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REVIEW

Air pollution interventions and their impact on public health

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Abstract

Introduction Numerous epidemiological studies have found a link between air pollution and health. We are reviewing a collection of published intervention studies with particular focus on studies assessing both improvements in air quality and associated health effects.

Methods Interventions, defined as events aimed at reducing air pollution or where reductions occurred as a side effect, e.g. strikes, German reunification, from the 1960s onwards were considered for inclusion. This review is not a complete record of all existing air pollution interventions. In total, 28 studies published in English were selected based on a systematic search of internet databases.

Results Overall air pollution interventions have succeeded at improving air quality. Consistently published evidence suggests that most of these interventions have been associated with health benefits, mainly by the way of reduced cardiovascular and/or respiratory mortality and/or morbidity. The decrease in mortality from the majority of the reviewed interventions has been estimated to exceed the expected predicted figures based on the estimates from time-series studies.

Conclusion There is consistent evidence that decreased air pollution levels following an intervention resulted in health benefits for the assessed population.

Keywords Air pollution · Intervention study · Public health

B. Forsberg and S. Medina on behalf of the Aphekom Collaborative Network. A detailed list of the Aphekom collaborative network is provided as an electronic appendix "Online Appendix I. Aphekom collaborative network".

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Introduction

As early as 1909, severe air pollution episodes have been associated with adverse health effects, with two episodes in Glasgow, Scotland associated with increased mortality (Godlee 1991). Other investigations of smog episodes include: Meuse Valley, 1930 responsible for over 60 deaths; Donora, Pennsylvania, 1948 18 deaths, and London, 1952 with 4,000–12,000 deaths (Bell and Davis 2001; Godlee 1991) and more recently Dublin 1982 with increases in respiratory deaths (Kelly and Clancy 1984).

These extreme pollution events raised public and policy makers' awareness of the adverse health effects of air pollution, and led to the development of air quality legislations (EC Report 2004). The implementation of these policies and legislations, together with improvements in car and industrial technology, has achieved marked improvements in air quality. As a consequence, interest in air pollution dwindled until the mid-1980s/1990s, when epidemiological studies reported adverse health effects of long- and short-term exposure to air pollution at relatively low levels that were previously thought to be harmless (Barnett et al. 2005; Dockery et al. 1993; Medina et al. 2004), and therefore, air pollution remains a matter of public concern (US EPA 2008).

It is known that increased air pollution is associated with increased morbidity and mortality; there is little evidence to show the health and monetary outcomes from reducing air pollution levels. Intervention\accountability studies play an important role in supporting and complementing scientific validation of the evidence from epidemiologic studies, they allow an examination of the hypothesized cause-effect relationship.

This is particularly relevant when the specific interventions have a clear exogenous source of change in exposure, and therefore, less potential for confounding (Pope 2010). They also inform policy makers about the effectiveness of specific interventions. "Interventions" may be unplanned side effects attributable to political, economic or other societal changes. The accountability studies are defined as a subset of intervention studies that attempt to assess policy-related, planned or controlled interventions usually reducing exposure (Pope 2010).

Here, we present an overview of relevant published studies that assess the health impact of changes in air quality due to interventions or accountability studies.

Methods

We focus on publications reporting human health effects associated with outdoor air pollution interventions. We define interventions as events aimed at reducing anthropogenic air pollution, and events where reductions occurred as a side effect of changes in human activity.

A systematic search of Pubmed, Google Scholar, ISI Web of Knowledge[SM], HEI Publications Database and Science Direct was conducted, using the search terms: "air pollution", "intervention", "health effect", "mortality", "morbidity", "Olympic Games", "strike", "congestion" and "air pollution decline". Additional studies were identified through references from other articles (i.e. reviews, or intervention papers), details are given in Fig. 1 and Table 1. The studies were divided into four broad groups, multiple sources over a large geographical area, traffic, Olympic Games and domestic sources. This review is not a complete record of all air pollution interventions; there are many which are not considered here. The details of the reviewed studies are shown in Table 2.

We compare the observed reductions in mortality with the predicted values calculated using effect estimates from Katsouyanni et al. (1997), Samoli et al. (2005).

Results

Multiple sources over a large geographical area

The nationwide copper smelter strike in the US in the late 1960s

A nationwide copper smelter strike in the US in 1967/1968 was associated with a 60 % drop in regional sulphur dioxide (SO_2). Pope et al. (2007) reported a 2.5 % decrease in mortality associated with the strike.

Closure and reopening of a steel mill in Utah Valley, US, 1986

In a similar, but separate event, the steel mill in Utah Valley accounting for ~82 % of industrial Particulate Matter $(PM)_{10}$ emissions closed due to a strike in August 1986 for 13 months. Pope (1989) reported a strong association between ambient PM_{10} concentrations and respiratory illnesses. The associations for bronchitis and asthma were stronger than for pneumonia and pleurisy with a higher incidence rate in children than in adults, i.e., hospital admissions for children aged 0–17 years tripled, and adults increased by 44 % during the study period when the 24-h average PM_{10} exceeded 150 $\mu g/m^3$. Hospital admissions for children doubled and adults increased by ~47 %, when the arithmetic mean PM_{10} levels were $\geq$50 $\mu g/m^3$.

