality effect of $PM_{10}$ was estimated separately. Morbidity endpoints included chronic bronchitis, respiratory and cardiac hospital admissions, respiratory medication use (children and adults), respiratory symptoms and restricted activity days.

The review of epidemiology relating to children undertaken by Hurley in CAFE (2005) gave most attention to mortality. He stated that "the most important endpoint, and the one

[3] http://ec.europa.eu/environment/air/cafe/pdf/cba_methodology_vol2.pdf

most amenable to monetary valuation, is that of infant mortality". In his review of the evidence, he suggested the effects of air pollution on mortality and other indices of infant health in Europe have been studied most extensively by Bobak and co-workers, initially in the Czech Republic, but also more widely (Bobak and Leon (1992, 1999); Bobak (2000); Bobak *et al*. (2001)).

However, Hurley places more weight on the study by Woodruff *et al.* (1997) which uses outputs from cohort analysis rather than time-series studies which suffer from the weaknesses outlined above. In line with the cost-benefit analysis of the **US Clean Air Act,** he adopts the results from this study for the cost benefit analysis of the CAFÉ scenarios.

Other economic analyses of air quality legislation in Europe are available at the EU website (http://ec.europa.eu/environment/pubs/studies.htm), but with no specific result for health impacts for children other than updates of the estimates produced in the ExternE project for morbidity endpoints. The studies assessing policies in waste management and drinking water regulation in Europe (http://ec.europa.eu/environment/pubs/studies.htm) do not provide health effects estimates.

As indicated above, the US EPA have quantified infant mortality risks in their economic analysis of their air pollution regulation, known currently as the US Clean Air Act. The other notable application of child health impact analysis in policy design is the inclusion of elevated blood lead levels in children (implying potential IQ changes etc) in the Toxic Substances Control Act (2000).

## 5. Conclusion and discussions

The above review of the epidemiological literature, combined with relevant criteria relating to the characterisation of unit values, allows us to consider which children's health end-points would most usefully be valued in the VERHI project[4]. A summary table, (Table 6 below), brings the key decision criteria together and allows us to weigh up the alternative end-points against each other. The table uses a set of criteria to (subjectively) evaluate the mortality and morbidity end-points associated with specific environmental hazards. These criteria include: robustness of epidemiological evidence; the existence of quantitative risk factors; features of the sample population; potential for complementary revealed preference valuation, and the potential existence of corresponding joint products; the existence of public good and externality properties that add complexity to the valuation exercise, and finally the degree of policy interest in the environmental hazard.

In interpreting this table it seems most sensible to give most weight to the first two and the last criteria listed, since these determine whether the unit value results emanating from VERHI can be applied in subsequent quantitative health impact assessment, and the likelihood that such an assessment will be needed for policy analysis.

On the basis of these criteria we conclude that local air pollution end-points – impacts from which are primarily derived from transport and energy-induced $PM_{10}$, CO and $O_3$ - are the most important. Within this category we judge the most important air-pollution end-points to be: mortality from respiratory constriction; asthma exacerbation and; other respiratory symptoms, in that order of priority.

Whilst we feel that the health risk from pesticides it potentially sizeable in the EU, the relative lack of robust quantitative evidence, would appear to preclude us from choosing the associated end-points to be valued.

[4] Table 7 is summarising the links between environmental risks and potential health outcomes to children.

Table 6: Summary of decision criteria outcomes applied to potential children's health end-points for valuation