During winter when the steel mill was operating, hospital admissions for children were approximately three times higher compared to when the mill was closed; bronchitis and asthma admissions were doubled during autumn when the mill was open compared to when closed (Pope 1989). No similar clear association was found for adult admissions. In winter, when the steel mill was closed, PM_{10} levels were approximately halved.

Pope et al. (1992) reported a 3.2 % drop in daily deaths and a simultaneous decrease of PM_{10} levels by approximately 15 $\mu g/m^3$ during the steel mill closure with the strongest association for respiratory deaths. Ransom and Pope (1992) reported that annual school absenteeism was about 25 % when the mill was operating. Ransom and Pope

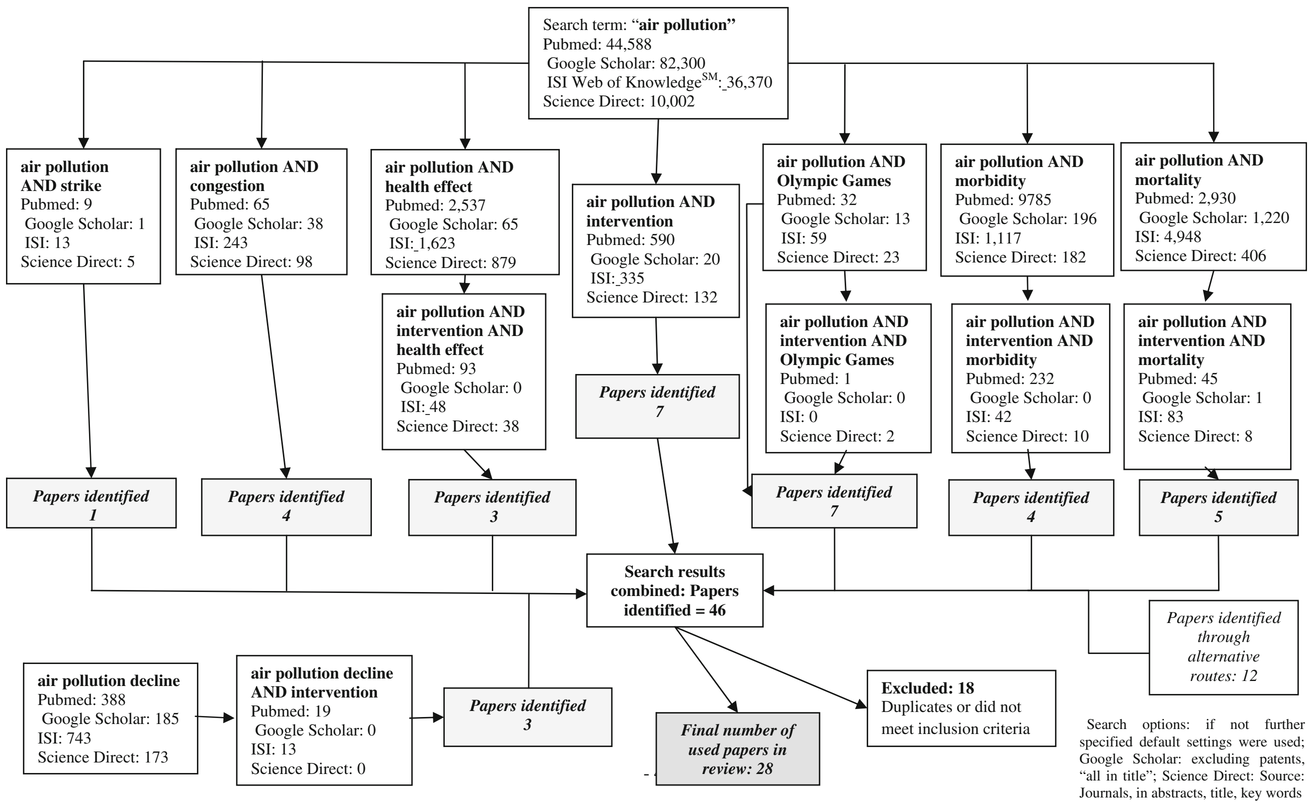

Fig. 1 Summary of the search process of the internet-databases for various combinations of search terms with the number of abstracts found

Table 1 Summary of inclusion and exclusion criteria for studies

Criterion	Inclusion	Exclusion
Available in full text	Yes	No
Language: English	Yes	No
Geographical area considered: worldwide	–	–
Restrictions on study population (i.e. age groups, mortality groups): none	–	–
Year of intervention	1960s to May 2011	Prior 1960
Epidemiologic study—ideally looking at pre- and post-intervention and assessed health benefits	Yes	No
Assessing public health benefit of interventions	Yes	No
Study assessing only change in air quality due to intervention	No	Yes
Same intervention examined on more than one occasion	Main/most representative and/or most recent study	Others

(1995) estimated external health costs of the mill for excess hospitalisations and mortality of approximately $2Million (M) and $40 M per year, respectively.