| Environmen-tal risk factor source | Mortality | Mortality End-points | Morbidity | Morbidity End-points | Strength of Epidemiol-ogical Evidence | Quantitative Risk Factors | Ease of Sample ID | Suitability for RP | Joint Products from RP | HH Public Good | HH Externality | Policy Relevance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Local Air Pollutants | Acute | Neo-natal; infant | Acute | Asthma | Good | Yes | Parents (all) | Limited: housing location choice | yes | Yes | No | High |
| | Latent | Cancer (child; adult) | Chronic | Asthma | Good | Yes | | Limited: housing location choice | | | | |
| Lead Exposure | - | - | Chronic | Concentration; memory | Good | Yes | Parents (all) | Both G (chelation) and A (bottled water, paint not containing lead) | No | either | No | Medium |
| | | | Latent | IQ | Good | Yes | | Both G (chelation) and A (bottled water, paint not containing lead) | | | | |
| UV Radiation | Latent | Cancer (child; adult) | Acute | Cancer | Good | Yes | Parents (all) | A (lotion purchase) | No | No | No | Low/Medium |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pesticides | Latent | Cancer (child; adult) | Acute | Nausea | Poor | No | Parents (all) | A (organics purchase) | No | either | No | Medium |
| | | | Latent | Cancer | Reasonable | Yes | | A (organics purchase) | | | | |
| HH Toxics | Accident | Blood Poisoning | Acute | Nausea | Poor | No | Parents (all) | A (purchase decision) | No | yes | No | Low |
| ET Smoke | Acute | Neo-natal; infant | Acute | Asthma | Good | Yes | Smokers/ non-smokers | A (purchase decision) | Yes | Yes | Yes | High |
| | Latent | Cancer (child; adult) | Chronic | Respiratory illness; cog. devt. | Reasonable | Yes | Smokers/ non-smokers | A (purchase decision) | | | | |
| Drinking water | - | - | Acute | Cancer | Good | No | Parents (all) | A (bottled water, water purificator) | No | No | No | Medium |
| Recreational water | - | - | Acute | Nausea | Poor | No | Parents (all) | A (kms driven to have better water quality, pool entrance fees) | yes | No | No | Low |
| Radon | Latent | Cancer (child; adult) | Chronic | Cancer | Poor | No | Parents (all) | A (soil depressuriz ation) | No | Yes | No | Low |

Table 7: Summary table linking environmental risks to potential health outcomes to children [references]

| | Outdoor air pollution (PM, CO, $SO_2$, $NO_X$, $O_3$) | Indoor air pollution (ETS and biomass fuels) | Lead exposure (home or industrial) | Pesticides (parental exposure and food chain) | Waterborne diseases (Drinking water and sanitation) | Noise (induced or from aircraft or road traffic) | Ozone depletion (ultraviolet radiation) |
|---|---|---|---|---|---|---|---|
| All-cause or respiratory mortality | ↕ [16; 15; 25; 31] | | | | | | |
| Sudden infant death syndrome | ↕ [60] | ↕ [11] | | | | | |
| Genetic damage | ↔ [35] | ↔ [35] | | | ↔ [35] | | |
| Cancer | | | | ↕ ↔ 62 | ↔ [58] | | ↕ ↔ [23] |
| Asthma | ↕ ↔ [24; 34; 43; 13; 51] | ↕ ↔ [11] | | | | | |
| Respiratory infections (Pneumonia and acute lower respiratory infection) | ↕ ↔ [24; 53] | ↕ ↔ [11] | | | | | |
| Reduced lung function | ↔ [55] | | | | | | |
| Respiratory symptoms (*e.g.* cough, phlegm, wheezing,) | ↕ ↔ [24; 29; 39; 44; 45] | | | | | ↔ [36] | |
| Allergy | ↔ [38] | | | | | | |
| Anaemia | | | ↔ [27] | | | | |
| Eye diseases (cataract, conjunctival neoplasm) | | | | | | | ↔ [23] |
| Cognitive performance (lower IQ; behavioural disorders; reading impairment; recognition memory; visual construction abilities) | | ↔ [11; 30; 33; 61] | | | | ↔ [54] | |
| Low birth weight (LBW) | ↔ [4; 20; 22; 46] | | | | | | |

Note: ↕ = possible mortality effect; ↔= potential morbidity effects, from minor symptoms to hospitalisation.

## REFERENCES


1. Abbey, D.E., Nishino, N., McDonnell W.F., *et al.* (1999), "Long-term Inhalable Particles and Other Pollutants Related to Mortality in Non-smokers", *American Journal of Respiratory and Critical Care Medicine*, Vol. 159, p. 373-382.

2. Armstrong, T.W., Zaleski, R.T., Konkel, W.J., and Parkerton, T.J., (2002), "A Tiered Approach to Assessing Children's Exposure: a review of methods and data", *Toxicology Letters*, Vol. 127, p. 111-119.

3. Atkinson, S.E. and Halvorsen, R., (1990), "The valuation of risks to life: evidence from the market for automobiles", *Review of Economics and Statistics*, Vol. 72, No. 1, p. 133-136.

4. Bobak, M., and Leon, D.A., (1999), "Pregnancy Outcomes and Outdoor Air Pollution: an ecological study in districts of the Czech Republic 1986-8", *Occupational and Environmental Medicine*, Vol. 56, p. 539-543.

5. Braga, A.L.F., Saldiva, P.H.N., Pereira, L.A.A., Menezes, J.J.C., Conceicao, G.M.S., Lin, C.A., Zanobetti, A., Schwartz, J., and Dockery, D.W., (2001), "Health effects of air pollution exposure on children and adolescents in Sao Paulo, Brazil", *Pediatric Pulmonology*, Vol. 31, p. 106-113.

6. Braga, A.L.F., Zanobetti, A., Schwartz, J., (2000), "Do respiratory epidemics confound the association between air pollution and daily deaths?", *European Respiratory Journal*, Vol. 16, p. 723-728.

7. Black, R.E., Morris, S.S., and Bryce, J., (2003), "Where and Why are 10 million Children Dying every year?", *The Lancet*, Vol. 361, p. 2226-2234.

8. Blomquist, G., (1979), "Value of life saving: implications of consumption activity", *Journal of Political Economy*, Vol. 87, No. 3, p. 540-558.

9. CAFE (2005), "The Directive on Ambient Air Quality and Cleaner Air for Europe: impact assessment", available at http://ec.europa.eu/environment/air/cafe/pdf/ia_report_en050921_final.pdf

10. Carlin, P.S., and Sandy, R., (1991), "Estimating the implicit value of a young child's life", *Southern Economic Journal*, Vol. 58, No. 1, p. 186-202.

11. CEC (2006), "Children's Health and the Environment in North America: a first report on available indicators and measures", a report prepared by the Commission for Environmental Cooperation, available at http://www.cec.org/pubs_docs/documents/index.cfm?varlan=english&ID=1917

12. Chance, G.W., (2001), "Environmental Contaminants and Children's Health: cause for concern, time for action", *Pediatrics and Child Health*, Vol. 6, No. 10, p. 731-743.

13. Chauhan, A.J., Inskip, H.M., Linaker C.H., *et al.* (2003), "Personal Exposure to Nitrogen Dioxide (NO2) and the Severity of Virus-induced Asthma in Children", *The Lancet*, Vol. 361, p. 1939-1944.

14. Chay, K.Y., and Greenstone, M., (1999), “The Impact of Air Pollution on Infant Mortality: evidence from geographic variation in pollution shocks induced by a recession”, *NBER Working Paper Series*, 7442, available at http://www.nber.org/papers/w7442.

15. Conceicao, G.M.S., Miraglia, S.G.E.K., Kishi, H.S., Saldiva, P.H.N., and Singer, J.M., (2001), “Air pollution and child mortality: a time-series study in Sao Paulo, Brazil”, *Environmental Health Perspectives*, Vol. 109, No. 3, p. 347-350.

16. Currie, J., and Neidell, M., (2005), “Air Pollution and Infant Health: what can we learn from California’s recent experience?”, *The Quarterly Journal of Economics*, Vol. 120, No. 3, p. 1003-1030.

17. Curl, C.L., Fenske, R.A., and Elgethun, K., (2003), “Organophosphorus Pesticide Exposure of Urban and Suburban Preschool Children with Organic and Conventional Diets”, Environmental Health Perspectives, Vol. 111, No. 3, p. 377-382.

18. Dardis, R., (1980), “The value of life: new evidence from the marketplace”, *American Economic Review*, Vol. 70, No. 5, p. 1977-1082.