German reunification, Germany, 1990

The reunification of the German Democratic Republic ("East Germany") and the Federal Republic of Germany ("West Germany") in 1990 led not only to changes in the political environment, but also in the socio-economic structures. Major parts of the economy in East Germany collapsed, resulting in an instant, remarkable drop in pollutant emissions between 1989 and 1991. In addition, air pollution controls were implemented in 1992 and 1996 (Ebelt et al. 2001). In East Germany, prior to reunification, the major energy source for industries, power plants and

Table 2 Summary of air pollution intervention studies

Intervention	Investigator	Pollutant	Health outcome	Statistics	Controls	Main findings
Multiple sources over a large geographical area						
Short-term change						
Copper smelter strike in the US, 1960s	Pope et al. 2007	SO_2	Mortality counts (1960–1975)	12 different Poisson regression models (GAM, PROC GAM) adjusting for time trend	Mortality counts in bordering states, and nationwide mortality counts for influenza/pneumonia, cardiovascular, and other respiratory deaths; non-strike period	Decrease in mortality of 2.5 %
Closure and reopening of a steel mill in Utah (U.S.)	Pope 1989	PM_{10}	Respiratory hospital admissions (1985–1988)	Comparative and multiple regression analysis (18 models adjusting for different weather variables: mean high and low Temp., rain- and snowfall, evaporation, inversion seasons)	"All other" hospital admissions from two hospital used for analysis excluding in-county ones for pneumonia, pleurisy, bronchitis and asthma; out-of-county admissions to Utah Valley Regional Medical Center and to Mountain View Hospital, Payson (32 km away from mill), for pneumonia, pleurisy, bronchitis, asthma; non-closure period	Closure → PM_{10} winter levels were ~½ Reopening → Hospital admissions for children ×3 → for adults ↑ ~44 % with 24-h PM_{10} > 150 μg/m³ Regression analysis: strong correlation between admissions and PM_{10}
	Pope et al. 1992	PM_{10}	Mortality (respiratory, cardiovascular, other-cause)	Poisson regression adjusted for temperature, time trend, seasonality, humidity	Non-closure period	Closure → ↓ ~15 μg/m³ in PM_{10} levels → simultaneous 3.2 % ↓ in average daily deaths
Long-term change						
German reunification 1990	Peters et al. 2009	$PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, O_3, UFP	Daily mortality counts (1990–2002)	Time-varying coefficient modelling and Poisson regression adjusting for temperature, humidity, influenza epidemics, trend, season, calendar effects		• No clear association between all-cause mortality or specific-cause mortality and $PM_{2.5}$, PM_{10}, or SO_2 • Association between daily mortality and UFP, NO_2, CO and O_3 (lag day3 or 4)
	Suguri et al. 2006	TSPs	Lung function (LF) in children (5–7 years old) in 9 German cities (1991–2000)	Linear regression (GENMOD) adjusting for temperature, traffic exposure, physiological variables, parental education, home heating & cooking, bedroom sharing, tobacco smoke exposure, SO_2; random effect modelling	West German health and pollution data in comparison to East Germany	1991 East Germany: TSP ↑↑, 6-year-olds worse LF than West 1991 to 1997: difference in LF and in TSP concentration vanished simultaneously
	Frye et al. 2003	TSP, SO_2	LF of schoolchildren (11–14 years old) in 3 East German communities (1992–1999)	Linear regression (MIXED) controlling for sex, height, season of examination, LF equipment, parental education, parental atopy, environmental tobacco smoke, uncorrelated random effects for nine combinations of area and survey	Two highly polluted cities and one city with low air pollution	• Drastic overtime ↓ of TSP and SO_2 levels • ↑ of FVC (significant) and FEV_1 (not significant) • ↓ in bronchitic symptoms and bronchitis