19. Dasdon, G., Faustman, E., Ginsberg, G., Fenner-Crisp, P., *et al*. (2004), “A Framework for Assessing Risks to Children from Exposure to Environmental Agents”, *Environmental Health Perspectives*, Vol. 112, No. 2, p. 238-256.

20. Dejmek, J., Solansky, I., Benes, I., Lenicek, J., Sram, R.J., (2000), “The Impact of Polycyclic Aromatic Hydrocarbons and Fine Particles on Pregnancy Outcome”, *Environmental Health Perspectives*, Vol. 108, No. 12, p. 1159-1164.

21. Desai, M.A., Mehta, S., and Smith, K.R., (2004), “Indoor smoke from solid fuels: Assessing the environmental burden of disease at national and local levels”, *Environmental Burden of Disease Series*, 4. Geneva, World Health Organization (WHO).

22. Dugandzic, R., Dodds, L., Stieb, D., and Smith-Doiron, M., (2006), “The Association Between Low-Level Exposures to Ambient Air Pollution and Term Low Birth Weight: a retrospective cohort study”, *Environmental Health: A Global Access Science Source*, Vol. 5, No. 3, p. 1-8.

23. Gallagher, R.P., and Lee, T.K., (2006), “Adverse Effects of Ultraviolet Radiation: a brief reiew”, *Progress in Biophysics and Molecular Biology*, Vol. 92, No. 1, p. 119-131.

24. Gouveia, N., and Fletcher, T., (2000a), “Respiratory Diseases in Children and Outdoor Air Pollution in São Paulo, Brazil: a time-series study”, *Occupational and Environmental Medicine*, Vol. 57, No. 7.

25. Gouveia, N., and Fletcher, T., (2000b), “Time Series Analysis of Air Pollution and Mortality: effects by cause, age and socio-economic status”, *Journal of Epidemiologicalal Community Health*, 54.

26. ISAAC Steering Committee (1998), “Worldwide Variations in the Prevalence of Asthma Symptoms: the International Study of Asthma and Allergies in Childhood (ISAAC)”, *European Respiratory Journal*, Vol. 12, p. 315-335.

27. Jain, N.B., Laden, F., Guller, U., Shankar, A., Kazani, S., and Garshick, E., (2005), “Relation Between Blood Lead Levels and Childhood Anemia in India”, *American Journal of Epidemiology*, Vol. 161, No. 10, p. 968-973.

28. Jenkins, R.R., Owens, N., and Wiggins, L.B., (2001), "Valuing reduced risks to children: the case of bicycle safety helmets", *Contemporary Economic Policy*, Vol. 19, No. 3, p. 397-408.

29. Kuehni, C.E., Stripoli, M.P., Zwahlen, M., and Silverman, M., (2006), "Association Between Reported Exposure to Road Traffic and Respiratory Symptoms in Children: evidence of bias", *International Journal of Epidemiology*, Vol. 35, No. 3, p. 779-783.

30. Lanphear, B.P., Hornung, R., Khoury, J., *et al.* (2005), "Low-level Environmental Lead Exposure and Children's Intellectual Function: an international pooled analysis", *Environmental Health Perspectives*, Vol. 113, No. 7, p. 894-899.

31. Lin, C.A., Pereira, L.A.A., Nishioka, D.C., Conceicao, G.M.S., Braga A.L.F., and Saldiva, P.H.N., (2004), "Air pollution and neonatal deaths in Sao Paulo, Brazil", *Brazilian Journal of Medical and Biological Research*, Vol. 37, No. 5, p. 765-770.

32. Millstein, J., Gilliland, F., Berhane, K., *et al.* (2004), "Effects of Ambient Air Pollutants on Asthma Medication Use and Wheezing Among Fourth-grade School Children from 12 Southern California Communities Enrolled in the Children's Health Study", *Archives of Environmental Health*, Vol. 59, No. 10, p. 505-514.

33. Needleman, H.L., and Gatsonis, C.A., (1990), "Low-level Lead Exposure and the IQ of Children: a meta-analysis of modern studies", *Journal of the American Medical Association*, Vol. 263, No. 5.