Table 2 continued

Intervention	Investigator	Pollutant	Health outcome	Statistics	Controls	Main findings
Reduction of fuel sulphur content in Hong Kong	Hedley et al. 2002	PM_{10}, SO_4RSP, NO_2, O_3, SO_2	Monthly mortality data (all-cause, cardio-respiratory, neoplasmic and other) (1985–1995)	Poisson regression adjusting for trends, seasonality, temperature, and relative humidity, with stratification into two 5-year periods, prior and post-intervention	Baseline period (5 years prior fuel intervention)	• ↓ SO_2 levels ~50 % citywide • ↓ annual all-cause mortality by 2.1 %, respiratory by 3.9 % and cardiovascular by 2.0 %; • Estimated gain in life expectancy 20 days for women, 41 days for men
	Wong et al. 1998	SO_2	Bronchial responsiveness in children (9–12 years old) in two city districts (1990–1992) excluding children with asthma and wheezing history	Generalised estimating equations procedure modelling adjusting for correlation between repeated measurements and for age, sex, examination year and time, father's education level, tobacco smoke exposure, logistic and multiple regression	Less polluted city district	Consistent downward trend for bronchial responsiveness in both districts, but bigger reductions in more polluted district
European Air Emission Policies	European Environment Agency (2011)	CO, $PM_{2.5}$, NO_x, O_3, SO_2	Years of life lost using country-specific baseline incidences from the WHO Burden of Disease project	LOTOS-EUROS regional chemical transport model	Comparison of no application scenario with full application scenario	• air quality and public health improved in 32 EEA member-states with variation btw the countries • However, not all possible improvements yet achieved
Olympic Games						
Short-term change						
1996 Summer Olympic Games in Atlanta, Georgia, U.S.	Friedman et al. 2001	CO, PM_{10}, NO_2, O_3, SO_2	Daily asthma and of non-asthma acute care events in children (1–16 years old) in Atlanta 4 weeks prior, during and after Olympics	Time-series Poisson regression model (GENMOD) adjusting for day of the week, lag day 1 minimum temperature	Baseline period (4-week periods before and after the Olympics)	• ↓ of 13 % for O_3 levels, 18.5 % for CO, 16.1 % for PM_{10}, 6.8 % for NO_2; ↑ of 22.1 % of SO_2 • Significant ↓ of asthma emergency care visits and hospitalisations by 41.6 % in Medicaid database
	Peel et al. 2010	CO, PM_{10}, NO_2, NO_x, O_3, SO_2	Cardio-respiratory Emergency Department (ED) visits in Olympic period compared to baseline in surrounding years	Poisson GLMs adjusting for time trends, meteorological conditions	• Air pollution and meteorological data: Sites in Georgia outside study area and Southeastern States • 11-year combined Olympic period (1993–2004) and baseline period (4-week periods before and after the Olympics) • ED visits for finger wounds (ICD-883.0)	• ↑ in ER visits for COPD • Results sensitive to choice of analytical model
2008 Summer Olympic Games in Beijing, China	Li et al. 2010	$PM_{2.5}$, O_3, SO_2, NO_2, CO	Daily outpatient asthma visits of adults at Beijing Chaoyang Hospital (June–Sept. 2008)	Time-series Poisson regression models adjusting for day of the week, mean temperature (lag day 1), humidity	1 month baseline period before any air pollution controls; 5 weeks pre-Olympic period with some restrictions in effect	• Significant ↓ in asthma visits during Olympic period • ↑ 10 μg/m^3 of $PM_{2.5}$ and ↑ 10 ppb of O_3 found to be associated with ↑ 2 % and ↑ 4.4 % in asthma outpatient visits
	Huang et al. 2009, ISEE Abstract,	$PM_{2.5}$, PM_{10}, NO_2, BC	Repeated 24-h ambulatory ECG monitoring data from 43 elderly during summer 2007 and 2008	Mixed models	Summer 2007, summer 2008 except Olympic period	Significant ↓ of the root mean square of successive inter beat intervals (−2.47 %) and of the high frequency (−3.15 %) in association ↓ $PM_{2.5}$

Table 2 continued

Intervention	Investigator	Pollutant	Health outcome	Statistics	Controls	Main findings
Traffic related initiatives						
Long-term change						
The London Congestion Charging Scheme	Tonne et al. 2008	PM_{10}, NO_2	All-cause mortality counts of Greater London city residents 2001–2003)	Combined emission-dispersion and regression modelling	Pre-CCS scenario	In CCZ: ↑↑ Reductions levels: ↓ 2.3 % of NO_x, ↓ 0.8 % of PM_{10}; YLG_{NO2} per 100,000 population 26 years for Greater London, 183 years within CCZ; $YLGP_{M10}$ only 8 years for Greater London
						Outside: ↓ 0.4 % of NO_x, ↓ 0.1 % of PM_{10}
	Tonne et al. 2010	NO_x	Cardio-respiratory hospital admissions in Greater London (2001–2004)	Logistic regression and an instrumental variable approach	Pre-CCS years 2001–2002	• Significant association btw. ↓ NO_x and ↓ admissions only for bronchiolitis • Substantial spatial dependence in the data
The Stockholm Congestion Charging Trial	Johansson et al. 2009	PM_{10}, NO, NO_2, CO	Residents of Stockholm comparing with and without the CCST for 2006	Wind model and Gaussian dispersion model (Airvivo), life-table analysis	Without CCST scenario in 2006	↑↑ Reductions levels in city centre in CCZ: −10.0 % for NO_x, −7.6 % for PM_{10}; Greater Stockholm: −5.3 % for NO_x, −3.8 % for PM_{10}; 206 YLG per 100,000 people for Greater Stockholm over a 10-year period
Domestic emissions						
Long-term change						
The Irish coal ban	Clancy et al. (2002)	BS, SO_2	Mortality counts in Dublin: non-trauma, respiratory, cardiovascular (1984–1996)	Interrupted time-series analysis: Poisson GLM adjusting for temperature, humidity, day of week, respiratory epidemics, directly standardised death rates in the rest of Ireland	Pre-ban period (6 years), other deaths (total non-trauma minus cardiovascular and respiratory)	↓ BS by ~70 %, ↓ SO_2 by 34 %; ↓ non-trauma death rates by 5.7 %, ↓ respiratory by 15.5 %, ↓ cardiovascular by 10.3 %
	Goodman[a] et al. (2009)	BS, SO_2	Daily BS and SO_2 measurements for the sequential bans in 11 cities	*t* statistics	Pre-ban period (5 years)	•↓ BS in all centres post-ban (−45 to −70 %) largest in winter • No clear pattern in SO_2 changes
	Rich et al. 2009, Abstract	BS, SO_2	Weekly cause-specific mortality rates in County Cork (1981–2004)	Poisson regression adjusting for temperature, influenza epidemics, mortality in non-ban areas	Pre-ban period (15 years), non-cardio-respiratory deaths and digestive (ICD-9 520–579) deaths, cancer deaths (ICD-9 140–239) and specifically lung cancer deaths (ICD-9 160–165)	• ↓ BS by −49 %, but ↑ 24 % of SO_2 • ↓ total mortality by 7 %, ↓ respiratory by 8 %, ↓ cardiovascular by 13 %
Residential Wood Burning Regulations in S.J. Valley, Ca., US	Lighthall et al. 2009	$PM_{2.5}$	Mortality and morbidity in Bakersfield and Fresno/Clovis (F./C.) (2000–2006)	Diurnal profiling, meteorological model, U.S. EPA's BenMAP	Pre-rule period (3 years)	Annual ↓ $PM_{2.5}$ in 4 post-rule winters: F./C. −13.63 %, Bakersfield −12.94 %; annual mortality costs savings: \$367.5–430.6 M in F./C., from \$189.1–239.9 M in Bakersfield; morbidity costs savings: \$11–26.6 M in F./C., \$5.7–14.1 M in Bakersfield

domestic space heating was brown coal. Within a decade, an almost complete conversion to natural gas occurred (Peters et al. 2009). Ebelt et al. (2001) reported that these changes were associated with marked decreases in air pollution, mainly in SO_2 levels. In addition, changes in vehicle fleet composition took place, leading to a decrease in PM_{10}, $PM_{2.5}$, SO_2 and Nitrogen Monoxide (NO).

Peters et al (2009) assessed the influence of improved air quality on daily mortality in Erfurt from 1990 to 2000. No clear association between all-cause and specific-cause mortality and $PM_{2.5}$, PM_{10}, or SO_2 was observed. They reported a delayed decline in daily mortality, associated with Nitrogen Dioxide (NO_2), Carbon Monoxide (CO), Ultrafine Particles (UFP), and Ozone (O_3). Breitner et al. (2008) observed similar results examining the same data set, but employing a different statistical approach.

Suguri et al. (2006) assessed the decline of total suspended particles (TSP) and lung function in 5–7 years old children in 9 East and West German cities from 1991 to 2000. They showed that 6-year-olds in East Germany in 1991 had a worse lung function than children in the West; by 1997, this difference had vanished simultaneously with the difference in TSP concentration. These positive health impacts corroborated the findings of Frye et al. (2003). In addition, a decrease in bronchitic symptoms was detected confirming results from earlier studies (Heinrich et al. 2000; Krämer et al. 1999).

The reduction of the sulphur content of fuel in Hong Kong, 1990

Hong Kong is one of the most densely populated places worldwide, with numerous industries and high traffic and shipping density, and hence experiencing severe air pollution events. In 1990, the government introduced a regulation restricting the sulphur content of fuel to 0.5 % by weight affecting power plants and vehicles.

Hedley et al. (2002) reported that in the first year post-intervention, mean SO_2 levels decreased by 53.0 % citywide and approximately 80 % in the highly polluted Kwai Tsing district. The reduction in SO_2 levels was sustained post-intervention. They reported an instant reduction in cool-season deaths in the first year post-intervention. This was followed by a peak the following year with a return to pre-intervention seasonal patterns afterwards. Compared to predictions, a higher than expected decrease in annual all-cause mortality of 2.1 %, respiratory of 3.9 % and cardiovascular deaths of 2.0 %, but no effect on neoplasmic and other-cause deaths was observed. A gain in life expectancy of 20 days for women and 41 days for men per year of exposure to lower air pollutant levels was estimated (Hedley et al. 2002).

Consistent with this, Wong et al. (1998) compared the effect of this intervention on respiratory health in children in the highly polluted Kwai Tsing and the moderately polluted southern district. Their findings imply that the children in the higher polluted area benefited more from the intervention than in the less polluted area, where children had better initial bronchial values from the start. This is consistent with Peters et al. (1996).