34. Neidell, M.J., (2004), "Air Pollution, Health, and Socio-Economic Status: the effect of outdoor air quality on childhood asthma", *Journal of Health Economics*, Vol. 23, No. 6, p. 1209-1236.

35. Neri, M., Ugolini, D., Bonassi, S., *et al.* (2006), "Children's Exposure to Environmental Pollutants and Biomarkers of Genetic Damage: results of a comprehensive literature search and meta-analysis", *Mutation Research*, Vol. 612, p. 14-39.

36. Niemann, H., Maschke, C., and Hecht, K., (2005), "Noise Induced Annoyance and Morbidity: results from the Pan European LARES-survey", Abstract available at http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list_uids=15768304&dopt=Citation

37. OECD (2006), "Economic Valuation of Environmental Health Risks to Children", Organization for Economic Co-Operation and Development, Paris: OECD Publishing.

38. Penard-Morand, C., Charpin, D., Raherison, C., Kopferschmitt, C., Caillaud, D., Lavaud, F., and Annesi-Maesano, I., (2005), "Long-term Exposure to Background Air Pollution Related to Respiratory and Allergic Health in Schoolchildren", *Clinical and Experimental Allergy*, Vol. 35, p. 1279-1287.

39. Pierse, N., Rushton, L., Harris, R.S., Kuehni, C.E., Silverman, M., and Grigg, J., (2006), "Locally Generated Particulate Pollution and Respiratory Symptoms in Young Children", *Thorax*, Vol. 61, p. 216-220.

40. Pinkerton, K.E., and Joad, J.P., (2006), "Influence of Air Pollution on Respiratory Health During Perinatal Development", *Clinical and Experimental Pharmacology and Physiology*, Vol. 33, p. 269-272.

41. Pope, C.A., Burnett, R.T., Thun, M.J., Calle, E.E., Krewski, D., Ito, K., and Thurston, G.D., (2002), "Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution", *Journal of the American Medical Association*, Vol. 287, p. 1132-1141.

42. Pope, C.A., Burnett, R.T., Thurston, G.D., Thun, M.J., Calle, E.E., Krewski, D., and Godleski, J.J., (2004), "Cardiopulmonary mortality and long-term exposure to particulate air pollution: epidemiologicalal evidence of general pathophysiological pathways of disease", *Circulation*, Vol. 109, p. 71-77.

43. Rabinovitch, N., Zhang, L., Murphy, J.R., Vedal, S., Duton, S.J., and Gelfand, E.W., (2004), "Effects of Wintertime Ambient Air Pollutants on Asthma Exacerbations in Urban Minority Children with Moderate to Severe Disease", *Journal of Allergy and Clinical Immunology*, Vol. 114, No. 5, p. 1131-1137.

44. Ribeiro, H., and Cardoso, M.R.A., (2003), "Air Pollution and Children's health in Sao Paulo (1986-1998)", *Social Science and Medicine*, Vol. 57, p. 2013-2022

45. Roemer, W., Hoek, G., and Brunekreef, B., (2000), "Pollution Effects on Asthmatic Children in Europe: the PEACE study", *Clinical and Experimental Allergy*, Vol. 30, p. 1067-1075.

46. Rogers, J.F., Thompson, S.J., Addy, C.L., *et al.* (2000), "Association of Very Low Birth Weight with Exposures to Environmental Sulfur Dioxide and Total Suspended Particulates", *American Journal of Epidemiology*, Vol. 151, No. 8, p. 602-613.

47. Sagiv, S.K., Mendola, P., Loomis, D., Herring, A.H., *et al.* (2005), "A Time-Series Analysis of Air Pollution and Preterm Birth in Pennsylvania, 1997-2001", *Environmental Health Perspectives*, Vol. 113, No. 5, p. 602-606.