The impact of European air emission policies, 1990–2005

Europe has implemented a number of legislative instruments to improve air quality by controlling emissions from various sectors; the European Environment Agency (2011) reviewed the impact of selected policy measures in EEA-32 member-countries from 1990 to 2005, including Euro emission standards for road vehicles and directives on Integrated Pollution Prevention and Control (IPPC) and large combustion plants (LCP). The road transport directives are thought to have led to significant reductions in emissions, especially for CO (−80 %), Non-methane volatile organic compounds (NMVOC) (−68 %), Nitrogen Oxides (NO_x) (−40 %) and $PM_{2.5}$ (−60 %) compared to a non-policy scenario by 2005 (European Environment Agency 2011).

Averaged across all EEA member countries, abatement measures reduced the health impact of the road transport sector (in terms of years of life lost (YOLL)) by 13 and 17 % for $PM_{2.5}$ and O_3, respectively. In the industrial combustion sector, a reduction in YOLL by 60 % for $PM_{2.5}$ was observed, but an increase by 17 % for O_3.

Olympic Games

1996 Summer Olympic Games in Atlanta, US

During the 1996 Atlanta Olympics, measures to reduce traffic congestion, while providing a functional transport network, were implemented. These measures included additions to the bus fleet, around-the-clock public transportation, flexible working hours, telecommuting, etc.

Friedman et al. (2001) reported improvements in air quality and an associated reduction in asthma Emergency Room (ER) visits and hospitalisations; recently Peel et al. (2010) contradicted these findings stating that important potential confounders had not been addressed in the original study.

2008 Summer Olympic Games in Beijing, China

Beijing, a city with a population of over 17 M, hosted the 29th Olympic and Paralympics Games between August 8 and September 17, 2008. To reduce traffic congestion and improve air quality, the Beijing Municipal Government implemented a number of control regulations. Positive improvements in air pollution levels were observed comparing the pre-Olympic to the Olympic period (Wang et al. 2009). However, the weather conditions during the Olympics have to be taken into account. It is estimated that their contribution to variations in PM levels was approximately 40 %, whereas the source control accounted only for 16 % (Wang et al. 2009).

Li et al. (2010) observed a significant reduction in asthma outpatient visits amongst adults at the Beijing Chaoyang Hospital during the Olympic Games compared to the baseline period.

Hou et al. (2010) observed that human exposure to PM_{10} and associated health economic costs were lowest during the Olympic period compared to the pre- and post-period.

Huang et al. (2009)reported improvements of heart rate variability (HRV) in 43 elderly residents, previously diagnosed with cardiovascular diseases, associated with improved air quality during summer 2008 compared to summer 2007. Wu et al. (2010) corroborated these results when assessing HRV in 11 young healthy taxi drivers. Also Zhang et al. (2009) report preliminary results indicating improvements in respiratory and cardiovascular endpoints.

Traffic related initiatives

The London Congestion Charging Scheme, UK, 2003

In London, the traffic Congestion Charging Scheme (CCS) was launched covering approximately 22 km^2 of the city centre on the 17th February 2003 with the main objective to reduce traffic congestion, which was being amongst the worst in Europe. Upon implementation, further measures were taken to improve traffic flow, e.g. improvements to bus networks and walking and cycling schemes. After 1 year, a traffic volume reduction of 18 %, and 30 % less congestion was successfully achieved (TfL 2007).

Tonne et al. (2008) modelled the impact of the CCS on traffic indicted air pollution and mortality on different groups of population, down to census ward level. They observed a clear variability of pollution levels in different parts of the city. Concentrations were in general higher in more deprived areas, mainly located outside the Congestion Charging Zone (CCZ). The overall decline in NO_x was found to be higher in deprived areas than within the CCZ. The estimated years of life gained (YLG) per 100,000 population according to the modelled declines in NO_2 were predicted to be 26 years for Greater London, 183 years for residents within the CCZ wards, applying to a very small fraction of the London population and hence being a smaller overall impact compared to the outside wards, and only 18 years for the remaining wards. Furthermore, a clear trend was observed regarding socioeconomic patterns; with increasing deprivation an increasing benefit in number of YLG with reductions in NO_2 was noted. In addition the estimated YLG according to modelled declines in PM_{10} were predicted to be only 8 years for Greater London, 63 years for residents within the CCZ wards and 5 years for outside wards of the CCZ. Again an upward trend for YLG with increasing deprivation, but not as pronounced as for NO_2, was found.

Further research by Tonne et al. (2010) examining associations between changes in NO_x and cardio-respiratory hospital admissions over a 4-year period found a significant association between reductions in NO_x and reductions in admission for bronchiolitis after adjustment for spatial dependence at the borough level, but with quite substantial variations across the wards.

The Stockholm Congestion Charging Trial, Sweden, 2006

In Stockholm, Sweden, a congestion charging scheme trial (CCST) was implemented from the 3rd January 2006 until 31st July 2006, encompassing the inner city centre of approximately 30 km^2. Public transport was expanded allowing higher capacity and frequency. Traffic flow magnitude during charging hour stabilized around 22 % less traffic compared to corresponding periods in 2005 (Eliasson et al. 2009).

Johansson et al. (2009) estimated reductions in air pollution levels in the inner city centre comparing with and without CCST for 2006 of −10.0 % for NO_x, −7.6 % for total PM_{10} and −10 % for the PM_{10} fraction from vehicle exhausts. Taking NO_x as a marker for traffic emissions, they estimated a health impact of 206 YLG per 100,000 people for the area of Greater Stockholm over a 10-year period, assuming that the decrease of the exposure level persists, which is very similar to the calculations for London by Tonne et al. (2008).

The improvement due to the CCST was perceived positive amongst the majority of the public affirmed by a subsequent referendum on a proposal for making the system permanent (Eliasson et al. 2009).

A recent study by Invernizzi et al. (2011) assessing the effect of the implementation of the traffic restriction regulation named “Ecopass” on air quality in Milan, in January 2008 showed significant reductions for Black Carbon, but no change in PM_1, $PM_{2.5}$, and PM_{10} levels. They do not report any health effects.

Domestic emissions

The Irish coal ban, Ireland, 1990

Dublin experienced extreme air pollution episodes during the 1980s, mainly due to space heating from solid fuel, bituminous coal and peat (Goodman and Clancy 2002).

Kelly and Clancy (1984) reported marked increases in respiratory deaths at a main Dublin hospital in 1982 associated with an extraordinarily severe pollution episode. Eventually, the government acted to improve air quality, introducing a ban on the marketing, sale and distribution of coal in Dublin from September 1990 (Air Pollution Acta 1987a).

Clancy et al. (2002) reported an immediate drop in Black Smoke (BS) levels associated with the ban; overall BS decreased by 70 % and SO_2 by 34 %. They reported a decrease of 5.7 % in non-trauma, 15.5 % in respiratory and 10.3 % in cardiovascular deaths. The observed health impact was estimated to account for 243 fewer cardiovascular and 116 fewer respiratory annual deaths in Dublin post-ban.

Due to the success of this intervention, the ban was extended stepwise to 11 other Irish cities (Air Pollution Act 1987b; Goodman et al. 2009a). Goodman et al. (2009a) reported significant reductions in BS levels in all cities post-ban. Rich et al. (2009) reported a drop in total (7 %), cardiovascular (13 %) and respiratory (8 %) mortality in Cork post-ban.

Residential wood burning regulations in San Joaquin Valley, California, US, 2003

The San Joaquin Valley (SJV), California is classified by the U.S. EPA as a serious non-attainment area for the National Ambient Air Quality Standards (NAAQS) (Hall et al. 2008) and known for experiencing some of the worst air pollution episode in the US.

To improve the seasonal poor air quality in wintertime, due to residential wood burning, a regulation, "Rule 4901", was implemented in 2003 banning residential wood burning in areas below 3,000 ft with natural gas, when forecasts predict poor air quality (Web-reference 1, 2003).

Lighthall et al. (2009) evaluated this control, conducting comparative case studies in Bakersfield and Fresno/Clovis focusing on reductions of $PM_{2.5}$ during the winter months. They reported that $PM_{2.5}$ levels in the post-rule winters were reduced compared to the estimated values for a non-ban scenario, with annual reductions of 13.63 % in Fresno/Clovis and 12.94 % in Bakersfield. The mean annual mortality costs saved by the intervention were calculated to range from \$367.5 to \$430.6 M in Fresno/Clovis and \$189.1 to \$239.9 M in Bakersfield, with saved morbidity costs ranging from \$11 to \$26.6 M and \$5.7 to \$14.1 M, respectively.

Discussion

The variety of interventions reviewed have shown, in most cases, associations between improved ambient air quality and health benefits, mostly by reduced cardiovascular and/or respiratory mortality and/or morbidity, with associated health care savings (Lighthall et al. 2009).

Due to the heterogeneity of assessed study populations, time periods, pollutants, health outcomes and methodologies used, a direct comparison between the individual studies of the observed associations of the declining pollutant levels and positive health impacts is difficult. Emissions, exposure rates and hence health effects are influenced by the type of intervention. This heterogeneity may partially account for differences in the observed effect estimates between the various intervention studies and as well between intervention studies and time-series studies. This implies a need for generalised/standardised guidelines how to assess different types of interventions to facilitate comparison of health impact assessment results.

In addition, the choice, number and measurement methods of the assessed pollutants may pose limitations to conducting studies, e.g. Peters et al. (2009) and Breitner et al. (2008) assessing the German reunification used air pollution data of only two and one monitoring stations, respectively. The choice of the assessed pollutant plays an important role in quantifying the effect of an intervention as shown by Invernizzi et al. (2011).

Consistent results were observed for the effect of decreased pollutant levels and the positive impact on respiratory health in children throughout different intervention studies. An improvement in lung function associated with decrease in air pollution was observed throughout multiple studies examining the effect of the German reunification (Frye et al. 2003; Suguri et al. 2006) and in Hong Kong following fuel regulations (Peters et al. 1996; Wong et al. 1998). Those results corroborate with findings from Bayer-Oglesby et al. (2005) from a study in Switzerland. Avol et al. (2001) reported that relocation into areas with higher pollution levels had negative impacts of lung function, while relocation to areas with lower air pollution had a positive health impact.