48. Saldiva, P.H.N., Lichtenfels, A.J.F., Paiva, C.P.S.O., Barone, I.A., Parada, M.A.C., Martins, M.A., Massad, E., Pereira, J.C.R.., Xavier, V.P., Singer, J.M., Bohm, G.M., (1994), "Association between air pollution and mortality due to respiratory diseases in children in São Paulo, Brazil: a preliminary report", *Environmental Research*, Vol. 65, p. 218-225.

49. Schwartz, J., (2001), "Is there harvesting in the association of airborne particles with daily deaths and hospital admissions?", *Epidemiology*, Vol. 12, No. 1, p. 55-61.

50. Schwartz, J., (1994), "Air Pollution and Daily Mortality: a review and meta-analysis", *Environmental Research*, Vol. 64, p. 36-52.

51. Segala, C., Fauroux, B., Just, J., *et al.* (1998), "Short-term Effect of Winter Air Pollution on Respiratory Health of Asthmatic Children in Paris", *European Respiratory Journal*, Vol. 11, p. 677-685.

52. Sharovsky, R., Cesar, L.A.M., and Ramires, J.A.F., (2004), "Temperature, air pollution, and mortality from myocardial infarction in Sao Paulo, Brazil", *Brazilian Journal of Medical and Biological Research*, Vol. 37, p. 1651-1657.

53. Smith, K.R., Samet, J.M., Romieu, I., and Bruce, N., (2000), "Indoor Air Pollution in Developing Countries and Acute Lower Respiratory Infections in Children", *Thorax*, Vol. 55, p. 518-532.

54. Stansfeld, S.A., Berglung, B., Clark, C., Lopez-Barrio, I., *et al.* (2005), "Aircraft and Road Noise and Children's Cognition and Health: a cross-national study", *The Lancet*, Vol. 365, p. 1942-1949.

55. Trasande, L., and Thurston, G.D., (2005), “The Role of Air Pollution in Asthma and other Pediatric Morbidities”, *Journal of Allergy and Clinical Immunology*, Vol. 115, No. 4, p. 689-699.

56. Valent, F., Little, D., Bertollini, R., Nemer, L.E., Barbone, F., Tamburlini, G., (2004), “Burden of Disease Atributable to Selected Environmental Factors and Injury Among Children and Adolescents in Europe”, *The Lancet*, Vol. 363, p. 2032-2039.

57. Viscusi, W.K, and Aldy, J.E., (2003), “The Value of a Statistical Life: a critical review of market estimates throughout the world”, *NBER Working Paper*, 9487, available at http://www.nber.org/papers/w9487.

58. Ward, M., deKok, T.M., Levallois, P., Brender, J., Gulis, G., Nolan, B.T., and VanDerslice, J., (2005), “Drinking-Water Nitrate and Health: recent findings and research needs”, *Environmental Health Perspectives*, Vol. 113, No. 11, p. 1607-1614.

59. Wong, E.Y., Gohlke, J., Griffith, W.C., Farrow, S., and Faustman, E.M., (2004), “Assessing the Health Benefits of Air Pollution Reduction for Children”, *Environmental Health Perspectives*, Vol. 112, No. 2, p. 226-232.

60. Woodruff, T., Grillo, J., and Schoendorf, K.C., (1997), “The Relationship between Selected Causes of Postneonatal Infant Mortality and Particulate Air Pollution in the United States”, *Environmental Health Perspectives*, Vol. 105, No. 6.

61. Yolton, K., Dietrich, K., Auinger, P., Lanphear, B.P., and Hornung, R., (2005), “Exposure to Environmental Tobacco Smoke and Cognitive Abilities Among U.S. Children and Adolescents”, *Environmental Health Perspectives*, Vol. 113, No. 1, p. 98-103.

62. Zahm, S.H. and Ward, M.H., (1998), “Pesticides and Childhood Cancer”, *Environmental Health Perspectives*, Vol. 106, No. 3, p. 893-908.

63. Zanobetti, A., Schwartz, J., Samoli, E., *et al.* (2003), “The temporal pattern of respiratory and heart disease mortality in response to air pollution”, *Environmental Health Perspectives*, Vol. 111, No. 9, p. 1188-1193.