Coherent associations between increases in asthma admissions and increasing levels of PM and O_3 have been reported (Friedman et al. 2001; Li et al. 2010; Pope 1989). Results from various studies may be sensitive to the assessed time-span and analytical methodology, as shown by the comparison of study results by Peel et al. (2010) and Friedman et al. (2001). The results found in the intervention studies regarding the effect of PM_{10}, $PM_{2.5}$ and O_3 on respiratory admissions are corroborated by Lee et al. (2007), who observed reduced pollutant levels (1–25 %) due to regulations during the 2002 Summer Asian Games in Busan, Korea, and an associated relative risk reduction for childhood asthma hospitalisations, and in various long- and short-term studies from different countries worldwide (Atkinson et al. 2001; Barnett et al. 2005; Peel et al. 2005).

The positive effect of decreased air pollution on respiratory mortality has been observed in the majority of the reviewed intervention studies varying in intensity.

Table 3 Comparison of predicted (Expected) and observed (Real) mortality reductions (%) associated with the observed decrease in pollutant levels (μg/m^3) in each intervention study

Study	City/area	Assessed pollutant	All-cause		Respiratory		Cardiovascular	
			Real (%)	Expected (%)	Real (%)	Expected (%)	Real (%)	Expected (%)
Clancy et al. (2002)	Dublin	BS	−5.7	−2.1	−15.9	−2.8	−10.3	−1.4
Rich et al. Abstract, 2009	Cork	BS	−7	−1	−8	−1.3	−13	−0.7
Pope et al. (1992)	Utah Valley (Steel mill)	PM_{10}	−3.2	−0.6	−4.3	−0.7	−2	−0.7
Pope et al. (2007)	Utah Valley (Copper smelter)	SO_2	−2.5	−0.2	n.a.	n.a.	n.a.	n.a.
Hedley et al. (2002)	Hong Kong	SO_2	−2.1	−1.4	−3.9	−2.3	−2	−1.9

The expected mortality reductions are calculated using the observed decrease in pollutant levels (μgm^{-3}) from the reviewed interventions and the effect estimates of Katsouyanni et al. (1997) and for cardio-respiratory deaths and PM_{10} of Samoli et al. (2005)

A number of studies (Clancy et al. 2002; Hedley et al. 2002; Pope et al. 1992; Rich et al. 2009) found a downwards trend for daily deaths due to a decrease in air pollutant concentrations. Contradicting results were reported by Peters et al. (2009). This might be due to low statistical power, the analytical approach, and uncertainty about adequacy of control for confounding.

A strikingly consistent result throughout the majority of reviewed interventions is that the observed decrease in mortality exceeds the expected predicted figures based on observations in meta-analysis of short-term health effects of air pollution (Katsouyanni et al. 1997). They estimated a decrease of 3, 3 and 2 % for all-cause mortality in association with a drop of 50 μg/m^3 in SO_2, BS and PM_{10}, respectively, and a decrease of 4 and 2 % for cardiovascular and 5 and 4 % for respiratory deaths for a 50 μg/m^3 drop in SO_2 and BS. Samoli et al. (2005) predicted a decrease of 2.5 % for total and 3.5 % for cardiovascular and respiratory mortality in European cities for a 50 μg/m^3 drop in PM_{10}. The estimates of decreased mortality associated with declines in PM_{10} were found to be similar in the US and Europe, but higher in Canada (Samoli et al. 2008), summarized in Table 3.

The observed differences maybe due to a decline in cumulative exposure yielding a bigger beneficial effect than predicted by time-series studies of acute effects (Goodman et al. 2004; Pope and Dockery 2006).The time window assessed in intervention studies has been described as an intermediate between time-series studies assessing short-term health effects within a certain number of days, whereas cohort studies, such as the Harvard Six Cities Study by Dockery et al. (1993) and the American Cancer Society study by Pope et al. (2002) assess a much longer time period (10+ years) reported considerably higher effect estimates (Pope and Dockery 2006).

Interestingly, results from intervention studies are remarkably consistent with workplace smoking-bans (Goodman et al. 2009b).

Conclusions

We conclude that based on the papers reviewed, there is evidence that reductions in air pollution from interventions, or as a consequence from external events associated with improvements in general public health and with reduced mortality. Most of the reviewed studies showed a positive health impact to varying extents. The quantification of the impact of such interventions on public health still remains difficult to interpret due to the heterogeneity in methods. A standardized approach/protocol including guidelines on appropriate time windows, pollution monitoring networks, health data, controls, study population and statistical methods will assist in this process.

Consistent findings of the reviewed studies imply a causal relationship between a decrease in air pollution and in cause-specific mortality and morbidity. Bigger effects were observed for mortality and morbidity for respiratory and cardiovascular causes. Further research is required to evaluate interventions to ensure appropriate policy formulation, implementation and subsequent monitoring.

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